CONTROL OF Q/U FOR CONNECTING REMOTE FARMS OF WIND POWER PLANTS IN 110 KV NETWORKS

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ABSTRACT

In many cases, renewable energy sources are built in locations where the distribution system has not sufficient capacity for connecting their power output into the network. Relatively long MV cable routes – even 15 to 20 km long – with a corresponding capacitive reactive power are being built for the connection of these sources to the distribution system at a suitable point of connection.

Distribution system operators require from the manufacturer, in the whole range of output power, to maintain a neutral power factor at the point of common coupling (PCC) and/or, in the case of sources with higher power, their integration into the voltage regulation system. For fulfillment of these conditions, a regulator of the reactive power flow must be included into the connection of the wind park into the network.

INTRODUCTION

The Rules of distribution network operation, Amendment 4 [1] chapter 9, define the requirements for reactive power control. This paper describes possible solutions of Q control in the point of common coupling (PCC) suggested for a specific application of a wind power-plant, connected to the middle voltage network by means of a long cable route. The capacity of a long cable influences the voltage conditions and should be compensated either using the generator control or, in case the generator produces minimal power, by means of decompensation coil.

WIND FARM AND CONDITIONS IN PCC

Wind farm description

The suggested solution of U/Q control is proposed for a wind power farm with total power of 16 MW. It consists of eight 2 MW generators produced by VESTAS. The main parameters of this generator are summarised in the following Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power, kW</td>
<td>2083 kW (Consp = 0.96)</td>
</tr>
<tr>
<td>Generator type</td>
<td>Asynchronous with wound rotor, slip rings and VCS</td>
</tr>
<tr>
<td>Building size, kVA</td>
<td>500</td>
</tr>
<tr>
<td>Degree of protection (Gen)</td>
<td>IP54</td>
</tr>
<tr>
<td>Voltage, converter:</td>
<td>690 V</td>
</tr>
<tr>
<td>Frequency, Hz</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Number of poles</td>
<td>4</td>
</tr>
<tr>
<td>Winding connection, stator:</td>
<td>Star/delta</td>
</tr>
<tr>
<td>Rated efficiency with converter, %</td>
<td>96 %</td>
</tr>
<tr>
<td>Power factor, default (cos ϕ)</td>
<td>1.0</td>
</tr>
<tr>
<td>Possible cos ϕ regulation, capacitive/inductive</td>
<td>0.98/0.96</td>
</tr>
</tbody>
</table>

Regulation characteristics of generator and available reactive power in all regimes of operation are illustrated in Figure 1.

Conditions in PCC

PCC is a distribution network feeding node with transformer 400/110 kV 250 MVA. In the year of 2014, the short circuit power on the 400 kV side should reach 12.42 [kA] (8604 [MVA]). For the evaluation of voltage conditions and reverse influences, the present short circuit power S' = 4967 MVA on the 400 kV side, i.e. 1360 MVA on the 110 kV side, was used.

Single-line connection diagram

Figure 2 shows the single line connection diagram of the bringing out the power from the wind farm. The chosen
voltage level is 33 kV, the highest possible output voltage of used generators, with regard to the cable route length and minimisation of transmission losses.

![Diagram](image)

**Figure 2**

**Cable connection**

For bringing out the power from the wind farm, a 33 kV cable with cross section 300 mm$^2$ (AXEKVCEY 35 kV) was chosen. The total length of cable route connecting the wind farm with PCC is approximately 20 km. The total value of one phase capacitive current is 32.8 A (1834.5 kVAr), from that the capacitive current of wind park internal network is 4.8 A (269.8 kVAr) and the connecting cable has 28.02 A (1559.5 kVAr).

**REQUIREMENTS ON THE U/Q REGULATION**

**Requirements defined by the Amendment 4**

The rule of distribution network operation, Amendment 4, defines the basic requirements on Q/U regulation for distributed power generation coupled to the distribution grid. Sources generating 5 MW and more should be equipped with one of following techniques of reactive power regulation:

- maintain the preset value of power factor
- maintain the preset value of reactive power
- maintain the preset voltage value in PCC

The technique of reactive power control depends on conditions in individual node of the distribution network and is specified by the network operator having consulted the energy producer.

**Requirements of the network operator**

The distribution network operator defined following requirements for the control system and for the voltage regulator:

- wind energy producer installs a 110/33 kV transformer with tap-changer
- a decompensation reactance coil will be provided for cable capacitive current compensation
- wind energy producer provides for automatic regulator of reactive power, based on setpoint value of Q, power factor or voltage in PCC by means of:
  - changing reactive power of the generators
  - switching tap on the 110 kV/MV transformer
  - switching the reactance coil on/off
- parameters of the regulation will be defined by the distribution network operator before putting the wind farm into operation and it will be possible to change them during wind farm operation.
- the dividing line of the control system is the serial interface of the regulator

**ANALYSIS OF REGULATION POSSIBILITIES**

The behaviour of wind power farm at the change of operation conditions, either on the generator side or in the PCC.

The necessary Q/U regulator in the 110/33 kV transformer station will operate the tap changer, switch the reactance coil and by means of external communication interface send setpoint values of active and reactive power to the wind farm control system. The latter should be able to supply the regulator with measured values and status signals necessary for Q/U regulation (P, Q, U values and states of individual generators etc.).

The designed regulation algorithm respects not only conditions set by the network operator, but also values necessary for failure-free operation of the wind farm, especially the voltage tolerance on machine terminals.
At the assessment of wind farm regulation possibilities we elaborated following analyses, whose results define the range of regulation:

- voltage change on the wind farm output (switching station 33 kV) in dependence on tap change of the feeding transformer (110/33 kV) – Figure 3
- voltage change on the wind farm output (switching station 33 kV) in dependence on Qg (wind farm reactive power) – Figure 4
- change of cable reactive power in dependence on Pg (wind farm active power) – Figure 5

The presented curves show evidently that the PCC voltage can be influenced by the wind farm minimally due to the high short circuit power; however in nodes with low short reactive power and voltage in PCC with respect to possible 33 kV voltage change on the wind farm and voltage tolerance in the PCC, curves of Q_{PCC} (reactive power in PCC) and dU_{PCC} (PCC voltage change) were constructed for different taps on the 110/33 kV transformer different active power and number of active generators.

For more detailed description of mutual dependence of

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**Figure 3**

Voltage in the switching station as function of T4 tap

\[ y = 0.0194x^2 + 1.5931x + 0.0765 \]

**Figure 4**

Voltage in the switching station as function of Qg

\[ y = 0.0043x + 1.7465 \]

**Figure 5**

Q of the cable as function of Qgen

\[ y = -0.0004x^2 - 0.0273x + 1694.6 \]
circuit power the reactive power regulation can be used for supporting the voltage level in the distribution network.

PROPOSED SOLUTION OF Q/U CONTROL

The wind power producer interest is to deliver as much energy as possible. This reduces the wind farm Q regulation range. The curve in Figure 1 shows that from one generator active power of 1400 kW the Q regulation range starts being limited and at the rated power – $P_n$ it is just -600 to +400 kVAR. On the other hand, at very low active power (less than 10% of rated power) the Q regulation range falls quickly down to zero.

The Q/U regulator should allow for a coordinated management of wind farm reactive power, transformer tap changer and switching the decompensation reactance coil in order to keep following values within predefined limits:
- 33 kV voltage in the switching station
- reactive power or power factor (or voltage) in PCC

The regulation should basically distinguish between two modes of operation:

1. The wind farm produces less than 10% of $P_n$

This includes also no power production. The regulation of wind farm reactive power is limited or impossible and the $Q_{PCC}$ can be controlled only by means of the decompensation reactance coil. The 33 kV voltage in the switching station should be kept at $U_n$ ± 5% using the transformer tap changer. When the voltage on generator terminals exceeds the limit $U_n$ ± 10%, the generator protection relay trips and disconnects it from the network.

2. Normal production

Active and reactive power of generators will be regulated, so as the reactive power (or power factor) in the PCC is within the preset tolerance band. The decompensation reactance coil can be switched off or it can also in this case compensate the capacitive reactive power of the connecting cables and the generator reactive power control would compensate only deviations from normal state of network. The power loss of the permanently connected coil is mostly negligible; it brings however the advantage of no capacitive load in the case of wind stop.

The regulator will also communicate with the SCADA system of the regional dispatching centre. Following data will be transferred in monitoring direction:
- position of all switches on the HV side of the transformer
- position of the local/remote switch
- signals of HV and transformer protections
- measured value P, Q, U, I from the HV side
- tap changer position
- current limits of P, Q regulation

Switches remotely operated from the dispatching centre:
- circuit breaker on the HV side of the transformer
- isolators and earthing switches on the HV side

Setpoints:
- reactive power in the PCC
- active power in the PCC in emergency situations (overfrequency).

The need to keep the voltage in the switching station at $U_n$ ± 5% requires the transfer of its value to the regulator, located in the PCC. The VESTAS wind farm controller has unfortunately no standard communication interface, only analog I/O for measured values and setpoints and digital I/O for signals and commands. For this reason, the switching station must be equipped with an RTU, communicating with the regulator. The RTU configuration will be:
- 2 analog inputs for measured values
- 2 analog outputs for setpoint output to the wind farm controller (Q, P)
- 16 digital inputs for the signals of wind farm states
- 8 digital outputs for commands.

In the cable route – 15 to 20 km – between the PCC and the switching station, an optical communication cable will be placed together with the power cable.

CONCLUSION

The paper describes one of possible methods of wind farm reactive power control in order to keep voltage and reactive power balance in point of common coupling (PCC) and presents the results of network behavior simulation.

REFERENCES
