Analysis of Problems and Prospects for Improving Automatic Control Systems of Interconnected Electric Drives

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***Abstract*—The aim of this study was to analyse the problems and prospects for improving automatic control systems of interconnected electric drives. Various methods, including analytical, classification, functional, statistical, and synthesis, were used to provide recommendations for error correction in the design processes of these systems and to detail their functioning. The study revealed the peculiarities and differences of automatic control systems of interconnected electric drives. The study analysed the errors made during the operation of these systems and the reasons for their occurrence. It also identified uncertainties in the development process and their impact on the functioning of the systems. The mechanism's efficiency, development, and complexity in different spheres were analysed. The text also considered issues related to estimating the operation of systems, limitations during operation, and the influence of limitations on results. Recommendations for promoting more effective regulation have been provided. The research showed that these systems play a crucial role in complex technological processes. The results have vague practical implications for developing the mechanism of automatic control systems for interconnected electric drives to apply and influence a certain device. In conclusion, the study analysed the problems and prospects for improving automatic control systems for interconnected electric drives.**

Keywords*—*Device; Control Action; Technological Process; Technological Manufacture; Processing.

I. INTRODUCTION

Automatic control systems for interconnected electric drives are the process of controlling and providing one object with a required change in the state of another object on demand. One of the main priorities of using these systems is that these systems collect and process information about the course of technological processes based on given algorithms, produce and give control actions to a certain device which ensures a suitable course of technological process. Problems in the automatic control system of the interconnected electric drive are errors at the stage of development. This is related to the issue of the definition and optimization of indicators at the stages of design, functioning, and development [1]. These errors can stem from different sources. Sensor failures, for example, can occur when erroneous or missing data is received from sensors that monitor critical parameters such as temperature, pressure, and speed. This can lead to faulty feedback within the control system [2][3]. Signal noise, which is often caused by electromagnetic interference, can corrupt control signals and lead to unintended operations, particularly in systems with long connections [4]. Latency issues, resulting in delays in control command propagation, can disrupt the necessary timing and synchronization that are crucial for the coordinated operation of interconnected drives. Inaccurate modelling of control algorithms that do not accurately reflect the dynamics of the physical drives can result in instability, oscillations and other operational issues. Component wear, involving the gradual degradation of actuators, drives and control hardware, can subtly alter system behaviour over time, leading to progressive errors [5]. In addition, external disturbances such as vibration, shock or power fluctuations can cause uncontrolled responses in the system. These issues range from minor performance degradation to complete loss of control. It is important to have a holistic understanding of the nature and sources of these errors to enhance the reliability and capabilities of automatic control systems in industrial applications. Interconnected electric drives play a critical role in this regard [6]. Following V.A. Ichev and A.D. Umurzakova [7], the improvement of automatic control systems of interrelated electric drive and automatic speed control systems is not sufficiently studied. But because of the introduction of metallurgical productions of foreign equipment of development, aimed to improve automatic control systems of the interconnected electric drive and control systems, many organizations are rapidly modernizing. Issues of development and research of systems of automatic control of the interconnected electric drive and speed modes of the electric drive are currently topical due to the introduction of industrial controllers. A specific area of focus in this development is the enhancement of stands and automatic control systems for the interconnected electric drive.

Stands and automatic control systems play a vital role in achieving a natural cross-linking and nodal connection between different components. According to M.S.

Kulgildinov et al. [8], stands and automatic control systems of the interconnected electric drive are separate systems, through which a natural cross-linking, and the nodal connection of stands is the power connection through the metal that is processed. The physical characteristic of force-feed coupling is the tension or support of the rolled strip in the inter stand area. In continuous rolling stands other drive connections may also be present, e.g., through the supply network [9][10]. Following O.A. Baimuratov et al. [11], currently great attention is devoted to the development and improvement of electrical engineering systems, as an example of automated electric drives and systems of automatic control of technical parameters. The problems associated with the development of electric drives and control systems of the continuous subgroup are not sufficiently investigated [12][13]. Therefore, the development of design and modelling of automatic control systems of the interconnected electric drive is inefficient. The correct geometric dimensions of the rolled strip at the outlet of the roughing group also have a great influence on the dimensional accuracy of the strips on the machine output.

H. Pratama et al. [14] note that the analysis and research of automatic control systems for the interrelated electric drive have long been based on deterministic assumptions. The application of possible features of return operations helps to improve the qualitative values of the regulated electric drive-in comparison with popular control systems, in which the whole range of disturbances has not been considered. As a result, the synchronous electric drive of compressor stations together with the power supply system must be represented as a multi-connected stochastic object of automated control. Following G. Bhatti et al. [15], robust-adaptive systems help compensate for dynamic defects in automated interconnected electric drives by addressing factors such as the control channel and load variability. To improve motion control performance, interconnected model schemes are applied to each trajectory section, the features of which are refined during operation. The control basics are based on the theory of non-linear robust-adaptive control and are corrected as the mathematical model is refined [16].

The article presents a functional diagram of an innovative automatic control system designed to regulate process parameters and reduce external factors that affect information processing. It provides an in-depth analysis of the causes of errors in information processing in interconnected drive systems, which is identified as a key issue. These factors include staff training, modelling and design flaws, and technology gaps. New recommendations have been proposed to address the errors identified through professional development programs, implementation of technologies such as modelling tools, and system upgrades. The study provides an objective analysis of current problems in interconnected drive systems, offering insights into error sources. It highlights priority areas for improvement, such as information processing, staff skills, and modelling capabilities, which can guide future research. The proposed solutions and functional diagram offer a framework to improve the reliability and performance of interconnected drive systems. The research advances the development of interconnected drive control systems by systematically evaluating limitations and providing targeted recommendations. The findings can inform strategies to optimize these systems.

The aim of this research is to conduct an objective analysis to identify problems and errors in the operation of these systems. Implementing this analysis will enable progressive improvements in control schemes. To accomplish this, the study applies a mix of methods, including analytical techniques to highlight sources of error, statistical analysis of factors affecting system reliability, empirical approaches to investigate system limitations, and functional modelling to map system architectures. In addition, deductive and synthetic approaches are used to define key concepts and consolidate findings.

II. Materials and Methods

The research on the problems of developing automatic control systems for interconnected electric drives has been carried out by applying methods that reveal the theoretical and practical content of the object. Analytical techniques were applied to logically scrutinize and explain the theoretical and practical factors involved in interconnected electric drive systems. This allowed for systematic isolation of specific error sources based on current academic literature and industrial observations. The analytical method was chosen due to its strength in breaking down complex systems into understandable components. Statistical analysis was used to objectively quantify error frequencies, system reliability metrics, and factors that impact development and operation. This data-driven approach provided measurable validation of key problem parameters. Statistical methods were chosen for their ability to extract empirical patterns. One of the empirical methods was used, namely, the method of modular development, the causes of errors in the development of automatic control systems of interconnected electric drives, and the effective process of the development of this mechanism. Its prospects were also determined. In addition, a drawing of the functional diagram of the automatic control system of the interconnected electric actuator was developed and presented.

Diagrams and flowcharts were used to model the system's functionality and structure, including its architecture, dependencies, and decision flows. This approach helped to visualize the processes and identify procedural issues. The functional approach was particularly useful for mapping the relationships between system components. The structural-functional method has helped in the analysis of trends, factors, and models of automatic control systems, it was found that to solve problems with errors in the development, with improved maintenance of these systems and their components, with the development of new schemes to reduce inaccuracies in the operation of this mechanism and optimize the indicators in the design stages of systems, will require increased public funding, a new approach to service systems control and development of their quality elements, improving the technical quality in the sphere. The deduction method helped in defining the concept of an “automatic control system of interconnected electric drive” through the prism of highlighting its characteristic features for a full analysis of the operation and problems of this mechanism. Applying the method of synthesis, the results of theoretical and practical nature were summarized to identify recommendations that contribute to solving problems and improving efficiency, prospects for reducing errors in the development of schemes, developments in modelling and design of constituent elements in these systems, namely in automatic control systems of interrelated electric drive.

The research was carried out in a certain sequence, revealing some aspects. Firstly, the theoretical component of the research was disclosed. It provided an opportunity to carry out a more detailed analysis of the concept of an "automatic control system of interrelated electric drive". This allowed the characterization of the features and principles of this mechanism in complex technological processes in enterprises. Next, the practical component was studied. It included a study of the bases of the mechanism and problems of approach to the development and application of systems of automatic control, their advantages, and drawbacks, the functioning of this mechanism, and an analysis of the activity of this object in different areas. An important step is to analyse prospects for use of systems of automatic control of the interrelated electric drive, implementation of new technologies to improve these systems, and ways to reduce errors in system design to determine the effectiveness and perspectives of the mechanism. The final part aimed to consider the necessary recommendations in the selection of problems and in the development of schemes and activities of the mechanism based on the research results, namely the automatic control systems of interrelated electric drives, which will contribute to the solution of these issues and development in different areas. As a result, the goal of this sequence was to develop the presented schematics of these systems.

III. RESULTS AND DISCUSSION

A. Errors and Issues in Current Systems

The primary objective is to enhance the design, performance, and control of interconnected electric drive systems through a comprehensive approach that involves improving automatic control systems. This is achieved by identifying issues in current systems, developing innovative control algorithms and techniques, utilizing modelling and simulation for a deeper understanding, and emphasizing a systematic, complex systems approach to drive system control. The aim is to create more efficient and effective interconnected electric drive systems.

To ensure the productive operation of companies in various industries, developments in automatic control systems for interconnected electric drives are necessary, especially in the precise design and modelling of the systems that are most used. The development and design of new schematics for these systems offer enormous technical opportunities for improving load and speed control algorithms at an innovative, digital level. However, too few organizations are currently involved in the development of system layouts which results in a shortage of automatic control systems, and in most cases, their impact on the operation is neglected. An important modern issue that needs to be addressed is errors in the design of automatic control systems for the interconnected electric drive and their modelling, the reliability of the results of processing this object, the efficiency of operation in various areas of their mechanisms, and further development in these areas [17]. Significant influence on geometrical dimensions of rolls of systems is made by correct maintenance of tension, which is close to zero, in inter-cell intervals of an integral subgroup [18]. Solving the problem of effective control of these complexes of automatic control systems of interconnected electric drives needs the development of identification algorithms and various methods of acceptable coupled control systems under spontaneous perturbations.

In the operation of interconnected electric drive automatic control systems, it is necessary to find and solve the causes of information processing errors and effects on the device. The process of continuously improving robust and adaptive automatic control systems for interconnected electric drives in robotic engineering is based only on the very innovative advantages of systematic research and modelling of heavy-duty automatic control systems [19]. The load is automatically distributed among the actuators when they move out of the desired range. This technological solution is based on arranging the spreading distance when it is required in proportion to the characteristics of the load that affects the object and avoiding overestimating the power of the actuators compared to the power required for the movement of the mechanism [20]. The development of scientific methods for error correction solutions in the development and design of automatic control systems for interconnected electric drives in various fields is currently advanced and promising [21]. Popular malfunctions in automatic control systems are mainly static torque. Other malfunctions are supply voltage fluctuations, instability of system components (transistors in amplifier mode), and various types of disturbances (in the circuit, in the power circuit) [22][23]. The operating staff mainly must control the operation of the automatic control system, i.e., to start it up and shut it down.

The use of modern electronics and computerized data processing in automatic control systems for interconnected drives can significantly increase the capability and demand for the systems. A study of the speed and load processes of an electric drive has shown that when rolling a billet at low speeds, the speed of the rollers decreases and reaches a steady speed [24]. At present, as a part of the automatic control system of interconnected electric drives, there is an automatic zero-tensioning control system, which is a guiding program placed in the controller that predetermines the speed order of operation of main drives, horizontal and vertical stands [25]. The objectives of effective mode control of automatic control systems of interconnected electric drives and their problems with the application and development of schemes are becoming increasingly relevant and practical [26]. However, the occurrence of instantaneous undercutting and permanent oscillation processes in automatic control systems of vertical rolls of conventional stands during the gripping of the strip by horizontal rolls has not been sufficiently learned. As a result, correlation functions and spectral densities of the disturbing influence are detected.

B. Modelling and Simulation Insights and Control Architecture Limitations

In this complex process, the revision of errors of information processing in systems of automatic control of the interconnected electric drives and their decision is of high priority as the development of the given mechanism in Kazakhstan is one of the actual problems of modernity. The systematic way also consists of the fact that the following robust-adaptive systems of automatic control of interrelated electric drives cannot be considered without considering all completeness and complexity of design, unity, multi-coupling, and interdependence of all components of interdependent systems between themselves and external technical factors [27]. This is since the load torque of a given object appears to be proactive, variable, and conditioned by the angle of lift [28]-[30]. Very often the processing of proper information in automatic control systems of interconnected actuators has certain errors, which impairs the efficiency of these systems. Every automatic control system for interrelated drives can be thought of as a system that receives and processes a certain amount of information, depending on the number of information channels and their design used in these systems, it can be identified several types of automatic control: open-loop, closed-loop, and combined-loop. The disadvantage of automatic systems, however, is the control, which is partly dependent on humans, which means that the human factor plays a huge role, which increases the number of errors and accidents during the operation of the systems [29].

In general, the problem of optimized error elimination in the design of automatic control systems of interlinked electric drives has not been fully solved. Reducing the speed of the rollers below normal leads to a smudge pattern on their surface and poor strip quality. Tension values in the automatic control system are maintained at inter-cell intervals by indirect control. Automatic control systems for interconnected electric drives are often used in a variety of applications to control appliances [31]. To improve data quality, it is necessary to improve reliability and reduce processing errors. These problems require further extensive research. In the construction of mathematical models of multi-coupled mechanisms and the analysis of suitable automatic control systems for interrelated drive systems, it is assumed that the disturbing actions are computationally available when perturbations are not constant [32].

Automatic control systems for interconnected electric drive systems are currently the most widespread and developed in various plants and industries. Only in the complexity and optimality of the analysis of innovative multi-coupled systems of robust-adaptive automatic control systems for interconnected electric drives, a renewed quality is obtained which was not present in the details of its components. The load torque in automatic control systems changes its trajectory when passing the vertical, which affects the opening of the backlash in the kinematic transition and the product of the oscillation [33]. A requirement for the reliable operation of automatic control systems of interlocked electric actuators is to ensure stable operation, both of some elements and the system as a whole. Systems that operate behind an open loop are assigned the absence of any calculation and control of the final marking of the controlled variable. The simplest automatic control systems consist of a controllable mechanism in contact with each other and, of course, an automatic control unit [34]. The suspension of operating rolls in these systems in the location of permanent rolling creates emergency stoppages in the mill [35]. As a result, it can be concluded that the existing systems for the automatic control and maintenance of zero tension do not meet current requirements and are effective in the state of expansion of the strip range in question. The inert tests in this mill, due to their limitations, cannot provide options for obtaining the desired outcomes and results.

C. Process Interactions and Effects

Automatic control systems for interconnected electric drives in the country have a huge potential for development and longer implementation terms than other automatic control systems. In some cases, however, these systems can be difficult to access because of their sparse and expensive components. The precise heavy functional objects of a robotized technical system, set in motion by certain interrelated actuators, are non-spherical ellipsoids of inertia, loosely positioned concerning the rotation axis [36]. At angles of elevation that are close to the horizontal, the load torque is very high, and the backlash is locked under its influence [37]. The regulating effect does not depend on the adjusted value. It is also important to focus on the quality of the process that the controlled object performs, for better functioning of the systems in general. The problem of optimization and reduction of information processing errors in automatic control systems for interlinked electric drive systems is still open and unsolved, due to the lack of attention paid to this issue [38][39]. The solution to this problem is the use of a brief, aggressive deceleration of the stands before or during strip clamping. The causes for inadequate tension control are inconsistencies in speeds between adjacent stands during strip clamping; impracticality in counting and correcting static slack in a system with an equally dimensioned speed control; and the presence of uncontrolled longitudinal forces in the roll between adjacent stands [40].

The best way to research automatic control systems for interconnected electric actuators is through mathematical modelling [41]. The output controllable coordinates of the interrelated control device are suitable for computation. As a result, it turns out that at interrelated movements of electric drives, there is an interaction of inertial, centrifugal, and gyroscopic forces of movement of one of the electric drives produce a disturbing interrelated moment, additional to other electric drives [42]. The solution to reducing processing errors requires the introduction of effective modelling tools for the automatic control of interrelated drive systems and their constituent elements. In addition, near vertical positioning, wind loading helps to open the backlash. In these automatic control systems, there is one channel of information, which is the guidance channel, and the fidelity of the execution of the mode provided is negligible.

The rapid development of automatic control system design now will aid in efficient problem-solving at greater speed and bring the quality of the results to a new, state-of-the-art level [43]. The error-free execution of this work is due to the set of instructions executed by the processing algorithm. Accomplishing these goals can only be done by improving the speed interplay of the interconnected stands of the finishing sub-assembly. Slow speed mode correction system, low reliability of indirect calculation system of tension by values of electric drive, insufficient accuracy of speed mode algorithms from automatic control systems – all these are some disadvantages of these systems operation and their modes [44][45]. To this end, it is necessary to develop mathematical models of interconnected electromechanical systems of a constant subgroup of the mill.

An indicative mode of operation of the adaptive automatic control system of interrelated electric drives is the mode of output changes of set values due to the vector of input actions, rather than the mode of matching of a shift in zero state [46]-[48]. The system of automatic control of the machine working process should provide an automatic regulation and control of change and stability of rotation frequency concerning the physical and mechanical properties, change of forward speed, and angle of inclination of the device concerning the actual physical and mechanical properties [49]. The presented development of a scheme of an automatic control system of interconnected electric drives will allow to regulate more accurately the depth of stroke of operated machines and reduce the main external factors that affect the process of information processing (Fig. 1).

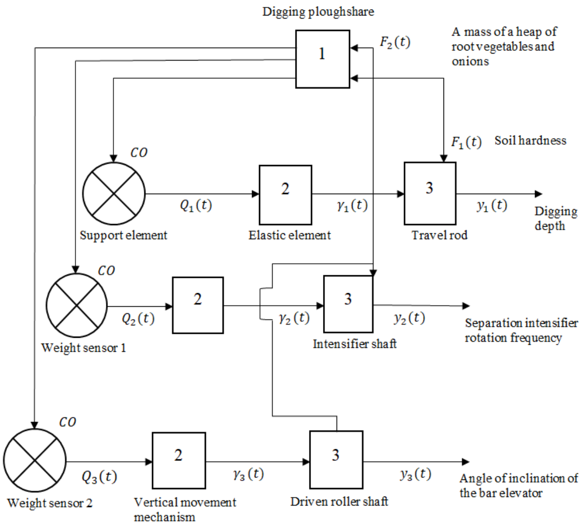

Fig. 1. Functional diagram of an automatic control system for interconnected electric drives of mode and process parameters: 1 – Measuring Device; 2 – Operating Device; 3 – Control Object.

At each point in time, a change in influence F_2 (t) occurs, which is sensed by the measuring element and transmitted to the comparative element, or more precisely to the control unit. If this value is greater than a certain calculated value, the signal is transmitted to the actuator (vertical movement mechanism) and transferred to the control object (driven roller shaft) which changes the value y_2 (t) and y_3 (t). Automatic control systems for interconnected drive systems, need to be improved in all directions, especially in terms of environmental and economic development [50]. At the very least, heavy cross-coupling between the coupled actuators is created. The interconnected drive value control system comprises a torque control loop, specific to each of the drives, and a positioning control loop shared by the drives. This system is used to start and brake motors and to regulate speeds within certain limits [51][52]. However, for this object to be able to execute a processing algorithm, it is necessary that the automatic control system of the interconnected drives can have a certain degree of organized influence from the outside [53]. The quality of tension control and strip gripping conditions are most influenced by the reliability of the calculation of the rolling arm [54]. Therefore, the pressure signal to the rolls from mesdozas is used in the automatic control system, so the influence of the reliability of pressure calculations in this automatic control system is decisive.

Improving interconnected electric drive systems involves a comprehensive approach to enhance their design, performance, and control through several strategies. Identifying current issues in existing systems is critical to understanding areas that require improvement, such as system reliability, efficiency, or adaptability. The development of innovative control algorithms and techniques is central to this effort. Crafting new, more intelligent algorithms is essential for advancing the systems' performance. These algorithms are expected to be adaptive and capable of dynamically responding to changing operational scenarios, thereby enhancing the system's functionality. The use of modelling and simulation is crucial in this approach. These techniques provide deeper insights into the workings of systems, aiding in the understanding and prediction of system behaviour under various conditions. These techniques provide deeper insights into the workings of systems, aiding in the understanding and prediction of system behaviour under various conditions. This is essential for designing effective control strategies. The approach emphasises a systematic, complex systems approach. This perspective considers interconnected electric drive systems as parts of a larger, integrated whole, rather than individual components. To optimize overall performance and reliability, it is crucial to understand the interplay and dependencies within these systems.

The aim of these efforts is to develop interconnected electric drive systems that are more efficient and effective. This is essential for the improved operation of industries where these systems are used. Another critical aspect is addressing errors in information processing within these systems, which involves improving the accuracy and reliability of data collection and processing by the control systems. Improving data processing directly contributes to better decision-making and more responsive system behaviour.

The development of identification algorithms for coupled control systems is vital. These algorithms accurately identify and respond to spontaneous perturbations, maintaining stability and performance. Improving load and speed control algorithms is another important aspect of this comprehensive approach. Enhancing these algorithms can lead to more precise and efficient operation, particularly in industries where precision and reliability are crucial. The developments in interconnected electric drives have significant implications for modern industries such as manufacturing and robotics. The advancements in automatic control systems are expected to improve productivity, safety, and efficiency.

These results validate the need for developing more robust adaptive control techniques, improved mathematical modelling considering complex couplings, systematic study of disturbances, and corrective solutions to information processing errors in interconnected electric drive systems. The following discussion proposes methods such as aggressive braking algorithms, enhanced speed control strategies, and detailed electromechanical system models to address the issues raised by the results. The solutions directly address the problems and limitations exposed by the modelling, simulation, and analysis results on current systems.

D. Research and Challenges in Automatic Control Systems for Interconnected Electric Drives

The quality of research that has been carried out on automatic control systems for interlocking electric drive systems to detect errors and problems in the functioning of this mechanism, and their efficiency is one of the most urgent issues of our time, and some problems need to be solved immediately. It is necessary to start the development of mathematical models for interconnected rough motor systems, in a special software environment, for the development of these systems [55]-[57]. This model is a control program that is put into the automatic control system controller which predetermines the speed modes of the main electric drives of the stands of this group. This study, carried out in the context of the operation of automatic control systems of interconnected electric drives, has allowed a better understanding of the causes of errors during operation, especially during information processing, to assess the possibility of solving these problems and to identify at what stage they may occur. As a result, correlation functions and spectral densities of disturbing actions in automatic control systems are predetermined. Cross-correlations of influence on each other spoil the dynamics of multi-coupled subsystems of robust-adaptive automatic control systems and control systems in general [58][59].

The study conducted by M. Nandakumar et al. [57] proposes a new method of eliminating the front-end converters used in direct current (DC) bus voltage variation, allowing for control of the speed of a brushless DC (BLDC) motor. The study aimed to improve the efficiency of electric drives, which are highly nonlinear, multivariable, time-varying systems, and require more complex methods of control. At the same time, P. Alkorta et al. [55] focus on advancing the control systems for three-phase motors, a critical component in various industrial applications. The research aims to enhance the performance and stability of these motors through a series of innovative designs and analyses. The study centres on the development of a position control system for three-phase motors using a proportional derivative (PD) controller with a feedforward design. This approach aims to enhance the responsiveness and stability of the motor control system. The study delves into the dynamics of induction motors, which are widely used in industry, to provide a better understanding of their operational characteristics and control requirements. The proposed PD controller design with an integrated feed-forward mechanism presents a promising avenue for enhancing the performance and stability of three-phase motors, making it a noteworthy contribution to industrial applications and future research endeavours.

It is worth noting that in the development of the design and modelling of automatic control systems for interconnected electric drives, Kazakhstan has made a large step forward in the last few years. Many recommendations on the analysis of these systems are ineffective in their application. In closed-loop automatic control systems, several channels of information are applied simultaneously: a channel of reference information and a channel of information about the actual aspect of the settled feedback value [60]-[62]. When exchanging and processing information in automatic control systems of interconnected electric drives and their components, models must adequately describe the nature of the operation, and be simple and implementable, to better commence a complex technological process. The nature of these technological processes is established by a set of instructions in automatic control systems, denoted as a control algorithm. In the role of initial parameters in modelling and design, the parameters of interrelated electric drives of roughing stands and rolling specifications are used.

Professional personnel and timely diagnosis of equipment play a major role in ensuring the efficiency of automatic control systems of interlinked electric drives to process and provide certain information in different areas [63][64]. The automatic control system assists a set strip tension in two different stands by changing the standing speed, and the resulting tension between a pair of stands is regulated by changing the standing speed [65]. However, in the case of multiple perturbations in this system, probable analysis is not available. Following a recent study by H.S. Das et al. [66] and E. F. Fuchs et al. [67], this value of torque is calculated by a non-linear piece with a trapezoidal output-input feature depending on the mismatch placement performed by the controller, the presented and actual angular position of the drive unit axis, which can allow an indirect estimate of the load torque value. The development of a software tool as a means for automatic control systems of the interconnected electric drive has great potential for the future operation of this mechanism. When modelling the software of a microprocessor-based control system, it is necessary to introduce model-based design capabilities [68][69].

For these developments, it is necessary to produce a mock-up to reproduce the design of the lifting microprocessor system and this mechanism. The whole mechanism of automatic control systems of the interconnected electric drive was analysed, and it was finally decided that to apply different constructions, especially theoretical ones, it is necessary to have the basic knowledge to designate physical devices and their quantity, which will help to understand the process of development of microprocessor control system software under proper conditions [70]. Some problems which are related to insufficient professionalism of personnel and software developers can be solved by applying certain programs aimed at professional development, therefore professional development of working staff is a priority in the training of specialists, which promotes the professional development of communication workers and activates their regulatory base for quality maintenance of automatic control systems of interconnected electric actuators.

Referring to the definition of M.G. Ioannides et al. [71], this information is related to feedback information, the control error is set, and depending on the value and sign of the presented error the stable influence on the actuator is reproduced via the control channel so that the error value leads to zero, this helps to change the controlled value following the required law. However, no malfunction is calculated and their effect on the stable value is adopted by the automatic control system via the feedback channel. This type of control is referred to as error control, but the feedback behind the stable value is basic, negative, or rigid feedback. This shows that when designing and modelling the automatic control of an interlocking electric drive, all factors that affect the quality of the presented type of control must be considered [72][73]. The fact that, in addition to the basic feedback, these systems also use additional feedback has not been considered.

An analysis of error determinants and their causes in the operation of automatic control systems of the interconnected electric drive has revealed the section where the most errors occur, which includes the process of information processing and provision. The researcher E. Celik [72] determined that the main and important conditions imposed on the automatic control systems of interlocking electric drives of the finishing subgroup of a wide strip mill during the rolling of heavy strips are reduction of impossible reductions of speed during strip gripping, which occurs when rolling wide strips of steel grades that are hard to deform; providing high reliability of the adopted tension support during the rolling of narrow strips through automatic correction of speeds.

But to compensate for static speed discrepancies during lane pick-up, it is necessary to develop and implement a general speed control option when using equivalent speed controllers. It is therefore very important to consider the application of this type of system, to study the data and possible causes of malfunctions in good time, and to further develop the application of these systems in different production facilities [73]. The advantage of fault cause analysis is that it will make it possible to design more stable elements of automatic control systems to different influences, based on information about design faults and errors in the operation of automatic control systems of interconnected electric drives. J. Nanda et al. [74] determined that during the research of dynamic modes, which appear in the rolling mode, some facts were found, for example, vertical stands have minimal influence on speed matching, so during the development of innovative kind of automatic control systems they can be disregarded.

The results of this research have been analysed and considered more precisely. It can be concluded that analysis of these effects should consider the dynamic shocks that occur due to speed inconsistencies. The current state of the machinery and the complexity, the significant number of errors in the technological processes, of the automatic control systems of the interconnected electric drive requires the workers to be constantly aware of the current challenges, dynamic and flexible solutions, adjusting to the situation during the operational process. J. Stoustrup et al. [75] determined that the speed of the stand was practically unaffected by the automatic control system. The strip model is shown in blocks, which contain a mathematical description of pressure and momentum variations in the rolling process. It also includes blocks that have a mathematical description of the elastic characteristics of the strip among the horizontal rolls of adjacent stands and the vertical and horizontal rolls of a single horizontal stand.

This mathematical model may have a certain modification, this being due to the properties of the observed mechanism. Other variations in the application of the band features in these intervals are provided by equal analytical proportions, in automatic control systems and cannot also be useful and effective as they have insufficient accuracy in contrast to those presented. One of the challenges in recent years has been to significantly improve communication and implement new technologies to improve the operation and development of automatic control systems for interconnected motor drives, to prevent many errors in the processing of information [76]. As pointed out by W. Xu et al. [77] the output stable values of a multidimensional control object are suitable for computation.

The presented calculation requires the development of a methodology for forming state equations of the interrelated electric drive using probabilistic features of output quantities and analysis of multidimensional automatic control systems suitable by the mean-square condition of reliability [78]-[80]. It is necessary to increase funding and qualification of employees, to start implementation of new technologies to improve the design and simulation of automatic control systems of interrelated electric drives and to reduce errors during a complex technological process in these automatic control systems.

This study has limitations. The simulations used idealized models, which may not capture all real-world complexities. In addition, the disturbance profiles may not fully represent actual load variations. The range of control algorithms and system architectures evaluated was limited, which could introduce bias. Furthermore, the failure modes were theoretical rather than based on empirical data. The study has notable gaps, including a lack of physical prototype testing to validate the simulations and a narrow focus on drive systems without full production line integration. These gaps may limit the applicability of the findings in real-world scenarios. The limitations indicate that the results should be considered preliminary findings that demonstrate potential rather than conclusive performance guarantees. Aspects such as real-world behaviours, statistical failure rates, unmodelled effects and physical validations remain topics for further investigation to build upon these initial results. Acknowledging these boundaries provides important context and caveats for proper interpretation of the study's systems analysis.

IV. CONCLUSIONS

This research on automatic control systems for interconnected electric drives has led to several insightful conclusions that highlight critical areas for improvement and future exploration. The study identified several errors in the process of information processing and delivery. These errors include sensor failures resulting in incorrect speed and tension data, software bugs causing improper control signals, and network latency leading to delays in feedback loops. These errors have been found to significantly diminish system performance and cause operational disruptions. The application of modelling and simulations has been crucial in identifying problematic areas in these systems. Specifically, issues such as oscillation during gripping, backlash impacts at particular angles, and instability at low speeds have been observed. These findings indicate that these systems display complex nonlinear behaviours, requiring a deeper understanding and improved modelling techniques. The research indicates that control techniques requiring human operators are susceptible to human error, which can negatively impact system reliability and efficiency. To minimize these errors, the study suggests implementing autonomous adaptive control algorithms as a viable solution. The study found that open-loop systems lack precision in tracking desired operating modes. To significantly enhance fidelity and accuracy, closed-loop control systems complemented with robust state estimation should be employed. The existing mathematical models were observed to be degraded by disturbances and dynamic loads, highlighting the need for advanced modelling methods that can more accurately account for variations in real-world conditions. Based on these findings, the research suggests opportunities to enhance the efficiency and effectiveness of interconnected electric drives. These opportunities include improving information processing, addressing technical challenges, and innovating in the areas of sensing, algorithms, modelling, and control architectures.

Future research in the field of automatic control systems for interconnected electric drives is expected to take several promising directions. One key area of focus will be the development of more sophisticated methods for detecting and compensating for sensor errors. The task involves developing algorithms and systems that can detect inaccurate sensor data and implement strategies to correct or mitigate its impact on the system's performance. Advancements are essential for maintaining the reliability and accuracy of control systems, particularly in environments where sensor data is critical for decision-making. The use of machine learning algorithms provides a significant opportunity to create more adaptive and responsive control strategies. By utilizing machine learning, control systems can learn from past data, adapt to new conditions, and predict future states, leading to more intelligent and efficient operation. This approach is especially advantageous in environments with variable and complex operating conditions. Future research should focus on developing more accurate and comprehensive electromechanical models using multiphysics simulations. These models should incorporate a wider range of physical phenomena, enabling a more detailed and nuanced understanding of how different factors impact the system. This can result in more precise control strategies and better predictions of system behaviour under various conditions. There is an increasing demand for advanced control strategies that can handle the nonlinearities inherent in interconnected electric drive systems. Designing model predictive and nonlinear control strategies can help these systems anticipate future states and make more informed control decisions, leading to improved stability and performance under various operating conditions.

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