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MODERNIZATION OF A K-1500 COMPRESSOR ELECTRIC DRIVE SYSTEM USING A MEDIUM-VOLTAGE VARIABLE FREQUENCY DRIVE

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Abstract:
This paper presents an engineering study on the modernization of a K-1500 compressor electric drive system operated within the technological equipment of a large metallurgical enterprise. The exact facility location and identifying production data are not disclosed because of industrial security considerations. The existing drive concept is based on a high-power synchronous motor started directly from a 6 kV network through an excitation system. Operational analysis showed that this configuration is associated with high starting currents, vibration loads, thermal stress, limited restart capability and a negative influence on the plant power supply system. As a modernization solution, the study proposes a controlled drive system based on a 6 kV medium-voltage variable frequency drive, a squirrel-cage induction motor HRN3 719-48E and an Atlas Copco compressor unit replacing the former K-1500 installation. The methodology combines literature review, engineering comparison, analysis of technical parameters and MATLAB/Simulink modeling of transient processes. The results show that the proposed drive structure provides smoother acceleration, lower electromechanical stress, reduced network impact and improved controllability of the compressor unit.

Keywords: Compressor drive; K-1500; Atlas Copco; medium-voltage variable frequency drive; induction motor; soft start; MATLAB/Simulink; transient processes; energy efficiency; industrial automation; reliability

INTRODUCTION

Compressor units are among the most important auxiliary mechanisms in metallurgical production because they provide process air and support stable operation of related technological sections. The reliability of a compressor electric drive affects not only the compressor itself but also the stability of the production process, the quality of power supply and the operating conditions of mechanical components.

The considered object is a former K-1500 compressor installation used in a continuous industrial process. Due to the categorized nature of the facility, this paper intentionally avoids disclosing the exact enterprise name, location and detailed production route. The study is therefore focused on the technical characteristics of the electric drive and on the general engineering principles of modernization, which can be applied to similar high-power compressor systems.

The initial drive configuration is based on a synchronous electric motor supplied from a 6 kV network and started by direct-on-line energization. Although this solution is widely used in high-power industrial drives, it creates severe transient conditions during start-up. High starting current, rapid electromagnetic torque variation, vibration growth and thermal loading reduce the operational flexibility of the compressor installation and increase the requirements imposed on the power supply network.

The aim of the study is to substantiate a modernization concept in which the direct-start compressor drive is replaced by a controllable electric drive based on a medium-voltage variable frequency drive, a squirrel-cage induction motor and an upgraded Atlas Copco compressor unit. The main research task is to evaluate the expected technical effect of the proposed solution by comparing drive configurations and analyzing transient processes using MATLAB/Simulink modeling.

LITERATURE REVIEW

Modernization of high-power compressor electric drives is commonly discussed in relation to energy efficiency, power quality, mechanical reliability and process controllability. Industrial compressor standards and turbomachinery studies emphasize that the compressor, motor, coupling, power supply network and protection system should be evaluated as a single electromechanical system rather than as independent components [2-4].

Medium-voltage variable frequency drives are widely applied in heavy-duty industrial mechanisms because they provide controlled acceleration, current limitation, speed regulation and diagnostic functions. International standards for rotating electrical machines and adjustable-speed drive systems define the general requirements for rating, performance, electromagnetic compatibility and operation of power drive systems above 1 kV [7-10]. These requirements are particularly important for 6 kV compressor drives, where direct starting may affect both the motor and the plant power network.

Theoretical and applied works on electric drives show that the replacement of direct-on-line starting by frequency-controlled operation can reduce starting current, limit electromagnetic torque oscillations and improve the thermal condition of the electric machine [11-15]. For high-inertia compressor applications, such effects are essential because rapid torque variation can increase vibration, accelerate wear of mechanical elements and reduce the operational readiness of the unit.

Previous studies on asynchronous electric drives and MATLAB-based modeling demonstrate that simulation is an effective tool for evaluating transient processes before practical implementation [16-18]. Modeling makes it possible to estimate the behavior of stator voltage, electromagnetic torque and rotor speed during start-up and to compare the expected effect of different drive structures without performing risky tests on operating industrial equipment.

At the same time, the literature mainly addresses general principles of variable frequency drives or separate motor-control problems. Less attention is paid to the integrated modernization of specific high-power compressor installations under industrial security restrictions. Therefore, the present study applies known principles of medium-voltage drive technology to an anonymized compressor drive system associated with a former K-1500 installation and evaluates the expected effect using engineering comparison and MATLAB/Simulink transient analysis.

MATERIALS AND METHODS

Object of study and modernization concept

The study considers the modernization of a high-power compressor electric drive system used in metallurgical production. The proposed configuration includes an Atlas Copco compressor unit, a 6 kV medium-voltage variable frequency drive and a squirrel-cage induction motor, which together provide controlled start-up, reduced electromechanical stress and improved operational reliability.

The term medium-voltage variable frequency drive in this work denotes a power-electronic converter intended for the controlled supply of a high-power electric motor at a voltage class of approximately 6 kV. Its function is to form a regulated output voltage and frequency, limit starting current, control acceleration and provide diagnostic information for the automated process control system.

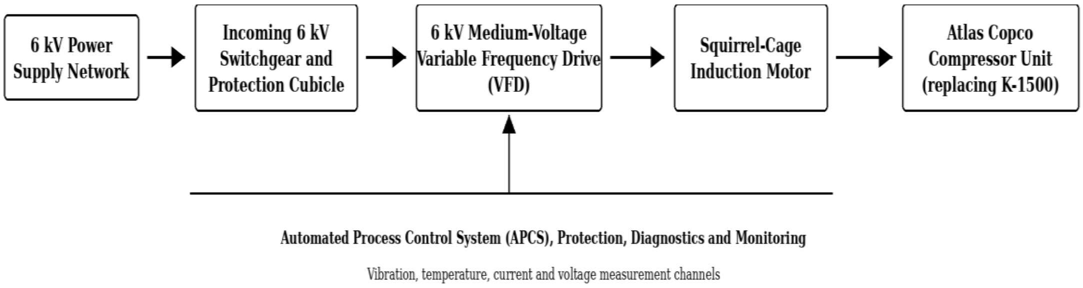

Fig. 1. Structure of the modernized compressor electric drive system based on a 6 kV medium-voltage variable frequency drive and an Atlas Copco compressor unit.

Technical data of the proposed induction motor

The main technical parameters of the proposed squirrel-cage induction motor HRN3 719-48E used for engineering calculations and simulation are summarized in Table 1. These data were used to define the rated operating point of the model and to estimate the expected behavior of the drive during start-up.

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Table 1. Technical characteristics of the proposed HRN3 719-48E induction motor

Parameter	Unit	Value
Motor model	-	HRN3 719-48E
Motor type	-	Squirrel-cage induction motor
Rated power	kW	7700
Rated voltage	V	6000
Rated current	A	842
Rated frequency	Hz	50
Rated speed	rpm	1492
Power factor	-	0.91
Efficiency	%	96.7
Duty cycle	-	S1
Protection degree	-	IP54
Cooling method	-	IC81W
Moment of inertia	kg·m²	297.7

Simulation procedure

The dynamic behavior of the proposed electric drive was analyzed using a MATLAB/Simulink model of an induction motor drive. The simulation model included the electrical part of the motor, mechanical inertia, load representation and measurement channels for stator voltage, electromagnetic torque and rotor speed. The analysis focused on start-up and transition to the rated-speed range.

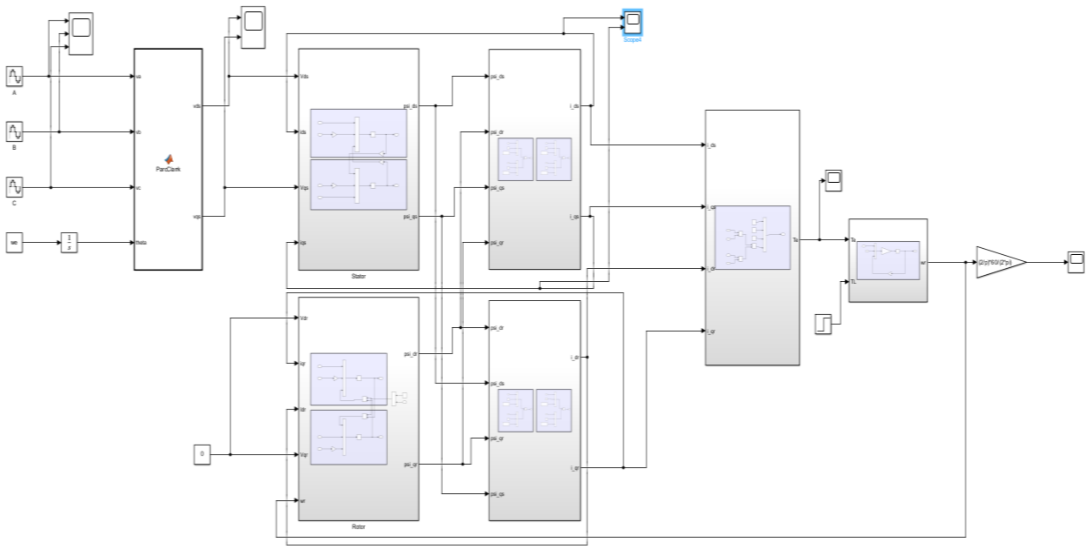

Fig. 2. MATLAB/Simulink model of the induction motor drive.

The simulation was used as a comparative engineering tool rather than as a final design calculation. For detailed project implementation, the model should be supplemented with verified manufacturer parameters, compressor load characteristics, cable data, harmonic filters, protection settings and site-specific operational constraints.

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RESULTS

The comparison of the initial and proposed drive configurations shows that the modernization changes the operating philosophy of the compressor installation. The former configuration relies on direct-on-line starting, whereas the modernized structure provides controlled acceleration, current limitation, speed adjustment, diagnostic capabilities and better integration with the automated process control system.

Table 2. Comparison of the compressor drive system before and after modernization

Indicator	Before modernization	After modernization
Driven equipment	Former K-1500 compressor installation	Atlas Copco compressor unit
Motor type	Synchronous motor	Squirrel-cage induction motor
Rated power	12500 kW	7700 kW
Supply voltage	6 kV	6 kV
Starting method	Direct-on-line start through excitation system	Controlled soft start through VFD
Speed control	Not provided	Frequency-based speed control
Starting current	5-7 x rated current	1.1-1.3 x rated current
Vibration level	Increased during hard start	Reduced due to controlled acceleration
Thermal loading	High during repeated starts	Normalized by current and torque limitation
Impact on 6 kV network	Significant voltage dips may occur	Reduced influence on the power network
Diagnostics	Limited external protection	Integrated VFD diagnostics and APCS signals

The first simulation output was the three-phase stator voltage waveform. As shown in Fig. 3, the voltage signals are symmetrical and sinusoidal in the model, which confirms the correct definition of the three-phase supply conditions used for transient analysis.

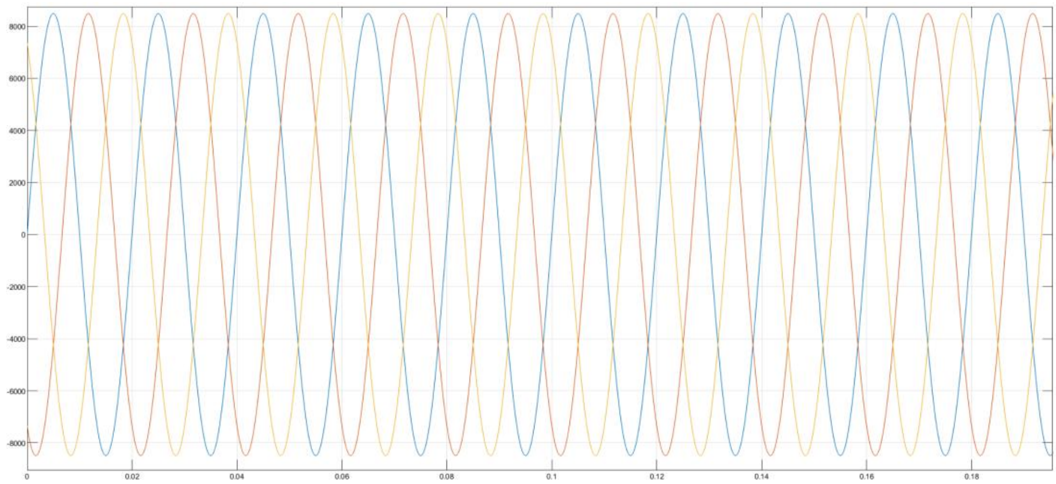

Fig. 3. Stator three-phase voltage waveforms in the simulation model.

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The electromagnetic torque transient is shown in Fig. 4. During the initial acceleration period, torque oscillations occur and then gradually decrease as the motor approaches a stable operating mode. This behavior confirms the need for controlled acceleration and torque limitation in high-power compressor drives.

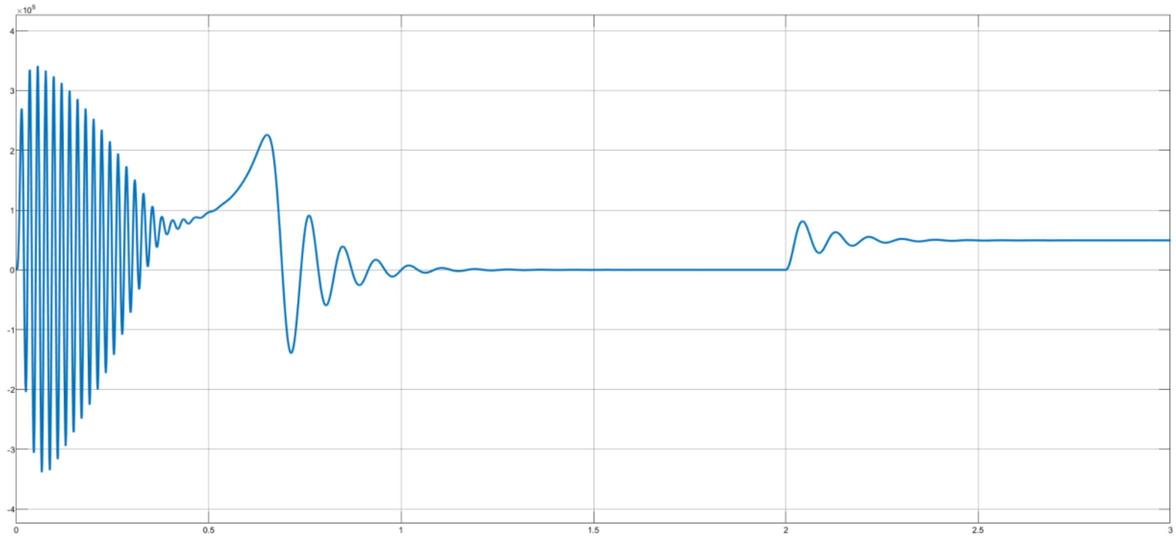

Fig. 4. Electromagnetic torque transient during start-up.

The rotor speed response is presented in Fig. 5. The motor accelerates and reaches the rated-speed range after the transient process. The obtained curve confirms that the proposed electric drive configuration is capable of establishing a stable operating regime suitable for the upgraded compressor unit.

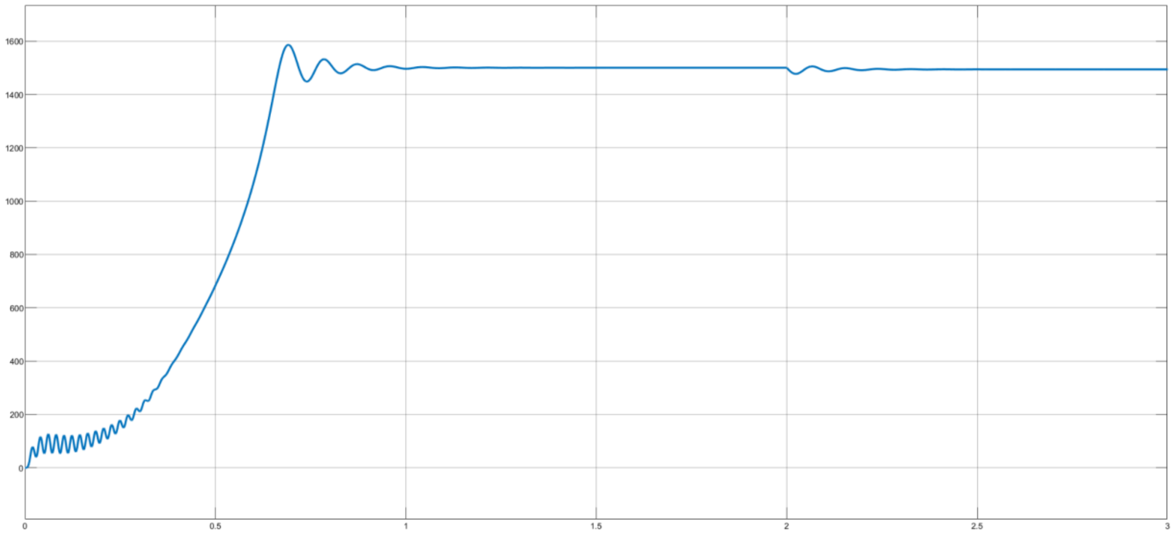

Fig. 5. Rotor speed transient during start-up.

DISCUSSION

The results indicate that the proposed modernization should be considered not as a simple replacement of individual equipment but as a transition from a rigid electromechanical system to a controllable drive architecture. The introduction of a medium-voltage VFD makes it possible to control the acceleration trajectory, reduce current surges and limit torque shocks applied to the shaft train.

From the power-supply perspective, the reduction of starting current is one of the most important effects. Direct starting of a large synchronous motor can cause voltage dips and additional stress on adjacent electrical consumers. In contrast, a VFD-based drive enables controlled current rise and therefore reduces the negative impact on the 6 kV plant network.

From the mechanical perspective, smoother torque development is beneficial for the compressor, coupling, bearings and support elements. Reduced vibration and thermal loading may increase the service life of equipment and decrease the probability of unplanned shutdowns. In addition, the diagnostic functions of the VFD and the integration of measurement channels into the APCS provide better observability of the drive system.

The main limitation of the present study is that the simulation is based on engineering input data and does not include a detailed compressor map or full manufacturer-verified VFD settings. Therefore, the obtained results should be interpreted as a technical justification for the modernization concept and as a basis for the next design stage rather than as final commissioning parameters.

CONCLUSIONS

The study substantiates the modernization of a K-1500 compressor electric drive system by replacing the direct-start concept with a controlled drive based on a 6 kV medium-voltage variable frequency drive, a squirrel-cage induction motor HRN3 719-48E and an Atlas Copco compressor unit.

The analysis showed that the proposed solution can reduce starting current, limit electromechanical shocks, decrease the influence on the power network, improve speed controllability and provide better diagnostic integration. MATLAB/Simulink simulation confirmed the presence of transient torque and speed processes and demonstrated the technical relevance of using controlled acceleration for a high-power compressor drive. The results can be used as an engineering basis for the preparation of a technical proposal and for subsequent design work on the modernization of high-power compressor drives at industrial enterprises, without disclosing the exact location of the categorized facility.

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AUTHOR CONTRIBUTIONS

Sh.B. Umarov contributed to scientific supervision, formulation of the research direction and review of the manuscript. R.I. Imanov performed the engineering analysis, preparation of the drive structure, MATLAB/Simulink modeling and drafting of the manuscript.

CONFLICT OF INTEREST DISCLOSURE

The authors declare no conflict of interest.

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