Adrian HALINKA, Piotr RZEPKA, Mateusz SZABLICKI

Silesian University of Technology, Faculty of Electrical Engineering, Institute of Power Systems & Control

doi:10.15199/48.2015.06.25

State identification of MV power network with wind power generation operating under manual and automatic voltage control in HV/MV substation

Abstract. *The paper presents results of computer simulations aimed at the operating conditions identification of the power system with local wind generation. The voltage conditions and power flows have been identified according to the voltage control modes in a substation and to the reactive power regulation modes of the wind farm. The simulation results made it possible to recommend optimal operating variants for the wind generators in the power network. These alternatives may be used by Distribution System Operators to specify optimal voltage regulation modes of wind power generation.*

Streszczenie. *W artykule przedstawiono wyniki badań symulacyjnych pracy układu sieciowego z przyłączonymi rozproszonymi (lokalnymi) źródłami wytwórczymi (na przykładzie źródła wiatrowego). Dokonano identyfikacji warunków napięciowych oraz rozpływu mocy w układzie zależnie od sposobu regulacji napięcia w stacji transformatorowej zasilającej układ oraz trybu sterowania mocą bierną generowaną przez źródło. W oparciu o uzyskane rezultaty zaproponowano zalecane warianty współpracy źródeł wiatrowych z siecią elektroenergetyczną. Może to posłużyć operatorom sieci dystrybucyjnych do określenia optymalnego sterowania pracą źródeł wiatrowych. (**Identyfikacja warunków pracy sieci SN ze źródłami wiatrowymi przy ręcznej i automatycznej regulacji napięcia w stacji WN/SN**).*

Keywords: distributed generation sources, wind turbine, reactive power control modes for wind power generation, voltage control in HV/MV substation.
Słowa kluczowe: rozproszone źródła wytwórcze, źródła wiatrowe, tryby sterowania mocą bierną źródła wiatrowego, regulacja napięcia stacji WN/SN.

Introduction

The implementation of the power and climate policy/regulations intensified development of the wind power generation technology and as a result the power balance includes a higher share of wind power generation.

Connecting distributed sources to a power network determines changes in its functionality which concerns issues as follows [1], [2], [3], [4]:

- power flow directions and active power levels;
- reactive power flow directions, levels and its character;
- power system elements load levels;
- power network node voltage levels;
- power quality indicators;
- operating conditions of power system control.

The paper presents results of computer simulations aimed at the operating conditions identification of the power system with wind power generation. The main focus was put on determining the differences caused by various voltage regulation modes used in HV/MV substations.

Voltage regulation in HV/MV substations

The basic task dedicated to the voltage regulation in transformer substations feeding MV power networks is maintaining voltage on the desired level. This is achieved by changing the turns ratio of HV/MV transformers by using tap changers. As a result the step increase or decrease of voltage is obtained on the low voltage side of the power transformer.

There are two ways of voltage control used in HV/MV power transformers:

- *Manual Voltage Regulation* (*MVR*) – transformation ratio modification is enforced by a power system operator managing the network. The modification takes into account the future expected power network operating conditions and are realized seasonally, i.e. several times a year.
- *Automatic Voltage Regulation* (*AVR*) – transformation ratio modification is enforced by an automation system and the regulation is obtained in a follow-up manner after voltage conditions changed. In a substation with an *AVR* taps are changed even several dozens a day.

The choice of a voltage regulation manner may have a crucial impact on the voltage conditions in MV network fed by the HV/MV power transformer. In particular the obtained difference should be observed in power network structures which are characterized by frequently and essentially changing operating conditions. Among these surely are power networks with wind power generation (see [1] and [4]). The identification of *AVR* operating conditions for substation with wind turbines is given in [5].

Simulation research

For operating state assessment of the power network with wind power generation fed from HV/MV substation with the *AVR* and *MVR* certain quantities were used. Among these were MV side busbar voltages and power flows in the network as a whole. Simulation studies were proceeded changing:

- operating conditions of the wind farm (the active power amount generated by the wind turbines, wind power source reactive power control modes);
- MV power network operating state (the active power amount and also amount and nature of reactive power used by loads connected to the MV power network).

The daily profile of the active power generation (P_{WG}) used in simulation is presented in Fig. 1. The daily HV/MV substation load profile (P_{load}, Q_{load}) is shown in Fig. 2. It was assumed that the wind turbine is able to be operated in two reactive power control modes i.e. *Reactive Mode Control* (*RMC*) and *Voltage Mode Control* (*VMC*). The *RMC* and *VMC* were described inter alia in [1] and [5]. In *RMC* the nature and the amount of generated reactive power from the wind farm is being set up. The other way of using the *RMC* is seting up the nature and the value of the power factor of the wind power source – in this mode the reactive power Q_{WG} of the source is proportional to its active power P_{WG}. In the *VMC* the voltage value in the point of the wind farm connection is being set up. Thus, the character and the value of reactive power are being set up in a way that allows achieving the desired voltage level.

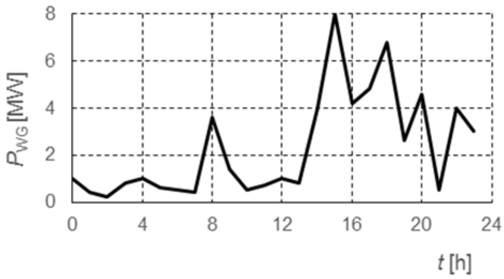

Fig.1. Daily active power generation profile of the wind farm

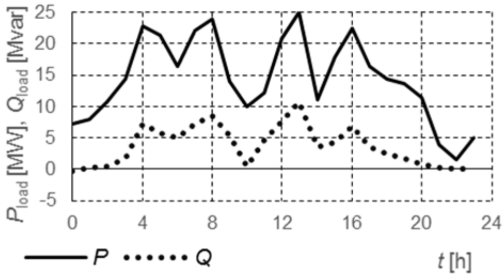

Fig.2. Daily load profile in the MV network

The simulations were proceeded in the DIgSILENT PowerFactory program. The diagram of the modelled power network is shown in figure 3.

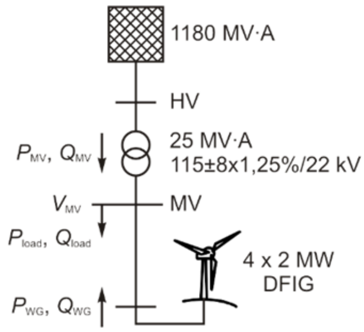

Fig.3. Diagram of the power network system

The voltage conditions in the MV power network

The simulations of voltage conditions were conducted with monitoring the effective voltage value (*RMS*) in the point of the wind farm connection to the MV power network (V_{MV}), i.e. the MV busbar (see Fig. 3). The simulations were conducted for the assumed changes of operating conditions in the power network and for wind power generation with the automatic and manual regulation modes. For the *MVR* and for the selected operating 24 hours of the power network structure it was assumed that the HV/MV power transformer turns ratio is constant. Meanwhile for the *AVR* it was assumed that tap changes were following-up the V_{MV} changes. Another assumption was that the change in the value of V_{MV} beyond the range of a change of a single tap forces the change of the transformation ratio. Fig. 4 presents the plots of V_{MV} value variations for assumed substation load profile and the source generation profile during 24 hours for *RMC* and *VMC*. The results for the *RMC* relates to control parameters that enable the wind farm to generate the power with the constant inductive power factor of 0,95 (*RMC ind*).

Comparison of diagrams depicted in Fig. 4 shows significant disparities in voltage conditions in the substation MV busbar depending on the substation voltage regulation mode and also on the wind power generation control mode. Using *AVR* allows for a meaningful limitation of the V_{MV} variation range. For example for the simulation with the wind turbines using the *RMC* (Fig. 4a) the reduction exceeds 76% in comparison to the results obtained using the *MVR*, wherein the rate of the limitation is determined by the assumed parameters *of AVR*.

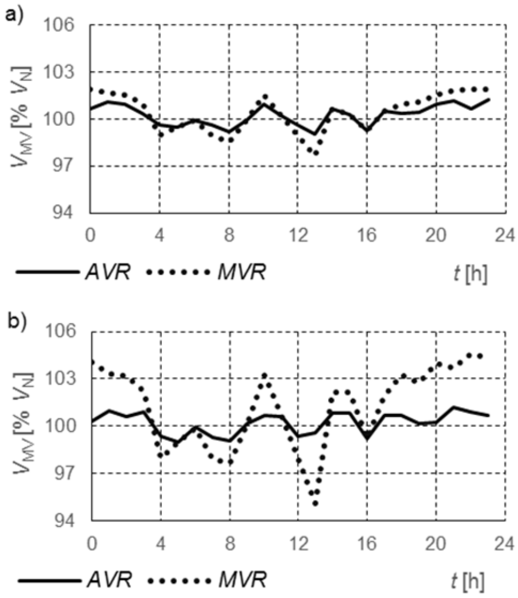

Fig.4. Voltage variations in the MV busbar of the HV/MV substation for *AVR* and *MVR* for the MV busbar 24 hour load profile and the 24 hour wind power generation profile with the *RMC* (a) and *VMC* (b)

Diverse substation MV busbar voltage conditions also occur in various wind power source reactive power control modes. The wind farm with *VMC* tends to maintain the equal voltage output level on every single wind turbine. This is why the V_{MV} variations range is then almost twice as small as for the *RMC*. The table 1 characterizes the voltage conditions in substation MV busbar for the assumed daily variations of substation load and active power generation in the wind farm. The presented results refer to the substation with *AVR* or with *MVR* and also refer to the wind farm with *VMC* or with *RMC*. For the *RMC* the regulation parameters included the inductive *RMC* (*RMC ind*) and capacitive *RMC* (*RMC cap* – the wind farm capacitive power factor equal to 0,95). For comparison, the table also contains the results obtained for the wind farm turned off.

The grid power flow

The simulations of power system conditions were conducted with respect to active power flow values and also the reactive power flow direction, its values and nature in the elements of the system. The main focus was put on the observation of reactive power generation (Q_{WG}) in the wind farm and also on the active and reactive powers feeding the MV power network (P_{MV}, Q_{MV}, i.e. the power flowing through the HV/MV power transformer.

P_{MV} is the difference between P_{load} and P_{WG} (see Fig. 3). These powers are practically not dependent from the substation voltage regulation manner/mode and the reactive power control mode in the wind farm. Thus, variations of P_{MV} observed during the 24 hours taken into account, are equal for all the operating scenarios of the system with wind power generation. On the other hand the nature and the value of Q_{MV} highly depend on the operation of both regulation systems, where for the wind farm with the *RMC* the Q_{MV} is determined by the assumed operating conditions of the wind farm (compare the diagrams for *RMC ind* and

RMC cap in Fig. 5a) and independent of the substation regulation manner/mode. For the wind farm with the *VMC* the parameters of Q_{MV} are highly dependent on the control mode/manner (compare the diagrams for *AVR* and *MVR* in Fig. 5b). The smaller the variation of V_{MV}, the smaller the variation range of Q_{WG}. Unfortunately, this fact causes the higher variation of the Q_{MV}. On the other hand, the variation range of Q_{MV} for the *AVR* is over two times higher in comparison to the observed variations in the same 24 hours with the *MVR*.

Table 1. Extreme V_{MV} values observed for variations of substation load and various scenarios of power network operating conditions

Power Network Structure Operating Conditions Scenarios							V_{MV}	
substation voltage regulation		wind farm status		wind farm reactive power control mode			max	min
AVR	*MVR*	on	off	*VMC*	*RMC ind*	*RMC cap*	% V_N	% V_N
	+	+		+			101,9	97,6
+		+		+			101,2	99,0
	+	+			+		104,6	95,1
+		+			+		101,2	99,0
	+	+				+	103,7	94,8
+		+				+	101,1	98,8
	+		+				103,8	94,8
+			+				101,2	99,0

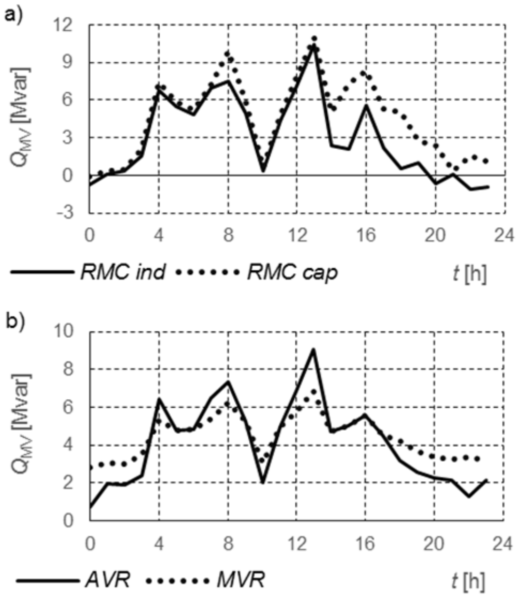

Fig.5. Variations of the reactive power feeding the MV power network of the analyzed power structure during the assumed 24 hour load profile changes and the wind power generation profile for: a) wind farm operating with the *RMC ind* and *RMC cap*; b) *AVR* and *MVR* in the substation and for the wind farm operating with the *VMC*

Conclusions

Operating conditions of power network with wind power generation during the normal/steady-state in the Polish Power System are determined by the voltage regulation mode (transformer tap changing) used in the power stations and also by the reactive power control mode used for the connected wind farm. The *Automatic Voltage Regulation* (*AVR*) in a substation makes it possible to highly reduce the voltage variation on the low voltage side of the power transformer during changes/variations of power network operating conditions. Even for the power network structures with the wind farms, characterized by often and significant variations of operating conditions, a few times' reduction of the voltage variation was observed in comparison to results obtained for the substation with the *Manual Voltage Regulation* (*MVR*).

The wind farms operating in the *Voltage Mode Control* (*VMC*) are able to help obtaining quasi-steady voltage conditions. Then, the parameters of generated reactive power of the wind farm are selected in a way allowing to maintain voltage in the connection point in the required range of variations. This can cause an increase in variations of the reactive power flow in the power network structure with the *AVR* in the HV/MV substation. Table 2 presents the recommended variants of cooperation of the power network with wind sources depending on the substation voltage regulation mode and on the reactive power control mode. The recommended variants have been chosen on the basis of the computer simulations identifying the voltage conditions and the power flows in the observed power network cooperating with the wind farm.

Table 2. Recommended reactive power control modes depending on the voltage regulation used in a substation

Voltage regulation in a substation	Reactive power control mode of a wind power source	
	VMC	*RMC*
AVR	+*	+
MVR	+	

* possible increase of the reactive power flow variations in a power network structure

REFERENCES

[1] Lubośny Z., *Farmy wiatrowe w systemie elektroenergetycznym*, WNT, Warszawa, 2009
[2] Paska J., *Wytwarzanie rozproszone energii elektrycznej i ciepła*, Oficyna Wydawnicza Politechniki Warszawskiej, 2010
[3] Halinka A., Szablicki M., Metoda estymacji składowych impedancji niewrażliwa na odczepowe przyłączanie źródeł wiatrowych (część 2 – minimalizacja wpływu niezerowej wartości rezystancji przejścia w miejscu zwarcia), *Przegląd Elektrotechniczny*, No 9a, 2012, 7-11
[4] Halinka A., Rzepka P., Szewczyk M., Szablicki M., Przyłączanie farm wiatrowych – potrzeba nowego podejścia do sposobu funkcjonowania automatyki elektroenergetycznej sieci WN, *Przegląd Elektrotechniczny*, No 9a, 2011, 218-221
[5] Halinka A., Rzepka P., Szablicki M., Układy regulacyjne infrastruktury transportu energii elektrycznej ze źródeł wiatrowych – identyfikacja warunków działania automatycznej regulacji napięcia stacji elektroenergetycznych, *Logistyka*, No 6, 2014

***Authors**: Professor Adrian Halinka, Ph.D., D.Sc. (EEng.), E-mail: Adrian.Halinka@polsl.pl; Piotr Rzepka, Ph.D. (EEng.), E-mail: Piotr.Rzepka@polsl.pl; Mateusz Szablicki, Ph.D. (EEng.), E-mail: Mateusz.Szablicki@polsl.pl; Silesian University of Technology, Faculty of Electrical Engineering, Institute of Power Systems & Control*