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Smart Grid – German and Russian Perspectives in Comparison

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Abstract—**The term Smart Grid describes the idea of the future power system. The shortage of fossil primary energy resources has led - under introduction of deregulation and liberalization of the electricity market - to this new concept of the power system. More local generation, especially from renewable, are already present in the power systems of Europe and other countries such as Japan and the USA. This change in generation has influenced the structure of the power system from a centralized to decentralized one and is the main challenge in its planning and operation.**

This paper shows the general perspective of the Smart Grid from the European and Russian point of view. The definition of Smart Grid is discussed and the important elements of it are presented. Furthermore, the distributed energy resources such as wind, PV, CHP are characterized and their role in the future power system related to the current experiences in Germany and in Russia is shown. The explanations are based on the experiences of the authors and literature studies.

Keywords- power system, distributed generation, renewable generation, Smart Grid, virtual power plant.

I. INTRODUCTION

The main task of an electrical power system is production of electrical energy and its delivery to the customers in order to supply the loads. The interconnected electrical power system, e.g. ENTSO-E in Europe, is one of the most complicated technical systems. On the one hand, the system combines a complex assemblage of different centralized and decentralized power plants, transmission and distribution grids as well as loads, and on the other hand, it is spread over a wide area. The liberalized European electricity market requires an improved data exchange between all market participants for optimizing the coordination between different national systems. These concepts aim to simplify the exchange of information about effective management, system technology and infrastructure protection among the participants.

The present power system was built – because of fuel – as a centralized system, which means the main energy production comes from large power stations and the electrical energy is transmitted to the customers. The advantage of such a system is the relatively simple coordination of several big generating units that are well controlled in order to provide the necessary balance between demand and generation that is crucial for frequency stability.

The shortage of fossil fuels leads to the continuous development of the power system structure with a high amount of dispersed generation. Most of the dispersed generation units are based on the renewable energies such as wind or photovoltaics.

These changes in power system structure result from three main goals:

- reduction of greenhouse gas emissions (The Kyoto Protocol [1]);
- increased usage of renewable energy sources / RES (the European RES Directive [2]);
- energy efficiency improvement (the European CHP (combined heat and power) Directive [3]).

The development of distributed generation has many advantages such as:

- reduction of CO2 emissions due to increased energy efficiency the reduction of coal electricity;
- minimized transmission losses;
- regulation of congestions in transmission system;
- partially avoidance of infrastructure investment.

Generally, Germany has a leading position - during the last years - regarding the development and use of renewable energies like wind generation, which results from different activities that were carried out in the last few years in order to support this development. These activities was pushed on the one hand by introduction a some pilot programs by the federal government providing increased subsidies for expensive investments in new renewable generation technologies, e.g. [4]:

- “100.000 Roofs” program (PV) [5];
- “100 MW Wind” program (WT) [6];
- “250 MW Wind” program (WT) [6];
- Tax reduction for biofuels [7].

Furthermore, after the phase of aforementioned pilot projects the sustainable development of renewables as well as combined heat and power was established by the introduction of federal laws regulating the issues regarding the grid access as well as a remuneration scheme for produced energy that was covered by the following acts:

- Electricity Feed-In Act (1991) [8];
- Renewable Energy Law (EEG) (2000 and 2009) [5];
- Combined Heat and Power Law (KWK) (2002) [9].

Compared to the fast modernization of the power system that can be observed in Germany and also some other European countries like Denmark, the development of the power system in Russia has been slow in the last 20 years and, therefore, the structure has become obsolete. The present power system in Russia is characterized by a high degree of depreciation, high losses (about 10-15 %) and lower reliability level [10]. The Russian government introduced some measures and set goals in order to perform modernization of the energy system that include:

- increasing the energy efficiency up to 40 %;
- incremental phasing out of incandescent lamp usage;
- developing the system of smart meters for industrial and private use and encouraging their usage.

In this paper the general perspective of the Smart Grid from the European and Russian point of view is considered. First of all the paper provides the definition of Smart Grid and presents the important elements of it. Furthermore, the distributed energy resources, wind, PV, CHP, are characterized and their role in the future power system is presented. Operational issues and information technologies (IT) are a very important and necessary element of the Smart Grid, so the requirements for the integration into the grid and for the IT services are discussed in the paper especially deeply.

II. TOWARDS TO THE SMART GRID

A traditional power system (Figure 1) has a vertical integrated scheme with centralized generation, distributed consumption, limited interaction and regulatory frameworks that are not harmonized for mutual advantage.

The traditional grid can be characterized by:

- large conventional power plants;
- technically optimized for regional power adequacy;
- centralized control;
- limited cross-border interaction;
- technology that is almost 100 years old.

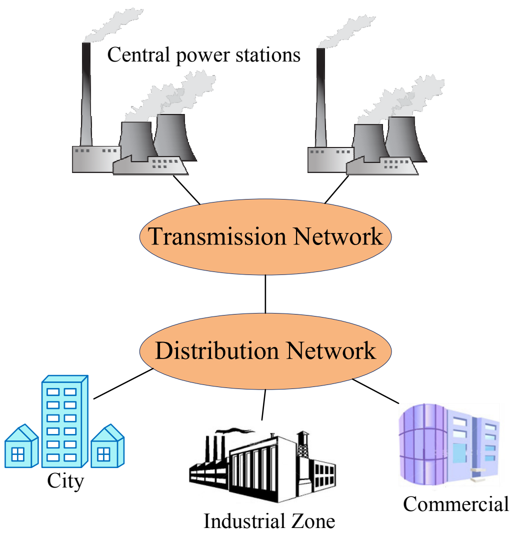

Figure 1. Structure of conventional power system.

The new generation units based on the wind, water, photovoltaic or other kinds of RES conversion – which are introduced last year - feed a respectable amount of electrical energy already today directly into the distribution level. Unfortunately the stochastic character of the power generation from most of the RES units (heavy dependency on the weather conditions) has a crucial influence on the operational behavior of the overall power system. Nevertheless a large amount of the decentralized generated energy will be consumed locally, giving the distribution network a local active network character. The change of the power system structure from centralized to decentralized, which was introduced by the distributed generation (DG) units, also requires changes in the monitoring, controlling and balancing concepts of the system. These concepts allow for optimizing the interaction between conventional power plants and DG in order to guarantee the necessary safety and security of supply at an economic level.

In existing power systems the power plants tasks include more than just power generation. They participate in frequency and voltage control, deliver fault current, and have "fault ride through" capability. Availability of these services guarantees the stable operation of the whole system. In order to replace the conventional generation by dispersed generation without violating proper operation of the power system, all services provided by conventional power plants have to be available from DG units, too. Besides the connection of large onshore and offshore wind farms to the transmission grid a fast growth of dispersed energy resources (DER) in distribution systems is expected.

The issues to be considered in this regard at the distribution level are:

- ensuring network conformity in accordance with the special rules of DER connection in medium and low voltage networks [11] e.g. regarding voltage quality, avoidance of equipment overloads, short circuit withstand-ability, influence on ripple control etc.;
- contributing to the reliability of supply through providing high availability and support of network recovery after faults;
- compensation of power fluctuations and dispatch of a stable power balance in clusters of different DER, storage units and controllable loads.

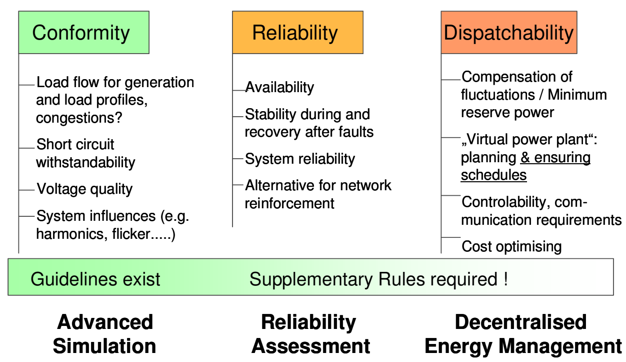

Figure 2. Requirements means for a large scale penetration of DER [12].

The comprehensive overview of the relevant issues connected to the expansion of dispersed generation in the power system is summarized in Figure 2.

Until now the transmission system operator has been obliged to ensure power balance. This task will become more and more difficult under the conditions of a growing contribution of uncertain and intermitting power output of DER. Therefore, a sufficient level of available system services still has to be provided even with a high amount of RES/DER connected to the grid, which have replaced the conventional generation units. This requires a further development of the system services delivery and its enhancement from the transmission to the distribution level, as presented in Figure 3.

The market for balancing capacity and ancillary service will become a decisive element in the price-setting of the electricity. The DER and finally the customer will also increasingly take part in the electricity market, which will have a real time pricing. User electrical network connection will operate in two directions, like a communication network. Buildings will have micro-generation systems and smart metering. They will also have smart appliances that take part in Demand Side Management.

In order to cope with this situation and guarantee the possibility to integrate further RES and DER units into the power system in an optimal way and to maintain the high level of security and reliability of supply, the development of intelligent electrical grids - so called Smart Grids – is indispensable.

III. Concept of Smart Grids

The concept of Smart Grid presents the idea of future power system. In general, the Smart Grid is a network for electricity transmission and distribution systems that uses a bi-directional communication between power plant, customer and control centre in order to optimize the power supply and demand which provides the increase of overall efficiency (see Figure 4). The Smart Grid infrastructure is based on the compatibility principles, opened standards and is built on the internet-protocols.

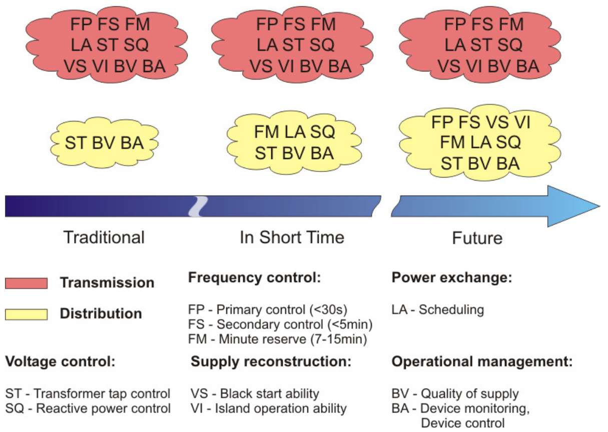

Figure 3. System services delivery at future distribution level [13].

The concept of Smart Grid has the following goals:

- giving the customer the ability to automatically manage their electricity usage and to minimize their expenses;
- self-repair in the case of failure;
- interconnection with a large quantity of energy resources, including renewable energy producers;
- improving the power quality and transmission of electricity.

An important point is that the Smart Grid technology will give customers the ability to understand how their household uses electricity, manage energy usage more efficiently and due to wide dedicated use of renewable reduce the carbon emissions.

This mentioned above, new grid technologies are able to increase the usage of renewable energy sources and make it possible to:

- avoid global blackouts by island operation mode ;
- provide real-time online information for customers about their energy use;
- encourage load management ;
- have dynamic tariffs;
- decrease grid usage due to an increase of local feed;
- provide a free market for system service;
- support a more widespread application of electric cars and vehicles.

Furthermore, application of Smart Grid will allow to:

- transmission of power in an optimal way;
- distribution of energy from many dispersed generation units;
- expansion of the energy supply and demand from the grid;
- better integration of the intermittent renewable generation such as wind energy.

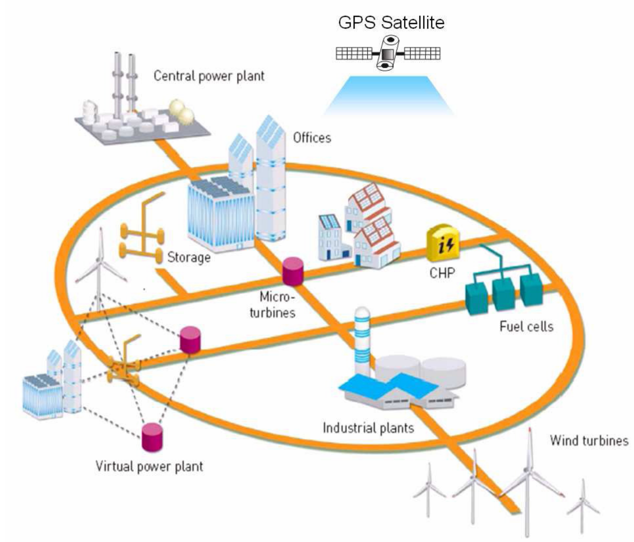

Figure 4. Concept of Smart Grid [4].

The Smart Grid is a self-healing grid, which improves the reliability of the system by process automation in disturbance situations in the following way:

- information from smart meters allows the utility program to determine potential power failures during the periods of peak load.
- utility regulates the power on the grid due to the automatically adjusting smart appliances and smart thermostats in homes e.g. via radio signals.
- the pole-mounted detectors make it possible to forward power from the utility program around the line breaks (during storms or accidents), isolating the disturbance location and mimizing the outages.

In the Smart Grid the system operation will be shared between central and distributed generators (see Figure 3). Control of distributed generators could be aggregated to form microgrids or virtual power plants (VPP) in order to facilitate their integration both in the physical system and in the market. VPP has similar reliable, planable, and controllable behavior like traditional power plants. A VPP structure is an aggregation composed of distributed generators, controllable loads and energy storage systems. The virtual power plants are introduced as a solution to handle the mix of conventional and DG energy sources in an optimal way. They are controlled by means of an Energy Management System (EMS) which coordinates them as if they worked like a unique power plant. For its purposes, the EMS makes use of remote control equipment and communication systems. The idea of a VPP is to create new systems of control, security and management, where all information would appear, be converted and operate the equipment in digital format. The project provides the development and integration into the power stations, the optical digital instrument transformers and the complexes of a new generation of digital equipment.

The Smart Grid technologies are being introduced step-wise in different European countries and in the USA in the scope of different pilot projects [4], [9]. But for each region this integration has to be realized in a specific way taking into account the regional power industry problems and depending on the government assistance. The introduction of VPPs is also being introduced throughout the world. Projects are underway in Europe and the USA, Japan, India and China. The project of VPP has also been realized by the Russian Federal Grid Company (FSK) [14]. The application of modern digital equipment for security and management makes possible the rapid direct information interchange between the devices, that results in the reduction of copper cables quantity, decreases the number of devices and has a more space-saving disposition. This makes the digital technologies more economical in all implementation phases: design, installation, adjustment and operation.

The Smart Grid concept is especially important for Russia, because there are many power supply problems in the energy sector, such as the ever more unreliable electric power grids, the necessity of energy supply in 8 time zones, and the obsolete single-direction energy transmission system. The energy resources in Russia are frequently wasted. Different sources show that losses during the energy distribution in Russia are significantly higher than in the European countries [10]. However, due to the specific economic situation in Russia the Smart Grid concept is not very popular there. The conversion of the Unified National (All-Russia) Electric Grid (UNEG) into the Smart Grid format allows for an increase the system reliability of power grid complex, reduces the capital investment into the building of new objects, receives the technical and economical efficiency from the disposition of the UNEG objects in 8 time zones, and decreases the impact of the energy sector on the environment [14].

IV. Smart Grid Realization Issues

The decentralized energy management inside Smart Grids requires communication facilities which are, for the most part, not applied in today's practice of the distribution system operation as shown in Figure 5. The communication network – generally a new one- in the Smart Grid must be able to provide all the information also from the lowest level of the network to Control Centers.

The information and communication technology (ICT) plays a crucial role in the realization of these tasks. ICT helps to manage in real time the value chain between providers, meters, customers, active networks and corporate systems.

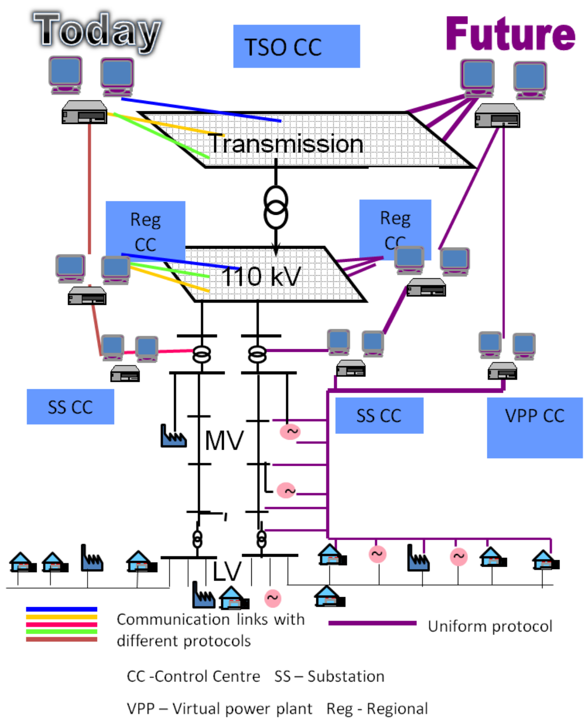

Figure 5. Structure of the communication system in the distribution grid today and in the future [15].

Moreover, the Smart Grid will include such new devices as:

- smart meters that are new digital meters, which collect hourly data of energy-usage from the individual homes and transmits that data via wireless radio signals to the electric utility. Due to such devices the customers will be able to examine their data online; manage their energy consumption themselves, and receive monthly bills about detailed information of energy usage.
- data collectors whose function is to collect the data from a large quantity of smart meters (about 500) and monitor the power flow on the grid
- smart tools that are intelligent devices for monitoring the energy usage and are able to switch off the selected loads, when the electricity tariffs are too expensive or the energy is needed in another place.
- new control room technology that can constantly monitor the real-time data which will enable a more efficient power distribution.

The efficiency of future communication networks at the distribution level requires some basic principles [16] as:

1. Contrary to the existing practice, where power generation is located in a rather concentrated area and, therefore, information and data is transferred on local networks or field busses, the supervisory control and dispatching of dispersed generation will be spread over a wide area. For economical reasons the already existing infrastructure has to be used; that also means the utilization of different communication channels like radio, fiber optics, power line carriers and telecommunication cables will be applied within one network as long as they are available in the environment.
2. The communication over the different physical layers has to be compliant to a common standard regarding data modeling and communication services. The main requirements for such a standard are:
   - plug and play ability,
   - possibilities for mapping to different physical layers,
   - expandability of the data models and introduction of new models in accordance with the new and enhanced communication tasks.
3. Thus, if the communication network for dispatching the VPP covers a whole distribution network additional system services can be provided by the same network. Therefore, communication tasks for distribution networks of the future include:
   - the contribution to the active power balancing through dispatch of power generation, storage and controllable loads in the framework of a VPP,
   - the transfer of metered values as a support for the decentralized energy management and for billing,
   - the provision of further system services like congestion management, reactive power and voltage control, fault location, network recovery after faults, islanded operation, black start capability etc.

According to Russian researchers the integration of smart technologies would be realized incrementally [10] in Russia. First the work would be done on the business and power industry level and would be focused on increasing the present power grid efficiency.

In Russia the first prototypes of smart measured equipment for substations have been already devised, such as instrument high-voltage transformers with digital output (JSC “Ramenskij electrotechnical plant “Energy” [17]), the complex of equipment for the energy and telemechanics assessment that work in the single digital interchange system (JSC "EC "Continuum Plus" [18]).

According to expert assessment [19], the integration of Smart Grid technology in Russia will make it possible to decrease the investment costs in the power grid development by 25 percent. In the end 2009 testing of the first high-temperature superconductive (HTS) cable with the length of 200 m for the voltage 20 kV was successfully completed [14], [20]. Applying such HTS cables makes it possible to significantly decrease the electricity losses, transfer the large power flows with ordinary cable sizes, extend the cable operation life, raise their fire and environmental safety level, and provide the power supply of large customers in megalopolises with a voltage of 20 kV.

Another important issue is the secure operation of the power system with a large amount of distributed generation. During the last year the new generation of fault clearing – so called Fault Ride Through (FRT) technology - has gained importance. Due to dominance of the wind generation in the renewable energy field, this new technique was investigated first on wind turbines and introduced into the grid code.

The main goal of the FRT is to control the behavior of wind turbines in the event of a disturbance that causes voltage drop in the power system. Originally (i.e. before 2003 in Germany) an undervoltage protection system would disconnect wind turbines from the grid if the voltage dropped under 0.8 p.u. at the point of common coupling (PCC). However, such behavior could lead to the disconnection of a high amount of wind turbines and the loss of a large generation capacity in the power system, which could lead to frequency stability problems – change of frequency due to the difference between load and generation in the power system (higher load than the generation causes a frequency decrease in the power system).

In the event of a short circuit, the application of FRT technology supports the operation of the wind turbine system during the disturbance. The main principle of the FRT-concept for wind turbines in Germany is shown in Figure 6. According to this concept, the wind turbines have to continue to operate and stay connected to the grid during the fault, even with a voltage drop to zero, for the time period of 150 ms. In such a situation if the fault is cleared before the 150 ms limit the wind turbine stays continuously connected to the grid, and after fault clearing it starts to supply active power to the grid in order to support frequency maintenance in the power system. As it can be seen in the diagram below the FRT procedure maintains the frequency in the system, which in this diagram is represented by the green curve that describes the angular speed of the generators. If there is no FRT procedure or if the fault is too long (exceeds 150 ms at voltage drop to zero), then the angular speed of the generators in the power system and therefore also the frequency will become strong, which is represented by the blue curve. In this situation frequency instability in the system can occur and lead to a large scale disconnection of system components.

According to the FRT procedure presented below the wind turbines can disconnect from the grid if the fault with voltage drop to zero lasts longer than 150 ms. If the voltage drop at the point of common coupling (PCC) is not so strong and equals, for example, 0.5 p.u. (50 % of rated voltage), than the wind turbines have to stay connected to the grid up to about 900 ms according to the characteristics given in the diagram below.

Nowadays the PV-generation also plays an important role in the renewable mix. For this kind of generation the FRT grid code is already being discussed and developed. In Figure 6 a proposal of a FRT-curve for PV-generation is shown. We can see the differences between the FRT requirement for wind and PV generators due to their construction, on one hand a rotated electromagnetic machine (Figure 6a) and on the other hand a static power electronic converter

V. Status of Smart Grids Development in Russia

Russia is the fourth largest electricity producer in the world after the USA, China and Japan with the total electric generation capacity of about 228.7 GW, and in 2008 it produced about 1,036 TWh of electric power. It has a unique unified power system that joins 70 local energy systems and provides the energy transfer across 8 time zones. The Russian electricity generation capacity consists of 68 % of thermal plant power generation, 21 % of hydropower generation, 10 % of nuclear, and about 1 % of renewables (geothermal, wind and waste heat).

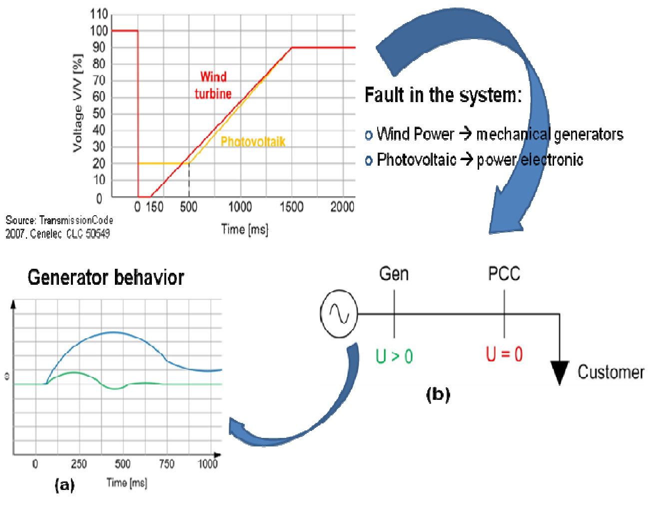

Figure 6: FRT requirements for wind and PV-generation.
a) rotating generator behavior, b) location of PCC.

Several power generators, which are situated in the far-east of Russia, are not connected into the power grid. The vast area of the Russian Federation with different landscapes has a huge development potential for renewable energy sources. There is large wind energy potential in Russia especially along seacoasts, in the steppes and in the mountains, but currently only 25 % of total wind potential is being used [21]. The total technical potential of biomass is about 15,000 MWe, which includes sewage sludge, cattle manure, and lumber waste. The operational reorganization of paper plants and the utilization of wood waste are becoming more popular. The geothermal potential is also big, about 3,000 MWe. The solar potential depends on the location, with the most favorable regions situated in southern Russia (Caucasus, Tuva, Astrakhan region, Chita region).

Russia has a huge hydro potential, about 9 % of the global hydro resources. Thus, the hydropower stations are the most popular of the renewable sources. The hydropower energy generation is currently 21 % of total energy production (in Germany it is about 1 %) [21] Very promising in Russia is the usage of CHP-systems. This is due to the predicted increase of tariffs for electricity (the CHP-systems are paid off quite rapidly, and if the tariffs are increased 10-15% the payback period would be significantly reduced). Today the application of gas CHP into the local CHP-systems is popular. Russia has huge natural gas resources and needs power supply in remote regions, so it has a good ability to solve the power supply problem by using the CHP-units of small power (up to 30 MW). The advantages of CHP are the cheapness of heat and electricity energy, proximity to the consumers, absence of expensive power lines and substations, environment friendless, mobility, and simple installation.

In Germany the usage of renewable energy sources is encouraged by governmental support. For example, the energy from renewables is sold at the higher prices: 0,08 € for 1 kWh for wind energy, 0,51 € - for solar energy. And the federative programs "100 Solar Roofs", "100 MW Wind", "250 MW Wind" have been accomplished.

The Russian Government Order from January 8,2009, determined the main values of energy generation from the renewable sources up to the year 2020 (excluding the hydropower stations with installed power of more than 25 MW) as follows: in 2010 1,5 %, 2015 – 2,5 %, 2020 – 4,5 %, [19].

Therefore, the renewable energy sector in Russia is expected to rise in the coming years. Today the renewable energy in Russia has such properties as:

- it is the main area in the Russian economy that would grow in the coming years,
- renewable energy in Russia has no monopoly of large state concerns, which makes the market very competitive,
- this sector is open for investment,
- it is the industrial area where federal and regional government encourage market participation particularly from foreign investor companies.

The reasons for the growth of the renewable energy sector in Russia are the following:

- the crisis in internal Russian gas-supply,
- the increase in the domestic tariffs on the energy carriers up to the level of European countries,
- the failure in supply units.

For Russia the Smart Grid technologies are first of all the means for distributed grid development for decreasing energy loss in the grid and for increasing the observability and automation. Secondly, they represent effective integration of small distributed energy sources integration.

The Smart Grid technologies in Russia will make it possible to accomplish the following tasks:

- improve the system reliability of the power supply complex,
- decrease the investment costs for building new units,
- flexible regulation of the power flows that are connected with changes in energy generation and energy consumption,
- decrease energy losses during transmission and reduce the influence of power industry units on the environment.

One step of the building of smart grids is the project of the Federal Grid Company (FGC) which involves the creation of a single automated technological management system [14]. Such a system is oriented to increase network observability, avoid emergency operation, create an online monitoring system and provide smart diagnostics of equipment state.

Smart grid technology requires the development and integration of a whole complex of innovation equipment and technologies: controlled devices of longitudinal compensation for increasing the transfer capability limit of power lines, high-voltage devices for rapid voltage control, energy storages based on powerful storage systems. Today the FGC, in the course of setting up the investment program, is incorporating 20 % of smart grid elements and other innovation developments into its system. Among them is the import and domestic production: electricity generating plants for increasing gird adaptability, high-temperature wires, polymer insulators, microprocessor protectors, substation control systems, etc.

The creation of smart power grids will use modern control tools, new diagnostic systems and high-speed communications systems, and it would be possible to connect the renewable energy sources (wind turbines, solar batteries, small water power station, micro-CHP and other local energy sources) into the grid.

VI. Summary

This paper provides an overview of the main issues regarding realization of the Smart Grid concept. This concept allows the optimal integration of new decentralized and renewable generation units (e.g. Wind or PV) that often have an intermittent character into the electrical power grid. Moreover, the Smart Grid concept will make it possible to keep or even improve the reliability of the future distribution systems, since new operational possibilities, such as islanding of the grid parts or remote fault location and removal, will be available thanks to the high penetration of the information and communication technologies up to the low voltage level. A comparison of the main factors of power systems conditions in Germany and Russia as well as the development of renewable energy sources in these two countries is given.

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