Smart grid and ripple control technologies in energy and road construction

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Abstract. The present paper is aimed at studies on innovational technologies of Smart Grid and Ripple Control, which offer means for intuitive integration of actions of all consumers of energy resources to provide sustainable, effective and reliable sources of power supply in road construction. Operating features of the Smart Grid system were analyzed in terms of its ground-breaking aspects and advanced methods for monitoring. These systems combine novel products and services with intelligent systems for monitoring, control, communication and self-restoration. Regarding the results of the research, there were given recommendations on how to reduce losses in transmission lines, improve operational stability and productivity of the grid without any technical modifications in the network.

1 Introduction

Innovative processes in the power grid can be divided into two integrated areas: modernization and intellectualization of electric networks. The first area includes processes that do not change the structure of the electric grid, its topology and build up principles. The most important of them are: keeping the equipment up to date and implementation of automated information systems, that will improve the efficiency of management and operation of the electrical network.

The second area covers the processes related to the intellectualization of the electric system as a whole. As a result of the implementation of these processes, a transition from “traditional” distribution networks to active adaptive ones (Smart Grid) should happen. Smart Grid will be the basis of Russia's intellectual energy system. This approach requires significant changes, both in the structure and in the functional features of the electricity and capacity markets, the relationship between energy supplying organizations and consumers [1].

The introduction of Smart Grid gives customers the opportunity to understand the principles of using electricity and energy, as well as the prospects for reducing carbon emissions by switching to renewable energy sources.

2 Theory

Smart Grid is characterized not only by technological innovations, but also by accurate economic planning and implementation of power supply. This concept can be presented as a pyramid that bases on the asset management - the key for the implementation of intelligent networks (Fig. 1).
The adoption of the Smart Grid system does not mean a complete replacement of existing electrical networks, since this is inappropriate from a technical and economic point of view. Smart Grid is focused on improving the electrical grid by integrating new technologies and services. There are several advantages of Smart Grid compared to traditional networks:

a) Improved reliability.

An energy system with high reliability is one that supplies electricity to consumers when necessary, and its quality must meet the requirements of consumers. Thus, the Smart Grid provides a stable power supply, reduces the frequency of outages, prevents interference, and also eliminates electrical problems. This is achieved through the use of digital information, automated operations and systems [2].

b) Improved security.

Smart Grid has protection from cyber attacks or assaults that can affect reliability and security of the grid. Information security, cybersecurity and privacy protection are guaranteed for all users of intelligent networks.

c) Energy efficiency.

Intelligent networks are more efficient traditional networks that reduce power consumption, peak load and energy loss. In addition, increased efficiency leads to lower costs for the production, transmission and consumption of electricity.

d) Environmental improvements.

Implementation of these networks logically results in the reduction of harmful emissions. These improvements contribute to the lower emissions of CO2 from the generating units and also reduce vehicle emissions in the case of electric cars.

e) Economic efficiency.

Using Smart Grid offers economic benefits. Consumers could learn about the energy they use and consequently manage their energy costs [3]. The top priority of systemic factors and conditions, i.e., reliability and cost effectiveness of the system as a whole, forms the basis for development of the smart grid and principles of energy system management. In general, the Smart Grid concept can be represented as a complex system with a number of forward and backward linkages (Fig. 2).
Currently, the Smart Grid concept has become widespread in the global electricity industry. Active-adaptive network involves the development of elements aimed at improving the efficiency of management of the processes of production, transmission and distribution of electric energy. The prerequisites for the development of an active-adaptive network are: infrastructural restrictions and technological risks for the development of network infrastructure; limited investment resources required to build new energy facilities; environmental constraints; almost complete impossibility to increase the efficiency of current production and transmission capacities. The innovative way of developing the electric power industry in accordance with the Smart Grid concept is based on a holistic system of approaches, principles and tools for creating a technological base in order to transform the electric power industry to comply with the demanding requirements for energy and environmental efficiency of the economy (table 1) [4].

Electric networks using Smart Grid technology are a multi-level system that includes measuring systems, automation equipment, and voltage and load control devices. Modern measuring systems provide smart metering with high accuracy. Both short-term and long-term forecasts of power consumption can be built on the basis of the measurements. Active-adaptive control of the modes can be pulled off by regulating the voltage and load in the network nodes, conducting switching, implementing reactive power compensation devices, etc.

**Table 1. Benefits from implementation of the Smart Grid.**

| Current electric power system | Source of the effect | Smart Grid-based electric power system |
|-------------------------------|----------------------|---------------------------------------|
| Less than 13%                 | Share of the used renewable energy sources | More than 30%                        |
| Less than 1%                  | Level of usage of energy generated by consumers | More than 10%                        |
| 50%                           | Level of usage of the transmission systems | 80%                                  |
| 30%                           | Level of usage of the distribution systems | 80%                                  |
| 47%                           | Consumer’s participation | 90%                                  |

5 main groups of basic technological areas can be formed to create a new technological base for the electric power industry:

1) Measuring equipment is smart meters and smart sensors. They are a key component of a modern energy system based on the Smart Grid concept. These technologies can perform various functions, such as ensuring continuous monitoring, network optimization and emission reduction due to the ability to manage demand, assess the state of equipment and the level of network integration and facilitate direct interaction between the energy supplier and the consumer [5].
2) Innovative components of the energy grid are based on the latest achievements of science and technology in areas such as the theory of superconductivity, power electronics, energy storage and system diagnostics. Examples are renewable energy, DC power transmission system, superconductors, intelligent modules, power electronics on the basis of modern semiconductor devices.

3) Advanced control methods are one of the important parts of the Smart Grid, which makes it possible to build a safe, reliable and environmentally friendly modern energy network. Advanced Control technologies are represented by various devices and algorithms that can analyze, diagnose and predict the operating conditions of a modern power system, as well as identify, make decisions to eliminate the negative impact and prevent failures in the power supply system. These methods provide control at the level of transmission, distribution and consumption of electricity. As a result of the above capacities, the energy network significantly increases its level of reliability.

4) Improvement of interfaces and decision-making methods - this area is necessary for operators and managers for the fully-fledged operation of the power grid. This technology converts complex power system data into information that is readily understandable. In many situations, the time, that takes operator to take a decision, is reduced from a few hours to minutes or even seconds. Thus, a modern energy system requires widespread use of real-time applications and special tools for operational decision making. For these purposes, there could be used animation, virtual reality and other modern technologies to display data, since their use can prevent overload and help operators to timely identify, analyze and properly respond to problems of the power system [5].

5) Implementation of integrated communications is the ground for the development of all above considered technologies and the entire modern energy network. Their functioning substantially depends on the collection, protection and control of data. Therefore, communication methods and technologies have the highest priority for the contemporary electric grid.

The integrated communications will facilitate a dynamically interactive infrastructure to access information in real time in order to change energy consumption. Consumers will gain access to the electronic devices in the network. In addition, these technologies can optimize reliability of the system and avoid any system failures. A power system with advanced communication technology can be restored by continuous monitoring, self-diagnostics and self-correction of errors to maintain high quality and reliability of power supply [6]. According to the most conservative estimates, the economic effect of introducing a Smart Grid-based system in the coming years may amount to tens of billions of dollars across the globe (table 2) [7].

| Table 2. Effects of introducing a Smart Grid-based energy system. |
|---------------------------------------------------------------|
| **year 2000**                                                       | **year 2025**                        | **Ratio of parameters of scenario 2 to scenario 1** |
| Parameters                                      | Basis                     | Energy system without Smart Grid (scenario 1) | Smart Grid-based energy system (scenario 2) | **Decline by 10% - 15%** |
| Electric energy consumption (billion kWh)     | 3.800                     | 5.800                                      | 4.900 – 5.200                                  |
| Intensity of distribution system (kWh/SGDP)   | 0.41                      | 0.28                                      | 0.20                                         | **Decline by 29%** |
| Peak demand reduction (%)                      | 6%                        | 15%                                       | 25%                                          | **Growth by 66%** |
| CO2 emission (million tons of carbon)          | 590                       | 900                                       | 720                                          | **Decline by 20%** |
| Productivity growth rate (%/year)              | 2.9                       | 2.5                                       | 3.2                                          | **Growth by 28%** |
| Real GDP (billion dollars)                     | 9.200                     | 20.700                                    | 24.300                                       | **Growth by 17%** |
| Value of the loss from accident for business (billion dollars) | 100                       | 200                                       | 20                                           | **Decline by 90%** |
At the present moment, energy management is considering two of the most important questions: the optimal use of electric energy and the efficiency of its consumption. Suppliers have limited control over the use of electric energy, when purchasing electricity from a power plant and then selling it to consumers, but they are interested in maintaining daily consumption at a stable level. One possible solution to this problem is to use special systems with Ripple Control technology.

The principle of operation of Ripple Control is to increase or decrease power consumption at a specific time (Figure 3). Consumer's equipment receives a signal, which either increases or decreases the load depending on the current requirements of the power company. If the total power load exceeds the limit, some load groups as electric heating, hot water boilers and heat pumps are shut off [8].

The Ripple Control system has found application in many areas of the electric power industry that are related to load management. So, several tasks can be solved at once:
- Load management. The technology under consideration allows to monitor the needs of customers using the embedded switching program. The program can be changed in real time;
- Lighting control. Street lighting costs can be reduced with a special switching schedule and general Ripple Control technology.
- Reduction of power losses in the network. Since losses during the maximum load are higher than at other times, Ripple Control allows to transfer part of the load to the time of its minimum [8].
- Control of the tariffs. There is a possibility to communicate with a particular client on the network and offer more flexible tariffs for one.

![Figure 3. Ripple Control system.](image)

### 3 Results

It should be noted that the construction of an active-adaptive network involves the implementation of a number of innovative solutions. At the same time, the integration of Smart Grid and Ripple Control technologies into the electric grid complex provides the possibility of their further use to increase the efficiency of implemented innovation processes. It is achieved by rational organization of the process of identifying demand for innovations, monitoring implementation of projects, evaluating the effectiveness of investment in innovation, etc.

Below is the algorithm of the novel process of introducing Smart Grid technologies into the electric grid complex in order to build an active-adaptive network (Fig. 4).
Figure 4. Functional features of the Smart Grid system.

From fig. 4 it follows that the process of implementing the Smart Grid technologies is coordinated by the innovating-coordinating center. This center is engaged in the search and selection of ideas in the field of breakthrough technologies. Moreover, it facilitates innovative projects and the development of novel products that will directly affect the development of an active-adaptive network. Technical and organizational preparations to introduce new technologies are carried out if the network architecture has been developed.

In this case, the processes associated with the technical preparation of the facility for operation and staff training are more important. A number of problems may arise when putting new equipment into operation. The reasons are often either flaw design or errors in the setup. Thus, this process should take place gradually in several stages, starting with the introduction of simpler elements with the subsequent complication of the system.

4 Discussion
Competence and open-mindedness of the staff strongly affect the efficiency of the active-adaptive network. There may even be situations where employees will be negative about innovations, so it is first necessary to organize courses for the training, education and retraining of staff. After the preliminary work, production is launched and tested. Only then products are certified and serial production takes place.

In recent years, there has been an increase in the activity of the Smart Grid and Ripple Control systems in Russia. It manifests itself in the political and scientific fields, as well as in the activities of energy companies. National policy will cover such issues of the electric power industry as the efficiency of renewable energy sources and smart grids. The main objectives of the power grid companies are to increase economic and environmental efficiency in the production, transportation, distribution and consumption of energy in the Russian Federation.

5 Conclusion
Smart Grid and Ripple Control technologies are developing intensively in many countries of the world. They allow not only to integrate new applications into the network, but also to increase the efficiency of power supply, providing ample opportunities for management and control. This indicates the interest of most countries in improving the energy sector with the help of modern smart devices and technologies.

The use of the Smart Grid and Ripple Control technologies in the power grid reduces power losses and energy costs. From a technical point of view, implementation of these technologies in Russia may lead to the reduction of energy losses in transmission lines and, consequently, to an improvement in
the operational stability and productivity of the power grid without any technical modifications in the network.

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