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Investigation of the general concept of the implementation of automation and digitalization tasks for production processes using innovative high-level solutions

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Abstract: The main issues are considered in this topic: the main problems of the design and implementation of high-level systems for the automation of production processes are considered. As part of the digitalization of production, there is a need for the operational management of all enterprise processes at all levels of the system. The work highlights several recommendations for the development of integration of such systems. The research describes the interoperability of various systems of resource management, processes, laboratory, planning for obtaining quality products.

KEYWORDS: DIGITALIZATION, MES, LIMS, ERP, AUTOMATED SYSTEMS, PRODUCTION PROCESSES

1. Introduction

Due to the development of microcontrollers and microprocessors, modern production, industry is very different from what it was 50-100 years ago. This is a natural process of replacing manual human labor with automated production, in which a person is no longer standing at the machine tool or with a plow in the field, and for the most part the role of a person in it is assigned to controlling and replacing faulty blocks. This makes it possible for a modern person to develop as a creator, to pay more attention to the qualitative development of himself.

2. Problem discussion

Information technology today has become an integral part of systems automation. The fast pace, the lightning speed of change and updating of information technology introduces tangible adjustments to the automation of systems and processes in general. As part of the “Industry 4.0”, it’s time to talk about the automation of production processes, when the control object is considered not only processes, but also the labor, financial and commodity flows and resources. When the level of digitalization of production allows for the operational management of all tasks at all levels of production, to plan all processes and tasks for effective management and control. To solve the problems of operational control of production processes, such a concept as MES (manufacturing execution system) systems appeared. Many enterprises faced a number of problems that arose during the transition to a system of automation of production processes, since there are no ready-made solutions, or clear guidelines, structures, algorithms for the implementation of such complex systems.

3. Objective and research methodologies

The main purpose of this work is the research of the general concept of realization of automation tasks and digitalization of production processes using innovative high-level decisions. The work reflects a study of the authorization problem using a solution in the field of building systems in terms of innovative software products and industrial network systems. The work presents recommendations for building a network structure using the example of a testing laboratory. The Testing Laboratory provides measurement data on product quality, including in real time, collected from the production level, ensuring proper quality control and focusing on critical points. Laboratory can propose actions to correct the situation at this point based on the analysis of correlation dependencies and statistical data on cause-effect relationships of controlled events. All processes are automated using the LIMS (Laboratory Information Management System) package. The LIMS system is designed to optimize the processes of the testing laboratory, improve the quality of information processing, with an integrated analytical analysis package. Upon receipt of an order for a new batch of products, a task for sampling arrives. A sample entering the laboratory is marked with a QR code or NFC labels and an identifier for entering a common sample base. All data is synchronized with the subsystems of the production process control system for optimized, continuous management, control and planning. The full production process, taking into account quality control of products and raw materials, is shown in Figure 1.

![Figure 1. Structure manufacturing process](image1.png)

The structure of the interaction of devices for working in the LIMS system is shown in Figure 2. A simple system includes one server with a database and a web server, and several clients. Clients can be stationary computers, PDAs or smartphones, a prerequisite is access to a local network or a WI-FI network. An employee, for example, having a smartphone or tablet connecting to a local network, enters data, performs various operations with test samples, analyzes the data received, accesses the web application of an automated laboratory. All test results, or quality control of products and raw materials, are automatically entered into a report, which is subsequently sent to MES. MES accepts the results and forms a series of tasks for further production. If necessary, a data center is possible, which will include a database server and a web server, such a structure is shown in Figure 3. All clients are connected to a web server. Storage, collection and processing of information is carried out using databases as the system exchanges a huge stream of information data.

![Figure 2. Structure of the interaction of devices for working in the LIMS system](image2.png)

Clients having access to a web browser after passing certain procedures to protect security (entering a password, login, having passed authentication levels), depending on their access level, can carry out various procedures and operations. For security purposes, the enterprise has its own internal local area network without access to the global network; all information may be available for other systems, production subsystems, such as ERP (Enterprise...
Resource Planning), MES, operational planning systems, automated technological process control systems ATPCS [1].

Figure 3. Complex structure of the interaction of devices for working in the LIMS system

LIMS interacts with various systems for data exchange, and continuous, operational management of all production processes. Quality control of raw materials and finished products is an integral part of any production, the efficiency, and most importantly the image of the company, and therefore the income and profits of the enterprise, depend on this. The structure of the LIMS interaction with other systems is shown in Figure 4. The ERP system exchanges data on resources, raw materials, the amount of material resources, and also contains information about suppliers and orders. The MES system performs operational control of all production tasks, forming a task list for all systems, tracking the status of all processes from receipt of an order to shipment of finished products to the customer. LIMS sends a report on the results of sample tests, or research of new formulations, on the basis of which MES forms production tasks. The operational planning system creates a schedule for all tasks, taking into account restrictions. The status of equipment, its readiness for the process, the timing of repairs, or inactivity in the event of a breakdown, the status of labor resources, taking into account the number of employees, shifts, and their qualifications, the status of processes, and standards for their implementation, etc. The process control system already carries out all the tasks taking into account the report on product quality control at various stages.

Figure 4. Structure of the LIMS interaction with other systems

For the interaction of all systems, a number of services are required that will integrate the current, necessary information into various systems without data loss and using data transfer standards understood by all production participants. The system needs to speak the same language so that the rest of the participants correctly understand and express their thoughts. In the framework of production, making everyone speak the same language is quite problematic, since a huge number of devices, types of interfaces, networks, taking into account the huge data stream that must be translated into an understandable language for the rest.

One solution to this problem is the use of services such as Uniconnect Agent, Uniconnect and Unilink, namely the transfer of XML files in which information is generated in the form of tags, with an identifier of all the necessary data.

Figure 5. Data transfer process

Figure 5 shows the process of transferring data from external systems to the LIMS system. A file is generated that is sent to the exchange folder, then the Uniconnect Agent polls the folder for the presence of the file, and sends the file to Uniconnect. Uniconnect parses incoming files and converts the file to Unilink-friendly syntax. Unilink stores data in a database. All data stored in the database is available to the user and further processing and analysis. In the printers, the same principle of communication via XML files is applied, or using customization of the Web application, prescribing the relationship with devices integrated in the application, but this option requires programming skills case of establishing communication with laboratory equipment, various analyzers, electronic scales, C #, HTML 5, CSS3, JavaScript. The data exchange process between laboratory equipment and the database is shown in Figure 6.

Figure 6. Data from laboratory equipment

4. Conclusion
This work highlights the problems encountered in the design and implementation of automated systems for production processes. When the task is to efficiently and effectively manage the production process from the receipt of the order and raw materials, after production, and the receipt of finished products, shipment to the customer and complete quality control at all stages of production. The complexity of introducing such systems to manage and plan the full production cycle lies in the lack of ready-made algorithms or recommendations for implementation, construction and integration into an existing production without possible losses. This study shows one of the solutions for the integration of such systems, allowing production facilities to step closer to the digitalization of production.

5. Literature
A generalization of approaches to creating a digital passport supporting the stages of the electronic product life cycle and the features of the formation of design decisions based on it

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Abstract: The paper substantiates the need to generalize approaches to creating a digital passport supporting the stages of the life cycle of an electronic product. For this, the results of the analysis of design and production procedures and product data at the stages of the life cycle are presented, on the basis of which the components of a digital passport are formulated as pairs of values “information object - design and production procedure”. Information objects are determined by PDM, ERP, MES, QMS systems and electronic document management systems. The list of design and production procedures is determined by the automated processes of a particular enterprise, which determines the variability of the digital passport. Also, the work substantiates the need for the formation of design decisions and the features of the formation of design decisions based on them are shown. The formation of design decisions is associated with the corresponding tasks formulated in the form of linguistic variables, which allowed to develop the generation of design solutions, according to which their desired version contains the associated components of a digital passport that fall inside the area specified by the values of the linguistic variable. The results obtained can be used in order to create signatures and semantics of applied unified services for a digital passport in the instrument-making industry, used in the development, delivery and maintenance of electronic products.

KEYWORDS: DIGITAL PASSPORT, SELECTION OF COMPONENTS OF A DIGITAL PASSPORT, TASKS OF DESIGN DECISIONS FORMATION.

1. Introduction

A modern electronic product is a complex hardware-software complex, the creation of which is performed on the basis of a customer’s application. The application determines the lists and terms of the work, as well as their executors, both from the number of divisions of the instrument-making enterprise and organizations, which sets the task of operational interaction between them - the exchange of relevant data on the product. The solution to this problem is provided by the operation of a variety of PDM, ERP, MES and / or QMS systems [1-4], including electronic document management systems (EDMS), which creates each enterprise's own integrated environment.

This increases the efficiency of interaction between divisions of one enterprise [5], but not interaction between enterprises. In most cases, it is implemented in the traditional way - correspondence by e-mail and the exchange of technical documentation on paper. At the same time, new methods are gaining popularity, which consist in introducing the same systems with synchronization of versions and models of stored data by all participants in the interaction [6-10] or in using a neutral data exchange format in the STEP language, which also requires prior coordination. The obvious disadvantages are as follows:

1) simultaneous support of several versions of the same software for interaction with various enterprises;
2) coordination of models and formats of data exchange between all participants of electronic interaction when concluding contracts;
3) coordination of the types of systems being introduced since it is impossible to transfer data about the product and the design and production procedure if the system is not implemented at the enterprise or information storage is not provided;
4) own interpretation of the contents of a file of a neutral data exchange format by each enterprise, which creates difficulties when reading it in other organizations.

The disadvantages are even more significant if we take into account the development vector of Industry 4.0 [11-15] - minimization, up to the complete exclusion, of the influence of the human factor on production processes. For the instrument-making industry, this means the selection, collection and analysis of product data and design-production procedures, which corresponds to the creation of a digital passport supporting the stages of the life cycle of an electronic product [16, 17] for making design decisions.

Thus, it is advisable to solve the following problem - a generalization of approaches to creating a digital passport and formulating the features of the formation of design solutions based on it at the stages of the life cycle in the instrument-making industry, which this article focuses on.

2. Procedures and data analysis on the electronic product at the stages of the life cycle

According to the research results, the content of the digital passport is determined by the types of data on the electronic product that are generated and modified in accordance with the design and production procedures at the stages of the life cycle. Therefore, at the stage of concluding a contract, the company’s employees consider applications received from customers, based on which they prepare materials for concluding contracts.

If an application for development is received, then with its agreement upon and approval, lists of the developed and supplied component parts of the product are formed, indicating the contractors in the form of divisions of the enterprise and organizations. If an application for the supply of products is received, then lists of the developed and / or corrected design and program documentation are formed, indicating the contractors in the form of enterprise units, as well as lists of supplied components and relevant organizations [18].

The data obtained in this case are the initial information in the form of lists and deadlines for the execution of work stages when drawing up contracts for the development or delivery of products, including contracts with co-contractors.

The development stage is to create sets of new or revised design data on the product in the form of an electronic product structure in a PDM system (ESI-PDM) containing 3D models, design and program documents for the product and its original components. Component parts supplied by third parties are designated as ESI-PDM elements and may not have associated documents and / or 3D models. It should be noted that the lists of developed and revised documentation are determined by the annexes to the concluded agreements with the customer.

The stage of production preparation is to create sets of technological data on the product and its components in the form of ESI-PDM, corresponding to ESI-PDM obtained at the development stage. Technological data includes routing or process maps, technological instructions, control programs, typical processes and / or documentation for technological equipment. They are developed according to the design documentation or 3D-models for each component part of the product, which is the company's own development [19].

In addition, the stage of preparation for production includes procurement procedures for purchased component parts, such as standard, other products and materials, according to the content of ESI-PDM of manufactured component parts of the product. These procedures are characterized by the conclusion of contracts with suppliers.
If the development of a technological document or the purchase of a product cannot be performed due to an error in the documentation or the absence of a supplier, the employee of the technological unit or supply service fixes a comment on the corresponding design documentation [20].

Production stage means the production of parts and assembly units, including the assembly of the product itself, based on the developed sets of design and software documentation. The result is a product copy with parameter values characterizing the quality in the form of the product copy structure, as well as, if available, comments on the design and program documentation.

The operation and repair phase is characterized by sending a service request or complaint to the company. The receipt of the first document means the formation of an additional agreement to the contract, verification of the need and planning for adjustments of previously issued documentation for the components of the product. This includes planning for the manufacture of component parts of the product for the assembly of spare parts for the products necessary for the customer during the operation of the product. Upon receipt of a complaint, the employees of the enterprise investigate the causes of the failure, in accordance with which a decision is made to change the supplier of components, products for inter-factory cooperations or to adjust design, software or technological documentation.

Thus, at each stage of the life cycle, design and production procedures are performed on the basis of the generated design decisions, which allows to formulate their features and generalize approaches to creating a digital passport.

3. **A generalization of approaches to creating a digital passport supporting the stages of the electronic product life cycle**

The list of data is set by the information objects of PDM, ERP, MES and / or QMS systems, including EDMS, and the list of design and production procedures is set by automated processes.

This allowed to analyze the activity of enterprises of the instrument-making industry at the stages of the life cycle and form a set of pairs “information object - design and production procedure”, which are components of a digital passport.

Thus, at the stage of concluding a contract, a digital passport generally contains:

1. The procedure “Consideration and approval of an application for the development or delivery of products”, which is performed by means of EDMS or PDM. In this case, information objects “Document” of the type “Application for development” or “Application for the supply of products” are created.

2. The procedure “Preparation, registration and signing of an agreement with the customer”, which is performed by means of EDMS, PDM or ERP. In this case, “Document” objects are created of the “Contract with the customer” type.

3. The procedure “Registration and signing of an agreement with a co-executor”, which is also performed by means of EDMS, PDM or ERP. In this case, “Document” objects are created of the “Contract with co-executor” type. The research results show that the objects being formed are interconnected and allow the content of the digital passport to be formed at the development stage in the form of:

   1. The procedures “Development, coordination and approval of an enlarged work schedule”, which is performed by means of PDM, ERP or EDMS, forming a work schedule, including in the form of a “Document” object of the “Unified Assignment” type, and an enlarged ESI-PDM, in the form related objects designating the main components - product devices.

   2. The procedures “Development, coordination and approval of the operational schedule of work”, which is performed by means of PDM, ERP or EDMS, forming a schedule of work, including in the form of a “Document” object of the “Unified Assignment” type [21].

3. The procedures “Development and design change of the printed circuit board”, which is performed by CAD tools under the control of PDM, which allows to create ESI-PDM devices in the form of their circuit components.

4. The procedures “Development and design change of the product”, which is performed by CAD tools under the control of PDM, which allows to create ESI-PDM devices in the form of their designs.

5. The procedures “Updating the database of purchased components (PC)”, for the implementation of which ERP or PDM are used when synchronizing with CAD and MES.

6. Procedures “Development and change of software for the product”, which allows to create the appropriate ESI-PDM using PDM.

7. Procedures “Development and change of operational data for the product”, during which the ESI-PDM created earlier is supplemented with operational documentation.

8. The procedures “Coordination, approval and delivery to the archive of a set of design and program documentation (DD and PD) for the product and its components”, performed by means of PDM.

The ESI-PDM developed at the same time is called the ESI-PDM of the design presentation and is the basis for performing such work at the stage of production preparation, as:

1. The procedure “Development and signing of an application to start production”, which is performed by means of PDM, ERP or EDMS, forming a list of works, including in the form of a “Document” object of the “Unified Assignment” type [21].

2. The procedure “Development and change of technological documentation (TD) for the product”, during which the ESI-PDM of the technological presentation is created, characterized by the unambiguous correspondence of the ESI-PDM of the design presentation.

3. The procedure “Coordination, approval and delivery to the archive of technological documentation” performed by means of PDM.

4. The procedure “Recording comments and decisions during the technological preparation of production” performed by PDM, which allows to create objects “Note” associated with objects “Document” type design documentation [4, 20].

5. The procedure “Recording remarks and decisions during the planning of procurements” performed by PDM, which allows to create objects “Remark” associated with objects “Document” type of design documentation [4, 20].

6. The procedure “Preparation and registration of contracts for the supply of PC, materials and products of IPC”, which is performed by means of EDMS, PDM or ERP. In this case, “Document” objects are created in the form of “Contract with the supplier”.

7. The procedure “Fixing and recording the receipt of a batch of PC, materials and products of the MPC”, which is performed by means of ERP or MES and PDM and means the formation of “Instance” objects corresponding to the received batches of products [4, 18].

8. The procedure “Formation of a production plan for manufacturing products”, which means planning work using MES tools in the form of lists of parts and assembly units to be manufactured at the factory. As a result, a production plan is generated, which is part of the “Unified Assignment” containing an application to start production.

A registered batch of products formed lists of manufactured component parts of the product allow to perform the actions of the production stage. These include:
1. The procedure “Dispatching the production process”, like the previous one, does not generate new digital passport objects, is performed by MES tools and contains lists of parts and assembly units to be manufactured in a specific production workshop. At the same time, a production plan is generated in the workshop, which is part of the “Unified Assignment” containing an application for production launch.

2. The procedure “Fixing the manufacturing operations of manufacturing parts and assembly units” is performed using MES tools, and its results are recorded as a set of “Instance” objects forming the product instance structure (SEI) using PDM tools.

3. The procedure “Recording remarks and decisions in the production process of parts and assembly units of the product”, performed by means of PDM, which allows to create objects “Note” associated with objects “Document” type of design and / or technological documentation [4, 20].

The final stage is the operation and repair, characterized by such works as:

1. The procedure "Registration of shipment of finished products from the warehouse", performed by means of ERP and / or PDM. At the same time, the PIS is supplemented by “Document” objects containing documentation on the shipment of products to the customer.

2. The procedure "Registration of the complaint and the result of the investigation of the refusal", performed by means of QMS and / or PDM. At the same time, the essence of the failure of the product instance — the “Remark” object — is associated with the corresponding “Instance” object, as well as the reason for its occurrence.

3. The procedure "Registration and control of service requests", which is performed by means of EDMS or PDM. In this case, information objects “Document” of the type “Application for service” and associated objects “Document” of the type “Additional agreement to the contract” are created. After that, using PDM, ERP or EDMS, a work schedule is formed in the form of a “Document” object of the “Unified task” type.

Consequently, k sets of digital passport components are obtained.

\[ C_1 = (c_{11}, c_{12}, ..., c_{1m}), C_2 = (c_{21}, c_{22}, ..., c_{2n}), ..., C_k = (c_{k1}, c_{k2}, ..., c_{kn}) \]

the elements of which are given by the pairs “object - design and production procedure” such that

\[ c_{ij} = \langle D_i, P_{ij} \rangle \quad (i = 1, \ldots, k; \ j = 1, \ldots, n_k) \]

where \( D_i \) — an information object containing data about the electronic product;

\( P_{ij} \) — design and production procedure that forms a specific type of product data.

In addition, research results show that the implementation of these procedures requires the generation of design solutions for managing product data and design and production procedures based on them.

4. Features of the formation of design decisions based on a digital passport

For this purpose, the corresponding tasks were formulated, which are further associated with specific design and production procedures and stages of the life cycle. The result of each of them is the same list of components of a digital passport that are interconnected.

In this case, the tasks are characterized by lists of the analyzed parameters that determine the range of permissible values of the formed design decisions. The first of them is the task of searching for data on products and their components, which consists in analyzing the values of parameters such as:

- type of product, component — complex, assembly unit, part, kit;
- manufacturer of the product, component - own production, purchase;
- feature of the component of the product - newly developed, borrowed, IPC;
- comments on the DD - no comments, there are unworked comments, there are worked-out comments;
- the presence of comments on the PD - there are no comments, there are unworked comments, there are worked-out comments;
- availability of comments on the TD - no comments, there are unworked comments, there are worked-out comments;
- a sign of products of inadequate quality - there are no problems, there are small problems, there are serious problems.

Another task is the task of searching for data on PC, materials, products of IPC and their suppliers, which consists in analyzing the values of parameters such as:

- type of product - a standard product, other product, materials, products IPC;
- availability of products in stock - not in stock, in stock;
- the presence of prohibitions on use - there is no prohibition, a complete ban, a ban for new developments;
- availability of restrictions on use - there are no restrictions, there are restrictions;
- the possibility of acquisition - there are no suppliers, there is only one supplier, there are several suppliers;
- a sign of products of inadequate quality - there are no problems, there are small problems, there are serious problems.

The next task is the task of finding data for the development and adjustment of documentation, which consists in analyzing the values of parameters such as:

- type of document - list of elements, specification, statement of specifications, statement of purchased products, statement of electronic documents, statement of spare parts, statement of spare parts for repairs, statement of documents for repairs, ESI;
- type of ESI - functional, constructive, production and technological, physical, operational;
- comments on the DD - no comments, there are unworked comments, there are worked-out comments;
- comments on the PD - no comments, there are unworked comments.

Another objective is the task of searching for data on DD, PD and TD on the components of a product to be developed or adjusted, which consists in analyzing the values of parameters such as:

- type of component of the product - complex, assembly unit, part, kit;
- feature of a component of a product - newly developed, borrowed;
- sign of the document - new DD, adjustment of DD, new PD, adjustment of PD, new TD, adjustment of TD;
- comments on the DD - no comments, there are unworked comments;
- comments on the PD — no comments, there are unworked comments;
- availability of comments on the TD - no comments, there are unworked comments.

The next task is the task of monitoring the results of the implementation of the positions of the unified task, which consists in analyzing the values of such parameters as:

- type of work - development of DD, development of PD, development of TD, adjustment of DD, adjustment of PD, adjustment of TD, purchase, production;
- controlled condition - “Under development”, “At check”, “Delivered to the archive”, “At revision”, “Litera ...”, “Completed”;
Another task is the task of managing production operations, which consists in analyzing the values of parameters such as:

- type of component of the product - complex, assembly unit, part, kit;
- comments on the DD - no comments, there are unworked comments;
- availability of comments on the TD - no comments, there are unworked comments;
- availability of products in stock - not in stock, in stock;
- sign of the production process - started, completed, suspended;
- sign of products of inadequate quality - no problems, there are problems.

And the last task is the task of creating design and production procedures, which consists in analyzing the values of parameters such as:

1) the current stage of the life cycle - the conclusion of the contract, development, preparation of production, production, operation, repair;
2) type of document from the customer - application for development, reclamation certificate, application for the supply of products, application for service;
3) the task of forming a design solution - a list of tasks listed earlier.

Therefore, for any design and production procedure at each stage of the product life cycle, the task of forming a design solution will be formed in the form of a linguistic variable, the output of which is based on elements of fuzzy logic.

5. Conclusion

Thus, the results of a generalization of approaches to creating a digital passport and the features of the formation of design decisions based on it were obtained:

1) the content of the digital passport is determined by the components in the form of pairs “object - design and production procedure”;
2) the combination of components allows to create a product structure that contains not only its composition, but all related documents, including lists of procedures used;
3) the content of the digital passport is used to generate design decisions for managing product data and design and production procedures;
4) the formation of design decisions is associated with the corresponding tasks formulated in the form of linguistic variables, which allows to set the range of acceptable values for the generated solutions.

This allowed us to develop an algorithm for the generation of design solutions, according to which their desired version contains the associated components of a digital passport that fall inside the area specified by the values of the linguistic variable. The results obtained can be used to create signatures and semantics of applied unified services for a digital passport in the instrument-making industry, used in the development, delivery and maintenance of electronic products.

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Automated testing framework with browserstack integration

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Abstract: Nowadays ensuring high-quality software product requires a lot of testing efforts. Automated tests in the 21st century are a must. Whether it’s code peer-review, unit, integration, system or exploratory user testing – it all has to be done with given insurance and expertise! Therefore, we look to automate our testing where is conceivable. Most applications today have the equivalent of Web and Mobile versions for the same functionality, but different platforms of action in order to facilitate the users. Therefore, parallel testing of both subtypes is required to provide smooth maintenance and rapidity. Running as many builds as possible, including tests to ensure quality is essential when comes up to reliable software product and agile development. With the implementation of Continuous Integration and Continuous Delivery tools, we guarantee a better way to deploy automated tests across multiple instances and execute them against those environments. BrowserStack is one common cloud solution to these requirements. It is a very powerful tool, which can be attached to our development process. This article explores detailed approach on the automation of cross-browser, device and compatibility testing in BrowserStack platform, using a custom extended automation framework to provide direct configuration output to this environment and give ease in the future Web and Mobile development.

Keywords: AUTOMATION, FRAMEWORK, TESTING, QUALITY, ASSURANCE, BROWSERSTACK

1. Introduction

There are many cloud-based applications available today that help with software development, regardless of the area we want to use or improve. It is especially important to keep in mind that when it comes to software quality assurance it is almost mandatory to take most of the automated tests on cloud infrastructure, such as: Amazon Web Service (AWS), BrowserStack, SourceLabs and etc. All of these platforms have similar functionalities and are easy to use.

The problem area of the current scientific work is focused on that in order to be able to take advantage of all the available features and functionalities, we need to have a well-defined and extended automated testing framework that programmatically interacts and communicates with the above-mentioned cloud-based systems, because they all provide own rules of operation and configuration, resulting in obstacles and delays in the transformation from on-premises development to cloud-based. In this study, we will track the extension of an automated software framework geared toward connecting to a cloud-based cross-browser testing platform and utilizing all the benefits of this approach.

2. BrowserStack introduction

BrowserStack is one of the world’s most trusted platforms for cross-browser testing. It allows interactively testing and debugging websites across thousands of browsers and real mobile device browsers to ensure that applications are working flawlessly. In real-time, it is difficult to test an application in different browsers using multiple operating systems, with varying versions.

It will cost a lot to buy many computer machines to install different operating systems. It is even more difficult to buy all the Android and iOS mobile devices that are available in the market today. Due to this reason, it is not practical to buy and set up all the devices. Thus, we go with the BrowserStack to avoid the complexity of switching between the operating systems, browsers, and different versions.

When it comes to mobile application testing, we can avoid buying all the mobile devices that are available today. Browser Stack is very flexible and scalable. We can test anywhere and anytime with the help of Browser Stack.

We can use Browser Stack as a remote lab and can use this as Real Desktop Browsers. It gives us free Javascript unit tests and supports 750 configurations. There is no set up required for using BrowserStack. We can use it directly on any independent machine by using the Browser Stack URL and its login credentials. [1]

3. Automated testing framework

The benefit of creating an automation framework is to use it as a template for every new project, offering us the leverage to avoid all of the known problems. When automated tests are created, the first thing we do is to interact with the browser. This can include navigating to a page, clicking a button, or filling in a login form and many different actions. After that, we need to verify and report the actual versus the expected results. While we have many different tests at our disposal, how and when we use them is dependent on the scenario. In some cases, we will execute several tests in a specified order. In others, only execute specific tests. In order to achieve all of this, testers usually need to implement different frameworks or libraries along with the Selenium Web driver. As we said most projects have common user actions that need to be accomplished in an automated flow. These interactions are developed and implemented in the framework itself and the testers can use them right away without wasting time to write or re-write them again from the start. [2]

With the advantages of the framework, there is no need to waste time developing this functionality since it is already done generally. Along with all positives, this development is integrated and extended from Selenium and Appium. This gives us the flexibility to easily choose which tests we want to execute: whole test suite / scenario, or only smoke, sanity tests and etc. also other perspectives or a specific set of tests. It supports data-driven behavior testing and flexible configuration setup.

Another benefit of creating an automated software framework is the ability to prepare ready-made configured classes and packages for the use of many external sources such as: cloud-based tools, external media, servers or resources. The use of the ready-made techniques in the automated framework saves us time, prevents additional effort and facilitates understanding of the business logic.

In Figure 1 we can see a detailed graphical representation and collaboration of all tools and libraries of the software testing framework architecture and the benefits of using BrowserStack cloud platform.
As we said BrowserStack is a wide open platform, its distribution is based on the following architecture: SaaS (Software as a service), which means that this is a cloud-based solution in a set of functionalities under certain rules. In order to facilitate the usage, we will go through these requirements and take advantage of all its benefits, we should also stick to those rules and set of desired capabilities, which BrowserStack expects from us.

The architecture is based on ‘Hubs’ and ‘Nodes’. The Hub is the central point that will receive all the requests along with information on which browser, platform (i.e. Windows or Linux) and which device the test should be run on. Based on the request received, it will distribute them to the registered nodes. Nodes are where the corresponding tests will run. Each node is a machine (physical/virtual machine) or a real mobile device that is registered with the hub. When we register a node, the hub has the information of the node and it will display the browser and configuration details of the nodes.

The prerequisites required to set up BrowserStack are the Capabilities object and Remote WebDriver. The capabilities object would help to configure the desired properties and platform for the tests, and Remote WebDriver is used to hit the BrowserStack API.

Based on the preferences set in the desired capabilities instance, the Hub will point the tests to a node that matches the preferences.

In the following chapter, we will review how BrowserStack API works.

### 4. BrowserStack Architecture

Here is a sample code snippet in Java that sets the capability to point the required node to the respective hub:

```java
final String USERNAME = "";
final String AUTOMATE_KEY = "";
final String URL = "https://" + USERNAME + ":" + AUTOMATE_KEY + "@hub-cloud.BrowserStack.com/wd/hub";

try {
    DesiredCapabilities caps = new DesiredCapabilities();
    caps.setCapability("browser",browser);
    caps.setCapability("browser_version","browser_version");
    caps.setCapability("os","os");
    caps.setCapability("os_version","os_version");
    caps.setCapability("resolution","resolution");
    caps.setCapability("project","Project-1");
    caps.setCapability("build","1.0");
    caps.setCapability("BrowserStack.debug","true");
    driver = new RemoteWebDriver(new URL(URL),caps);
} catch(MalformedURLException e) {
    e.getMessage();
}
```

Now we can run the desired test automation suite on BrowserStack. Each test run has a unique session ID associated with it. Based on the session ID, all the details required for test execution will be fetched. Each test execution has bug logs generated, for example: a text log that gives a textual representation of each process running in the background. There is also a visual log that shows screenshots of the test being executed. [3]

Methods in DesiredCapabilities for Selenium configuration:

Now let’s have a look at all the methods available in the DesiredCapabilities Class.

1. getCapability();
   This method helps in retrieving the capabilities of the current system on which the tests are being performed.
   ```java
   public java.lang.Object getCapability(java.lang.String capabilityName)
   ```

2. setCapability();
   The setCapability() method is used to declare the properties of test environments like device name, operating system name, operating system versions, browser, and browser versions.
   ```java
   public void setCapability(java.lang.String capabilityName,Platform value)
   ```

   The setCapability() method has the following declarations in Java:

   ```java
   setCapability :public void setCapability(java.lang.String capabilityName,boolean value)
   setCapability :public void setCapability(java.lang.String capabilityName,java.lang.String value)
   setCapability :public void setCapability(java.lang.String capabilityName,Platform value)
   setCapability :public void setCapability(java.lang.String key,java.lang.String value)
   ```

3. getBrowserName();
   This method helps in retrieving the browser name of the current system.
   ```java
   public java.lang.String getBrowserName()
   ```

4. setBrowserName();
   This method is used to set the name of the browser on which tests are to be executed.
   ```java
   public void setBrowserName(java.lang.String browserName)
   ```

5. getBrowserName();
   This method helps in retrieving the version of the browser or the operating system of the current system used for running the tests.
   ```java
   public java.lang.String getBrowserVersion()
   ```

6. getProject();
   This method helps in defining the version of the browser or the operating system on the background. There is also a visual log that shows screenshots of the test being executed. [3]

7. getPlatform();
   This method helps in retrieving the details of the operating system.
   ```java
   public java.lang.String getPlatform()
   ```

8. setBrowser();
   This method helps in defining the desired operating system to be used.
   ```java
   public void setBrowser(java.lang.String browserName)
   ```

Infrastructure model for interaction from our local machine and BrowserStack cloud platform:

1. BrowserStack Local makes a REST call using the user’s access key to BrowserStack.com.
2. BrowserStack.com chooses a repeater to establish a secure connection for Local Testing.
   The repeater exists within the BrowserStack cloud infrastructure.

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    caps.setCapability("os","os");
    caps.setCapability("os_version","os_version");
    caps.setCapability("resolution","resolution");
    caps.setCapability("project","Project-1");
    caps.setCapability("build","1.0");
    caps.setCapability("BrowserStack.debug","true");
    driver = new RemoteWebDriver(new URL(URL),caps);
} catch(MalformedURLException e) {
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```

Now we can run the desired test automation suite on BrowserStack. Each test run has a unique session ID associated with it. Based on the session ID, all the details required for test execution will be fetched. Each test execution has bug logs generated, for example: a text log that gives a textual representation of each process running in the background. There is also a visual log that shows screenshots of the test being executed. [3]

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   This method is used to set the name of the browser on which tests are to be executed.
   ```java
   public void setBrowserName(java.lang.String browserName)
   ```

5. getBrowserName();
   This method helps in retrieving the version of the browser or the operating system of the current system used for running the tests.
   ```java
   public java.lang.String getBrowserVersion()
   ```

6. setVersion();
   This method helps in defining the version of the browser or the operating system on the background. There is also a visual log that shows screenshots of the test being executed. [3]

7. getPlatform();
   This method helps in retrieving the details of the operating system.
   ```java
   public java.lang.String getPlatform()
   ```

8. setPlatform();
   This method helps in defining the desired operating system to be used.
   ```java
   public void setPlatform(java.lang.String version)
   ```

Infrastructure model for interaction from our local machine and BrowserStack cloud platform:

1. BrowserStack Local makes a REST call using the user’s access key to BrowserStack.com.
2. BrowserStack.com chooses a repeater to establish a secure connection for Local Testing.
   The repeater exists within the BrowserStack cloud infrastructure.
3. BrowserStack.com supplies BrowserStack Local with the information necessary to establish a connection with the repeater.

4. BrowserStack Local initiates a connection to the repeater on port 443, using our custom SSL-encrypted protocol.

   Note: The repeater cannot directly initiate a connection to BrowserStack Local.

5. A secure, bi-directional, and persistent connection is established between the end user machine and the repeater. We use Secure WebSockets as part of our communication framework. If your enterprise firewall blocks the WebSocket protocol, we fall back to a legacy protocol which is also SSL encrypted, but much slower than WebSockets. For best results, we recommend that outgoing WebSocket connections be allowed in your firewall.

   Note: The secure connection is only established up to the user’s machine.

5. Extended Framework Architecture

   As we said, in the beginning, our case study is focused on expanding the core software test framework, in this chapter we will follow the overall development of the framework targeting Mobile and Web configurations used and envisioned in BrowserStack.

   To be able to use and connect our tests to BrowserStack platform and run it as well, we should extend our automation framework to meet the given rules from BrowserStack architecture. We extended our custom automation framework based on Selenium WebDriver and TestNG, written in the programming language Java.[5][6]

   We have two types of tests in our testing framework, Web and Mobile tests. Web tests are concentrated to run on different browsers, versions, resolutions, projects and builds. Mobile tests, on the other hand, are supposed to run on different devices and operating systems (OS), including Android and iOS. For this purpose, we created the following packages: Device Manager to handle device metrics, prerequisites and configurations, Mobile Capabilities to get the given mobile resources and Web Capabilities.

   In Device Class diagram is the whole logic for device capabilities, which we described in BrowserStack architecture, with the given code:

   ```java
   public abstract class MobileCapability extends AbstractCapability {
       private String capabilityName;
       MobileCapability(final DesiredCapabilities capabilities, final String capabilityName) {
           // constructor implementation
        }
   }
   ```

   We can manipulate the whole device settings and configurations and also parse it through the testing framework for further explorations.

   When objects are locally set up we can proceed to transfer them via BrowserStack cloud base platform to handle the given capabilities, for Mobile and Web testing approach.

   For Mobile testing purpose, we created the following file: MobileCapability.java which is the main class to get the options from iOS and Android Capabilities instances, such as OS type and given versions. We also have BrowserStackMobileCapability which will transfer objects directly to BrowserStack Cloud platform.

   ```java
   public abstract class MobileCapability extends AbstractCapability {
       private String capabilityName;
       MobileCapability(final DesiredCapabilities capabilities, final String capabilityName) {
           // constructor implementation
        }
   }
   ```
super(capabilities);
    this.capabilityName = capabilityName;
}

@Override
public DesiredCapabilities get() {
    new CapabilityPreferences(this.capability, this.readCapabilities());
    return this.capability;
}

Figure 4. Mobile Capability Class Diagram

For Web testing, we created WebCapability.java to inherit different capabilities: depending on browsers, versions, resolutions, projects and builds.

Figure 5. BrowserStack Web Capability Class Diagram

From Web perspective, we are allowed to use all of the BrowserStack functionalities for different browser testing approach and versions, such as: Google Chrome, Mozilla Firefox, Internet Explorer, MS Edge and Safari. In the given class diagram there is a provided solution on every capability to be parsed from the automation testing framework through BrowserStack platform. We also can manage to choose from a list of supported browser versions.

6. Conclusion

In this paper, we have proposed creation of an automated testing framework with BrowserStack integration. Using this approach provide several benefits such as code re-usage, higher portability, easy maintainability, reduced script maintenance, low cost and “ready-go” configuration to use it directly with BrowserStack cloud platform. Automating most of the actions according to the guidelines reduces manual operations. Since maximum coverage is already in-built and achieved at the initial stage, there is very little or no intervention required by individuals to run the automation tests. Parameters can be parsed automatically from the local machine through BrowserStack, everything is set, only the subscription key is needed to activate the whole process between our development and BrowserStack platform. This article explores a detailed approach on the automation of cross-browser, device and compatibility testing in BrowserStack platform, using a custom extended automation framework to provide direct configuration output to this environment and give ease in the future Web and Mobile development.

7. References


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Analysis of the noise immunity of quadrature modulation method for turning signal constellations

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Abstract: The paper considers the effect of the rotation of the signal constellation on the noise immunity of quadrature multi-point modulation methods. Based on the error vector in the Matlab + Simulink simulation environment, models of M - QAM modulators and demodulators with rotation of the signal constellations at an arbitrary angle are proposed. Considered the most commonly used in digital data transmission systems modulation: 4-QAM, 16-QAM, 64-QAM and 256-QAM. The simulation results of the proposed models confirmed the coincidence of the values of the rotation angles of the signal constellations recommended by the DVB-T2 standard, and also revealed the values of other angles that can be used to improve the noise immunity of multipositional quadrature modulation methods.

KEYWORDS: ERROR VECTOR, NOISE IMMUNITY, SIGNAL CONSTELLATION, ROTATION OF THE SIGNAL CONSTELLATION

1. Introduction

To effectively use the allocated bandwidth of the communication channel, multi-position signals are used - multi-position phase shift keying (M - PSK (Phase Shift Keying)) and multiposition quadrature amplitude keying (M - QAM (Quadrature Amplitude Keying)). On the other hand, in case of loss of information about one of the coordinates, it can be restored most often built on quadrature circuits [1,3].

In the presence of nonlinear and phase distortions, interference and channel noise, transient interference between quadrature channels occurs. In this case, the signal constellations become blurred, that is, in each measure, the constellation point has random coordinates. The BER (Bit Error Ratio) is the best indicator to evaluate the quality of a transceiver, but BER testing is not always possible when developing an RF unit, because for measuring BER, along with the RF unit, you must have an information path for full digital processing of the received signal. An alternative to measuring the BER type of testing is to study the quality of the demodulated signal using vector analysis [7 - 10].

One of the most widely used quantitative indicators of the quality of modulation in digital communication systems is the EVM (Error Vector Magnitude). The magnitude of the error vector should not be confused with the magnitude error and the phase of the error vector.

The value of the EVM vector makes it possible to determine the sources of errors and their contribution to the process of generating and processing signals in digital systems. It is sensitive to any degradation in signal quality that affects the magnitude and phase trajectory of the demodulated signal. The most difficult from the point of view of correlation of the measured signal vector to the ideal is the case when the real measured signal falls exactly in the middle between the points of the signal constellation, as shown in Fig. 1.1 a.

In this case, the calculation of the minimum of the metric (Δr) gives an ambiguous result. The DVB-T2 standard uses a turn of the signal constellation at a certain circular angle [2], which allows to improve the noise immunity of the system. Table 1.1 shows the values of the rotation angle of the constellation depending on the type of modulation.

Table 1.1. The values of the rotation angle of the constellation for different types of modulation

<table>
<thead>
<tr>
<th>Modulation type</th>
<th>QPSK</th>
<th>16-QAM</th>
<th>64-QAM</th>
<th>256-QAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>The rotation angle of the constellation</td>
<td>29°</td>
<td>16,8°</td>
<td>8,6°</td>
<td>arctg(1/16)</td>
</tr>
</tbody>
</table>

Such a turn can significantly increase the stability of the signal with typical problems of the ether. Each vector of such a constellation acquires its individual coordinates I and Q (Fig. 1.1b). In this case, the values of the error vector Δr' and Δq' have different values and there are no ambiguities in the calculation of the minimum of the metric.

On the other hand, in case of loss of information about one of the coordinates, it can be restored. As a rule, to reduce the likelihood of packet errors, the original digital data is interleaved. As a result of interleaving, the components I and Q are transmitted separately, which reduces the probability of their simultaneous loss. Thus, if one carrier or symbol is lost as a result of interference, information about the other coordinate is saved, this will allow restoring the symbol, albeit with a lower signal-to-noise level.

By now, a number of studies on the effect of the turn of the signal constellation have been performed [5, 6], however, to this day, the effect of the turn of the signal constellation has not been fully investigated. In particular, the mutual influence of signals carrying the same information at different angles of rotation of the signal constellation was not studied.

The possibility of turning a signal constellation on angles other than those recommended by the standard, and studying the mutual influence of the same signal turned on different angles, is of particular interest for practical application.

2. Preconditions and means for resolving the problem

2.1. Theoretical Data

To analyze the effect of the signal constellation rotation on the quadrature modulation noise immunity, an improved model of the “QAM-modulator” →”AWGN” → “QAM-demodulator” subsystem was developed, which takes into account the rotation of the signal constellation at a given angle. The model was developed using the computer math system MATLAB / SIMULINK 9.0 (R2017b). Processing and analysis of the simulation results were carried out using the program Origin Pro 2017 [11,12].

The standard Simulink block "Rectangular QAM-Modulator" outputs a quadrature amplitude-modulated signal that can be considered as a vector of complex numbers, the real part of which is the in-phase component of the quadrature signal, and the imaginary part is the quadrature component:
QAM = Re^{QAM} + Im^{QAM} = I + jQ.

(1.1)

From the mathematical theory of complex numbers, we know a linear transformation on the complex plane, leading to a rotation of a point by a given angle \( \phi \):

\[
\begin{align*}
x' &= x \cos \phi - y \sin \phi, \\
y' &= x \cos \phi + y \sin \phi,
\end{align*}
\]

(1.2)

Since the abscissa of the complex plane is the real part of the complex number, and the ordinate is its imaginary part, formula (1.2) can be rewritten:

\[
\begin{align*}
Re' &= Re \cos \phi - Im \sin \phi, \\
Im' &= Re \cos \phi + Im \sin \phi.
\end{align*}
\]

(1.3)

Thus, in terms of quadrature modulation, taking into account (1.1) – (1.3), we can write this:

\[
\begin{align*}
I' &= I \cos \phi - Q \sin \phi, \\
Q' &= I \cos \phi + Q \sin \phi.
\end{align*}
\]

(1.4)

Based on formula (1.4), the Simulink model was created. To divide the quadrature signal into real (Re) and imaginary (Im) components, the standard block of the Simulink library "Complex to Real-Imag" is used, and the "Rectangular QAM-Modulator" block is used as the source of the quadrature signal. The block "Random Integer Generator" simulates the low-frequency signal of digital television broadcasting.

From the blocks of the library Simulink created subsystem "Transmitter" and "Receiver" taking into account the rotation of the signal constellation. In the receiver it is necessary to restore the initial position of the signal constellation. Therefore, before applying to the demodulator input, the received signal must be rotated through an angle that complements the rotation angle to 360° (denote it by \( \phi' \)).

In order to manually transfer the value of the angle \( \phi \) from degrees to radians each time and calculate the value of the additional angle \( \phi' \), we supplement the model of the system with a subsystem for performing these calculations.

2.2. Experimental Data

The final model for studying the effect of the rotation angle of the signal constellation on the noise immunity of the quadrature modulation schemes of M-QAM will take the following form (Fig. 1.2).

Setting the value of the angle of rotation in degrees (0 for the initial state without rotation), select the value of the parameter "\( E_b / N_0 \)" in the settings of the block "AWGN" at which the specified error is observed for before. Enter the values of the rotation angle \( \phi \) and the corresponding values of this angle "\( E_b / N_0 \)" in the table for building graphs of the functions "\( E_b / N_0 = f(\phi) \). Repeat the previous action for all angles in the range (0: 1: 90) for each type of modulation. The simulation results are shown in Fig.1.3 - Fig.1.6.
From the graphs it can be seen that for each modulation several energy minima were found, for which the signal-to-noise ratio is less than for an un-turned signal constellation. The data on the detected energy minima are summarized in Table 1.2, and the main statistical information in Table 1.3.

Table 1.2. Energetically favorable angles of rotation of the signal constellation

<table>
<thead>
<tr>
<th>Modulation Type</th>
<th>Angles of constellation,°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended</td>
<td>Experimentally found angles</td>
</tr>
<tr>
<td>4-QAM</td>
<td>29</td>
</tr>
<tr>
<td>16-QAM</td>
<td>16.8</td>
</tr>
<tr>
<td>64-QAM</td>
<td>8.6</td>
</tr>
<tr>
<td>256-QAM</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Graph of "$E_b / N_0 = f (\phi)$ for 256-QAM

From the graphs it can be seen that for each modulation several energy minima were found, for which the signal-to-noise ratio is less than for an un-turned signal constellation. The data on the detected energy minima are summarized in Table 1.2, and the main statistical information in Table 1.3.

Table 1.3. Statistical calculation data

<table>
<thead>
<tr>
<th>Modulation Type</th>
<th>$E_b / N_0$ min, dB</th>
<th>$E_b / N_0$ max, dB</th>
<th>$\sigma (E_b / N_0)$, dB</th>
<th>$\Delta (E_b / N_0)$, dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-QAM</td>
<td>29.4</td>
<td>29.95</td>
<td>0.1566</td>
<td>0.55</td>
</tr>
<tr>
<td>16-QAM</td>
<td>29.82</td>
<td>30.3</td>
<td>0.1184</td>
<td>0.48</td>
</tr>
<tr>
<td>64-QAM</td>
<td>29.95</td>
<td>30.5</td>
<td>0.1203</td>
<td>0.55</td>
</tr>
<tr>
<td>256-QAM</td>
<td>30</td>
<td>30.29</td>
<td>0.0714</td>
<td>0.29</td>
</tr>
</tbody>
</table>

3. Conclusion

In the program package MATLAB / SIMULINK, mathematical models of the subsystems "Transmitter", "Receiver" and "Model of recalculation of angles $\phi$ and $\phi'$" were developed. To investigate the effect of rotation of the signal constellation on the immunity system of transmission of digital information on the basis of the developed mathematical models of the subsystems is proposed mathematical model of the data transmission system with AWGN channel.

It can be seen from the graphs shown in Fig.1.3 – Fig.1.6 that for each modulation several energy minima were found for which the signal-to-noise ratio is less than for an un-rotated signal constellation. Based on the data presented in Table 1.2 and Table 1.3, we can draw the following conclusions:

- DVB-T2 recommended angles of rotation of the constellation received experimental confirmation.
- For all studied types of multi-point modulation, except for 16-QAM, besides the standard recommended by the standard, there are also other energetically favorable angles of rotation of the signal constellation. This opens up scope for further research on this topic.
- As M grows, the effect of turning the signal constellation decreases

4. References

Abstract: Virtual Private Networks (VPN) enable usage of the public Internet infrastructure to build secure and reliable connections providing functionally of private corporate IT networks. Back in 90s VPN were created to mainly allow access to corporate resources for employees who work remotely and/or travel. Today, VPN can be used to gain access to geographically isolated and highly protected Internet resources like websites, interactive platforms and more. Such VPN are good for protecting Internet users’ privacy and enhance their security especially when using public free Wi-Fi networks. Indeed, now VPN are used more and more and gain popularity for exactly those reasons - provide almost universal access and protect privacy of millions Internet users. This paper reviews building blocks and procedure to build our own VPN. This way power users are in full control of their privacy and security when using public Internet infrastructure while also gain access to otherwise restricted online resources.

Keywords: AWS, VPN, PRIVACY, SECURITY, CLOUD COMPUTING

1. Introduction

There are many VPN providers which offer paid VPN service for Windows, macOS, iOS and Android devices. Using freely available resources like AWS Free Tier and Open-VPN private and personal VPN can be deployed, configured and used for even higher level of protection and control for user data and privacy.

2. Deploying Virtual Machine in AWS Free Tier

First step in creating private and personal VPN is to register in Amazon for AWS free tier (1). Registration is straightforward as shown in Figure 1:

Fig. 1 Registering for AWS Free Tier

Once registration process is completed next steps is to login in Amazon console and deploy Amazon Elastic Computing Cloud (EC2) virtual machine (Figure 2) using proper Amazon Machine Image (AMI) as show in (Figure 3):

Fig. 2 Selecting Free-Tier EC2 instance

Fig. 3 Selecting proper public AMI image

3. OpenVPN Access Server Configuration

Once the AMI image is deployed and started it is time to configure OpenVPN Server. This can be done with graphical user interface wizard using associated elastic public IP for the AWS free tier instance visiting https://xxx.xxx.xxx.xxx/admin where xxx.xxx.xxx.xxx is public elastic AWS IP of the server. The process is completed by choosing password and then OpenVPN is started and accessible using same elastic IP as show in Figure 4:

Fig. 4 OpenVPN Access Server Admin Console

Additional fine tuning can be done using SSH (ssh keypair is created for access in AWS console) by connecting to the elastic public IP over SSH protocol as shown in Figure 5:
One of the most advanced SSH clients is MobaXterm client (3) which is also a free tool. Good SSH clients are also PuTTY (4) and mRemoteNG (5) and any default Linux native ssh client usually part of OpenSSH package (6). On Table 1 is provided comparison between the respective SSH clients.

Table 1: Comparison of commonly used SSH clients

<table>
<thead>
<tr>
<th>N</th>
<th>SSH Client</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MobaXTerm</td>
<td>Fast and reliable</td>
<td>Windows only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Many handy features</td>
<td>Closed source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stored sessions</td>
<td>Paid for non-academic use</td>
</tr>
<tr>
<td>2</td>
<td>PuTTY</td>
<td>Fast and reliable</td>
<td>Windows only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small footprint</td>
<td>Closed source</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stored sessions</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>mRemoteNG</td>
<td>Fast and reliable</td>
<td>Windows only</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Open source</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stored sessions</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>OpenSSH</td>
<td>Multiformat</td>
<td>Command Line Interface (CLI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Open source</td>
<td>only</td>
</tr>
</tbody>
</table>

Final step is to create new user in the VPN server and test with windows and Android clients. Creating user is done by using OpenVPN server GUI as shown in Figure 6:

Windows OpenVPN client can be downloaded from OpenVPN website (2) and respective mobile clients from Google PlayStore for Android (6) and Apple AppStore for iOS (7). Once those clients are installed and configured to access OpenVPN server instance in AWS cloud (by using public elastic IP) users can start their surfing in protected and secured environment as shown in Figure 7.

3. Conclusion

By using freely available resources from Amazon cloud and OpenVPN community along with applications for major mobile platforms like iOS and Android in conjunction with couple of solid SSH clients provides means of quick, based on author’s experience in matter of 1-2 hours, deployment, configuration and ready to use personal VPN server. This is is extremely helpful for access to otherwise protected and locked Internet resources. What is more such VPN help protecting user traffic from surveillance and keeping users privacy and blocking potential hackers hijacking public free Wi-Fi networks.

4. References

Solve parameter influence on the results of multilayer perceptron for estimating power output of a combined cycle power plant

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Abstract: Previous work has determined the ability of using the Multilayer Perceptron (MLP) type of Artificial Neural Network (ANN) to estimate the power output of a Combined Cycle Power Plant (CCPP) in which optimization did not focus on the solver parameter optimization. In previous work, the solvers used the default parameters. Possibility exists that optimizing solver parameters will net better results. Two solver algorithm’s parameters are optimized: Stochastic Gradient Descent (SGD) and Adam, with 140 and 720 parameter combinations respectively. Solutions are estimated through the use of Root Mean Square Error (RMSE). Lowest RMSE achieved is 4.275 [MW] for SGD and 4.256 [MW] for Adam, achieved with parameters: \( \alpha = 0.01, \beta_1 = 0.95, \beta_2 = 0.99, \) and \( \text{amsgrad} = \text{False} \) for Adam. Only a slight improvement is shown in comparison to previous results (RMSE=4.305 [MW]) which points towards the fact that solver parameter optimization with the goal of improving results does not justify the extra time taken for training.

KEYWORDS: COMBINED CYCLE POWER PLANT, MULTILAYER PERCEPTRON, ARTIFICIAL NEURAL NETWORKS, STOCHASTIC GRADIENT DESCENT, ADAM, SOLVER ALGORITHM

1. Introduction

Gas Turbine (GT) power plants are common in such cases where power along with heat production is acceptable. GTs are characterized with a higher heat production, which is commonly released into the atmosphere [1]. To avoid such losses, this heat can be used for steam production, which is in turn used by a steam turbine (ST) [2]. These turbines are used in various applications such as power production and ship propulsion systems. Such systems, which combine the use of ST and GT are commonly referred to as Combined Cycle Power Plants (CCPP) [3]. Determining the total power production of such complex systems is extremely complex, leading to the use of advanced techniques – such as artificial intelligence (AI) methods for their determination [4, 5]. Regressive AI methods, such as regression MLP ANN can be used to great effect in many fields such as maritime sciences [6, 7], robotics [8, 9] and medicine [10]. Previous work by Lorenčin et al. in “Genetic Algorithm Approach to Design of Multi-Layer Perceptron for Combined Cycle Power Plant Electrical Power Output Estimation” shows the ability of using Evolutionary Computing (EC) methods for optimization of MLP ANN parameters. EC algorithms are another branch of AI algorithms widely used for optimization [11]. In paper in question, authors propose a solution that optimizes the parameters of the MLP through the use of a genetic algorithm. Energy analyses like the one performed here are extremely important in energetics with the goal of predicting the satisfaction of energy needs and possible failures [12-14]. The optimal architecture found by authors was one with five hidden layers with 80, 25, 65, 75 and 80 neurons in each, with Sigmoid, Tanh, ReLU, ReLU and ReLU activation function for each respective layer and 13 epoch executions, and it achieved a RMSE of 4.305 [MW]. When it comes to the solvers used, authors have only varied the algorithm used between SGD and Adam. As these algorithms have the ability of setting various parameters, this paper proposes use of grid search method in the attempt of finding a better solution. RMSE will be used to estimate quality of solutions, with better solutions being ones with smaller error. Goal of the paper is to achieve a smaller error than previously achieved through adjusting the solver parameters.

2. Analyzed Power Plant and Dataset Description

This chapter describes the powerplant dataset used in the description, as well as the CCPP on which the measurements for dataset creation were made.

2.1. Analyzed Combined Cycle Power Plant

The CCPP used in this research consists of two GT and on ST. The motion energy of the described turbines is transmitted to power generators. The exhaust of GTs is connected to a heat recovery steam generator (HRSG), consisting of high pressure (HP) and low pressure (LP) ST. The schematic of the system is given on Figure 1.

**Fig. 1. Schematic of the CCPP used in research [5] (1 – LP super heater; 2 – LP evaporator; 3 – LP economizer; 4 – HP super heater; 5 – HP evaporator; 6 – HP economizer)**

System consists of two 160 [MW] ABB 13E2 GTs and one 160 [MW] ABB ST. Power plant used in this research has a nominal power generation capacity of 480 [MW].

2.2. Dataset Description

Dataset consists of 9568 total samples. Each sample consists of five parameters:
- temperature (T),
- ambient pressure (AP),
- relative humidity (RH),
- exhaust vacuum (V), and
- net hourly electrical energy output (EP).

First four parameters (T, AP, RH, V) are used as inputs, while the final (EP) is used as the output. T, AP and RH are measured as GT air intake parameters, and V is measured as ST exhaust vacuum. EP is measured at the electric power generators output. Ranges and units of the parameters are defined in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Ranges of individual parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td>AP</td>
</tr>
<tr>
<td>RH</td>
</tr>
<tr>
<td>V</td>
</tr>
<tr>
<td>EP</td>
</tr>
</tbody>
</table>
3. Multilayer Perceptron description

MLP is a feed-forward ANN consisting of a single input layer, a single output layer and one or more hidden layers. Each layer consists of neurons, that are connected to neurons in previous and following layers with connections. Input layer has a number of neurons equal to the inputs in the dataset (four in this case), while the output layer has a single neuron. Each connection connects the output of a neuron to the input of the other. When discussing MLP, usually a fully connected architecture is discussed. This denotes that each of the neurons in one layer is connected to every neuron in the following layer [15].

Each neuron has a value, with value of the neuron in the output layer being the output value of the ANN. Values of the input neurons are the input values of the dataset. Value of the output and hidden layer neurons is calculated as the weighted sum of inputs, passed to the activation function as shown in [15]:

\[ f(X_t) = \mathcal{F}(X_t \cdot \Theta) = \mathcal{F}(x_1 \cdot \theta_1 + x_2 \cdot \theta_2 + \cdots + x_n \cdot \theta_n) \] (1)

where \( f \) is the activation function which maps the input to the output. Basic activation functions are commonly designed to keep the data within a wanted range (sigmoid, TanH), or to eliminate the unwanted elements (ReLU); \( X_k \) is the input vector – vector containing each output value of neurons connected to the neuron, with \( x_1 \) to \( x_n \) being individual output values; and \( \Theta \) is a vector of connection weights, with \( \theta_1 \) to \( \theta_n \) being the connection weight values corresponding to each of the input values \( x_1 \) to \( x_n \) [16].

ANNS are multi-stage algorithms, consisting of a training and testing stage. First data is split into training and testing sets. In this research 7500 data points were used in the training set, with the remaining 2068 points being used in the testing set. Each iteration of the training stage is split into two parts – so called forward and backward propagation. First the initial weights of the MLP are set randomly. During the forward propagation input data from each data point is set as input to the neural network and propagated through the hidden layers. Once the output is reached the real, expected value (known from the dataset) is compared to the received value from the neural network. The difference between the expected and received value is used as the cost function (also known as Loss), defined as [15, 17]:

\[ J(\Theta) = \text{MSE} = \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{2n}, \] (2)

where cost function \( J(\Theta) \) is defined as a mean square error in which \( y_i \) is the expected value of the ANN output, \( \hat{y}_i \) is the predicted value, in other words the value calculated by the ANN, and \( n \) being the total number of data points in the set.

We aim to lower this value to zero, and to achieve this the weights need to be adjusted. This process is called backward propagation, in which the error of the neural network is propagated from the output to the input and each connection weight is adjusted. The amount of adjustment depends on the size of the error – with larger errors causing a larger weight adjustment. To determine the adjustment necessary the gradient is used, calculated as the partial derivative of the cost function by the current weight:

\[ \theta' = \frac{\partial J(\Theta)}{\partial \Theta}, \] (3)

The connection weight is being updated using:

\[ \theta_{new} = \theta_{old} - \frac{\alpha}{n} \theta', \] (4)

with the new weight value being denoted by \( \theta_{new} \), old value by \( \theta_{old} \); gradient \( \theta' \) is determined by equation (3), \( n \) is a total number of datapoints, and \( \alpha \) is the learning rate. Learning rate is a very important hyperparameter of the neural networks. It determines the speed at which the connection weights are updated. If set too low it will cause the weights not to converge to a value necessary to lower the cost function value to zero. If set to too high of a value the ANN will learn faster but this introduces the risk of the correct weight value being skipped due to the adjustment not being fine enough to converge to zero, which causes oscillations and divergence. The weight update strategy does not necessarily have to be the same as equation (4), but it is a commonly used description as most solver algorithms use it or a slightly modified version [16].

Once the entire training stage is finished, the trained neural network is used in the training stage. Training stage consists only of forward propagation. In this stage, the outputs of the dataset and the neural network are compared, but no adjustments are made. This stage determines the quality of the neural network – how correctly does it predict the values stored in the dataset. This is used to determine if the quality of the training was high, and if it was not hyperparameter adjustment is necessary [15].

4. Solvers Description

Solvers are one of the hyperparameters of the ANN. Solver is the algorithm used in the process of backpropagation to calculate the weights of the neural network. Because of them adjusting the weights of the ANN these algorithms play an important role in the final result of the ANN. If the neural network is trained badly, even with good architecture, it will not be capable of determining the correct weights needed to achieve low values of errors.

First solver used in performed research is SGD. SGD is an optimization algorithm designed for unconstrained optimization problems. Unlike some other solvers, SGD approximates the gradient of the neural networks for each individual training sample. The update is weight update is performed based on the equation [18]:

\[ \theta_{new} = \theta_{old} - \alpha \frac{\partial J(\Theta)}{\partial \Theta}, \] (5)

Note the similarity to the equation (4), with the difference being that SGD updates its value based on each individual sample’s cost function (error). This provides a better adjustment of individual weights. Two parameters can be adjusted: momentum, and whether the so called Nesterov momentum modification will be applied. Momentum is a value that further accelerates SGD in the relevant direction \( J(\Theta) \rightarrow 0 \). This works by adjusting the learning rate when the goal condition of minimizing the value of cost function – when \( J(\Theta) \) value is large the momentum parameter increases the value of learning rate and lowers it when value drops. This value helps with lowering oscillations and faster weight convergence. It’s introduced into the equation (5) as an additional component \( v \) which adjusts the gradient update depending on the overall ANN loss value, as shown in [18]:

\[ \theta_{new} = \theta_{old} - \alpha \frac{\partial J(\Theta)}{\partial \Theta} + v, \] (6)

Where \( v \) is determined by:

\[ v = \mu \cdot v_{t-1} - \alpha \hat{J}(\Theta), \] (7)

with parameter \( \mu \) being the momentum parameter controlling the influence of speed \( v \). Starting speed, \( v_0 \) equals zero.

Nesterov momentum (also known as Nesterov Accelerated Gradient – NAG) is a technique that adjusts the based on the intermediate position. The intermediate position is calculated based on the current value of the parameter \( \mu \), and the current loss is calculated. The gradient is then further adjusted to achieve a lower error. This method, while slower in each step, provides a more accurate weight adjustment which can lead to a faster overall convergence [19].
Adam is a different optimization algorithm, optimized for stochastic objective functions. It adaptively adjusts estimates of lower-order momentums and is designed to be computationally efficient. It adjusts the gradient in equation (4) in the similar manner as SGD does – shown in equation (6), but it uses two momentums and adjusts them differently. The weight in Adam algorithm are updated through [20]:

$$\theta_{\text{new}} = \theta_{\text{old}} - \alpha \cdot \frac{m_t}{\sqrt{v_t} + \theta^2}.$$ #(8)

The equation Adam uses to adjust the momentums are given by:

$$m_t = \frac{m_{t-1}}{1 - \beta_1^t}, \#(9)$$

and

$$v_t = (1 - \beta_2) \sum_{i=1}^{t} \beta_2^{t-i} \cdot \theta_i^2, \#(10)$$

with t being the current epoch (training iteration) – this means that weights are adjusted using all historical gradient values. Parameters $$\beta_1, \beta_2 \in [0, 1]$$ are constants with determine the exponential decay of the momentum values, or – in simpler terms, determine the speed of change for momentums m, v respectively [20, 21].

AMSGrad is an expansion of the Adam algorithm, in a similar way to NAG for SGD. AMSGrad was designed to help with convergence problems Adam exhibited in some cases, for example when momentum vt is larger than the gradient $\theta$. The difference between standard Adam and AMSGrad is that it stores the maximum historical average of the second momentum $v_t$, up to the current step and uses that value to normalize the gradient. With this, the learning rate change is stopped from increasing which results in easier convergence [21].

Both algorithms have default parameters, which are commonly used in research. Default SGD parameters are [22]: $\alpha = 0.01$, $\mu = 0.0$, and NAG not used. The default parameters for Adam are [22]: $\alpha = 0.001$, $\beta_1 = 0.9$, $\beta_2 = 0.99$, and AMSGrad not used.

5. Parameter choice

Hyperparameters of the neural network are those values that determine its architecture. In present research previously determined parameters are shown in Table 2. Values for each hidden layer (HL) are combined and written that the left most value is the hidden layer nearest the input.

Table 2. Predefined hyperparameters of the used ANN.

<table>
<thead>
<tr>
<th>Hyperparameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of HL</td>
<td>5</td>
</tr>
<tr>
<td>Neuron per HL</td>
<td>80,65,25,75,80</td>
</tr>
<tr>
<td>Activations per HL</td>
<td>Sigmoid, Tanh, ReLU, ReLU, ReLU</td>
</tr>
<tr>
<td>Epochs</td>
<td>13</td>
</tr>
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</table>

These parameters are fixed and variations are introduced via a modification of solver parameters. Parameters varied for each solver, along with their possible values are presented in Table 3. for SGD and Adam solver.

Table 3. Parameters used in the Grid Search for each of the optimized solvers

<table>
<thead>
<tr>
<th>Solver</th>
<th>Parameter</th>
<th>Possible Values</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both</td>
<td>$\alpha$</td>
<td>0.001, 0.005, 0.1, 0.01, 0.2, 0.02, 0.1, 0.5, 0.05, 0.5</td>
<td>10</td>
</tr>
<tr>
<td>SGD</td>
<td>$\mu$</td>
<td>0.0, 0.02, 0.005, 0.01, 0.01, 0.05, 0.9</td>
<td>7</td>
</tr>
<tr>
<td>NAG</td>
<td>True, False</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Adam</td>
<td>$\beta_1$</td>
<td>0.9, 0.95, 0.85</td>
<td>6</td>
</tr>
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AMSGrad used.

AMSGrad not used.

AMSGrad not used.

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<td>0.9, 0.95, 0.85</td>
<td>6</td>
</tr>
</tbody>
</table>

AMSGrad used.

AMSGrad not used.

AMSGrad not used.

AMSGrad not used.

AMSGrad not used.

AMSGrad not used.

6. Results

SGD algorithm has achieved the best results with following parameters:

- $\alpha = 0.05$,
- $\mu = 0.02$, and
- NAG used.

Over the course of 20 runs the average RMSE for given parameters was 4.275 [MW] with standard deviation of 0.08369.

Adam algorithm has achieved the best results with the following parameters:

- $\alpha = 0.001$,
- $\beta_1 = 0.95$,
- $\beta_2 = 0.99$, and
- AMSGrad not used.

Over the course of 20 runs the average RMSE with given parameters was 4.259 with the standard deviation of: 0.046395.

The achieved results show the average improvement over the results from the previous research of 0.03 [MW] for SGD and 0.046 [MW] for Adam.

7. Conclusion

Obtained results show only the slight improvement over the results previously obtained. While there is improvement, it is questionable whether the solver parameter adjustment beyond the default values is strictly necessary, considering the added complexity and the time needed to test all the combinations. It is also apparent that the values of best parameters are close to the default values for both algorithms. Still, if higher precision is needed the results point towards the fact that solver parameter adjustment can provide that. Further tests on different datasets are necessary to test the effect of solver parameter changes. Future work could also include the comparison between various implementations of solver algorithms, as different implementations could demonstrate different results (Keras framework has been used in this research). Furthermore, the difference in training times with different solver algorithms is apparent and further research in optimizing the parameters with the goal of faster training could be performed.

8. Acknowledgment

This research has been supported by the Croatian Science Foundation under the project IP-2018-01-3739, CEEPUS network CIII-HR-0108, European Regional Development Fund under the
grant KK.01.1.1.01.0009 (DATACROSS), University of Rijeka scientific grant uniri-tehnici-18-275-1447, University of Rijeka scientific grant uniri-tehnici-18-18-1146 and University of Rijeka scientific grant uniri-tehnici-18-14.

Dataset used in research was obtained from the paper Tüfekci, P. (2014) “Prediction of full load electrical power output of a base load operated combined cycle power plant using machine learning methods” [23].

9. Nomenclature

<table>
<thead>
<tr>
<th>Latin Symbols</th>
<th>Greek Symbols</th>
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<tbody>
<tr>
<td>m&lt;i&gt;</td>
<td>n</td>
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<td>v&lt;sub&gt;x&lt;/sub&gt;</td>
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<tr>
<td>Expected</td>
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<tr>
<td>Output</td>
<td>μ</td>
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<td>x</td>
<td>β&lt;sub&gt;1&lt;/sub&gt;</td>
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<td>y</td>
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10. References


Study of energy parameters in alternative power source microgrid systems with multilevel inverters

Исследование энергетических параметров в микрогрид системах с альтернативными источниками энергии при использовании многоуровневых инверторов

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Abstract: Microgrid-systems with alternative energy sources in which multilevel inverters are used are becoming more widespread. Possible circuit implementations of multilevel inverters for thus systems are shown. A comparative analysis of the energy parameters of multilevel inverters using various modulation algorithms is presented. Important requirement of multilevel voltage inverters is to ensure high quality output voltage, as well as ensuring minimum power loss and maximum efficiency. An overview of known modulation algorithms for output voltage generation in multilevel inverters is presented. The analysis of existing algorithms was performed and the choice of the optimal algorithm for use in the scheme of solar power plants was carried out.

KEYWORDS: MICROGRID SYSTEM, MULTILEVEL INVERTER, SOLAR POWER PLANT, PWM, AMPLITUDE MODULATION.

1. Introduction

Researchers are increasingly paying attention to alternative power sources [1, 2]. A wind power plant is designed to convert the kinetic energy of a wind stream into mechanical energy of rotation of the rotor with its subsequent conversion into electrical energy [3, 4]. Schematic diagram of a wind farm is shown in Fig. 1.

Fig. 1. Schematic diagram of a wind farm

A solar power plant is designed to convert solar radiation into electrical energy [5, 6]. The most common type of solar power plants is based on flat photovoltaic modules of single crystalline or polycrystalline type, which provide conversion of solar radiation to direct current. Depending on the circuit used, the direct current can be inverted to AC or stabilized to charge the batteries [7, 8]. Schematic diagram of a solar power plant is shown in Fig. 2.

Fig. 2. Schematic diagram of a solar power plant

The peculiarity of a solar power plant is that a large number of solar panels can be connected in series. In this case, the voltage on the solar panels, depending on the degree of illumination is variable [9, 10].

The task of the conversion system of both solar and wind power plants is the formation of sinusoidal output voltages with stable amplitude and frequency [11].

Different types of semiconductor converters as well as different control systems can be used to form a sinusoidal output voltage [12, 13]. At the same time, the urgent task is to create and research transformer systems that provide the creation of autonomous power supply systems with stable voltage.

2. The power part – conversion systems

It is possible to use different topologies of semiconductor converters in microgrid systems with alternative power sources [14, 15]. The most common topologies are as follows: multilevel inverters with fixed diodes (Fig. 3), modular multilevel inverters (Fig. 4), cascade multilevel inverters (Fig. 5). Each of these topologies has its advantages and disadvantages [16, 17].

Fig. 3. Multilevel inverter with fixed diodes

Advantages of multilevel inverter with fixed diodes include adjusting the amplitude of the first harmonic of the output current, which is necessary for scalar and vector control. At the same time, the disadvantages include high switching frequency of the power keys, which leads to the heating of semiconductor elements, parts of the isolation of the converter, increasing the dynamic losses and consequently reducing the efficiency of the converter. Other hybrid control systems are known, such as:

– phase disposition;
– phase opposition disposition;
– alternate phase opposition disposition;
– inverted sine carrier.
One of the basic requirements for multilevel inverters is to provide high sinusoidal output voltage and output current. Particularly relevant requirements for the form of output voltage for converters that operate as a power source for their own power supply [18, 19]. Therefore, the most critical requirements for the output inverter are:

– maximum efficiency;
– increased reliability (work in case of failure);
– providing maximum sinusoidal output voltage.

In this case, the realized parameters depend not only on the applied power scheme, but also on the applied modulation algorithm [20, 21].

### 3. Modulation algorithms in multilevel inverters

One of the most important parameters of multilevel inverters is the sinusoidality of output voltage. There are quite a number of different modulation algorithms that allow to obtain different sinusoidality of the output voltage and different contents of higher harmonics [22, 23].

The sine wave of the output voltage in multilevel inverters is accepted to be estimated by the total harmonic distortion (THD), which is an integral indicator of sine wave, which determines the rms content of higher harmonics [24, 25].

The realized sinusoidality of the output voltage are directly dependent on the modulation type implemented. There are many different modulation algorithms for output voltage generation in multilevel inverters. The most common of them are: various variations of sinusoidal PWM (level-shifted, phase-shifted, level-phase-shifted), space-vector PWM, amplitude modulation, etc. [26, 27]. At the same time, all these algorithms cause different sinusoidality (THD) of output voltage and current, as well as different power losses in the converter. This is due to the fact that higher voltage harmonics cause the presence of higher current harmonics, which causes additional power losses in the power lines and load. Among the described algorithms, the best indicators of sinusoidal output voltage are algorithms based on a single modulation [28, 29].

The main varieties of sinusoidal PWM are shown in Fig. 6.

Spatial-vector PWM modulation algorithm is shown in Fig. 7. Space-vector modulation is used to control active three-phase converters. With vector-modulation, it is not instantaneous voltage values applied to the windings that are calculated, but the moments of connecting the windings to the power bridge in order to form a given voltage vector.

The switch management algorithm of the autonomous inverter in the space-vector modulation mode is based on the formation of
the required position of the voltage vector in space at each time interval.

Fig. 7. Space-vector PWM

The amplitude modulation algorithm is shown in Fig. 8. The switching time of each level is determined during the intersection of sine amplitudes of 0.5; –0.5; 1.5; –1.5; 2.5; –2.5. The effect of amplitude sampling is the amplitude quantization of a sinusoidal signal into a stepped view. The output is calculated using the rounding method to the nearest value, which creates an output signal symmetric about zero [30, 31].

The number of quantization steps is determined by the physical number of possible stages when forming the output voltage in a multilevel inverter. Form optimization is achieved by determining the value of the \(A_{\text{sin}}\) amplitude, in which the rms content of the higher harmonics will be minimal [32, 33].

The concept of obtaining the optimum form of gradual-discrete voltage is reduced to minimizing and symmetrizing the area of higher harmonics with respect to the fourth period of the output voltage form [34].

Fig. 8. The algorithm of amplitude modulation

Comparison of the harmonic distortion coefficient for different modulation algorithms is shown in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Cell type and modulation algorithms</th>
<th>Output voltage CMLI, V</th>
<th>Output voltage of one cell, V</th>
<th>THD of the output voltage of one cell, %</th>
<th>THD total output voltage, %</th>
<th>THD output current, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-level cell with sinusoidal PWM</td>
<td>2571.44</td>
<td>2998.5</td>
<td>99.29</td>
<td>68.27</td>
<td>14.91</td>
</tr>
<tr>
<td>2-level phase-shifted PWM cell</td>
<td>2284.67</td>
<td>2392.47</td>
<td>51.74</td>
<td>40.05</td>
<td>4.54</td>
</tr>
<tr>
<td>2-level cell with phase-shifted PWM without interleaving</td>
<td>2320.9</td>
<td>2395.27</td>
<td>51.74</td>
<td>44.06</td>
<td>5.77</td>
</tr>
<tr>
<td>3-level cell with level-shifted PWM with interleaving</td>
<td>2666.4</td>
<td>2390.03</td>
<td>52.82</td>
<td>32.22</td>
<td>3.91</td>
</tr>
</tbody>
</table>

4. Results and discussion

Of the presented algorithms, the best performance is the algorithm of amplitude modulation, which allows to obtain the form of output voltage of a multilevel inverter with any number of degrees, optimized by the content of higher harmonics, namely by the minimum of the coefficient of harmonic distortions.

The proposed algorithm allows to obtain the lowest possible THD for any voltage level. The advantage of the proposed algorithm in comparison with similar optimization algorithms is the provision of smaller harmonic distortions and its relative simplicity. The presented algorithm is based on the amplitude modulation of a sinusoidal signal with 25% remodulation relative to the highest discretion.

5. Conclusion

The paper presents an overview of energy parameters of cascade multilevel inverter with different modulation algorithms. The best power parameters has MVSI with level-shifted PWM in interleaving mode. The analysis of existing algorithms was performed and the choice of the optimal algorithm for use in the scheme of solar power plants was carried out.
6. References


Magnetothermal finite element model of a new two-coil crucible induction furnace through the altair flux3d® software

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Abstract: A new two-coil cylindrical crucible induction furnace with the lateral coil connected to the one-phase electric power supply and the bottom coil connected to a capacitor bank with an appropriate value of the capacity is able to realize a desired balance between the diffusion of the power induced in the furnace bath through the lateral and the bottom faces of the crucible. Finite element magnetothermal model of the furnace is used to compute the temperature field, the thermal losses and the thermal efficiency associated with the furnace operation and to study three variants with the same bath volume of the new furnace related the diameter of the crucible bath.

Keywords: CRUCIBLE INDUCTION FURNACE, TWO-COIL INDUCTOR, FINITE ELEMENT MULTIPHYSIC ANALYSIS, MAGNETOTHERMAL MODEL, FURNACE EFFICIENCY

1. Introduction

The induction furnace of crucible type continue to be one of the most wide-spread device for melting, alloying, holding of metallic and non-metallic materials like glasses, salts and oxides [2, 4, 6]. Taking into account the evolution in the last decades of the hardware and software for numerical computations, the deeper investigation of phenomena associated with induction furnaces operation and the study of new configurations are becoming more and more accessible to peoples involved in research and industrial developments [1, 5, 7, 9, 11].

In a usual crucible induction furnace the molten bath is placed in a cylindrical volume surrounded by the inductor. The inductor produces the AC magnetic field, whose penetration/diffusion in the furnace charge is associated with the generation of induced currents in the electro-conductive material of the furnace bath.

In the usual crucible induction furnaces, one-phase electrically supplied, the mean value of the power associated with the Joule effect of the induced currents is much lower on the bottom face than on the lateral face of the furnace bath. As consequence, the induction heating of the bath bottom face is much less intense than the heating of the lateral face. The two-coil inductor configuration studied in this paper consists in a lateral coil, electrically supplied, and a bottom pancake coil, connected to a capacitor bank. The optimum design of such a two-coil one-phase inductor studied in the paper [1] ensures the same mean value of the induced power on the lateral face and on the bottom face of the furnace bath. As continuation, this paper considers the finite element magneto thermal model of the new furnace, able to evaluate the temperature field associated with the furnace operation, the thermal losses and the thermal efficiency of the furnace.

All applications of the Multiphysics – electromagnetic and thermal analysis in this paper correspond to the frequency supply 300 kHz and the volume of the molten glass bath 110.8 dm³. The reference value 550 mm is considered for the inner diameter of the furnace crucible and 45 mm is the thickness of the wall of the nonmagnetic and non-electro conductive crucible of the furnace. The steady state furnace operation with \( P_2 = 400 \text{ kW} \) induced power in the charge inside the nonconductive and nonmagnetic crucible and 1500 Celsius degrees for the maximum value of the temperature of the molten glass charge are considered.

2. Geometry, mesh and physical properties of the magneto thermal model

The images in Fig. 1 show the main components of the new two-coil crucible induction furnace with cylindrical bath. The inductor contains the one-turn LATERAL coil, with eight conductors parallel connected, and the five-turn BOTTOM spiral coil.

![Fig. 1. Geometry of the finite element magneto thermal model of the new two-coil crucible induction furnace](image_url)

The finite element analysis of the steady state AC electromagnetic field and of the steady state temperature field associated with furnace operation uses Flux3D models [13] with the meshing presented in Fig. 2.

As in the previous paper [1] the electromagnetic problem of the new magneto thermal model of the new two-coil furnace considers the electric supply for which the Joule/active power in the charge has the value \( P_2 = 400 \text{ kW} \). The optimal value of the capacity connected to the bottom coil - for equal powers diffused through the lateral and bottom faces of the furnace bath, is considered.
In the thermal problem of the magneto thermal models of the furnace the volume of the crucible is a thermal conduction region. All surfaces of the crucible to the neighboring air, yellow colored in Fig. 3, are face regions with thermal transfer through convection and radiation. The same type of boundary is the upper circular face of the furnace bath.

Since both coils of the furnace, tubular cooper made, are water cooled, their correspondent faces in opposite position with respect the crucible, yellow colored in Fig. 3, are thermal boundaries with imposed values of the temperature.

The maps of the volume density of induced power in the molten glass of the furnace charge in Figs. 4 and 5, put in evidence the differences between the one-coil furnace and the two-coil furnace related the distribution of the induced power in the furnace bath.

The path in turquoise consisting in two radiuses and a vertical line on the lateral cylindrical face of the furnace bath starts in the center of the upper circular face and end in the center of the charge bottom. The variations of the volume density of induced power along this path in Figs. 4 and 5 shows clearly the decrease of the induction heating effect in the upper half of the charge and the displacement of the maximum of this effect to the bath bottom when pass from the one-coil furnace to the two-coil furnace.

The results of the electromagnetic problems, Table 1, for the same value \( P_2 \) of the induced power, show lower values of the current, of voltage supply and of the Joule losses related the LATERAL coil in case of the two-coil furnace in comparison with the one-coil furnace. Compared with the one-coil furnace, the electric efficiency of the two-coil furnace is affected by the very important Joule losses in the BOTTOM coil. This disadvantage of the two-coil furnace disappears if this coil is of stranded conductor type instead of solid conductor type, as considered in this paper.

<table>
<thead>
<tr>
<th>Table 1: Comparison between the one-coil furnace and of the two-coil furnace – results of electromagnetic problems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Furnace type</strong></td>
</tr>
<tr>
<td>Charge induced power [kW]</td>
</tr>
<tr>
<td>LATERAL coil voltage [V]</td>
</tr>
<tr>
<td>LATERAL coil current [A]</td>
</tr>
<tr>
<td>BOTTOM coil voltage [V]</td>
</tr>
<tr>
<td>BOTTOM coil current [A]</td>
</tr>
<tr>
<td>LATERAL coil losses [kW]</td>
</tr>
<tr>
<td>BOTTOM coil losses [kW]</td>
</tr>
<tr>
<td>Furnace electric efficiency [%]</td>
</tr>
</tbody>
</table>
3. Temperature field and thermal losses of the one-coil and of the two-coil furnaces

The most important component of the $P_2 = 400 \text{ kW}$ active power induced in the furnace bath ensures the increase of the temperature and to the melting of the molten glass components. The rest of the power represents the furnace thermal losses, involved in the evaluation of the furnace thermal efficiency.

The thermal steady state model of the furnace for the computation of the furnace thermal losses and of the temperature field considers as thermal source the field of volume density of induced power evaluated in the electromagnetic problem multiplied by a subunit scaling factor $k$. This factor is iteratively determined so that the maximum of the bath temperature field have the value 1500 Celsius degrees. In a steady state thermal problem, the total power of the temperature field sources is equal with the power losses. Thus, the power losses of the furnace correspondent to 1500 Celsius degrees on the molten glass temperature are $P_t = P_2 \cdot k$ and the thermal efficiency of the furnace in $\%$ is $100 (P_2 - P_t)/P_2 = 100(1-k)$.

The scaling factors $k$ in the thermal problems whose results are further analyzed are $k_1 = 0.0506$ for the one-coil furnace and $k_2 = 0.0481$ for the new two-coil furnace. The values of the thermal conductivity in these steady state thermal problems are 20 W/m/Celsius degrees for the molten glass bath, 0.3 W/m/Celsius degrees for the refractory material of the furnace crucible and 390 W/m/Celsius degrees for the cooper of the furnace coils.

The comparison of the maps of the temperature field in the molten glass and of the variation of the temperature along a path, for the one-coil furnace in Fig. 6 and for the two-coil furnace in Fig. 7, shows the improvement of the temperature field to the bath bottom in the two-coil furnace. As result of the relatively high value of the molten glass thermal conductivity, the increase of mean value of the temperature in this part of the bath of the two-coil furnace is lower than the increase of the volume density of induced power.

There are no significant differences related the temperature field in the LATERAL coils, Fig. 8, between the one-coil furnace and the two-coil furnace. The temperature field of the BOTTOM coil in the two-coil furnace, Fig. 9, reflects the boundary conditions considered here, respectively the imposed values 50, 60, 70, 80 and 90 Celsius degrees on the outer faces of the five turns of this coil.

![Fig. 6. Temperature in the volume of the one-coil furnace bath and along a path](image)

![Fig. 7. Temperature in the volume of the two-coil furnace bath and along a path](image)

![Fig. 8. Temperature field in the LATERAL coils of the one-coil furnace and two-coil furnace](image)

![Fig. 9. Temperature field in the BOTTOM coil of the two-coil furnace](image)

The maps of the temperature in an axial cut plan, Fig. 10, show a slight difference between the one coil-furnace and the two-coil furnace related the variation of the temperature in the molten glass volume inside the crucible. The results of the thermal problems for practically the same maximal value of the molten glass temperature 1500 Celsius degrees, Table 2, related the mean value of the temperature and the difference between the extreme temperatures of the molten glass emphasize slight differences between the one-coil and the new two-coil furnace. Since the thermal losses of the two-coil furnace is about 5% lower, the thermal efficiency of this furnace is slightly higher than the same efficiency of the one-coil furnace.

![Table 2: Results of the thermal problems for the one-coil furnace and the two-coil furnace](image)
4. Influence of the two-coil furnace geometry

In the context of simulation driven optimal design of the studied crucible furnace for molten glasses it is important to see the influence of the furnace geometry for imposed values of the bath volume, of the induced power in the furnace bath and of the maximum of molten glass temperature. Until now, the reference value 550 mm of the bath diameter, which correspond to the image in the middle of Fig. 11, was considered. Together with two other values of this diameter, 430 mm and 670 mm, there are presented in Table 3 important results related the influence of the two-coil furnace geometry. The same volume 110.8 dm³, the same induced power 400 kW and the same maximum 1500 Celsius degrees of the molten glass temperature characterize the three variant of the two-coil furnace.

Table 3: Results for three two-coil furnaces with different bath diameters

<table>
<thead>
<tr>
<th>CHARGE diameter [mm]</th>
<th>430</th>
<th>550</th>
<th>670</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxi CHARGE temperature [Celsius]</td>
<td>1517</td>
<td>1506</td>
<td>1503.3</td>
</tr>
<tr>
<td>Mean CHARGE temperature [Celsius]</td>
<td>1358.1</td>
<td>1351.7</td>
<td>1357.4</td>
</tr>
<tr>
<td>Maxi - Mini CHARGE temp [Celsius]</td>
<td>584</td>
<td>520</td>
<td>446</td>
</tr>
<tr>
<td>Furnace thermal losses [kW]</td>
<td>15.72</td>
<td>19.24</td>
<td>25.98</td>
</tr>
<tr>
<td>Furnace thermal efficiency [%]</td>
<td>96.07</td>
<td>95.19</td>
<td>93.51</td>
</tr>
<tr>
<td>Furnace electric efficiency [%]</td>
<td>94.52</td>
<td>93.80</td>
<td>93.78</td>
</tr>
<tr>
<td>Furnace efficiency [%]</td>
<td>90.80</td>
<td>89.29</td>
<td>87.69</td>
</tr>
</tbody>
</table>

The maximum of the furnace electric, thermal and global efficiencies corresponds to the first value 430 mm of the bath diameter. For this geometry, the BOTTOM coil losses and the voltages of the two coils of the furnace are minimal. On the other hand, if the non-homogeneity of the molten glass temperature is characterized through the difference Maxi - Mini CHARGE temp, Table 3, the most advantageous is the geometry with the bath diameter 670 mm.

8. Conclusions

Through the magneto thermal 3D finite element model of the new two-coil crucible furnace Joule losses and thermal losses, the correspondent efficiencies and the global efficiency of the furnace are evaluated. Although the presence of bottom coil ensures the displacement of the maximum of induced power toward the furnace bottom, the temperature field in the bath volume is not much different in comparison with the one-coil furnace.

Related the influence of the furnace geometry, it was found that a bath svelte geometry is favorable to the increase of the furnace efficiency, while a relatively flat bath ensures the decrease of the molten charge temperature non-uniformity.

References

Control approaches of pem fuel cells: a review

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Abstract: Over the last two decades, polymer electrolyte membrane fuel cell technology has been increasing its share in power generation systems. In this work, the basic polymer electrolyte membrane fuel cell (PEMFC) system operation is presented first. Some most control-oriented modeling approaches are reviewed as the model is essential for further control. Optimal control of such a system can improve efficiency and hence reduce the cost of ownership. The objective of this work is to present the concept of control and depict some of the possible applications of PEMFC systems.

Keywords: POLYMER ELECTROLYTE MEMBRANE FUEL CELL (PEMFC), OPERATING CONDITIONS, CONTROL OBJECTIVES, OPTIMIZATION, OPTIMAL CONTROL.

1 Introduction

A PEMFC system with nearly zero emissions and high energy conversion efficiency has received worldwide attention in recent years. PEMFCs use hydrogen and oxygen to produce electrical energy, as shown in the following reaction:

\[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} + 2\text{e}^- \]

Byproducts of this conversion are water and heat which may be further used in auxiliary sub-systems like humidifiers. In that way, the energy loss is reduced and the system efficiency is increased. Furthermore, the direct conversion does not include any moving parts, so the maintenance costs are very low. Their noteworthy features also include low operating temperature, high power density, and easy scale-up, which make PEMFCs a promising candidate as the next generation of power source for transport, stationary and portable applications [1].

Figure 1. Concept of a PEMFC.

To provide a sense of history Sir William Robert Grove demonstrated the very first fuel cell in 1893 by showing that the electrochemical dissociation of water was almost reversible using Platinum (Pt) electrodes in sulfuric acid [2]. Another breakthrough was the first practical fuel cell developed by General Electric Company for the Gemini space mission in 1962 [3]. In the next few decades, many improvements were made for the construction parts used in the membrane electrode assembly (MEA). Fuel cells have become more efficient and also cheaper by reducing the Pt load and introducing new materials like Nafion [4]. Despite advancements and rising market deployment, several challenges remain such as reducing cost, maximizing efficiency, and improving durability.

2 The PEM fuel cells system

2.1 Fuel cell

This study focuses on PEMFCs operation and control. A PEMFC consists of a polymer electrolyte membrane, catalyst layers (CLs), gas diffusion layers (GDLs), and bipolar plates, also known as collector plates. Figure 2 shows the structure of a PEMFC. The core component of a fuel cell is the membrane, which is impermeable to gases but it conducts protons. On both sides of the membrane, there are two porous electrodes which are electrically conductive and typically made of carbon cloth or carbon paper [6]. At the interfaces between the polymer membrane and porous electrodes are the CLs which are covered with catalyst particles, usually platinum supported on carbon. GDLs are then placed next to the electrodes. Their purpose is to spread the gas and conduct the produced water. The membrane, the CLs, and the GDLs form an MEA and it represents the heart of the fuel cell [7]. The MEA is inserted between the bipolar plates, which support the whole structure and provide the pathways for the flow of the reactant.

Figure 2. PEM fuel cell construction [5].

Inside a PEMFC a few processes are carried out as shown in the following order: gases flow through the channels (1), gas diffusion through the porous media (2), electrochemical reactions (3), proton transport through proton conductive polymer membrane (4), electron conduction through electrically conductive cell components (5), water transport through polymer membrane due to electroosmotic drag and back diffusion (6), water transport through porous catalyst and gas diffusion layers (7), two-phase flow of unused gas carrying water droplets (8), heat transfer including both conductions through solid parts of the cell and convection to reactant gases and coolant medium (9).

Figure 3. Cell components and processes.

The electrochemical reactions take place simultaneously at the surfaces of the catalyst layers. In general, an electrochemical reaction involves either oxidation or reduction of the gases. Hydrogen that is fed on the anode side of the fuel cell diffuses to the catalyst layer on the anode side, where it splits into its primary constituent protons and electrons:
The reaction is called hydrogen oxidation. Each hydrogen atom consists of one electron and one proton. Protons travel through the proton conductive membrane whereas electrons travel through the electron conductive electrodes, current collector plates, and to the outside circuit where they perform useful work. While moving through the membrane protons attach onto water molecules forming hydronium complexes $\text{H}_2\text{O}^+$ that move through the membrane from the anode to the cathode. This process is called electro-osmotic drag. When they arrive at the other side of the membrane, more precisely at the cathode catalyst surface, the protons electrochemically combine with the electrons and the supplied oxygen:

$$2\text{H}_2^+ + 2e^- + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O} \quad (2.2)$$

The reaction on the cathode side is called oxygen reduction. Water that is created in this electrochemical reaction is partly pushed out of the cell with the excess oxygen. Also, water travels from the cathode to the anode due to a large concentration gradient across the membrane and is called back-diffusion water transport.

The overall reaction is presented as follows:

$$\text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O} + \text{electrical energy} + \text{heat} \quad (2.3)$$

The net result of these simultaneous reactions is a flow of electrons through an external circuit. Theoretically, a single fuel cell produces the potential of 1.23 V in open circuit, but when connected to a load, it decreases as the load draws current from the cell and the usual operating voltage ranges from 0.6 to 0.7 V. The voltage loss is caused by several factors: activation polarization, ohmic polarization, and concentration polarization. Activation polarization is caused by slow electrochemical reactions at both anode and cathode, ohmic polarization losses happen because of hydrogen crossover or electron short circuit through the membrane, while concentration polarization is caused by hydrogen and oxygen concentration gradients at both electrodes when both reactants are consumed rapidly and ohmic losses caused by the internal resistance of the cell.

### 2.2 Fuel cell stack

Most applications of the PEMFC system require higher power than can be delivered by a single fuel cell. Hence to obtain a system higher power, multiple PEMFCs must be stacked together to form a PEMFC stack, by attaching the cells in series to obtain a higher total voltage, and in parallel to obtain a larger total current [8]. A PEMFC stack consists of a multitude of single cells stacked up so that the cathode of one cell is electrically connected to the anode of the adjacent cell. The electrical circuit is closed, with both electron current passing through solid parts of the stack and ionic current passing through the electrolyte, with the electrochemical reactions at their interfaces, c.f. Грешка! Източникът на препратката не е намерен..

By stacking the fuel cells, the polarization phenomenon reduces the voltage that can be delivered by the system whenever more current is drawn. This may affect the performance of the appliances that require fixed voltage. Hence, the output voltage must be controlled by manipulating hydrogen and airflow rates or by boosting the voltage using a battery, supercapacitor, or both. Stacking multiple fuel cells also produces a larger heat reaction area which increases the cell temperature so the heat must be removed. By producing larger currents, water is also produced by the electrochemical reaction and should be removed to avoid membrane flooding. The flooding phenomena influences in reducing the fuel cell stack performance. Furthermore, starting-up the fuel cell after shutting-down for long period may require purging the anode to remove the leftover oxygen and hydrogen, but in many configurations anode purging is done sequentially.

The fuel cell system consists of PEMFC stack and Balance of Plant (BOP), which refers to all the peripherals needed for stack functioning, in particular, air blowers, control strategy, valves, water, and thermal management sub-systems, humidifiers, cooling units, insulation, sensors, and power conditioning. Four major components of BOP include fuel delivery, air delivery, humidification, and thermal management sub-systems.

### 2.3 BOP control in PEM fuel cell

The control strategy of the PEMFC system is to handle the supply of reactant gases and their exhausts, take care of waste heat and maintain the stack temperature, regulate and condition power output, monitor the stack vital parameters and control the startup operation and shutdown of the stack and system components [6]. Generally, the PEMFC system can be broken down into at least 4 subsystems as shown in Грешка! Източникът на препратката не е намерен.. The dynamical response of these systems has a wide range of time constants varying from very fast electric response to slow temperature variations and between. For this reason, the control strategy usually consists of multiple controllers for every subsystem. These controllers are often referred to as low-level controllers. Another important problem is finding the optimal operating point for the fuel cell under different conditions [11][12]. As the fuel cell ages, the transport properties in the fuel cell components change, and so does the optimal operating point. An adaptive controller that can find the optimal operating point during operation is referred to as high-level control [13]. This control can improve the overall system efficiency and life span.

#### 2.3.1 Flow subsystem

In the flow subsystem reactants, hydrogen and air are supplied to the PEMFC stack at a certain stoichiometric ratio. In most cases, the air is supplied to the cathode instead of pure oxygen. Pure oxygen is only used in applications where the air is not available. Depending on the stack power, the air is supplied on the cathode side of the PEMFC using either blower or compressor. To achieve the required stoichiometric ratio, inlet air pressure is controlled by a pressure regulator, as illustrated in Грешка! Източникът на препратката не е намерен..

![Flow subsystem](image)
Hydrogen is supplied on the anode side using a fuel processor or directly from a high pressurized hydrogen tank. The outlet pressure of the anode is controlled by a backpressure regulator to deliver the required hydrogen flow at certain stoichiometric ratio as demonstrated in [18].

In most cases, hydrogen is recirculated back to the anode inlet because releasing unused hydrogen affects the fuel cell in the context of cost-efficiency.

**Figure 7. Controlled hydrogen supply system [6].**

Determination of hydrogen and oxygen flow rate is a very complicated process because by increasing their flowrate the power density and partially the fuel cell efficiency increases but the net power is decreased because of higher parasitic power requirements [8]. Optimal control of these processes is necessary to achieve high efficiency.

### 2.3.2 Water and heat management subsystem

In addition to supplying the reactants to the fuel cell stack, the system balance of plant (BOP) also must take care of the reaction byproducts, water, and heat. Water plays an important role in fuel cell operation. It is essential for proton transport across the polymer membrane. For that reason, both cathode and anode reactants must be humidified before entering the cell as shown in [18].

At higher temperatures, PEMFC systems perform better but if the temperature is too high it can cause membrane dehydration which may result in voltage drop or even electrode flooding. Thermal management subsystems deserve attention because they play a crucial role in optimum PEMFC operation and prolonging its service time. Maintaining the temperature in the proper temperature range for stacks up to 1.5kW can be done by forced convection where a fan may be used to supply the cooling airflow [14].

Higher power stacks have to be controlled by a closed water-cooling system with a radiator that is capable of handling higher heat loads. Non-uniform temperature distributions may cause variations in the electrochemical reaction rates and may affect the evaporation and condensation of water in the reactant gases.

### 2.3.3 Power management subsystem

Power management subsystems are used to control the flow of electric power from unstable power sources as PEMFCs. They use electronic power devices that process, filter, and deliver the electricity efficiently and smoothly. Many different control strategies have been implemented in the power management subsystem of PEMFC systems to improve their performance.

Voltage regulators, DC/DC converters, and chopper circuits are often used to regulate the stack voltage at fixed values higher or lower than the stack operating voltage.

### 3 PEM fuel cell modeling for control

PEMFC models are of great importance for developing model-based controllers. They also provide a great framework for analyzing the performance of a PEMFC under different circumstances. PEMFC models can be divided based on the purpose of their use. Some of them, such as 1D, 2D, or 3D models tend to describe the inner dynamics in a very detailed way, unlike the models created only for control purposes which are often called zero-order models [15]. Modeling of PEMFCs can be achieved with: numerical equations that describe the internal processes, in semi-empirical fashion with curve fitting techniques or only with data using machine learning algorithms [16][17].

#### 3.1 Theoretical modeling

Accurate modeling of PEMFC requires detailed knowledge of physics of the electrochemical processes as well as knowledge of the specific parameters such as, membrane thickness, resistance, thermal coefficients, etc., which may be either unknown or only known to the manufacturer. The need for a wide knowledge of all processes and parameters is one of the disadvantages of this type of modeling, unlike data-driven modeling.

The PEMFC model usually comprises of an electrochemical model, cathode flow model, anode flow model, and membrane model [16]. Modeling the macroscopic dynamics will result in a very complex and computationally expensive model, so assumptions are often made to simplify the model. It is very important to understand the assumptions to understand the model's limitations and accurately interpret its results. Common assumptions used in fuel cell modeling are ideal gas properties, ideal gas mixture, incompressible flow, isotropic and homogeneous membrane, and electrode structures.

The electrochemical model is mostly a static model that outputs the fuel cell voltage, defined as follows.

\[
V_{EC} = V_0 - V_{act} - V_{ohm} - V_{conc}
\]  

(3.1)

The right-side voltages in Eq. (3.1) depend on reactant partial pressures, cell temperature, current, and membrane water content. Voltage-current dependence is often called the polarization curve, shown in [18].

The polarization curve characterizes the performance of the fuel cell and yields information on performance losses in the cell, as activation voltage \(V_{act}\), ohmic voltage \(V_{ohm}\), and concentration voltage \(V_{conc}\), whereas \(V_0\) is cell open-circuit voltage, as presented in Eq. (3.1).

**Figure 8. PEMFC polarization curve [18].**

Cathode and anode flow models usually consist of material balance equations. They represent the mass flow of input reactants and the mass flow of reactants used in the reaction and excess reactant exiting the cell. The ratio between the actual flow rate of reactant and the consumption rate of reactant is called the stoichiometric ratio.

PEMFC membrane or hydration model normally contains equations for membrane water content, proton transport, and water transport due to electro-osmotic drag and back-diffusion, as shown in [18].

In [18], a dynamic model is developed using theoretical methods for the 1.2kW Ballard stack which can be considered as a benchmark as it is widely used by research groups worldwide. The
model is capable of predicting both steady and transient response, flooding, cathode purges, etc., under the varying operating conditions and can be used for control and optimization purposes. A more detailed model is presented in [19]. The model can be used to predict enhanced performance owing to, for instance, improved electrode materials, and related changes in the measured performance to internal changes affecting influential physical parameters. This model also performs very well at high currents, which is not the case with every model in the literature. In [20], a high power PEMFC model is described which may be used for stationary power applications. Some models are focused on investigating individual phenomena like changing temperature effects on fuel cell performance [14]. The analysis presented in [14] shows that an increase in the temperature influences the activation losses the most, significantly increasing their value. On the contrary, ohmic losses are reduced which in turn causes an increase of nominal power output of the stack.

3.2 Data-driven modeling

Data-driven modeling, unlike theoretical modeling, does not require a complete understanding of the processes in the PEMFC. A basic understanding is still needed, so the engineer will be able to include the variables that are most critical to system performance. Data needed for modeling can be gathered experimentally through shifting the system in different operating conditions or through theoretical equations as in [17]. The purpose of the second approach is to reduce the existing model complexity and the required computational time.

A data-driven modeling approach for PEMFCs is very popular in the last decade. There are a lot of studies that compare these techniques with conventional ones [15]. Most of the reviewed studies include artificial neural networks (ANN) which are a type of artificial intelligence technique that mimic the behavior of the human brain. They can approximate a nonlinear relationship between input and output variables of a nonlinear, complex system without requiring explicit mathematical representation. In [21] the authors compare the performance of two neural networks in predicting the fuel cell voltage and current based on information about fuel cell operating conditions. In [22] a neural network solution for voltage prediction is proposed. The data set consists of information about current and past values of current and past voltage values. This paper shows an interesting connection between the past values of current and present values of voltage. They use the Levenberg–Marquardt training algorithm which can be transferred in the Gauss-Newton method with only one parameter change. This method can be used for optimization purposes. Other algorithms are also used as support vector machines (SVMs) in [23]. The occurring phenomena cannot be analyzed with the models created in this fashion so they are usually considered as a black-box. Still, the black-box model can be used in control applications but also for optimization of the operating point, because of their high accuracy [23]. From experimental data, it can be concluded that data-driven models have a very low error which is about 2% as shown in [15]. Nevertheless, the main drawbacks of this modeling approach are the huge number of experimental tests that are required to perform a well-suited model.

4 Classes of control problems and solutions: A discussion

As mentioned before, the temperature subsystem in a PEMFC has a very slow dynamic and is not hard to be controlled. Temperature regulation controllers are also well developed in the past and can be implemented in the fuel cell systems from third-party companies. For this reason, temperature regulation will not be considered in this review, as well as humidification and power control subsystems. The main focus of this section is to present control strategies for hydrogen and oxygen starvation avoidance [24][25]. These processes are major contributors to fuel cell performance degradation, damage of electrode surface, and shorter catalyst life.

A variety of control strategies have been implemented in PEMFC systems to avoid hydrogen and oxygen starvation. These strategies include classical feedback and feed-forward control using a proportional-integrative-derivative (PID) controller, adaptive control, model predictive control, neural network, and fuzzy logic control.

Classical feed-forward or feedback control using PID controllers is the most common type of control used to obtain better fuel cell performance [26]. Large deviations in pressure between anode and cathode can cause severe membrane damages in the fuel cell, so a conventional PID controller can be used to regulate the pressure change for hydrogen and oxygen at the desired value despite the change in the fuel cell current [10]. Speaking of nonlinear systems as the PEMFC systems are, the conventional PID controller cannot keep the system at a relatively steady state because the inner parameters of the nonlinear system always vary with the operating state. Thus, a self-adaptive fuzzy PID (SFPID) controller is developed for controlling the nonlinear system in real-time [27]. It has adaptive characteristics compared to the conventional PID controller which means the parameters of the PID controller can be adjusted by using the on-line fuzzy logic system, as shown in [28] and [29]. Fuzzy PID controllers are widely used for controlling other variables as well. In [27], fuzzy PID controller is used for controlling the triggering circuitry of the inverter. In [30], it is used as a voltage regulator for controlling the output voltage level of a power system.

Although conventional feed-forward and feedback control were often used to prevent oxygen starvation, the nonlinear, complex, and slow PEMFC dynamics associated with fuel starvation require control strategies that can provide a faster and more accurate response. Sliding mode control (SMC) is such a technique where recovery of oxygen stoichiometry towards the desired reference under step load change is moderately improved. This type of controller can not only regulate the oxygen excess ratio of the fuel cell system but improve the system robustness as well [31]. It is also capable of dealing with disturbances and uncertainties [32]. In [33], nonlinear cascade SMC that regulates the oxygen excess ratio for optimizing PEMFC is presented. The cascade controller consists of two loops. An external loop has been designed to control the oxygen excess ratio by providing compressor speed reference, considered as a fictive loop. Hence an internal loop has been applied to force the compressor speed to follow the compressor speed reference. The sliding mode control structure gives the possibility of swiftly tracking different loads without increasing the computational effort. It also allows the delivery of a solution to the control problem within the fast sampling time required by this kind of system. The load demand which is proportional to stack current in most of the control strategies is presented as a disturbance directly affecting the PEMFC performance. Since the current demand can be measured, it is feasible to consider a static or dynamic feed-forward scheme to compensate for its effects, and therefore improve the system performance. Only if there is an analytical model of the process available, it can be used for building a dynamic feedforward controller which perform better than a static
one. This type of controller is often considered as a disturbance cancelation controller because it nullifies the changes in the output caused by current variations. Pakrashan et al. [34] present a comparison between static and dynamic feed-forward controller performance.

Whenever a well-validated model is available, it can be used to predict future system outputs and to update the control action for current demand in model predictive control (MPC) configuration, by comparing the actual and predicted output current [24]. This comparison reduces the control error, limits the oxygen stoichiometric ratio above starvation, and achieves optimality [35]. MPC is considered as the most popular advanced control technique, due to its ability to operate the process in such a way that multiple and changing operational criteria can be fulfilled in the presence of changes in process characteristics [36]. In the literature, there are many types of MPC. In [37], three MPC-based strategies are experimentally demonstrated for the PEMFC unit. The third approach is a combination of two approaches, which are combined in a unified control framework to take advantage of both synergistic benefits.

Instead of expending long computational time to identify the parameters of a linearized model of the non-linear system, system output responses to input disturbances can be learned by an ANN. The neural network can be trained by input-output data which represents the studied non-linear system. The weights of the neural network can be determined by the back-propagation algorithm, as in [38]. To remove the harmful effect of fast pulse currents, authors in [39] employ a neural network model along with a classical PID controller.

Figure 10. NN predictive model [38].

5 Further work

A further step of this research is to develop a robust predictive controller that will perform better than classical control techniques. Model order reduction techniques (MOR) may be considered to determine the dependency between model complexity, execution time, and control accuracy. Optimal model complexity may be used to achieve sufficient accuracy and to minimize the execution time. Optimization algorithms such as gradient descent, Lagrange multiplier, and Newton’s method may also be tested and developed to fit the problem.

6 Conclusion

The advancement in materials and computational power enhances the research activity for PEM fuel cells in the last decades. In this review, various PEM fuel cell control strategies are presented. The research community for PEM fuel cell system control aims to develop new strategies that will minimize the degradation processes and provide high efficiency throughout optimal control. This study covers the main processes and working principles of PEM fuel cells. Dividing the whole system into several subsystems is also explained. The advantages of the control strategies are briefly introduced, as their drawbacks.

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8 References


The organizational concept of the virtual corporation and its integration into Industry 4.0

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Abstract: Examining the effects of the technological components of Industry 4.0 on the structure of companies, one is reminded of an organizational concept that was popular at the turn of the Millennium: the Virtual Corporation (VC). As early as 1993, the American authors William Davidoff and Michael Malone proclaimed the “virtual revolution”. For them, the decisive building block for the formation of a new economic system was the Virtual Corporation. The literature attributed to this concept the ability to solve the problems of large companies (such as inflexibility) and small enterprises (such as poor economies of scale) simultaneously and to combine the best features of both extremes of company size. This article discusses, which prerequisites for the implementation of VC, then mostly dreams of the future, are given today and how the concept of the VC can complement Industry 4.0 and serve as a role model on an organizational level.

Keywords: INDUSTRY 4.0; VIRTUAL CORPORATION; ORGANIZATION THEORY; INDUSTRIAL REVOLUTION; INFORMATION COMMUNICATION TECHNOLOGY; TECHNOLOGICAL ADVANCEMENTS

1. Introduction

The literature on Industry 4.0 mainly deals with the technological perspective and discusses trends in modern technologies such as Artificial Intelligence, the Administrative Shell or the Digital Twin. Analyzing the effects of these technological components on the organizational structure of companies, one is reminded of the organizational concept of the Virtual Corporation.

The goal of this article is to show how the two concepts Industry 4.0 and the Virtual Corporation (VC) complement each other and how the VC can serve on an organizational level to make companies more successful. Chapter two briefly describes the current status of Industry 4.0. The third chapter introduces the concept of the Virtual Corporation. Chapter 4 examines the similarities and differences between the concepts of Industry 4.0 and the Virtual Corporation, how the integration of the VC concept into Industry 4.0 could look like and why this is so important.

2. A Brief Analysis of Industry 4.0

The 4th Industrial Revolution is about to revolutionize the entire value chain of almost all branches of industry and to initiate a paradigm shift. Industry 4.0 bundles the answers to those challenges. This chapter briefly introduces the three most important principles of action of Industry 4.0: Digitization, automation and new business models as well as some key technologies.

2.1 Principles of Action of Industry 4.0

Companies are facing increasing external and internal complexity and dynamics. In many industries, the dominant technologies are being replaced. Disruptions occur because new business models turn everything upside down. Digitization is primarily responsible for this: It is changing our lives more than any other megatrend. People are constantly online - and companies have to follow them into these virtual spaces, forcing them to undergo a structural change, the digital transformation [1].

Information and communication technology (ICT) paved the way for Industry 4.0, and Cyber-Physical Systems (CPS) is its manifestation, because its paradigm is based on the fusion of the physical world with the virtual world into CPS [1]. These consist of buildings, production facilities, logistics components, equipment, means of transport and other objects. All these elements are uniquely identifiable, record their environment with sensors, evaluate the information thus obtained with the help of globally available data and services, save it and act in the physical world with the help of actuators such as robots. The individual elements communicate with each other via the Internet of Things (IoT). An advanced CPS can build autonomous and decentralized networks and optimize itself independently. Three interdependent principles of action are vital for Industry 4.0.

2.1.1 Digitization

Digitization is bringing the IoT into factories and leads to the creation of CPS. Digitization links material flows with data. This makes it possible to network resources, machines and logistics systems online. This enables decentralized, self-sufficient and self-optimizing production processes and supports companies in avoiding waste and reactive power, thus contributing to increased resource efficiency. Today, complete horizontal and vertical integration can link the entire supply and value chain and improve collaboration, coordination and transparency in global corporate networks. This fundamentally changes the relationship between suppliers and manufacturers [2].

2.1.2 Automation

In the past, there was a trade-off between automation and flexibility: the more automated the production, the less flexible it was. Progress in ICT is resolving this conflict of goals. Automation replaces mechanical work with software-controlled processes. Online algorithms continuously control and monitor the value-added process so that, for example, deviations can be detected and the production process can be automatically switched off to reduce scrap. Smart products play an important role here: They know their properties and know how they are to be manufactured, in which phase of the manufacturing process they are, and where they should be delivered next. They also know which machines or systems they can be connected to [2]. Automation can increase decentralization, scalability, transparency and flexibility along the entire value chain.

2.1.3 New Business Models

Man is empowered by technology: He becomes the conductor of the value chain and generates new business models. Other drivers are the changed and expanded processes. Formerly known value chains are developing strongly. All this not only changes existing business models, but also leads to the emergence of new ones. The focus is on a fundamental rethink: it is no longer products that are sold, but customer benefits. Examples of the digital finishing of products are, for example, ‘pay-per-use’ models: the customer no longer pays for a particular machine tool but for the number of pieces produced on that machine (‘pay-per-piece’) [1].

2.1.3 Key Technologies

As mentioned, the development of Industry 4.0 is technology-driven and is made possible by ICT. Figure 1 gives an overview of the most important technologies:
3. Introduction of the Virtual Corporation (VC)

Ever since the science fiction author William Gibson coined the term “cyberspace” in 1982, the attribute “virtual” has become very popular. It specifies phenomena that are not physically present, but whose full performance is nevertheless available. In the 90s, the attribute “virtual” seemed to provide a guarantee for the future in an ever faster changing world. In the economic literature, Scholz even proclaimed an evolution of the concepts of virtuality, ranging from “virtual memory” to “virtual product” to “virtual corporation” as the preliminary end point of a logical development [3].

The concept of the VC began with two groundbreaking publications in the early nineties: The 1992 bestseller of Davidow and Malone dealt with virtual products and their manufacturers. The authors enriched their argumentation with popular management trends and thus arrived to the VC as the concept of the future [4]. A cover story in 1993 in the Business Week by Byrne, Brandt and Port shaped the prevailing view of the VC as a temporary coupling of highly specialized units [5]. In the absence of a definition by Davidow and Malone, the definition by Byrne, Brandt and Port as co-authors of the concept is presented:

“The virtual corporation is a temporary network of independent companies, suppliers, customers, even erstwhile rivals linked by information technology to share skills, costs and access to another one's markets. It will neither have central office nor organizational chart. It will have no hierarchy, no vertical integration (...) In the concept's purest form, each company that links up with others to create a virtual corporation will be stripped to its essence. It will contribute only what it regards as its core competencies.” [5]

To date, no universally valid definition of the VC has been established. Since the concept developed rapidly, the definitions always lagged behind the discourse. In order to narrow down the phenomenon of the VC more precisely, the next step is to look at the concept from an intra- and interorganizational perspective.

3.1 Conception

In the literature, the concept is discussed from two perspectives: From an intra-organizational perspective, it is shown how a single company is structured internally to become a VC. The company changes from a hierarchical to a hybrid form of organization in which the company units are equipped with a higher degree of autonomy and cooperate on a project-related basis. From an inter-organizational point of view, a large number of legally independent companies merge to form a VC. Coming from the two opposing poles of market and hierarchy, a hybrid form of organization is thus realized from both perspectives.

3.1.1 Conception from an Intra-Organizational Perspective

Traditional business administration according to Scientific Management interprets companies as entities with rigid structures, which are characterized by clear horizontal and vertical boundaries separating departments and hierarchical levels. According to this approach, the essential two elements of a company are its dominating structural and a process organization [6]. In the “evolutionary paradigm”, however, companies are understood as complex and networked social systems. Their ability to survive is only given if self-organization replaces the external organization to a large extent by granting the system members more autonomy [7]. Self-organization is a central feature of VCs, along with consistent process orientation.

VCs take this into account primarily by using team-based forms of organization. Strict process orientation is made possible in an efficient way by these ad hoc organizational structures, which are project-related and therefore flexible in their formation and dissolution [8]. In this context, VCs are to be understood as a dynamic team system that spreads almost throughout the entire company [7]. This enables a very high flexibility and adaptability to constantly changing task constellations.

Too much vertical integration ties up too many resources, which are no longer available for the strategically important core tasks and also hinder the flexibility of a company [6]. Vertical integration and complexity are therefore reduced by outsourcing, supplier partnerships or other forms of cooperation. By delegating all other tasks, a VC can focus on its core competencies and optimize its own value chain [9].

"Teleworking" and “mobile computing” are dissolving the boundaries of the company even further. Through its focus on communication and cooperation, telework supports the self-organization of a VC in a significant way and also largely removes the barriers of space and time [10]. This is particularly evident in “mobile computing”. Moving away from classic employment relationships further increases the company's flexibility [8].

3.1.2 Conception from an Inter-Organizational Perspective

In classic business administration, the view is held that companies have external boundaries that are clearly defined and sharp. These boundaries are mostly defined by ownership and control rights, uniform management, business areas, common standards, objectives and values or regional structures [11]. Modern organizational theory contradicts this view. Richardson, for example, takes the view that market and hierarchy are only the two poles of a continuum of possible forms of transaction and cooperation [12]. In all types of cooperation, the boundaries between companies become blurred due to the interlinking with the cooperation partners [11].

VCs are based on dynamic networks that can be configured and dissolved quickly and flexibly according to the requirements. This promises high flexibility as well as high efficiency. Legally independent organizational units form the nodes of the network of an inter-organizational VC. When merging to form a VC, each company contributes its core competencies, which are ideally complemented by the core competencies of the other organizational units involved [13]. Since it is assumed that each participant offers the component in which he or she holds the absolute top position, this creates a “best-of-everything-organization” [13] in which all parts of the value chain are optimized.

At the network level, the principle of self-organization ensures the behavioral variety that is necessary to solve complex problems in a dynamic environment [7]. Due to the increasing networking
with market partners and the inclusion of customers in the network, the boundaries between the units involved are becoming increasingly blurred. VCs are to be understood as one-off mergers of organizational units that collaborate on a project-by-project basis to produce a specific product or service - for as long as the market allows [14].

Within these networks, the use of team-based forms of organization in and between companies helps to optimize the entire value chain. Analogous to the dissolution of departmental and hierarchical boundaries in internal team structures, cross-company teams blur the boundaries between organizational units [7]. In spite of the extreme spatial and temporal distribution of the actors and the processes, a VC appears to be a single company for customers and cooperation partners.

Information and communication technology (ICT) plays a particularly important role in this context. It ensures the efficient distribution and coordination of tasks within the company network. The virtual integration of resources through ICT means that neither additional facilities need to be built nor additional staff need to be hired. The already existing, distributed resources remain physically in their place, but are connected to each other electronically [14].

3.2 Strengths of Virtual Corporations

The four classic dimensions of profitability – cost, quality, time and flexibility – provide information on the competitiveness of a company and, accordingly, on the strengths and weaknesses of VCs. 

3.2.1 Strengths from an Intra-Organizational Perspective

From a cost perspective, an intra-organizational (i.e. internal) VC is attractive: by limiting the company to its core competencies, all resources are concentrated on the skills that the company can master best and most efficiently. Teleworking saves space and ancillary wage costs when teleworkers are self-employed and/or only add to the core workforce when necessary [7].

The restriction to the most well-managed value creation processes also leads to quality improvements. Team-based forms of organization motivate employees and make optimum use of their learning and performance potential. Mobile computing in particular improves market proximity and customer service significantly [7].

Time can be gained by focusing on core competencies. This enables a lower vertical integration and a shorter lead time. Teams that are configured to meet specific needs solve their tasks faster.

The flexible allocation of resources to constantly changing processes increases adaptability, which is further enhanced by ICT [7]. Telework can attract employees who live far away from the company headquarters. Finally, additional flexibility is achieved by using external capacities for peak balancing [7].

3.2.2 Strengths from an Inter-Organizational Perspective

The combination of the core competences of individual companies opens up the joint synergy potential of all the parties involved. Thanks to ICT, the transaction costs for handling the exchange of services are lower [6]. A minimized administrative apparatus saves fixed costs. Finally, the dissolution of the VC after the end of the project is carried out with little administrative and financial effort.

The qualitatively best components are combined, since each participant contributes the component in which it holds the absolute top position [15]. A VU can offer customer-specific and high-quality goods, which makes it highly attractive for customers. Time savings result from the fact that not every partner has to deal with the whole issue from the product idea to distribution [15]. Since each unit concentrates on the sub-process it controls best. The use of simultaneous processes increases the speed of the process. Due to the extraordinary speed with which a VC can be formed, the speed of adaptation reaches new dimensions [16].

Virtual Corporations are highly flexible due to the wide range of possible combinations of core competencies. The participants can use the size of the network without having to give up their own flexibility and manageability [16]. In this way, economies of scale and experience curve effects can be achieved without having to accept the inflexibility of a large company. The individual companies thus remain relatively small, but together reach a considerable virtual size [17].

3.3 Integration of both Perspectives and Conclusion

If one compares the elements of the intra- and inter-organizational perspective, one finds that there are basic similarities. From an abstract point of view, the same principles apply, only the specific form is different: Team-based forms of organization and cross-company teams differ only in whether one considers a single company or a corporate network. A VC limits itself internally to its core competencies in order to become part of a “best-of-everything” organization in an external network, i.e. an inter-organizational VC. After all, ICT is the key technology in both cases, enabling teleworking and mobile computing, which in turn form a basis for team-based work in both perspectives.

Both perspectives attach great importance to the principle of self-organization and apply the same design principle: the “dynamic and flexible assignment of abstract service requirements to service providers and the specific location of service provision” [18]. The fact that the concrete design is different can be attributed to the opposing starting positions.

Although being a very promising concept, the proliferation of VCs suffered for a number of reasons: The VC was viewed from a wide variety of angles, which painted a very heterogeneous picture. In theory, the ideas about the content and nature of VCs differed widely and, moreover, were often imprecise [10]. The concept therefore initially failed due to its theoretical shortcomings and thus turned out to be rather unsuitable for practice. Two further reasons were that the technological prerequisites for the successful formation of VCs were not yet in place at the end of the last century. And that the proclaimed challenges for companies, which were supposed to force the formation of VU, were not as pronounced then as they are today. As a result of this, the concept was not able to assert itself on a broad front and vanished slowly – until Industry 4.0 provided the conditions for a new proliferation.

4. Integration of Industry 4.0 and the VC into an Overall Concept

This chapter discusses possibilities to develop organizational aspects of Industry 4.0 through the approaches of VCs. First, the similarities and differences are discussed, as well as suggestions to strengthen Industry 4.0 companies through approaches of the VC concept. The next section introduces challenges that need to be overcome so that a further common development can take place. Finally, it is discussed how the integration of both concepts can lead to an overall concept.

4.1 Similarities and Differences

The basic idea of Industry 4.0 is grounded on two thoughts: the global networking of people, plants and products as well as the independent and decentralized self-organization and control of
these production units in real time. These two elements – the dynamic networking of partners and the principle of self-organization – are also at the heart of the concept of the Virtual Corporation. This striking similarity suggests that there might be more commonalities. This chapter therefore examines the similarities and differences between Industry 4.0 and the VC concept.

One fundamental common feature is that both concepts have an intra- and an inter-organizational perspective. After all, Industry 4.0 can also be treated from two poles: The intra-organizational perspective looks at individual companies that optimize their part of the value chain internally. From an inter-organizational perspective, several companies – suppliers, producers, customers – are interlinked by Industry 4.0 along the entire value chain.

The fundamental difference between the two concepts is that Industry 4.0 follows a technological approach and the VC follows an organizational theory approach. Further differences and commonalities are presented in the following.

4.1.1 The Role of Globalization

Globalization represents both a threat and an opportunity for VCs: On the one hand, the deregulation of markets increases the number of rivals from other countries. On the other hand, a company can make optimum use of the world’s best resources to provide its services and expand into previously closed markets.

Globalization is also one of the germ cells of Industry 4.0, which covers all parts of the value chain. Due to the growing complexity of production and supply chains in connection with increasing customer requirements and the strong dynamics in the markets, companies must become more flexible and agile in order to adapt to changes. They can only meet those challenges if they completely change the way they create value. The VC concept can support Industry 4.0 significantly on an organizational level.

4.1.2 Central Importance of ICT and the Internet

Only ICT and the Internet can tackle the challenges described above. Because of its universal applicability in all functional areas of companies as well as its networking with suppliers, customers and other companies, it is not only the decisive driver of Industry 4.0, but the prerequisite for successful, ICT-driven networking with other companies, as envisaged by the VC concept.

The Internet as a global infrastructure for the exchange of information and data enables the use of the world’s best input factors as well as sales on a global scale. One vision of the concept of the VC was the to pave the way to the “global village”. It has become a reality for many companies in Industry 4.0 as the Internet as a global infrastructure for the exchange of information and data enables the use of the world’s best input factors as well as sales on a global scale.

In Industry 4.0, companies retain their legal form, headquarters and employees [5], a VC can adapt efficiently to market dynamics and rapidly changing customer needs.

In Industry 4.0, companies retain their legal form, headquarters and identity. However, these companies still rely on the same principles of process orientation. The value-added process is continuously monitored online so that, e.g. deviations are detected and automatically corrected within the ongoing production process. By networking all value creation processes in real time, the original conflict of goals between efficiency and flexibility is eliminated. This even enables flexible and efficient production in lot size 1 [1].

This resolution of the trade-off between efficiency and flexibility also characterizes the VC concept - even though existing VCs could not keep this promise at the time. Implementing the VC
design principles of dynamic allocation and self-organization brings about fundamental changes in the overall organization of Industry 4.0 companies. Cross-divisional thinking also leads to the reduction or elimination of indirect divisions, i.e. the supporting functions – and makes an Industry 4.0 company increasingly resemble a VC. Radical cross-divisional thinking can be an important contribution of the VC concept for Industry 4.0.

4.2 Challenges for a Further Common Development

If one wants to enrich Industry 4.0 with the principles of the VC concept, certain challenges have to be overcome in order to find a promising path towards an overall concept.

4.2.1 Selection of Core Competencies

If core competencies of companies are to be networked in order to generate synergies, the selection process of the cooperation partners plays an important role. It results in “initiation costs” and later in “coordination costs” during the period of cooperation. These costs must be kept low. The computer-assisted supplier selection processes already used in Industry 4.0 serve as important tools for global sourcing. The criteria only need to be adapted to the needs of VCs. It is crucial whether the core competencies to be selected are really complementary and thus will realize synergy effects. It is equally important to check the corporate cultures of the potential network partners for compatibility. It is also advisable to carefully study the difficulties often observed in failed or difficult mergers in order to achieve successful networking and avoid those mistakes.

4.2.2 Multitude of Interfaces

In Industry 4.0, many technical interfaces have to be mastered. The following standards should be used for secure, cross-company communication in virtual networks [20]:

- **Automation ML:** Automation Markup Language as a neutral, open data exchange format.
- **eCl@ss:** A consortium standard managed by the eCl@ss association.
- **IEC CDD:** Common Data Dictionary (CDD) of the International Electrotechnical Commission (IEC).
- **OPC UA:** Open Platform Communications Unified Architecture, an open interface standard published as standard IEC 62541.

For the networking of different areas outside the company, as it is typical for VC, the OPC UA approach has the greatest potential. Its advantage is that it is a manufacturer-independent information model, which is essential for integrating the VC concept into the Industry 4.0 approach. Only the necessary IoT platforms yet to be developed will guarantee that the large number of technical, economic, and organizational interfaces can be mastered.

4.2.3 Guarantee of Flexibility

Flexibility is mandatory when merging Industry 4.0 with the VC concept. All participants must be enabled to use the size of the network without having to give up their own flexibility and manageability [16]. Only then, economies of scale and experience curve effects can be realized without having to accept the inflexibility of a large company [19], and the individual companies can remain relatively small yet together achieve a considerable virtual size [17]. This is of particular interest for consortia of SMEs.

4.2.4 Realization of Time Advantages

Care must be taken to make sure that, in the integration of VC concepts into the environment of Industry 4.0, the theoretical time advantages through rapid adaptation to the market and to quickly changing customer needs are actually realized. For example, time-consuming processes, such as partner searches, must be solved with computer-aided software.

4.2.5 Remuneration and Protection of Intellectual Property

In a network linking Industry 4.0 employees to form a VC, clear rules must be agreed upon for the remuneration of all employees and for the use of intellectual property. It would seem sensible to extend the provisions of the Employee Invention Act to all employees and to regulate remuneration fairly everywhere.

4.2.6 Role of the Human Being

People play an important role in Industry 4.0. They must collaborate responsibly in teams. If man is to become the conductor of the value chain [1], she/he must constantly adapt processes to changing conditions, redefine value chains and generate new business models. However, management tasks in the Industry 4.0 environment have become more demanding. According to a study by the RWTH Aachen University and VDMA, the following five fields of action were identified, which must be taken into account for innovations in digital products, processes and services [21]:

- **Designing Innovation Portfolios:** The aim is to strengthen the ability to innovate. This can be done by cooperating with start-ups, universities or other business partners. In this respect, communication within virtual networks of VCs can be an important driver of innovation.
- **Overcoming Tendencies of Persistence:** Every innovation initially meets with resistance. This can be overcome with joint projects within the company (cross-departmental) or together with external partners in the VC.
- **Building an Innovation-friendly Culture:** When recruiting employees and selecting managers for Industry 4.0 and VCs, the decisive criteria should be their enthusiasm for innovation and new approaches, for flexibility and openness.
- **Building Digital Skills:** Training should further develop the ability to analyze data in Industry 4.0. Given their experience, employees of VCs can provide important input. This will also strengthen the cohesion between employees in Industry 4.0 and in VCs. When hiring new employees, special attention must be paid to digital skills.
- **Exploiting Digitization Potentials:** Often employees are not aware of the advantages of digitization. Above all, the customer benefits of digitization must be elaborated and communicated. As a result, digitization will gain acceptance both within and outside the companies and their virtual network.

The demands on employees in VCs are not lower. In addition to in-depth specialist knowledge, they must be able to manage and motivate themselves to a large extent, have strong communication and social skills and a confident command of new communication technologies [10]. Managers working in Industry 4.0 can support employees of VCs by providing targeted mentoring and training. This also conveys a feeling of solidarity and cooperation, which often doesn’t exist in VCs.

VCs carry the risk that teleworking will result in less traditional, permanent employment relationships. As a result of performance-based recruitment and remuneration, each employee is fully responsible for the company but enjoys little material security. There is also a latent danger that employees within the (compared to Industry 4.0 short-term) VC network will look for other job offers.
that seem more attractive or will be poached by headhunters. A more solid network in an Industry 4.0 environment achieves a bond with the company more easily. Joint projects, congresses, symposia, training courses, trade fairs and educational trips also can create a sense of belonging to the company. In addition, employees can be supported in their personal development or gain material advantages through possible profit sharing in successfully implemented projects. To sum it up: The personal appreciation of VC employees plays a decisive role. And the activities in Industry 4.0 and VCs should be aligned to a common corporate goal that is worthwhile for all partners. The combined Industry 4.0 and VC networks should also offer suitable promotion and career opportunities for ambitious employees.

The trust of the partners is one of the decisive factors for the success of the cooperation between employees in Industry 4.0, even more so in VCs. This trust must be strengthened by appropriate measures, as presented in this section. Applied correctly, Industry 4.0 fully exploits human and technological potential and combines them in an ideal way [2]. For instance, if the principles of ergonomics in the workplace and occupational safety are observed, it becomes possible to keep older and more experienced workers as active factors in the production process for much longer.

5. Conclusion

Industry 4.0 has already found its way into many companies and will continue to establish itself, including small and medium-sized enterprises. This strong concept is almost exclusively technological. It shows the technical state of the art of industrial production and its networking with suppliers and customers. It also describes how the technical view of Industry 4.0 and the organizational view of the partners is one of the decisive factors for the success of the cooperation between employees in Industry 4.0, even more so in VCs. This trust must be strengthened by appropriate measures, as presented in this section. Applied correctly, Industry 4.0 fully exploits human and technological potential and combines them in an ideal way [2]. For instance, if the principles of ergonomics in the workplace and occupational safety are observed, it becomes possible to keep older and more experienced workers as active factors in the production process for much longer.

The Virtual Corporation provides a completely different perspective. At its core is not as much technology but the organization of many networked elements. What both Industry 4.0 and VCs have in common is that they rely on a powerful ICT. With cost-effective and powerful network connections, it is possible to attract the world’s best specialists and their core competencies to meet the current and future needs. This network of competencies creates products that are flexible, cost-effective and tailored to the customer’s needs. In order to achieve this, a company does not have to hire employees permanently for each requirement, but can bring in the appropriate people as needed. Because of the many additional specialist skills, the core company is perceived virtually as much bigger than it actually is because of its increase in performance. Thereby, it becomes a Virtual Corporation.

Industry 4.0 and Virtual Corporations have many similarities. Special efforts are required to combine both concepts in such a way that success is achieved in the highly competitive international market. With the exact knowledge of the characteristics of Industry 4.0 and Virtual Corporations, strategies can be created how the technical view of Industry 4.0 and the organizational view of Virtual Corporation can be combined in such a way that a successful and synergetic overall concept can be created for all sides. An important task for the future is therefore to further develop this overall concept and adapt it to today’s conditions and requirements. The more important value creation by new digital business models becomes and the more cross-company collaborations represent daily practice, the more urgent this task will become.

6. References

Changes of human resource management in the context of impact of the fourth industrial revolution

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Abstract: Fourth industrial revolution also called Industry 4.0, is considered as the most discussed topics among experts nowadays. The excitement for the Industry 4.0 goes two ways. First says that the fourth industrial revolution deals with the question of “a priori” and not “ex-post”. Organizations and research institutions gain opportunities for active building and forming of the future. Secondly, it has significant economic impact, which promises much higher operational efficiency, as well as development of brand-new business models, services and products. At the moment, organizations are able to run without elements of the Industry 4.0, but only for a limited time. They have to look for a path of further development, and that is digitalization in each field of business. With help of human resource management, organizations are able to form skills, abilities, behaviour and attitude of employees in order to achieve the targets of organization. Human resources represent significant factor for competitive advantage in the knowledge economy. In the Industry 4.0 considering human resource management, managers have to mainly focus on supporting of innovation and learning in the organization. The main goal of this article is to identify changes in methods and techniques during realization of human resource management in the context of the impact of fourth industrial revolution in theory, based on research of available scientific literature. Attention is mainly focused on selected functions of human resource management like job design, staffing, training and performance appraisal.

Keywords: FOURTH INDUSTRIAL REVOLUTION, HUMAN RESOURCE MANAGEMENT, INNOVATION, AUTOMATIZATION, DIGITALIZATION

1. Introduction

The dynamic development of the fourth industry revolution is the result of several processes. It was mainly influenced by internationalization, the development of information technologies and also by hypercompetition. The fourth industrial revolution describes the growing digitization of the value chain and the resulting interconnection of subjects, objects and systems through real-time data exchange. [1] The term fourth industrial revolution is often referred to as Industry 4.0. This period expanded the possibilities of digital transformation, and also emphasized its importance for business. Industry 4.0 connects and combines digital and physical technologies - artificial intelligence, the internet of things, robotics, cloud computing and more, with a view of more flexible and efficient management, and the interconnection of companies, that are able to make decisions based on more detailed information. [2]

Nowadays Industry 4.0 is considered as a heart of today’s discussions of modern business. It is considered to be a socio-technical system that organizes the relationship among human capital, companies, technologies, production systems, production and consumption, thus creating a newly created relationship between industry and society in the process of digitalization. [3]

The effects of Industry 4.0 are expected to reflect in all areas of scientific progress. Although, it is very difficult to predict certain facts, there are assumptions that human resource management theories will need to rely on building stronger environment, social responsibility and ethical dimensions, as communities and workers demand, that companies increasingly respond to these global challenges more strategically. In the evolving “fight” for talent, companies that do not respond to a changing environment will have difficulty competing, because branding of employers becomes an essential part of selecting a young generation of workers. Human resource professionals will need to focus more intensively on proactive human resource planning, global and local environmental problem-solving, which will transfer many traditional functions to managers, external service providers using artificial intelligence and robotic technologies. The growing interest in “big data” and a more sophisticated human resource information management system will become an essential part of modern business, as well as greater responsibility for individual strategies, processes and results. [4]

The aim of this presented article is to identify, at a theoretical level, changes in human resource management in the context of the impact of the Fourth Industrial Revolution, through the available scientific literature.

2. The Fourth Industrial Revolution

The Fourth Industrial Revolution brings endless and unlimited opportunities for technological investment. Companies during the digital transformation should consider several questions: “What would they like to transform thanks to digitalisation?”; “Where to invest resources?”; “What advanced technologies to use to improve strategic needs?” During answering these questions, it is important to realize, that a real digital transformation has significant implications for companies. It influences the company’s strategy, talents, business models, and even the way the company is organized. [2]

We share the view of PwC director Kumar Krishnamurthy, that while the Third Industrial Revolution focused on the automation of individual machines and processes, the Fourth Industrial Revolution focuses mainly on the digitization of all physical assets and the integration of digital ecosystems with value chain partners. [5]

Industry 4.0 is thus surrounded by a diverse network of advanced technologies throughout the value chain. Services, automation, artificial intelligence, the Internet of Things and additive manufacturing bring a whole new era of production processes. The boundaries between the real world and virtual reality are blurring and causing a phenomenon known as cyber-physical production systems. [6]

Advanced digital technology has been used in industry for a long time, but thanks to Industry 4.0 it can transform the entire production. This will ensure greater efficiency and change the traditional relations in production among suppliers, manufacturers and customers. Technological trends, which form the building blocks of Industry 4.0, play an important role. [8] According to the mentioned technological trends, the Boston Consulting Group proposes following trends: simulation, autonomous robots, internet of things, cyber-physical systems, cloud computing, virtual reality, communication among machines and cyber security. [7]

Companies face major challenges in adopting and implementing these new technologies. In order to build and keep leading position, they need to broaden and deepen their practical knowledge about digital technologies and the way, how to use them. [7] Subsequently, they need to develop and implement customized digital production strategies. With the implementation of new technologies in companies, mechanical industries have been transformed into highly automated industries. These industries are sensitively adapting to changing environmental conditions, and customer requirements. When implementing Industry 4.0 techniques, it should be borne in mind, that companies may face several challenges [9], which are listed in the following table.
Improving the quality of Industry 4.0 can be achieved by properly integrating existing new technologies. With more advanced technologies, such as cyber-physical systems and industrial information integration, it builds on the overall quality of Industry 4.0, as it is based on interdisciplinary and transdisciplinary integration, including industrial information integration. In recent years, there have been significant developments in technology, as well as actual and potential applications in various industries. However, the development of advanced methodologies, in particular formal methods and system approaches, must be aligned with rapid technological developments. [10] As Weber said, Industry 4.0 is primarily about the application of advanced manufacturing technologies. [5] The US National Science Foundation has noted, that significant advances have been made in cyber-physical systems, however, we still have insufficiently advanced science to support the system engineering of highly confidential cyber-physical systems. [11] Despite progress in Industry 4.0, new challenges are still emerging in academia and industry. Sufficient attention needs to be paid to them, in order to realize the full potential of the Fourth Industrial Revolution. [10]

We can come to the conclusion that today technological development and innovation play an important role in every company. This is reflected mainly in increasing the competitiveness of the business. It is the Fourth Industrial Revolution that seeks to lead to possible profound changes in a number of areas that go beyond the industrial sector. Industry 4.0 blurs the line among people and technology.

### 3. Human Resource Management

Human resources are a term used for employees, company managers, and possibly for some external collaborators. It is an awareness of the importance of the workforce compared to other resources (land, capital). In the scientific literature, we also meet the term human capital. Thus, human resources constitute significant assets for any business, or a significant loss. [12]

Recently, it has been pointed out that we consider human resources to be the basic and primary sources of a company’s competitive advantage. Based on them, the goals of the company are determined, the strategy is formulated and subsequently implemented. The challenge of recent years is to focus on key successful progress, meaning it focuses on the quality of human resource management. The intention of the newer view is to point out, that combining the efforts of both stakeholders (employee - company) into a compact unit is very important and significant.

There is mutual satisfaction, under what we understand, that the company is a place to meet the needs of the employee, and the employee represents an effective benefit for the company. [13]

Given this fact, human resource management can be defined as a strategic and logically thought-out approach for managing the most valuable thing a company has - people who work in the company, who individually and collectively contribute in achieving business goals. [14]

We consider human resources management as a strategic and active integrated system approach in management, focused on achieving a match among personnel needs and the real potential of human resources. By personnel needs we understand the required number of employees of individual categories, that are characterized by the required skills, knowledge and competencies. The real potential of human resources can be activated in fulfilling the company’s goals. Employees must be adequately motivated and willing to do their job for the company. [15]

The role of human resource management is to ensure that people in the company - human resources - are used in a way that brings the employer the greatest benefit from their abilities, and consequently, employees receive material and psychological rewards for their work. The importance of human resource management lies in addressing the consequences of organizational decisions for productivity and the conditions under which the company's employees work. We can therefore conclude, that the main importance and purpose of human resource management is to realize the potential of employees, and to state, that employees are not only necessary expenses and costs in business, but are the most important assets, a source of competitive advantage and thus an investment producing significant added value. [16]

The basic functions of human resource management include: personnel planning, job analysis and job design, recruitment, staff selection, staff adaptation, staff training, career management and planning, performance appraisal and management, employee remuneration, working conditions and employment relationships, redundancies employees and termination of employment. In the article we will focus only on selected functions, which will be mentioned in the next part of article.

From the above, we come to a conclusion, that human resources are an integral part of any business. They are a source of competitive advantage and contribute to the achievement of business goals.

### 4. Results and discussion

The Fourth Industrial Revolution obscures the boundaries between human capital and technology. The resulting changes affect people, as well as the value produced by companies, and redefine the future of work. An impetus is being created for transformation in human resource management. Thus, human resources are not immune to the situation, that has arisen, and they must also adapt to the modern phenomenon. The following part draws attention to the importance of intelligent human resource management, the so-called “Smart HR 4.0”. There is pressure on existing companies to align personnel processes with the changing technological environment.

Smart human resources 4.0 is a new concept that is evolving as part of the Fourth Industrial Revolution and features innovations in digital technologies such as the Internet of Things, big data, artificial intelligence and fast data networks such as 4G and 5G to effectively manage next-generation employees. [17]

Smart HR 4.0 has its own set of implementation challenges, and a set of benefits based on the customization of individual companies. Implementation challenges include:

- Choosing the right set of new technological tools;
- Transformation of the existing organizational structure;
- Managing the expectations of multiple generations of employees.

The implementation of Smart HR 4.0 brings many benefits. Among the most important we can include:

- Attracting, developing, retaining new talent;
- Slimmer human resources departments;

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**Table 1: Overview of Industry 4.0 challenges**

<table>
<thead>
<tr>
<th>Number</th>
<th>Challenges</th>
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<tbody>
<tr>
<td>1.</td>
<td>Modernization of existing elements</td>
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<tr>
<td>2.</td>
<td>Capital requirements</td>
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<tr>
<td>3.</td>
<td>Errors in data processing</td>
</tr>
<tr>
<td>4.</td>
<td>Compatibility of workers with new technology</td>
</tr>
<tr>
<td>5.</td>
<td>Cyber-attacks – data sensitivity</td>
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<tr>
<td>6.</td>
<td>Low availability of standard and comparison processes</td>
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<tr>
<td>7.</td>
<td>High accuracy of data collected from systems without loss of quality</td>
</tr>
<tr>
<td>8.</td>
<td>Automation as a substitute for shortcomings cheap labor</td>
</tr>
<tr>
<td>9.</td>
<td>Impact of automation on faster depletion of non-renewable resources</td>
</tr>
<tr>
<td>10.</td>
<td>The need for new business models</td>
</tr>
</tbody>
</table>

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• More efficient and faster processes within human resources. [18]

The human resource department is responsible for managing all aspects related to the employee's life cycle, from recruitment to termination of employment. While the role of human resources is the key to organizational growth, most human resources departments in various companies perform mainly operational activities due to highly inefficient processes caused by insufficient and outdated technological infrastructure. However, it should be noted, that technology is undergoing rapid change. New technologies, such as the Internet of Things, allow physical things to connect to the digital world, causing a huge amount of "real-time" organizational data to be generated and stored on cloud technology. Not only major changes have happened in field of technology, but Industry 4.0 is also affecting generations of employees. In 2020, half of the workforce is expected to be made up of "millennials" or Generation Y (born among 1980 and 2000). Generations Y and Z (born after 2000) grew up and are growing up in the period of the Internet, social media, smartphones and are characterized by different expectations from employers. These include: cooperation, which is possible anytime and anywhere; immediate feedback, open culture and data-based decisions. Powered by new technologies and next-generation employees, Smart HR 4.0 has the potential to transform end-to-end human resource processes covering all aspects of emerging talent. [18]

Recruitment of talents into the company

The spreading of smartphones has led to the development of intelligent applications. Generations Y and Z are increasingly being approached by job advertisements in their mobile applications based on the individual profile and preferences selected in the settings of these applications. [18]

Big Data and artificial intelligence help automate the search for a candidate's resumes and job preferences. This is a high probability for meeting the requirements of the job. As a result, the amount of time and manual effort currently expended is reduced. [18]

Interview techniques may include automated and customized testing, instead of generic testing procedures that predict better workplace performance in the future. The faster data network (4G / 5G) enables distance conversations via real-time remote video, which helps to shorten the overall recruitment cycle. AI chat robots can help interpret and verify candidates' reactions in real time, reducing the number of candidates invited to the interview. [18]

After recruiting, it is recommended that induction programs will be adapted to individuals, instead of traditional universal programs. Augmented Reality / Virtual Reality (AR / VR) could help new employees with different processes in the company and monitor whether they are productive from day one. [18]

Talent development in the company

After starting working, increasing knowledge and skills is a necessary requirement for success in today's competitive environment. Artificial intelligence helps to identify knowledge gaps for each employee, based on market requirements. [18]

Generations Y and Z are characterized by the fact, that they want to do career planning themselves. They only want to undergo training, that would help them achieve their professional goals. Again, faster networks enable virtual training that can be done from anywhere, anytime. [18]

As with training, performance goals should be set on an individual basis, instead of setting the same goals for each employee in the group, using artificial intelligence. Feedback would be an ongoing activity in providing information on employee performance. [18]

The structure of benefits and compensation should be derived from the supply and demand for skills analyzed from employee databases. [18]

In addition to compensation, employee health is an important aspect of a company's productivity. Through health-oriented applications, employees are able to monitor their fitness parameters in real time, which helps to reduce the number of days of incapacity for work. [18]

Evaluation of employee performance

A performance appraisal system that is appropriate for Industry 4.0 should focus on employee development. In particular, it is a results-based approach and a behavior-based approach, as these approaches support education and innovation. It is recommended that employees receive feedback on their performance. [19]

The goal-based approach (MBO) is becoming increasingly popular. The MBO is characterized by specific objectives, where the objectives are brief statements of expected results. Managers and employees set goals and ways to achieve them through mutual discussion and consensus. An integral part of the MBO is also feedback, which allows managers and employees to monitor activities and take corrective action accordingly. MBO is a suitable approach to performance evaluation, so that the company's compatibility with Industry 4.0 is again ensured. [19]

Termination of employment

The employee's intention to leave the organization can be predicted by analyzing the employee's profile. The human resources department might take proactive steps to prevent high-performing employees from leaving the company by providing better internal opportunities. [18]

Low-performing employees can be identified on the basis of ongoing annual evaluations instead of evaluations from their superiors. Programs designed to enhance employee performance are recommended to be automatically adjusted to employee deficiencies within abilities, skills, knowledge. [18]

Although the prospects for implementing the Smart HR 4.0 concept seem to be optimal, HR departments should also pay sufficient attention to changes in organizational structures and management styles. [18]

Organizational structure and leadership styles

The flat agile organizational structure creates a suitable environment for the implementation of Smart HR 4.0. A flat hierarchy will reduce communication levels and speed up decision-making. Decentralization of power will force project teams to work more autonomously and will have to adapt immediately to project requirements. [20]

Leadership styles need to be more open, help manage education and innovation culture, focus on improving knowledge and reward innovative thinking. Leadership is expected to have to initiate changes in organizational culture in such a way as to avoid conflicts among different generational groups. [20]

Smart HR 4.0 is required to modernize technology in line with the company's long-term goals, in order to attract the most talented human capital of the Y and Z generations. Automation of many human resources processes is expected to reduce HR team size and give HR departments more time to perform tasks in the company. [20]

New concept - SMART HR 4.0

Emerging technologies such as the Internet of Things, big data analytics, artificial intelligence and augmented reality, together with changes in the generations of employees, where especially in generations Y and Z dominates IT and the priority is "only me", affect the new concept of SMART HR 4.0.

According to the previous statements, we can summarize the basic facts, that create the new concept of SMART HR 4.0:

Recruitment of talents to the company:
• Intelligent job search applications
• Automatic search for CVs using AI
• Automated and customized testing
• Interview via video chat
• Induction programs via AR / VR
Talent development in the company
• Identification of gaps in AI capability
• Virtual training anytime, anywhere
• Continuous performance feedback
• Data-compensated compensation
• Applications for the welfare of employees

Evaluation of employee performance
• Evaluation system focused on employee development
• A behavioral approach
• Performance feedback
• Management by objectives – MBO

Termination of employment
• Reduction of wear and tear caused by analytics
• Data-oriented identification of persons

Organizational structure and leadership styles
• Slimming the hierarchy
• Agile and decentralized teams
• Multi-generation employee management
• Open and data-based styles

5. Conclusion
With digital conversion, all processes and customer expectations change. With the widespread introduction of robots, technological unemployment will emerge. Technological developments will change the structure of the workforce in the short term and partly cause unemployment. In the long run, the quantity and quality of the workforce will increase. The strong hand of past decisions will be replaced by thinking. Intelligence will increase the level and quality of education. In the long run, highly qualified individuals will be employed. Humans and robots will work together in harmony. [21] It is up to each business to deal with the situation. It has two options: either it will adapt to the reality and move forward with time, in order to gain a competitive advantage in its business, or it will succumb to situations, and sooner or later it will disappear.

From the individual statements of this article, we can conclude, that in order for companies to be able to cope with the transformational challenges of Industry 4.0, it is essential, that they develop a successful Smart HR 4.0 strategy. New technologies such as Big Data and artificial intelligence will automate most processes in the human resources department, leading to more efficient and leaner HR teams. Intelligent mobile applications, along with virtual and augmented reality will attract the next generation of talent to businesses, and enable distance interactions between them. Changes in organizational structures and leadership styles will be necessary for the effective implementation of Smart HR 4.0, which will allow it to play a more strategic role in the overall growth of the company. [18]

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Information-measuring system for monitoring the sanitary condition of tree stands

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Abstract: The article presents the results of the development of an information-measuring system for monitoring the sanitary status of tree stands. The main purpose of such a system is to minimize the impact of the operator on the results of monitoring the sanitary status of tree stands by indirectly controlling the quality characteristics of the tree sap (by establishing the dependence of these characteristics on climatic factors) with the possibility of remote monitoring and control of the process of express control. The developed monitoring system allows to conduct a contactless (remote) survey of sensors, which are recorded in close proximity to the root system of selective trees from an array of tree plantations, and further, by mathematical treatment of climatic characteristics (acidity and salinity index, air temperature) zoning temperature health status. The system also allows you to predict the dynamics of extending the areas of tree planting. This enables those responsible for tree planting to take preventative measures to prevent such droughts. The main advantage of the developed information measurement system is its complete computerization, which eliminates a number of external subjective influences by the operator or the responsible person (necessity of visual inspection of the maximum number of trees in the array, erroneous perception of visual information, etc.). This, in turn, avoids systematic methodological errors, thereby improving the accuracy, speed and reliability of the monitoring and control results of this system.

Keywords: INFORMATION-MEASURING SYSTEM, MONITORING, SANITARY CONDITION, TREE PLANTINGS, MEASUREMENT, CONTROL

1. Introduction

Recent changes in climate change in the world have a negative impact on the health of the forest plantations. So, in 2019 alone, fires that have occurred around the world (the largest of them: Australia, October 2019 - January 2020; Amazon, January-August 2019; Russia, May-October 2019) have destroyed more than 20 million hectares of forest (about 0.5% of the total area of world forest plantations) [1]. The cause of forest fires, in addition to abnormally high temperatures and dry climate, is forest cover, lack of care for the sanitary condition of trees, and an anthropogenic factor [2].

In addition to forest fires, factors such as deterioration of soil composition (hydrogen index, salinity, etc.), pest propagation, etc. have a negative impact on the sanitary condition of trees [3, 4]. However, the study of the sanitary status of tree plantations and their further zoning for preventive and sanitary measures is still limited by the method of visual observation [5], as well as by a number of methods (resistigraphic, boroscopic and other) that do not allow to quickly and accurately determine the sanitary condition of trees on large lands [6-8]. Thus, studies of the sanitary condition conducted in the works [9-12] by scientists: Oliynyk V.S., Sklyar V.G., Antsiferov A., Meshkova V.L., Keeley J.E., Ciesla W.M., Ross R. and others, devoted mainly to the development of theoretical-experimental methods for individual trees.

At the same time, with the development of measuring methods and technical means for their implementation, there is an urgent need for prompt and high-precision monitoring of the sanitary status of tree stands.

Therefore, the purpose of this work is to develop and test an information-measuring system (IMS) for monitoring the sanitary status of tree stands by applying modern approaches and computer hardware, which allows to minimize the influence of subjective factors, to increase the accuracy, reliability and speed of monitoring results to predict the zoning of tree plantations by categories of their health status.

2. Development of information-measuring system of monitoring

Selection and justification of a complex of functional tasks for monitoring the sanitary condition of trees are one of the most important elements of creating information-measuring systems. The analysis of functional problems [13] indicates that their practical implementation in the conditions of information-measuring systems is multivariate. The same problem can be implemented by different methods, models and algorithms.

There are banks of models and algorithms, from which in the process of development of IMS choose the most effective for a specific object of management.

Virtually all data processing systems, regardless of their scope, contain the same set of components (components) - types of security. For the developed class of information and measurement systems, the following types of security should be noted: information (a set of methods and means for information placement and organization, methods for creating and placing an information database of the IMS measured data); methodological (a set of methods and means of their implementation - techniques, testing devices and stands, models, etc., which allow to monitor the determined parameters with minimal errors); software (computer implementation of the IMS architecture, which ensures its maintenance, optimization and protection of the received data, ensuring its integrity, as well as conducting error-free exchange of information between IMS units); technical (set of technical means: sensors, communication units, data storage and processing, etc.).

The reliability and quality of the decisions made by the IMS in the process of zoning and forecasting of the sanitary status of tree plantations depend significantly on the quality of the developed provision.

Therefore, in order to observe the most rational structure of providing the developed IMS, minimize the impact of the operator on the results of monitoring, as well as to control the sanitary condition of tree stands with the possibility of remote monitoring and control of the process of express control, in the work it is proposed to automate the process of monitoring the quality characteristics of soil characteristics, survey of sensors that are introduced into the sample trees from the array of tree stands, and...
The monitoring process begins with the establishment and orientation of acidity and soil salinity sensors, as well as a precision temperature meter. This is the only process that cannot be performed without the involvement of the operator. After the sensors are installed, they are tested using test samples. Such samples shall be at least five in order to avoid the likelihood of subjective errors and unpredictable human factors (erroneous installation of a temperature sensor in a place subject to direct sunlight, or installation of pH / salinity sensors in a place with artificially disturbed soil). If the test results do not match with the visual assessment of the sanitary condition of the tree, a signal is issued to the system, requiring the operator to replace the location of the measuring sensors.

After a test check, the IMS allows you to start the monitoring process automatically in the following sequence.

The controller sends a request to the external sensors to obtain the necessary data.

The encoder accepts the request, processes it and sends to the control device the data on which it received the request.

The client-server two-tier model is optimal for tasks with a number of external sensors less than 100, since the server operating system will overload the server with a large number of client connections when serving a large number of clients.

Such a client-server IMS has several advantages over other IMS architectures. First, network traffic when querying is reduced. Second, the client-server architecture becomes irreplaceable when the number of interrogated sensors exceeds 10-15. Another advantage of the client-server architecture is the extensive ability to manage user privileges and permissions to various database objects, backup and archive data, and optimize query execution.

Thus, the developed IMS allows not only to automate the process of monitoring the sanitary status, but also to predict changes in this state in the selected area of plantations.

Development of the functional scheme of the monitoring system. The electronic measurement unit is the link between the control panel and specially designed ion-selective measuring sensors [14]. It contains electronic circuits that receive and process the input data from sensors by the control panel commands, as well as transmitting the measurement data to the control program, Fig.3.

The electronic control unit consists of six functionally completed modules: portable power supply (1); sensors: temperature (2), acidity (4) and salinity (5); the sensor module control unit (3) and PTC remote control module (6).

The measurement unit communicates with the control unit (PTC) via the wireless data link (7). The electronic unit of measurement works as follows. Request commands from the PTC control program are sent via the wireless communication channel (depending on the schematic design of the unit of measurement – WiFi, Bluetooth, etc.) (7) to the module of wireless communication of the unit of measurement (6) and are transmitted over the common bus to the microcontroller module control of the sensor unit (3), which integrates all the unit's measuring modules. The common 16-bit bus contains a 3-bit address bus, a 10-bit data bus, and a 3-bit control bus. The portable power supply (1) is intended to supply the electronic elements of the unit of measurement and is selected from the condition of the longest possible conservation of electrical energy.

In the absence of a request from the control unit (PTC) in accordance with the set initial parameters, the control unit of the measuring sensor unit (3) is in “sleep” mode with minimum energy...
consumption, information from external sensors to the control module is not received.

In the case when a request for information about the status of the measuring sensors is received from the control unit (6) from the control unit, the module of control of the unit of measuring sensors (3) enters the operating mode of power consumption and begins to analyze the signals about the operating status from the temperature sensors (2), acidity (4) and salinity (5) and generates a signal describing the operating "x111" or emergency mode for all "x000" or for some sensors (e.g. emergency mode of the acidity sensor "x101") and via the remote module connection (6) transmits this information to the control device. According to such information, a database is formed on the coordinates of the location of the measuring sensors and their performance.

When a request for measurement information is received from the control unit (6) from the control unit, the control unit of the measuring sensor unit (3) starts to receive information from temperature sensors (2), acidity (4) at a time (at least nine cycles) and, by the average value obtained, generates an 8-bit signal about the average value of each of the measured indicators (ninth and tenth bits – information indicating the parameter that is transmitted: x01 – temperature; x10 – acidity, x11 – salinity) which is transmitted through the data bus in module remote connection to the PTC (6) and then through a wireless data channel (7) – the control unit. According to the information obtained, the dependence of the distribution of tree plantations on the zones corresponding to different categories of sanitary status is being constructed.

In general, the developed IMS allows to control the processes of scanning the measuring blocks, obtaining and processing the measured information, as well as carrying out graphical zoning and further prediction of the sanitary state of tree stands without the participation of the operator and allows to solve the problem of insufficiently flexible communication between the control unit and the measuring channels ulcer. The functional scheme of the IMS of the sanitary status of the plantations is shown in Fig. 4.

The IMS functional circuit consists of five blocks, the main purpose of which is as follows:

1. **Portable power** is the primary IMS. It consists of two units – an optional (but one that significantly extends the reliable life of the measuring unit) – an energy source that can be used, for example, a piezoelectric element [15] or – a solar battery; and an optional battery pack (such as an electrolytic capacitor or battery). The device works to provide the required energy to the main modules of the measuring unit through the FC1-FC8 power supply channels. There is no information exchange channel between the power source and other system modules.

2. **The module of measuring sensors** is intended for prompt collection, digitization and transmission of information from sensors of air temperature (TS), acidity (AS) and salinity (SS) of the soil through information channels IC1-IC3 – to the control module.

3. **Control module**: intended for scanning of measuring sensors and preliminary processing of measured values. The main units of this unit are: an SMD signal matching device representing a switch of information signals coming from a module of measuring sensors; a DPI pre-processing device, in which the received information about the state of the sensors is checked for correctness and efficiency, as well as the average value of the measured parameter is determined and a 16-bit information signal is generated; The DTI is intended to transmit a previously generated signal through the IC6 communication channel to the feedback module. On the contrary, from the feedback module to the DTI via

![Fig. 4 Functional diagram of the information-measuring system of sanitary state of tree stands:
ESU – energy storage unit; TS – air temperature sensor; AS – soil acidity sensor; SS – soil salinity sensor; SEG is a source of energy generation (for example, a piezoelectric cell or a solar cell); BTI is a block of remote transmission of information; IC – information channel; FC – feed; DPI is a device for requesting information; DPT – the device of preliminary processing of information; DTI is a device for transmitting information; SMD is a signal matching device](image-url)

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the information channel IC7, a signal is sent to request information exchange between the measuring unit and the PTC.

Thus, this unit has seven communication channels, of which two channels for exchange with internal devices (one-way IC4 channel for transmitting a matched signal from the SMD matching device to the DPI processing device; two-way IC5 channel for exchanging information between the DPI and the transmission device DTI) and with external modules: four receive channels (IC1′-IC3′ – from the sensor module, IC7′ – request from the feedback module) and one transmission channel (IC6) per feedback module.

The devices of this module are powered through three low-voltage power supplies FC4-FC6.

4. The feedback module is designed to provide and ensure uninterrupted and reliable feedback between the measuring unit and the control unit. Thus, through the information channel IC11′, the request for the provision of one or other information from the PTC is sent to the block BTI, in which the received radio signal is converted into an electrical pulse, which, via the information channel IC9 goes to the device request information. After processing the last received request, it is transmitted through the IC7 channel to the control module, as a set of data representing the request for information received. Back from the control module on the information channel IC6′ formed information through the requesting device, and then, the channel IC8 enters the transmission unit BTI, in which the conversion of the wire signal to a wireless radio, and then transmit it to the control PTC. The module devices are powered by two low-voltage FC7-FC8 power supplies.

5. The PTC control is a core element of the IMS under consideration, which coordinates the operation of the software for defining tree areas by category of sanitary condition and measurement unit that generates the initial data of the monitoring process, allows to accumulate, process, analyze and store the results obtained.

The measurement unit requests information directly from the PTC (IC11 information channel) using wireless technologies (WiFi, Bluetooth, and more). On the other wireless channel IC10′ receiving information from the measurement unit. In addition to the command and control functions and functions of the information exchange from the unit of measurement, other functions are provided in the control unit. Thus, with the help of two-sided information channel IC12, received, processed and generated data can be stored on an external storage device (usually an SSD card). Another two-way IC13 information channel, the generated data set may be transmitted over the Internet to a remote (“cloud”) medium where it will be stored and used from any Internet address that has access to this database.

The main advantage of using the proposed IMS scheme is the ability to remotely interrogate the sensors located in a sufficiently large area (modern high-frequency radio means allow you to connect and exchange information between devices from a distance of 150 meters to several kilometers), as well as full automation of the process of receiving, processing and visualization of information on the sanitary status of tree stands, which eliminates a number of external influences on the part of the operator (manual adjustment of measuring systems, entering false data, etc.). This, in turn, will avoid systematic methodological errors, which will increase the accuracy, speed and reliability of the results of operational control.

It is the application of the article developed by the authors of IMS monitoring that reduces the time of inquiry and feedback by 3 – 4 times, thus ensuring timely correction of the calculation equation and selection of the most rational modes of IMS operation. This increases the measurement accuracy by 12.5 – 15%, the research speed by 65 – 80% and provides high reliability of all blocks of the system (the probability of trouble-free operation increases from 0.89 – 0.93 to 0.95 – 0.97). To quickly save and accumulate the results with their further study and analysis, PTC has a remote Internet connection to an external storage server, which can be accessed quickly from any PC, such as “cloud” data exchange technologies.

**Software of information-measuring system of monitoring.** The developed IMS is a highly intelligent measurement and control tool whose development is correlated with the development of computer technology. Modern software expands the research capabilities of such a tool.

Specialized software developed on the basis of a special Java programming language specifically for the operating system of most modern Androide tablet computers, which can be used for scientific research on the health of tree plantations. It is a convenient tool for debugging, diagnosing, selecting optimal research modes and processing results.

A distinctive feature of this software implementation compared to existing software products today is the ability to conduct research in automatic mode. On the other hand, even if third-party interference with the monitoring system setup is required, the operator can manually select the study modes, try them out on the test samples and enter them in the database for future use. Another advantage of the developed software product is the ability to save the device configuration results and research results on a remote server, which allows you to retrieve this data from any PC connected to the Internet.

In general, using the developed software greatly simplifies the work of the IMS operator, both at the stage of its debugging and at the stage of scientific research.

Object-oriented programming (OOP) is based on the model of program construction as a set of objects of abstract data type. Object-oriented development defines the types that define the objects of the problem. Operations in object types, as well as functions in procedural programming, are abstract operations that solve programming problems. An object type can serve as a module that is used to solve another problem of the same type. Objects define both the structure of the data about the object and the operations that can be performed on the object. OOP is often used as a Java language, which combines several of the most important modern technologies: a high-performance compiler into machine code, an object-oriented component model, visual application building from software prototypes, scaling of database building tools.

Also, Java supports such low-level features as subclasses of Androide and Windows controls, overlapping of message processing cycle, use of the built-in assembler.

Due to the advantages described, IMS uses the Eclipse development environment as a writing tool for information processing software.

The operating instructions of the control program will help the user to master the work of IMS and make adjustments, choose the optimal modes, and also to establish the work in the remote-remote mode [16].

Thus, it can be concluded that the advantage of structure and software implementation of software based on object-oriented language ‘Java’ to support the developed IMS is its relative simplicity, easy adaptation to different systems of interpretation (‘Builder J’, ‘Eclipse’, etc.) in various versions of the Androide operating systems, as well as the possibility of further development.
of this software by adapting it to Web-technologies, which will greatly improve the reliability and adaptability of the software to modern virtual technologies (including "cloud").

4. Testing of the information-measuring system of monitoring

Monitoring using the developed IMS eliminates the operator’s external influence (setting up and collecting data using the IMS), eliminates the need to connect to an external storage server, and minimizes the energy and time spent on data acquisition and storage. The operator only has to follow the established route with the IMS control unit included and further launch of specialized software that conducts zoning and forecasting of the distribution of tree plantations by categories of sanitary condition.

The principle of the developed IMS is as follows: the operator, after arriving at the location of the information capture and pre-configuring the control device, downloads to it a developed software application, in which, selecting the necessary parameters, starts the monitoring process. After that, the program automatically generates a set of commands transmitted to the measurement unit. Further, the control device is decoding the received commands and generating data for calculation and simulation. Upon completion of the on-going monitoring process, the accumulated data is processed by specialized software, with the help of which visualization of sanitary areas of tree stands is rendered.

It is this configuration of the IMS that can significantly speed up the processing and transmission of data between the PTC and the unit of measurement (from 2.0 – 3.5 s to 0.5 – 1.2 s); avoid a number of hardware failures leading to monitoring errors, which will increase the accuracy of the results by 12.5 – 15%; automate and speed up the operation of the device by 65 – 80%, eliminating the influence of the operator on the monitoring process.

According to the selected topology, the PTC requests a measurement block, the latter receives and returns information to the PTC. At the same time, the PTC can process up to a hundred requests, so a control unit that is on the same network as the measuring unit allows it to be effectively administered and configured. As the measuring unit is constantly under information load (even in the case of "sleep" mode - information is constantly supplied to the control module from the measuring sensors), for example, a set of wireless standards is selected as a configuration that can simultaneously serve the maximum number of users. IEEE 802.11 Series (a, ac, b, g, n).

Thus, the implementation of the developed IMS monitoring was to create a measuring unit to determine the climatic factors (air temperature, soil acidity and salinity), the appearance of which is shown in Fig.5.

During the testing of the developed IMS monitoring, the site of the Park “Sportyvnii” (Cherkasy), approximately 0.1 hectare, was investigated. The results of this test, namely the zoning of tree plantations in this area by category of sanitary condition, are shown in Fig.6.

To confirm the adequacy of the obtained results, a control check of the sanitary condition of the trees in the studied area was carried out using the traditional – visual method. Such a control test showed a high convergence of observation results (the correlation coefficient for the monitoring results obtained by the above methods was 0.89), and the discrepancy in the points of establishment of the measurement unit according to the developed IMS monitoring did not exceed 5.1%.

Thus, the paper proposes a fundamentally new approach to the construction of information-measuring systems and monitoring and control systems, which may consist of equipment spaced territorially, and which can be integrated by wireless communication channels, which improve the speed of information retrieval by the measuring system, minimize the impact of subjective factors, increase the accuracy and reliability of results, in particular when dividing tree plantations by category of sanitary condition.

5. Conclusion

The article presents the results of development and testing of information-measuring system for monitoring the sanitary condition of tree stands, the main purpose of which is to improve the accuracy, reliability and efficiency of monitoring the sanitary condition of tree stands and minimize the impact of the operator on these results by controlling the quality characteristics of the tree and managing the express control process.

The information-measuring system allows to predict the dynamics of expansion of areas of drying of tree plantations, which enables the persons responsible for tree planting to apply preventive measures to prevent such drying.

Through experimental testing it is proved that the developed information-measuring system of monitoring and control allows to automate the process of control, which significantly increases the speed of the study (3 – 4 times) and the accuracy of the obtained results (by 12.5 – 15%), and also provides high reliability of all units of the system (the probability of failure-free operation with increases from 0.89 – 0.93 to 0.95 – 0.97).
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Online education models' comprehensive analysis

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Abstract: Nowadays online learning is among the most progressive and most popular educational practices in the world. Both European and United States universities try to implement this way of learning into the educational process. Several models of online education are used in the world’s practice. The article aims to analyze online learning models to find a way for the best implementation in higher education based on Ukrainian educational system during COVID 19 pandemic in 2020.

Keywords: BLENDED LEARNING, DIGITAL LITERACY, LIFELONG LEARNING, MASSIVE OPEN ONLINE COURSE, ONLINE-LEARNING.

1. Introduction

In the context of a coronavirus disease pandemic, all processes, including education, move to a new stage. Since the mid-1960s, more and more automated technologies and educational systems have been introduced into the educational process of higher education institutions. Since 2008, the term massive open online course has been established and used, and since 2012 such courses were introduced by top-rated universities in the world. The challenges of 2020 have clearly demonstrated that in the context of global total lockdown, the transition to remote mode is no longer a selective option for organizing the educational process, but a necessity. Without the use of online courses, it is impossible to train a modern specialist. Further developments indicate that the pandemic is not only not over, but also continues and will intensify at the beginning of the new educational year in the fall. Therefore, right now it is extremely necessary to restructure all educational processes to a new model of education - the model of online education and the use of online technologies.

A classifications review for online learning models showed that their authors consider the process of online learning from their own points of view, without proceeding from the established opinion in the scientific community, as currently there is almost no thorough scientific work on this topic. In their research, they use small sets of classification criteria, which are quite one-sided and do not intersect on the scale of different studies.

During the latest Coursera conference held in May 2020, the biggest massive open online course’s platform has presented its pandemic statistics clearly showing the new era in online education [1].

- 10.3 million enrollments in 30 days, 644% up compared to last year.
- 5 million+ new user registrations post COVID-19.
- million enrollments in 2020 in Yale’s The Science of Well-Being (this shows how many people need support to their mental health).
- 415,000+ students and 6,600+ unique institutions on Coursera for Campus.

Here are the top five countries:
US — 12M
India — 6.5M
China — 3.2M
Mexico — 3.1M
Brazil — 2.4M

2. Preconditions and means for resolving the problem

Top-rated American universities were the first to respond to the global lockdown and new educational model with online classes only. Six American universities have cancelled in-person classes and have moved instruction online in response to the coronavirus. Stanford University, Northeastern University’s Seattle Campus, Brandman University, Seattle University, Seattle Pacific University, and the University of Washington all announced closures on March 6th and 7th. In general, the transition to online instruction was not smooth given the short timeframe instructors have to make the switch. For example, Stanford University put together a website titled “Teach Anywhere” listing advice and resources for instructors. The website recommends using video conferencing tools like Zoom as an alternative to delivering in-person lectures. However, noting that “scheduling can be a problem, and only a few students will actively participate (just like in your classroom),” the website recommends that instructors use asynchronous communication tools, like discussion boards, when possible [2]. This has shown educational institutions are not ready to fully embrace online education as the way to proceed.

In Ukraine, quarantine in higher education institutions began on March 12 and is currently ongoing. This has led to the transition to an online format in all institutions using a variety of models and technologies. Among the most popular solutions is the use of universities’ or institutes’ own online learning platform, the use of video services for lectures (Skype, Zoom, Google Meet, Facetime, etc.), the use of free services for training (eg, GSuite for Education), the use of massive open online courses’ platforms.

3. The solution of the examined problem

Phil Hill in his article “Online Educational Delivery Models: A Descriptive View” [3] classifies the models both from the perspective of educational material delivery techniques and the course design approaches. He suggests the following models: ad-hoc online courses and programs, fully online programs, school-as-a-service, educational partnerships, competency-based education, blended learning, and flipped classroom, as well as massive open online courses.

A. W. Bates in his book “Teaching in a Digital Age” [4] provides a classification of design models for massive open online courses such as xMOOCs and cMOOCs. xMOOCs is the common name for courses developed by Coursera, Udacity, and edX. They are based on the use of specialized software platforms based on cloud technologies. In turn, cMOOCs are based on the use of social networks and other means of exchanging content, such as software that aggregates posts from various sources on a certain hashtag, and so on.

Amit Shauhan in his article “Massive Open Online Courses (MOOCs): Emerging Trends in Assessment and Accreditation” [5] provides an even broader classification of mass open online courses (BOOCs, DOCCs, LOOC, MOORs, SPOCs, SMOCs).

We can argue that massive open online courses and their derivates are the most common model to introduce a full online educational course into the learning process. MOOCs are including video lectures (5-7 minutes long parts of the big lecture or lectures), additional notes, presentations, tests to self-check or lecturer’s check, a discussion board to change thoughts and to ask questions, etc.

One of the best examples in the world is “Computer Science 50 (CS50)” by Harvard University. They state it is “introduction to the intellectual enterprises of computer science and the art of...
Some online courses have their massive online courses, but during the pandemic, the only about 20 lecturers of higher education institutions in Ukraine placed on the platform, and then thoroughly tested. As of today, access.

In the latest course’s version that was firstly presented at Harvard and Yale during the autumn semester in 2019, David J. Malan made a lot of changes compared to the 2018 version. First of all, the course was completely re-shot and changes were made in all the testing materials. This course includes 18 hours of video lectures, notes for every lecture. Self-check tests and additional tasks to understand how students have learned material [8].

Andreas M. Kaplan and Michael Haenlein provide a nuanced analysis of the phenomenon of online distance learning and conclude that the only thing MOOCs cannot provide is socializing which has become over the years one of the top reasons to enroll in the institution and universities for young adults.

Sharing of resources and metadata is a central principle in scientific and educational contexts, especially in our research that is based on open source technologies for education.

However, not every lecturer can switch to this format during a pandemic. To do this, he or she must already have previously created and developed an online course, which is installed on the platform and is in the active phase of learning. It usually takes 6 to 9 months to develop a full-fledged massive open online course. Each lecture should be turned into a script developed into small fragments for video recording. The lecturer needs to submit a synopsis and test tasks for each lecture, develop a set of exercises and assessments. After that, the course must be shot, edited, and placed on the platform, and then thoroughly tested. As of today, only about 20 lecturers of higher education institutions in Ukraine have their massive online courses, but during the pandemic, the demand for courses’ creation has increased significantly.

The second model to use during the pandemic is a blended learning format. The blended learning technologies introduction enables the lecturer to focus on communicating with students, assessing their skills and abilities, rather than presenting information material, which is sometimes difficult to hold in classroom. In a blended format, the student can spend time by himself at home or dormitory to learn the material and, during a problem-oriented lecture held online via video communication services, present new materials and examples for both students and the teacher. Using media content increases the visibility of the material provided, develops associative relationships, which, in turn, increases the remembering new information quality. The materials availability online simplifies the learning process in general — no barriers and full access make it possible to master the discipline in a student-friendly manner and in a convenient place.

The blended format allows you to take previously created massive open online course or part or several courses and, with the author’s of massive open online course permission and the platform’s permission to implement it in the learning process. In this case, the lecturer or professor no longer has to spend time creating their own online learning product, but must comprehensively master the course, which he or she introduces in a blended form.

The blended learning provides an opportunity to overcome the general lack of skilled staff in all areas of knowledge in Ukraine. Specialists in Ukraine do not have free access to most of the world’s scientific developments, but due to the openness of massive online courses and the possibility of using lectures by leading specialists in the field, it is possible to overcome the gap in knowledge and provide students with relevant and substantiated material from the world’s experts. A serious human resource problem in regional higher education institutions in Ukraine can be overcome by creating professional courses at higher education institutions that are leaders in Ukrainian education in training [10, 11].

However, the proposed models give only a general idea of how to implement online learning in the current environment. We believe that within each individual educational institution it is necessary to analyze the available courses and human potential and develop our own approach and our own model, based on world practice and approaches. This requires further in-depth analysis, development of concepts classifications.

4. Results

To further analyze the models of online learning in terms of the degree of automation of learning and assessment of students, personalization of the presentation of materials, and increase the motivation of students developed their own classification. The classification is based on the following criteria.

- Use of automated incentive systems.
- Use of motivational elements of the interface.
- Using game gamification.
- Use of social networks.
- Use of third-party online services.
- Use of manually assessed tasks.
- Use of “big data” analytics tools.
- Use of automated systems to create recommendations for students and personalize the content of courses.

Since the start of the COVID-19 quarantine in Ukraine the biggest Ukrainian massive open online courses platform Prometheus has opened 9 new online courses, 4 are in development. The average web-traffic of the platform has doubled in the first 3 weeks of quarantine and at the time of writing is 1.5 times bigger than it was in the last three pre-quarantine months.

Over 300 Ukrainian universities have implemented online education process, either based on their own web platforms and online courses or using the courses and platforms of bigger universities and open online courses platforms, such as Prometheus, Coursera, edX, etc.

Fast implementation of online education models in Ukrainian universities helped to overcome the crisis of Ukrainian higher education, which could be caused by the COVID-19 quarantine.

5. Conclusions

Although mentioned online education models’ classifications are successfully used within the tasks for which they were developed, in general they cannot be considered complete, and do not provide generalized understanding of the concept of online education model.

Our own classification for further analysis of online education models in terms of the degree of learning and assessment processes automation, course materials automatic personification, and use of students’ motivation increase technics is being developed.

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