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SAFETY OF ENERGY-GENERATING EQUIPMENT THROUGH INNOVATIVE CYBERSECURITY APPROACHES. (Issues of ensuring the reliability, stability, and operational safety of energy-generating equipment, including through the application of innovative cybersecurity technologies and advanced cyber-protection solutions)

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Abstract

The article examines issues related to ensuring the stable, reliable, and secure operation of energy-generating equipment through the application of innovative cybersecurity technologies and advanced fuel-management solutions. Particular attention is devoted to the role of embedded processors and controllers in supporting autonomous operation, online monitoring, operational control, and computer modeling of equipment operating parameters without requiring significant external computing resources.

The publication analyzes contemporary approaches to adapting energy-generating systems to alternative fuel technologies, including the increasing use of methanol-based fuel mixtures. Special emphasis is placed on engineering solutions developed for gas turbines operating with methanol concentrations ranging from partial substitution to the complete replacement of conventional diesel fuel.

The study considers the technological challenges associated with changes in fuel composition, including the need for the rapid reconfiguration of monitoring and control systems, software updates, and recalibration of operational parameters. The author examines innovative methods for the dynamic mixing of methanol with conventional diesel fuel to improve combustion characteristics, increase operational efficiency, and compensate for the specific thermodynamic properties of methanol.

Particular attention is given to the development of simple, reliable, and mobile cybersecurity solutions designed to protect control and information systems without requiring substantial modifications to existing equipment designs, operational schemes, or engineering configurations. The article highlights the importance of information-security systems capable of protecting operational software and data-storage media while maintaining compatibility with existing energy infrastructure.

The conclusion emphasizes the prospects for integrating advanced cybersecurity technologies, intelligent monitoring systems, and innovative fuel-management solutions into modern energy-generating equipment in order to improve operational safety, increase fuel efficiency, enhance environmental performance, and support the long-term modernization of energy-production systems.
Keywords: *Energy-generating equipment; Cybersecurity; Innovative aspects of cybersecurity; Computer modeling of operating-cycle parameters of energy-generating equipment; Engineering resources; Embedded processors and controllers; Increasing proportion of methanol in fuel mixtures; Designs and circuit configurations of energy-generating equipment; Modification and optimization approaches for turbine fuel systems; Complete substitution of diesel fuel with methanol; Innovative methods of dynamic mixing of methanol with small proportions of conventional diesel fuel; Intelligent monitoring and control systems; Fuel-efficiency optimization; Digital technologies in energy production; Reliability and operational safety of power-generation systems; Advanced fuel-management technologies*

Introduction

Energy-generating equipment is inherently highly autonomous during operation, and issues related to operational management and online monitoring can, in many cases, be effectively addressed using the processing capabilities of the equipment's embedded processors and controllers.

In numerous applications, computer modeling of operating-cycle parameters can also be performed using these internal computational resources, provided that the modeling tasks are properly formulated and optimized from both technical and economic perspectives.

The Israel Electric Corporation possesses substantial engineering resources dedicated to optimizing electricity-generation processes, including the application of advanced fuel mixtures consisting of diesel fuel and methanol, with an increasing trend toward methanol concentrations reaching 95- 100% of the fuel composition.

Changes in fuel type and composition require the rapid reconfiguration of all monitoring and control systems, as well as the deployment of specialized software capable of accounting for all modifications in equipment operating parameters, control-system settings, and calibration procedures.

Industrial operating conditions require protection methods and devices that can provide comprehensive and reliable protection for monitoring and control equipment without complicating existing operating procedures. Such solutions should preserve virtually all circuit, kinematic, and fundamental design elements of the original equipment while introducing new protective components that do not require modifications to the base equipment during implementation.

Industrial experience and operational practice have demonstrated the need for mobile and highly simplified protection systems capable of supporting autonomous equipment operation without introducing additional information-storage media into existing operational architectures.

During the evaluation and analysis of available protection technologies, specialists of the Israel Electric Corporation concluded that the most economical and effective approach would be a data-storage protection system that does not require substantial modifications to the design or circuit architecture of energy-generating equipment.

The Israel Electric Corporation is recognized as a pioneer in the application of methanol as an alternative fuel for power-generating gas turbines.

Gas turbines of this capacity range (20–
–25 MW) traditionally utilize Diesel Fuel No. 2 as their primary fuel source.

One of the original objectives established by the development team responsible for the new innovative technology was the utilization of the so-called evaporation energy of methanol, which is significantly higher than that of other commonly used liquid fuels.

To achieve this and other innovative objectives, various modifications and optimizations of the turbine fuel system were developed. In addition to configurations providing complete replacement of diesel fuel with methanol, these solutions included innovative systems for the dynamic mixing of methanol with small proportions of conventional diesel fuel.

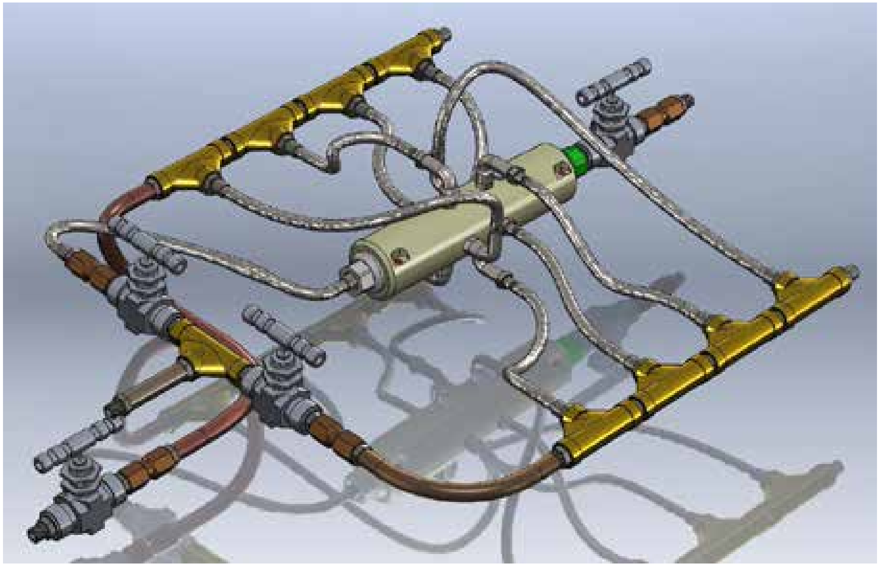
Such mixing strategies made it possible to reduce the influence of certain methanol properties on the combustion process, particularly those associated with methanol's relatively low flame temperature.

Given that hundreds and thousands of long-service-life turbines currently remain in operation worldwide and utilize a variety of fuels—including heavy diesel fuels such as fuel oil, natural gas, coal dust, and other fuel blends—it is appropriate to examine the differences between adaptation systems designed for the dynamic mixing of methanol with these fuel types, as well as the characteristics of the mixing devices themselves.

During prototype verification and qualification testing, the fundamental technical solutions associated with such devices were evaluated. These solutions demonstrated certain design differences depending on the type of fuel utilized and the number of fuel components involved in the mixing process.

At the same time, despite the high degree of unification and standardization achieved in modern fuel-preparation and fuel-mixture systems, the overall infrastructure of thermodynamic equipment remains highly dependent on the mobility, efficiency, and reliability of control, monitoring, and calibration systems, including the real-time adaptation of all incoming and outgoing operational signals.

Figure 1.



The first figure presents a three-dimensional model of a device designed for the dynamic mixing of diesel fuel and methanol directly within the fuel line of thermodynamic equipment.

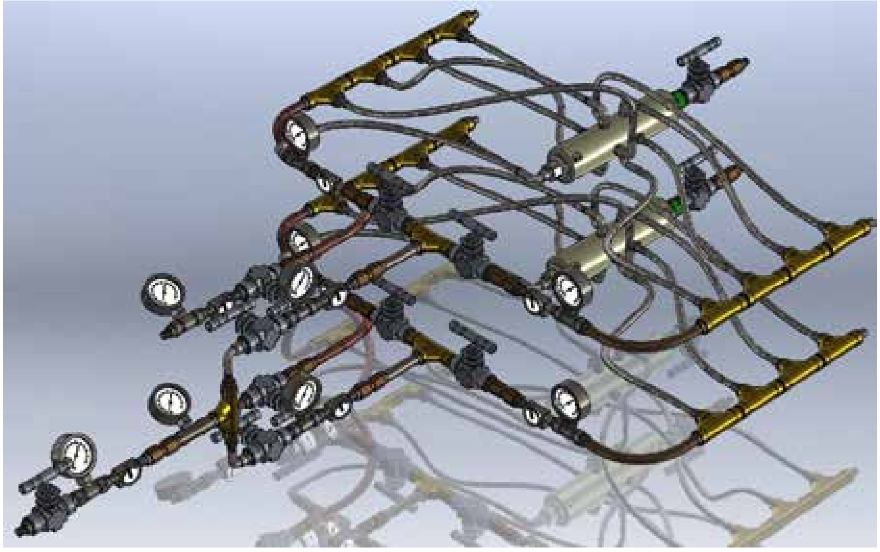
The device is extremely simple in design and, even in this configuration, may be used in at least two different ways: as a static mixer, since it contains no moving parts, and as a static online fuel-homogenization device operating directly within the fuel-supply line.

Due to the unique characteristics and complexity of energy-generating equipment, the integration of even such a compact and simple device into the fuel system requires appropriate adjustments to the operating parameters of the equipment. This, in turn, necessitates modifications to the software controlling the embedded processors and onboard computer systems.

From the perspective of mechanical and hydraulic installation, the process of implementing such modifications is entirely conventional and does not present significant technical difficulties. However, from the standpoint of cybersecurity, the temporary interval required for software modification, updating, or replacement creates a potential vulnerability window through which malicious software or computer viruses may gain access to the control and monitoring systems of thermodynamic equipment.

Considering the inherent inertia of such systems, it may be assumed that the detection of unauthorized intrusion could occur only after a certain period of operation. During this time, malicious software could potentially affect or disable critical components and subsystems of the equipment before the intrusion is identified and corrective measures are implemented.

Figure 2.



Furthermore, if a dual mixing system is integrated into the equipment, the corresponding cybersecurity risk is effectively doubled. In addition, where the system incorporates a recirculation loop for excess fuel, a significantly larger number of components and mechanisms may become exposed to the influence of malicious software, thereby further increasing the risks associated with modernization and system adaptation.

Under real operating conditions, there is often a need for substantially higher volumetric or mass fuel-flow rates. For example, when comparing the calorific value of methanol with that of conventional diesel fuel, methanol possesses approximately half the energy content of diesel fuel. Consequently, modernization for methanol operation requires an increase in fuel consumption by more than two times in order to maintain equivalent energy output.

This requirement further complicates the modernization process and necessitates the installation of approximately twice as many fuel-handling devices, together with all associated monitoring, control, and management elements.

Such a configuration imposes additional demands on the processing power, memory capacity, and operational capabilities of embedded processors and programmable controllers, thereby further confirming the validity of the conclusions outlined above.

The following figure illustrates such a quadruple-system configuration comprising four independent units, each of which may, if necessary, operate autonomously within the overall fuel-management and control architecture.

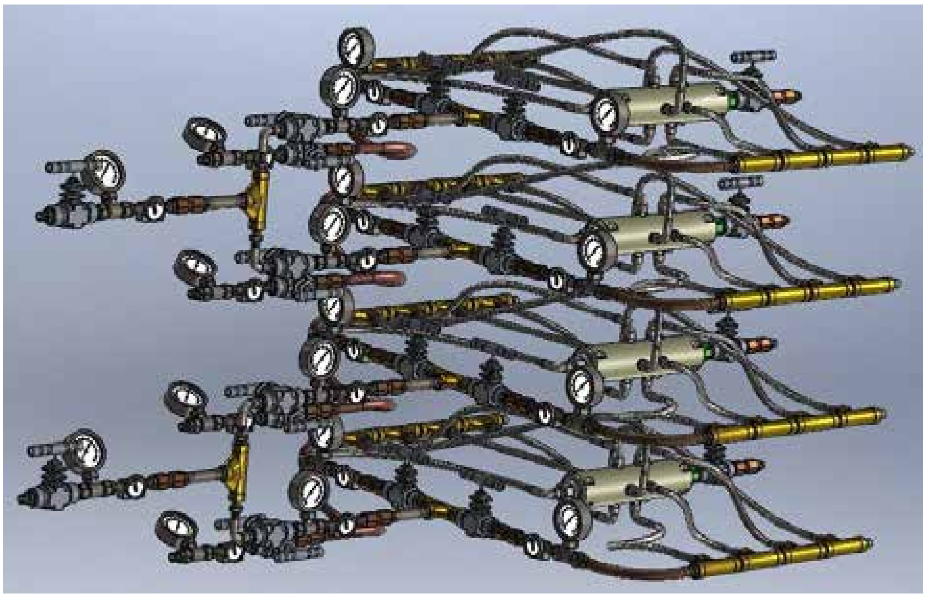
In recent years, powerful and highly productive systems have emerged that are capable, in principle, of replacing multi-component configurations while maintaining equivalent or even superior thermodynamic performance characteristics.

The following figure illustrates such a system with a processing capacity of 1,000 liters per hour.

Although this system incorporates only three external inlets and a single outlet, the specific requirements associated with its control, monitoring, and hydrodynamic coordination demand no fewer control and management operations than more complex multi-component systems. Consequently, it requires comparable computational capabilities from the associated control, monitoring, and operating-cycle simulation systems used in thermodynamic equipment.

Accordingly, the importance of ensuring high-quality and guaranteed protection of software components during the operational loading of control, monitoring, and analytical systems remains critically important regardless of the type or configuration of the fuel-mixing device employed.

Figure 3.



When considering the fundamental technical requirements applicable to such systems, the following key criteria may be identified:

- Information-storage media must possess original integrated security features;
- Software loading and updating procedures must be protected against unauthorized access and malicious interference;
- Control and monitoring systems must ensure the integrity, authenticity, and traceability of operational software throughout the entire service life of the equipment;
- Protection mechanisms should function without requiring substantial modifications to the existing design, architecture, or operational principles of the equipment;
- Security systems should support autonomous operation and maintain functionality under industrial operating conditions;
- Cybersecurity measures should ensure reliable protection against unauthorized software modification, malicious code injection, and external cyber threats targeting critical control and monitoring infrastructure.

Figure 4.

- Information-storage media must possess an identification system and methodology equivalent to those used in processor-based and onboard computer systems for data recognition and verification;
- The identification code must be applied to the information-storage medium in such a manner that the standard dimensions, geometry, and configuration of the medium's interface and connection elements remain unchanged;
- The identification code should be based on a single control and measurement parameter;
- Identification of this parameter must be performed using a non-contact method.

The above requirements represent only a portion of the key technical criteria. However, under current technological conditions, no commonly used mobile information-storage medium fully satisfies these requirements, even partially.

In this regard, it should be noted that, after reviewing the highly significant publications of *Babadzhanian Heorhii*, an Associate Member of the Ukrainian Academy of Sciences, dedicated to this field, our working group concluded that it was extremely important to evaluate and test the information-storage media coding system proposed in his publications.

Figure 5.

As demonstrated in these publications, the developments proposed by *Babadzhanian Heorhii* collectively satisfy all of the above-mentioned technical requirements, as well as a considerable number of additional independent requirements and their combinations. Furthermore, these developments establish the foundation for a new and promising technological field based on magnetic-resonance, non-contact methods of control and nano-scale measurement.

From the perspective of a specialist involved in the operation of industrial power-generation equipment, the most effective application of this method appears to be its dissemination among manufacturers and operators of specialized computer systems used in power-generation facilities.

Given the clear scalability characteristics of fuel-mixing and fuel-preparation equipment, it may be reasonably assumed that the proposed coding system can be implemented throughout virtually all sectors of the energy industry, including gas turbines, diesel generators, boiler systems, combined heat and power plants, and other types of thermodynamic equipment.

The following figure presents three-dimensional models of dynamic fuel-mixing devices arranged according to size and scale factors. The smallest systems may be integrated into compact industrial or domestic equipment, whereas the largest systems are capable of supporting fuel-flow rates reaching tens of thousands of liters per hour.

The proposal developed by *Babadzhanian Heorhii* significantly expands the potential integration opportunities for innovative energy projects. Even within a single power-generation facility with a capacity of several tens of megawatts, such an approach may generate annual savings measured in hundreds of thousands of dollars while simultaneously providing the highest achievable level of protection for energy-equipment control architectures and management systems.

Moreover, within the context of modern energy technologies, this proposal demonstrates originality of concept, innovative thinking, and the exceptional nature of a new technological and software-oriented direction. With relatively modest implementation costs, it offers a practical solution to one of the most critical challenges facing contemporary energy systems—the achievement of an adequate and reliable level of cybersecurity.

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