Analysis of the active and reactive power of a wind power plant with SCIG generators, connected to a high power electrical grid

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Abstract. The paper presents the results from studies of both the active and reactive power of a wind power plant, connected in parallel with a high power electrical grid. The wind power plant is with SCIG asynchronous generators and a step-up substation 21/115 kV, realized by means of cable lines. The analyses have been made with the help of a computer model, synthesized in MatLab environment. The dependencies of the power, the power factor and the phase angle on the mechanical moment of the generator shaft in the cases of only one generator operating and all generators operating have been obtained. The inductive reactive power for compensating the capacitive power of the wind plant has been calculated at turned off generators. The parameters of the inductive compensating reactor have been determined. The capacitive power for compensating the inductive reactive power has been defined at loaded generators.

1. Introduction
Wind power plants have a significant share in the volume of electricity production from renewable energy sources. What makes them specific with respect to the other types of electrical power stations is the significant fluctuation of the primary energy, provided by the wind. Mostly asynchronous generators SCIG or DFIG type are used in the wind power plants. Compared to synchronous generators, they have certain advantages in the great fluctuations of the parameters (velocity, momentum) of rotation of the generators [1].

The paper presents the results from studies of the active and reactive power of a wind power plant, connected in parallel to a high power electrical grid. A single-line diagram of the considered wind power plant is given in Fig.1. It consists of eight identical asynchronous DFIG generators, complemented with 0.69/21 kV transformers, whose outputs are connected to a step-up transformer 21/115 kV. The substation is realized by means of cable lines, made of NA2XS(F)2Y cables. The wind power plant is connected in parallel with the electrical power grid through a cable line W₁. A cable line for the future expansion of the wind power plant is envisaged.
Figure 1. One-line diagram of the wind power plant.

Fig. 2 presents a time segment of 24 hours from the load schedule of the active and reactive power of the wind plant.

Figure 2. Load schedule of the active and reactive power of the wind power plant for a period of 24 hours: 1 – generated active power; 2 – reactive power.

The typical for this type of electrical power stations fluctuations of the generated active power are observed, as well as consumption of considerable reactive capacitive power at turned off generators or generators with a small load. The load schedule is for the wind plant operation with DFIG generators, allowing for automatic compensation of the reactive inductive power at working generators by means of controlling the rotor chain of the generator [1]. This paper presents an analysis of the wind plant operation with SCIG generators. The other parameters of the wind power plant are not changed. The main reason for the presence of a significant reactive capacitive power at turned off generators are the capacitive conductivities of the cables, by means of which the substation, connecting the wind plant...
with the electrical power grid is realized. The reactive capacitive power is one of the factors, degrading the quality of electricity [2], [3] and therefore the operation of the wind power plant in this mode is not recommended. One of the basic ways of solving this problem without turning off the power plant from the electrical power grid is to connect an inductive compensating reactor to it. Some specific problems, related to the influence of the reactive power at parallel operation of wind power plans have been considered in [3], [4], [5], [6].

The paper presents the results from studies of the active and reactive power of the described wind power plant. The studies were conducted by means of especially developed computer models in MatLab/Simulink. The computer models were synthesized taking into account: the network topology in accordance with 1; the length of the cable lines and their parameters in accordance with the catalogue data of the cables, transformers and generators.

2. Results, obtained by means of the computer model at turned off generators

Both the reactive capacitive power \( Q_c \) and the active power \( P_{\text{in}} \) were defined at turned off generators. The active power is defined by the losses in the active resistances of the cables and by the losses in the windings and the magnetic system of the transformers.

\[ Q_c = 1407 \text{ kVAr}; \quad P_{\text{in}} = 29.82 \text{ kW} \]  

(1)

The defined parameters of the phase shift angle between the idle run powers are:

\[ \tan \varphi_{\text{in}} = -47.203; \quad \cos \varphi_{\text{in}} = 0.212; \quad \varphi_{\text{in}} = -88.8^\circ \]  

(2)

Based on the above data at a normed power factor and after compensating by \( \cos \varphi_I = 0.94 \) (inductive), the value of the inductive compensating power is obtained.

\[ Q_k = P_{\text{in}} \cdot (\tan \varphi_{\text{in}} - \tan \varphi_I) = 1418 \text{ kVAr} \]  

(3)

where: \( Q_k \) is the value of the inductive compensating power; \( \varphi_I \) is the phase shift angle after compensation.

The compensation is realized by means of two identical compensating reactors, connected at the beginning of the 21 kV line (at the input of the 21/115 kV transformer). The reactors are oil type with discrete regulation of the reactive power under a five-degree load.

| Position of the regulator | Rated power \([\text{kVAr}]\) | Rated current \([\text{A}]\) | Ind. resistance \([\Omega]\) |
|--------------------------|----------------------|----------------------|---------------------|
| 1                        | 640                  | 17.6                 | 690.41              |
| 2                        | 680                  | 18.7                 | 651.16              |
| 3                        | 720                  | 19.8                 | 615.92              |
| 4                        | 760                  | 20.9                 | 583.98              |
| 5                        | 800                  | 22                   | 554.91              |

3. Results, obtained by means of the computer model at loaded generators

The dependencies of the active power \( P \), the reactive power \( Q \), the power factor \( \cos(\varphi_I) \) and the phase angle \( \varphi_I \) on the shaft moment of the generators \( M \) were studied by means of the computer model. The values of the active power, the reactive power and the shaft moment of the generators \( M \) are presented in relative units.
\[ P = \frac{P}{S_n}; \quad Q = \frac{Q}{S_n}; \quad M^* = \frac{M}{M_n} \]  

(4)

where: \( P \) and \( Q \) are the measured values of the active and reactive power; \( S_n \) is the rated power of the wind power plant.

The studies were conducted for the following cases:
- load on one generator in the range up to a maximum moment at a compensating reactor, turned on at maximum power, as well as at a turned off compensating reactor;
- equal load on all generators in the range up to a maximum moment at a compensating reactor, turned on at maximum power or at a turned off compensating reactor.

The results are graphically presented in Fig. 3÷10 with the following location of the capacities in the complex plane:
- the generated active power is along the positive part of the real axis, while the active power at operating generators in motion mode is along the negative part of the real axis;
- the capacitive reactive power is along the negative part of the imaginary axis, and the inductive reactive power is along the positive part of the imaginary axis.

Figure 3. Active power at one loaded generator with turned on or turned off compensating reactor.

Figure 4. Active power at load on all generators with turned on or turned off compensating reactor.

Figure 5. Reactive power at one loaded generator with: 1 – turned on compensating reactor; 2 – turned off compensating reactor.

Figure 6. Reactive power at load on all generators with: 1 – turned on compensating reactor; 2 – turned off compensating reactor.
4. Conclusion
Based on the obtained results from the conducted studies the following conclusions can be drawn up:
- The required inductive compensating power at turned off generators has been determined. Two inductive controllable reactors have been chosen. The parameters of the reactors provide a reserve for the future expansion of the wind power plant.
- The inductive reactors do not influence the value of the generated active power, regardless of the number of working generators.
- When one generator is loaded without a compensating reactor, the capacitive power is compensated by the inductive power of the generator at reaching the rated load of the generator. This imposes the need to connect a compensating reactor at smaller loads, defining its power by choosing the corresponding degree.
- At load on all generators without a compensating reactor in the interval from idle run to summed rated power of all generators, the reactive power is inductive. If connected, the compensating reactors additionally degrade the power factor.
- The maximum power of the source of capacitive compensating power can be determined by (3) and by the data about the active power and the power factor at load on all generators, as well as by the
power factor after compensation. The required compensating power depends on the generated active power, which imposes the use of a source, capable of smooth and stepwise adjustment in the entire range, determined by its maximum power.

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