DEVELOPMENT OF A MICROPROCESSOR-BASED SYSTEM FOR OPERATIONAL INTERLOCKING AND PROTECTION OF ELECTRICAL EQUIPMENT IN DIGITAL SUBSTATIONS

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Abstract: The rapid evolution of digital technologies has significantly transformed the electric power industry, leading to the emergence of advanced automation systems. One of the most important innovations in this field is the transition from conventional substations to digital substations, which rely on intelligent electronic devices (IEDs) and microprocessor-based solutions. These systems provide enhanced monitoring, control, and protection capabilities. This paper presents the design and development of a modern microprocessor-based system for operational interlocking and protection of electrical equipment in digital substations. The proposed system is aimed at improving reliability, response speed, and safety under various operating conditions. Special attention is given to system architecture, data modeling based on electrical схемes, and compliance with international standards such as IEC 61850. The results demonstrate that the implementation of such systems significantly enhances automation efficiency and ensures stable operation of power facilities.

Keywords: digital substation, microprocessor system, protection, interlocking, IEC 61850, automation.

Annotatsiya: Raqamli texnologiyalarning tez rivojlanishi elektr energetikasi sanoatini sezilarli darajada o'zgartirdi va ilg‘or avtomatlashtirish tizimlarining paydo bo'lishiga olib keldi. Bu sohadagi eng muhim yangiliklardan biri an’anaviy podstansiyalardan raqamli podstansiyalarga o'tish bo'lib, ular aqlli elektron qurilmalar (IED) va mikroprotsessorga asoslangan yechimlarga tayanadi. Ushbu tizimlar

yaxshilangan monitoring, boshqarish va himoya qilish imkoniyatlarini taqdim etadi. Ushbu maqolada raqamli podstansiyalarda elektr uskunalarini operatsion markazlashtirish va himoya qilish uchun zamonaviy mikroprotsessorga asoslangan tizimni loyihalash va ishlab chiqish taqdim etilgan. Taklif etilayotgan tizim turli ish sharoitlarida ishonchlilik, javob tezligi va xavfsizligini oshirishga qaratilgan. Tizim arxitekturasiga, elektr sxemalariga asoslangan ma'lumotlarni modellashtirishga va IEC 61850 kabi xalqaro standartlarga muvofiqlikka alohida e'tibor qaratiladi. Natijalar shuni ko'rsatadiki, bunday tizimlarni joriy etish avtomatlashtirish samaradorligini sezilarli darajada oshiradi va energiya inshootlarining barqaror ishlashini ta'minlaydi.

Kalit so‘zlar: raqamli podstansiya, mikroprotsessor tizimi, himoya, markazlashtirish, IEC 61850, avtomatlashtirish.

Аннотация: Быстрое развитие цифровых технологий значительно преобразовало электроэнергетическую отрасль, приведя к появлению передовых систем автоматизации. Одним из важнейших нововведений в этой области является переход от традиционных подстанций к цифровым подстанциям, которые используют интеллектуальные электронные устройства (ИЭУ) и микропроцессорные решения. Эти системы обеспечивают расширенные возможности мониторинга, управления и защиты. В данной статье представлены проектирование и разработка современной микропроцессорной системы для оперативной блокировки и защиты электрооборудования на цифровых подстанциях. Предложенная система направлена на повышение надежности, скорости реакции и безопасности в различных условиях эксплуатации. Особое внимание уделено архитектуре системы, моделированию данных на основе электрических схем и соответствию международным стандартам, таким как IEC 61850. Результаты показывают, что внедрение таких систем значительно повышает эффективность автоматизации и обеспечивает стабильную работу энергосистем.

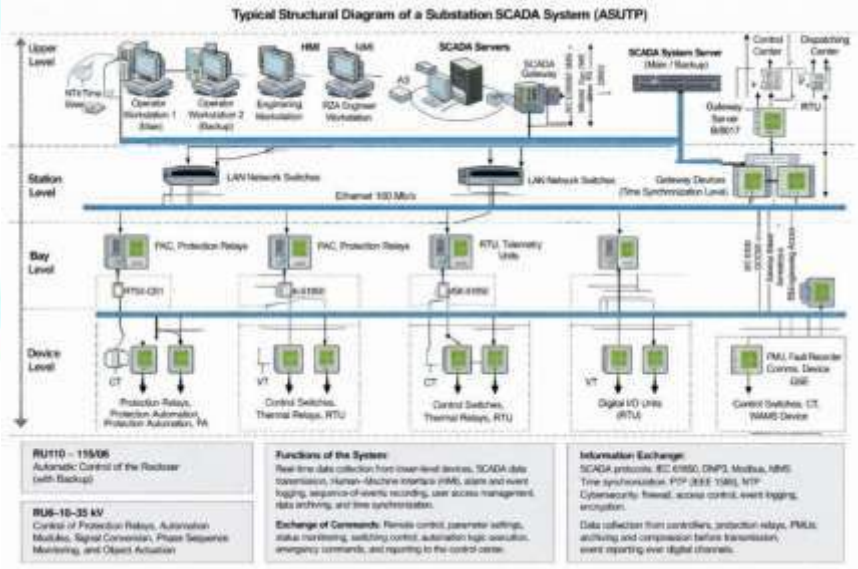
Ключевые слова: цифровая подстанция, микропроцессорная система, защита, блокировка, IEC 61850, автоматизация.

Introduction

In recent years, the power engineering sector has undergone substantial modernization due to the integration of information and communication technologies. Traditional substations are gradually being replaced by digital ones, which utilize advanced computing and communication infrastructures. Digital substations are built on intelligent electronic devices that enable real-time data exchange, remote control, and automated decision-making. These features allow operators to improve system reliability, reduce human errors, and respond quickly to emergency situations. One of the key challenges in such systems is ensuring effective protection and operational interlocking of electrical equipment. Failures or incorrect switching operations can lead to serious damage and system instability. Therefore, the development of intelligent protection systems based on microprocessors is essential. The objective of this study is to design a flexible and efficient protection and interlocking system that meets modern technical requirements and supports integration into Smart Grid environments. [1, 165]

Results

Figure1. Structure of the Automated Process Control System (APCS).



Architecture of the Proposed System

The developed system is based on a modular architecture that includes the following main components: Intelligent electronic devices (IEDs), Communication network, Central control unit, Monitoring and diagnostic modules. [1, 15]

Each component performs a specific function within the system. The IEDs are responsible for collecting data, executing protection algorithms, and sending signals to other devices. The communication network ensures fast and reliable data exchange. The central control unit processes incoming data and makes decisions based on predefined logic. Additionally, diagnostic modules continuously monitor system performance and detect faults at early stages. Such an architecture allows scalability and flexibility, making it suitable for various types of substations. [2, 65]

Information Modeling Based on Electrical Schemes. An important aspect of digital substations is the creation of an information model based on the electrical scheme. This model describes all system elements and their interconnections. Each element of the electrical system is represented as an object with specific attributes, including: Equipment type (breaker, transformer, relay, etc.), Identification number, Electrical parameters (voltage, current, power), Functional role, Operational status. [3, 55]

Discussion

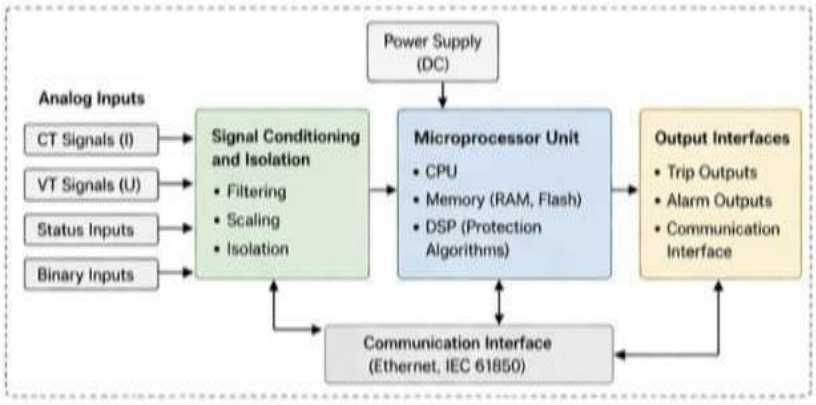
Connections between elements are also modeled to represent both electrical and communication links. The use of standardized data models ensures compatibility between devices from different manufacturers and simplifies system integration. [4, 19]

Role of IEC 61850 Standard. The IEC 61850 standard plays a crucial role in the development of digital substations. It defines communication protocols, da ta structures, and device models. By following this standard, engineers can:

1. Ensure interoperability between equipment
2. Reduce engineering and configuration time
3. Improve data exchange speed
4. Enhance system reliability

In the proposed system, all components are designed according to IEC 61850 requirements. Logical nodes are used to represent system functions, while communication is performed through standardized protocols.

Figure 2. Hardware structure of the microprocessor- based protection device.



Operational Interlocking and Protection Mechanisms. Operational interlocking is essential to prevent incorrect switching operations. It ensures that equipment operates only under safe conditions. The proposed system implements interlocking logic using microprocessor-based controllers. These controllers analyze system states and block unsafe actions automatically. Experimental Results and Analysis. To evaluate the performance of the system, several tests were conducted under different operating conditions. [1, 47]

Conclusion

The transition to digital substations requires advanced protection and control systems. The microprocessor-based interlocking and protection system presented in this paper provides an effective solution to these challenges. By utilizing modern technologies and international standards, the system ensures safe, reliable, and efficient operation of electrical equipment. Future research may focus on integrating artificial intelligence for predictive maintenance and further optimization.

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