Reactive power management in wind power plants with induction machines in Smart Grid

Radosław Kołaciński
ENERGA OPERATOR Produkcja Sp. z o.o.,
Oddział w Kaliszu
62-800 Kalisz, Al. Wolności 8

Marek Paluszczak
ENERGA OPERATOR Techniczna Obsługa Odbiorców, Sp. z o.o.,
Oddział w Kaliszu
62-800 Kalisz, Al. Wolności 8

Grzegorz Twardosz
Politechnika Poznańska
60-965 Poznań, ul. Piotrowo 3a, e-mail: Grzegorz.Twardosz@put.poznan.pl

Reduction of CO_2 emission, improvement of efficiency of the use of electric power, management of and communication between particular parts of the electric power system, improvement of power delivery security, or ensuring higher security of data access were conductive to definition of a new notion of Smart Grid. The paper presents the research results in case of reactive power control at a small wind farm P_N = 0.9MW. The measurements were conducted for two modes: with additional battery of capacitors disconnected and with the battery cooperating with the capacities installed by the equipment manufacturer. The measurement results indicate the need of the use of additional capacities, with a view to attain proper power management of the wind farm.

1. Introduction

Smart Grid is an electric power network, the technology and infrastructure of which is used and managed on a broad range, with bi-directional process of communication, control and service with final customer of electric power. Smart Grid provides a way to attain the objective defined by UE 3×20 Directive. Full development of Smart Grid is forecasted to 2025. A very important problem arises taking into account the need of security of the data access and their further use. The notion of Smart Grid is correlated with the definition of virtual electric plant. This is particularly important from the level of the distribution network.

Structural changes in production of electric energy that result, first of all, from development of renewable power sources (RPS) are presented in the Directive 2009/28/UE [1]. The diffused generation will certainly remain until 2050 in the structure of sources, the development of which will be aided at the level of

European Union and Polish regulations. Proper control and management of the power delivered from RPS and correct choice of the connection point and power of the sources enable a delay in network development or reduction of network losses related to power delivery to customers.

The wind power plants are reckoned among the sources in which forecasting of power production is difficult. Therefore, are made the attempts aimed at permanent improvement of quality of the power derived from these sources. One of the parameters deciding on the quality of electric power is the level of reactive power.

2. Smart Grid conception

In order to ensure stable operation of an electric power system in real time the generated power must be balanced with the received one, and vice versa. According to recommendations of the Directive UE 3×20 emission of greenhouse gases must be reduced by 20 percent by 2020. Similarly, electric power consumption should decrease by 20 percent and, at the same time, 20 percent of the energy should come from renewable power sources. The percent shares of RPS in electric power production in 2020 are different in particular EU countries. In Poland it amounts to 15 percent. Germany plans to produce 100 percent of electric power from renewable power sources in 2050. In the USA it is forecasted that in 2035 85 per cent of the energy will be generated from RPS. According to German sources in 2100 50 per cent of the world-wide electric power will be derived from photovoltaic cells.

Figure 1 presents the Smart Grid conception.

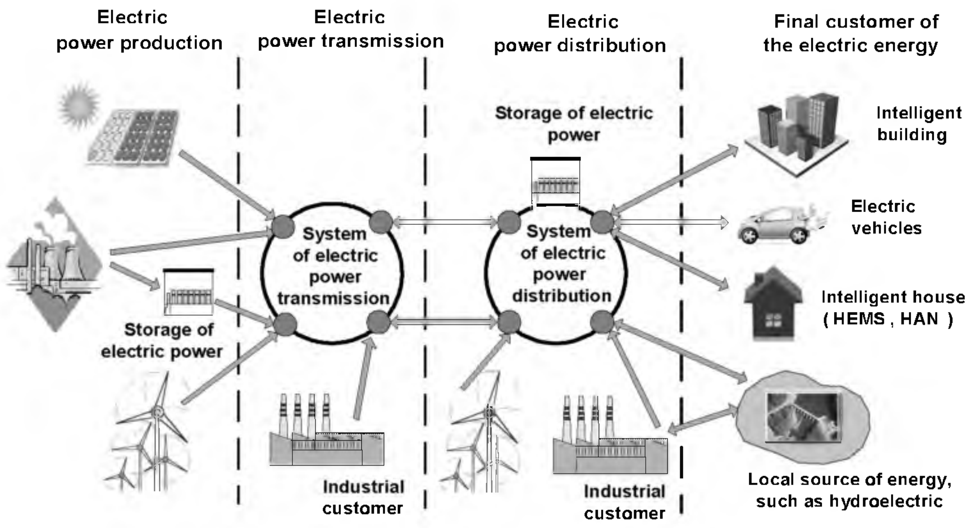

Fig. 1. Smart Grid conception

In each of the sectors the effectiveness management and reasonable power use are realized. An important problem consists in management of reactive power flow. It is also a case of a diffused generation of e.g. wind farms. The work [2] describes a conception of construction of the Volt/Var Management System (VVAR). The system operation is based on the use of proper control algorithms, among others, relative to the flow of reactive power. These requirements are fulfilled by several reactive power controllers, e.g. the equipment of LOVATO Electric [3], TWELVE Electric, FRAKO, or ELEKTROMONTAX. The equipment is based on microprocessors of high integration scale, good reliability, accuracy, and operation precision. The batteries may be provided with local intelligence controllers or may operate with remote control, with the use of SCADA system.

3. Reactive power control in wind power plants

Asynchronous generators are commonly used in wind power plants of the power P_N < 800 kW. In the units of the power 800 < P_N < 1500 kW the asynchronous generators are used in about 95 per cent cases. In the turbines of the power exceeding 1.5 MW the asynchronous generators are used only in about 17 percent of the devices. The other 83 per cent are provided with synchronous slow-speed generators [4].

The system of asynchronous generator control with adjusted resistance in the rotor circuit affects the generated power output from the wind power plant to the system by means of variation of the rotor slide. The difference between the power obtained from the wind and the one input to the system is proportional to the rotor slide. Hence, the change in rotor slide affects the difference between these power values and, in consequence, the character of the changes in power input to the electric power system. In asynchronous machines provided with squirrel-cage rotor the slide variations are small (usually below 2÷3 per cent). Therefore, the changes in mechanical power (resulting from wind speed variations) are transmitted to the stator side almost directly. In asynchronous ring machines the rotor circuit is additionally provided with resistors and, in consequence, the mechanical characteristics of the machine may be modified. The change in resistance allows to vary the rotor slide and, at the same time, for a given moment the power input to the network varies accordingly. It is the main goal favouring such a solution. Nevertheless, this solution is conducive to increase of power loss arising at this additional resistance. In order to avoid the case a power-electronic converter is used which enables power flow from the rotor to a machine located in the network. Such a system is called an hyper-synchronous cascade, since the converter allows the power to be transmitted only in one direction (from rotor to network). Therefore, the generator may operate only at the speed exceeding the synchronous speed. It also precludes reactive power control. This may be attained with the help of other systems, e.g. a battery of capacitors.

Another power plant type is a system provided with two-sided supply asynchronous generator. The control system of such a generator is more complex. It consists of the network converter controller and the converter of generator controller, i.e. the inverter connected to the machine rotor winding. The first one of them controls the parameters of the intermediation system – i.e. the voltage at the capacitor of the inverter system, and voltage or current in the system with current inverter. It also enables current or reactive power adjustment at the AC side of the converter (from the network side). Reactive power at the network side is usually maintained at the level near zero. The generator converter then allows to control the reactive power generated (input) by the wind power plant [5].

The converter control system consists of the controllers which enable controlling the active power or the rotor speed and the reactive power. In this case usually the idea of separate control of the powers is applied, by adjusting the levels of rotor voltage values obtained in result of transformations of the current, voltage, magnetic flux values etc. The active and reactive power at the rotor output (rings) is proportional to the product of the slide and power of the stator. Neglecting the losses, the active power is transmitted beyond the network inverter transformer, while the reactive power beyond the transformer may be regulated by this converter. In consequence, the power obtained at the electric power plant busducts may be controlled by this converter. In result, the power at the electric power plant busducts, being a sum of the stator power and, approximately, the rotor power, may be effectively controlled by variation of the rotor current components.

4. Results of the studies on reactive power regulation and their analysis

The measurements have been carried out at a small wind farm of total power P_N = 0.9 MW. The farm was composed of one BONUS turbine, two WINDWORLD turbines and three NORDTANK ones. Power of each of them amounted to P_N = 150 kW. Capacity of the capacitors installed by the manufacturers is too low to ensure proper management of reactive power in Polish conditions. The standard capacities are connected 40 s after putting the wind power plant into operation. The measurements of active and reactive power, as well the cosφ calculation, have been carried out with the use of the network parameter analyzer HT – Italia, model PQA824.

The active and reactive power was measured with the use of the network parameter analyzer HT-PAQ824. Internal memory of the device enables recording 251 parameters simultaneously. It communicates with external memory by USB port and compact flash sockets. The measurements may be displayed on a monitor of 320×240 pixels resolution, in the form of numerical values, histograms, time-function patterns or indicator plots. The information obtained by the reactive power controllers during the measurement are input to the microprocessor. This enables fully computerized management and control of switching on and off proper values of capacity and choice of the capacitors from among available set.

Figures 2-4 present measurement results obtained with the additional battery of capacitors switched off. Figure 2 shows the pattern of variations of active and reactive power vs. time which are generated for the wind speed varying as in Fig. 3. Figure 4 presents the pattern of variation of the power coefficient of the wind farm. As it is shown, the value cosφ (cosφ ≥ 0.93) required by the Distribution Network Operator has not been achieved.

Figures 5-7 present the measurement results of the above mentioned values obtained with switched on additional battery of capacitors designed and installed by ASEL Company. Instantaneous remarkable growth of reactive power up to about 260 kvar was due to quick change in wind speed and slower cycle of connection of the additional capacities. The connection duration in the controllers usually remains within the range 1s ≤ t ≤ 250 s. It is recommended to set the response time to several seconds. Short connection time requires the use of large number of capacitors, which results in considerable growth of the battery price. Average power coefficient is kept at the level 0.9. Overcompensation does not occur.

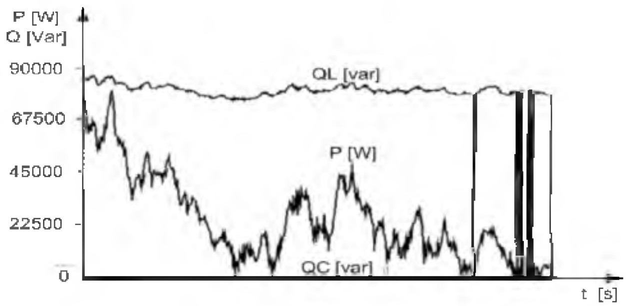

Fig. 2. The pattern of active and reactive power of wind farm with additional battery of capacitors switched off

Fig. 3. The pattern of wind speed vs. time

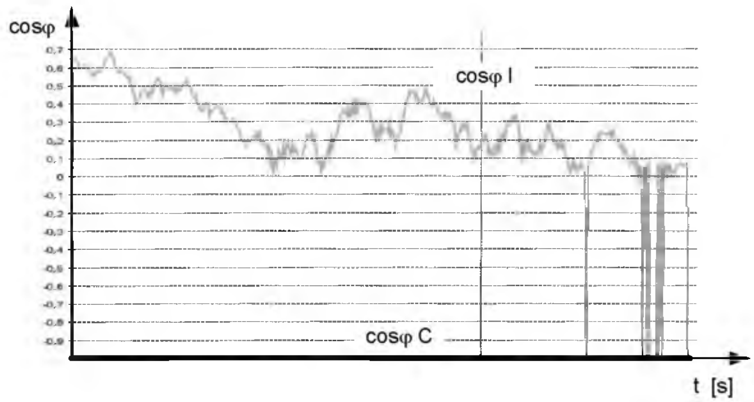

Fig. 4. pattern of cosφ of wind farm with additional battery of capacitors switched off

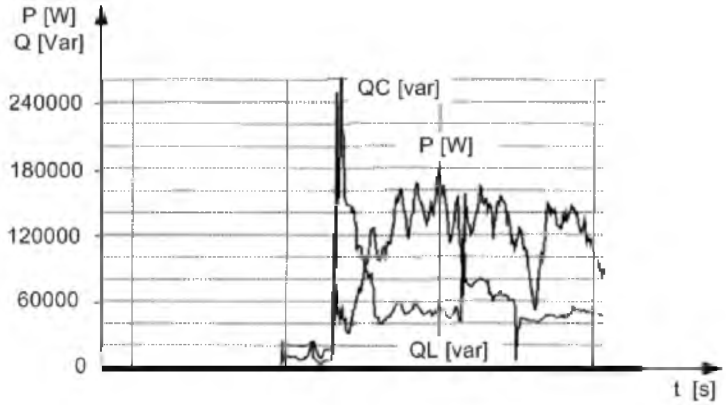

Fig. 5. The pattern of active and reactive power of wind farm with additional battery of capacitors switched on

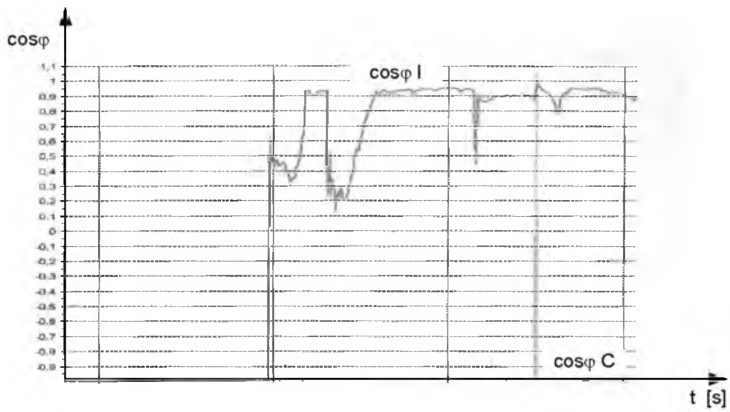

Fig. 6. The pattern of power coefficient of wind farm with additional battery of capacitors switched on

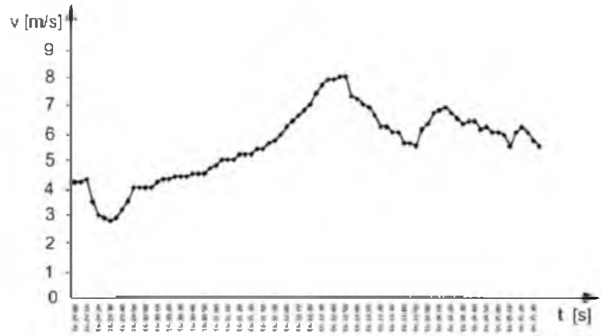

Fig. 7. The pattern of wind speed vs. time

4. Final notes and conclusions

Regulation of reactive power of the system composed of wind power plant and electric power network consists in determination of the value of cosφ (the connection conditions), controller sensitivity (individually), and the way of selection of capacity of the set, according to delivered active power (individually). Taking into account considerable changes in active power value generated as time function by wind power plants, the linear and circular regulation is not applied in most cases, but instead, special regulation series are developed individually. Reactive power regulation of a real object is carried out on a complex manner. It means that operation of all production sources delivering the power parallel to the electric power network is controlled. It is the most difficult method of regulation, as the turbines have various values of the power and efficiency. Nevertheless, it is, at the same time, the sole economically justified method. Measurement results indicate that the compensation is correct. Circuit overcompensation affecting the RC characteristics does not occur. With the battery of capacitors switched on the reactive capacitance power is equal to zero. It means, that reactive power delivered by the set of capacitors partially compensates the induction reactive power.

According to European Union forecast total demand of electric power should be fulfilled by 2050 by renewable power sources. Management and control of electric power resources will consist not only in power regulation, but important role will be played by energy storages, that should be related rather to the distribution network instead of the transmission network. Similar role is at present played by the systems FACTS, SVC, or CAES.

In 2013 the Law related to the renewable power sources is expected to be passed. For the network operators it may be conducive to the need for ensuring possible connecting these sources to the network according to other principles than the ones valid to-day. Thus, implementation of the intelligent network will surely pass to the next stage.

References

[1] Dyrektywa 2009/29/UE Parlamentu Europejskiego i Rady z dnia 23 kwietnia 2009.
[2] Czapla Ł., Goryczak T.: System zarządzania napięciem i mocą bierną obszaru sieci inteligentnej (Smart Grid). Elektroinfo 7/8 2012, s. 40-46.
[3] Borek N., Regulacja współczynnika mocy przy użyciu osprzętu LOVATO Electric.Elektroinfo 12/2012, s. 37-39.
[4] Lubośny Z.: Elektrownie wiatrowe w systemie elektroenergetycznym. WNT, Warszawa, 2006.
[5] Anuszczyk J.: Maszyny elektryczne w energetyce. WNT, Warszawa, 2005.