CONTROLLABILITY OF WIND POWER PLANTS CAPABILITIES REGARDING VOLTAGE CONTROL AND DATA EXCHANGE

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ABSTRACT

The penetration of renewable generation and especially wind energy in European power systems at all voltage levels is ever growing. This paper focuses on the challenges of increased cumulated embedded renewable generation capacity with regards to retaining steady-state voltage profiles within the operational limits. The voltage control capabilities of type IV Wind Power Plants are outlined and an overview is given of selected relevant requirements from Distribution System Operators (DSOs) in Italy, Germany, together with efforts at a European level. Key experiences from the pilot project in the area of Westnetz, a German DSO, are outlined, demonstrating how the technology capabilities allow forward thinking DSOs to optimise system operation and reduce grid reinforcement costs.

INTRODUCTION

Over the past decade, Wind Power Plants (WPPs) in Europe have grown considerably in number and in size [1]. This trend is expected to continue in the coming years as strategies are being developed Europe-wide, e.g. [2], to harness untapped wind resources through the use of mature Wind Turbine Generator (WTG) technologies.

Although the pattern and progression of renewable penetration in different European states may not be uniform, a tendency can be seen towards an accumulation of WPPs of various capacities embedded in the distribution system, primarily at MV level. This fact poses interesting new challenges to Distribution System Operators (DSOs) concerning the balance between reliable operation and reinforcement costs of a network that was originally suited to the delivery rather than the production of energy.

Amongst such challenges, a pressing issue is actively addressing steady-state voltage profiles within the applicable operational limits according to IEC 50160 [3] and ensuring transient voltage stability. Towards these goals modern WPPs are envisaged to allow DSOs to develop flexible operating strategies, though the provision of a wide steady-state and highly dynamic reactive power capability, combined with WPP controller and interface options [4].

The conventional method of controlling the voltage of downstream nodes through single On Load Tap Changer (OLTC) transformers appears to no longer be the most efficient solution. The non-constant power flow direction calls nowadays for integrated and advanced voltage control approaches considering all available sources of reactive power. This has gained growing attention by several European DSOs through the development of a variety of new connection conditions for embedded generation, selected examples of which are summarised in this work.

The experience presented here from Westnetz, a German DSO with more than 8GW of embedded generation in their system, concerns the performance of a voltage control scheme in an embedded project. The ENERCON WTG used in this project is capable of reactive power provision independently from the prevailing wind conditions. After the acquired experience of voltage control schemes at the transmission level [5], the available yet mostly underutilised capabilities of WPPs presented here demonstrate a meaningful contribution to achieving reliable grid operation in highly changing distribution networks.

WIND POWER PLANT CAPABILITIES

Wind Turbine Generator Reactive Power Capabilities

In type IV WTGs the generator is decoupled from the grid using a full scale frequency converter providing essential grid integration features, such as wide operating ranges in terms of voltage and frequency and a flexible reactive power capability. The type IV design as implemented by ENERCON is shown in Fig. 1. The generator produces variable-frequency output which is rectified to DC and fed into the DC link. The closed loop inverter control system is controlling the modular inverters to inject output current according to the grid voltage and frequency.

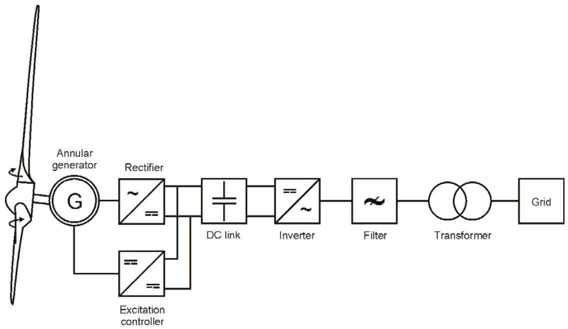

Figure 1. Typical type IV WTG configuration.

Today, ENERCON WTGs are offered with so-called FACTS capabilities, typically achieving reactive power capability as shown in light green in Fig. 2. As an advantage of the full scale frequency converter design, the WTG reactive power capability can be increased if required (dark green area in Fig. 2) by installing additional inverters. Additionally, the reactive power capability can be expanded down to 0pu active power output, providing the WTG with capabilities that are technically equal to external STATCOM units.

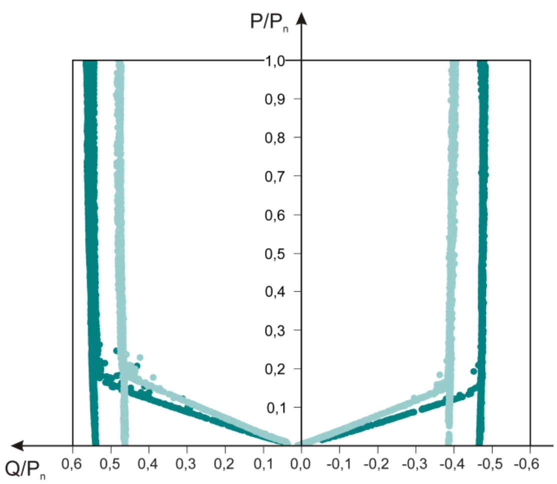

Figure 2. Measurements of reactive power capability of ENERCON WTG.

Wind Power Plant Control and Interface Options

Controllability of WPPs is usually provided by a central control unit taking measurements at the Point of Connection (PoC) and sending setpoints to the individual WTGs in order to achieve a specified behaviour.

ENERCON is offering two different controllers to meet a variety of requirements in terms of regulation modes, performance and interfaces. Developed to meet the requirements of German DSOs about basic control performance, the ENERCON Remote Terminal Unit – Control (RTU-C) is using the WPP data bus system to send setpoints to the WTGs (see Fig. 3 below). The ENERCON Farm Control Unit (FCU) was designed to meet high controller performance requirements e.g. the rise time of the reactive power response of the WPP. Thus, it is using an additional dedicated WPP control fibre optic bus system. Both controllers are providing reactive power control modes including but not limited to voltage droop control, reactive power control and active factor control.

The system operator can send setpoints to the WPP to adapt its behaviour to the current circumstances in their power system. Depending on the control mode, different setpoints can be sent to the WPP, e.g. using a voltage droop control, the reference voltage of the control characteristic can be changed. A wide variety of interfaces and communication protocols is available, including digital and analogue I/Os, IEC 60870-5-104, Modbus, DNP3, and OPC XML DA.

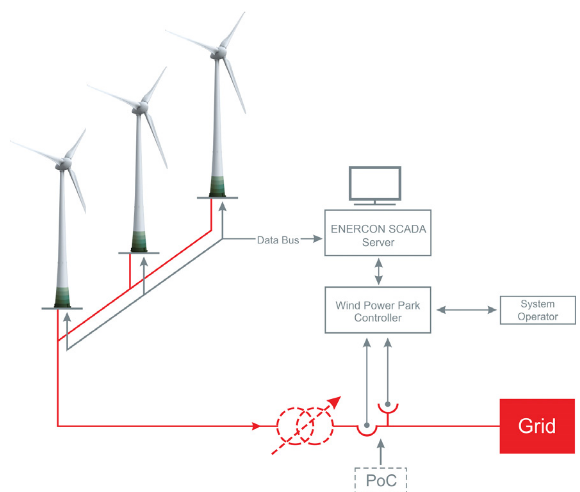

Figure 3. Typical WPP control and communication topology.

VOLTAGE CONTROL REQUIREMENTS

Realising the potential benefits, several DSOs have already opted for the introduction of voltage control requirements in their connection conditions, based on the technology employed and/or the installed capacity of the generating plant. From a number of applicable conditions, e.g. regarding the behaviour of the generating plant during certain faults and voltage dips, focus is given in this work to the steady-state voltage control.

As an example of such efforts from DSOs, in the following a summary is presented of the new requirements in Italy through the national norm CEI 0-16: 2012-12 [6], together with the conditions imposed on German DSOs through the standard "BDEW

Generating Plants Connected to the Medium-Voltage Network" [7]. Westnetz, Germany's largest DSO, supplying electricity and gas to approximately 7.5 million people, has specified these requirements from BDEW in order to be applicable for their network operation philosophy. Against Westnetz requirements, the real life performance of a type IV WPP will be examined later, demonstrating the achieved benefits for all involved parties.

Before these national requirements are elaborated, we present the attempt of CENELEC to provide a Europe-wide common ground for the "Requirements for generating plants to be connected in parallel with a medium-voltage distribution network", through the Technical Specification (TS) 50549-2 [8].

CENELEC TS 50549-2

Having been developed by the working group CENELEC/TC8X/WG03, the TS 50549-2 describes the requirements for the connection of generating plants to a MV distribution network. This document currently runs through different administrative stages with its publication expected for the end of 2014. Although TSs are not binding, they are normally used as a template for binding national guidelines and legislation.

The voltage control requirements for generating plants contained in TS 50549-2 are split into three areas, namely the operating range capability, the voltage support during faults and voltage steps and finally the voltage support within the normal operation voltage range, which has to be 90%-110% of the declared supply voltage at the PoC.

Regarding the required active factor range, it should extend from 0.90 underexcited to 0.90 overexcited, applicable either at the PoC or at the generating unit terminals, selected by the relevant DSO. The generating plant has to be capable of being controlled through any of the following: closed loop reactive power control, closed loop active factor control, Q(U) characteristic, Q(P) characteristic, cosφ(U) characteristic, or cosφ(P) characteristic.

CEI 0-16 : 2012-12

The Italian electrotechnical committee (CEI) prepared the norm CEI 0-16: 2012-12, with the active involvement of TERNA, the Italian Transmission System Operator (TSO), and ENEL Distribuzione, the Italian DSO. The aim of this norm, which came into force in the beginning of 2013, is to tackle the challenges related to the security, continuity and quality of the Italian electrical system that were raised by the growing volumes of distributed generation, especially photovoltaic plants and WPPs, connected to the Italian LV and MV grids in the last 4 years. It defines the technical requirements for the connection of consumers and generators to the distribution grid between 1kV and 150kV.

In this standard, beyond the requirement for a cosφ(P) characteristic, was introduced the requirement for a so-called voltage droop control Q(U) either at WTG level or at WPP level, however only when the active power production is above 10% of its nominal value. The DSO is free to decide in which of these two controls the power plant shall operate. The Q(U) characteristic is depicted in Fig. 4, with the values of the parameters V_{1s}, V_{2s}, V_{1i} and V_{2i} representing the default case. However, based on local network conditions, the DSO may require them to be adjusted. The settling time of the response of WPP and photovoltaic plants when operating anywhere on this characteristic curve shall not exceed 10s, whereas the maximum reactive power capability (Q_{max} and $-Q_{max}$) correspond to an active factor of 0.95 at nominal active power.

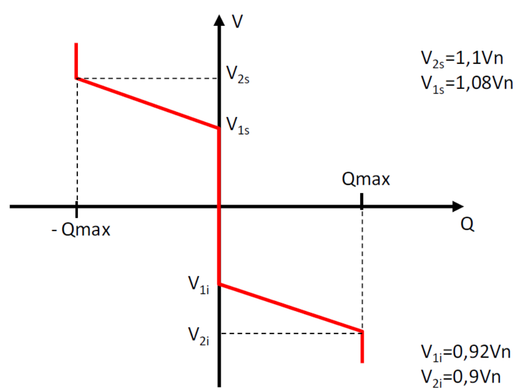

Figure 4. Q(U) characteristic requested by CEI 0-16.

BDEW, Generating Plants Connected to the Medium-Voltage Network

This technical guideline governs the connection of generating plants to the MV network in Germany. As of 01/01/2013, the 4th and latest supplement to this document surpasses all previous ones.

According to the requirements there, generating plants shall be capable of steady-state and continuous operation within the range of 90%-110% of the declared supply voltage at the PoC. Furthermore, they shall be able to operate with an active factor range of at least 0.95 underexcited to 0.95 overexcited at the PoC. Depending on the applicable restrictions, the responsible DSO may require any of the following control modes: closed loop active factor control, cosφ(P) characteristic, closed loop reactive power control or Q(U) characteristic. From these control modes, Westnetz normally require cosφ(P) or Q(U) control. Regarding the latter, a typical control curve is shown in the following section.

PILOT PROJECT IN WESTNETZ AREA

In a pilot project between Westnetz and ENERCON, the benefits of the decentralized voltage control by a WPP in a rural area were examined. The WPP, consisting of an ENERCON E-82 WTG (with a nominal power of 2.3MW) and controlled by an RTU-C, is connected to a 20kV line with an overall length of more than 30km.

Initial load flow simulations showed two potential PoCs for the WPP, one being geographically further but ensuring the steady-state voltage profiles would stay within the limits, and the other one being geographically closer but leading to unacceptable voltage rise during periods of low load consumption and high production from the other renewable generating plants in the proximity. However, the WTG's technology offered the opportunity to extend the reactive power capability to 1.59MVAr underexcited-overexcited and have it available independently of the wind conditions, hence enabling voltage control at every active power injection level. This capability combined with a fine-tuned voltage-droop controller revealed in load-flow analyses an influence on the operational voltage of maximum 2.4% and therefore made the selection of the geographically closer PoC possible (denoted with "WPP" in Fig. 6, having an X/R ratio of 1.7 and a short-circuit power of about 80MVA).

In order to accommodate the WPP's extended reactive power capability and take into account the electrical properties of this part of the network, the standard Q(U) control characteristic required by Westnetz was adapted and optimised; both standard and customized curves are shown in Fig. 5 with black and blue colour respectively.

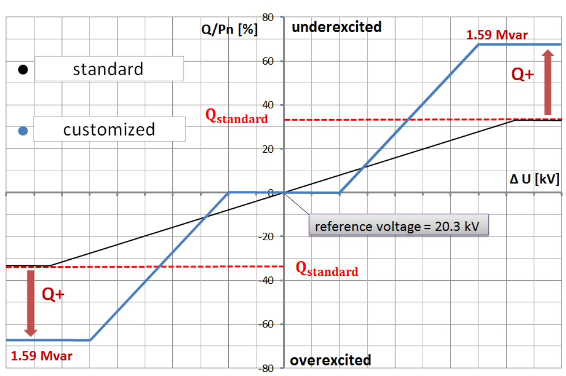

Figure 5. Standard and PoC-customised Q(U) characteristics required by Westnetz.

More specifically, the gradient was amended so that for voltage deviations higher than 0.7kV of the reference, the WPP should contribute with its maximum reactive power. A deadband of ± 1% was introduced as well, so that unnecessary voltage control in this voltage range would be avoided and therefore transport losses caused by reactive power can be reduced. Westnetz shall use the OPC XML DA interface to access the RTU-C and change the voltage control properties without the involvement of the WPP operator.

Given the pilot nature of the project, after the start of the operation of the WPP, the calculated influence of the WPP on the operational voltage had to be validated. To this end the voltage was measured in various network nodes (as Fig. 6 shows) and consequently analysed, while the WPP was injecting/absorbing reactive power, responding in this way to reactive power setpoint step changes. A graph of such voltage and reactive power recordings is presented in Fig. 7, where we can see that the difference in the voltage of the measured nodes is proportional to the reactive power injected/absorbed from the WPP.

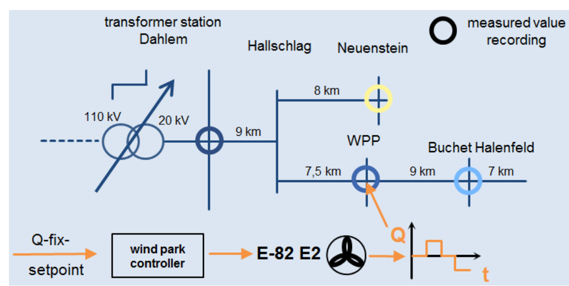

Figure 6. Pilot project set-up.

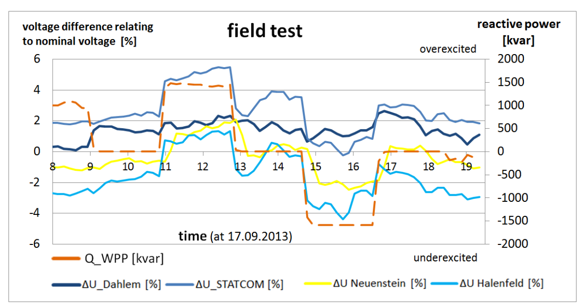

Figure 7. Influence of the reactive power contribution from the WPP on different nodes of the network.

A conservative assessment of the measurement results showed that on every node downstream of the transformer station "Dahlem" (excluding the voltage there that, given the node's high short-circuit fault level, is only fractionally influenced) the WPP's reactive current injection and absorption could lead to a maximum 1.7% voltage rise and a maximum 2.4% voltage drop, respectively. As a result, the validity of the earlier load flow simulations was confirmed.

This positive influence on the voltage of the network nodes is illustrated in Fig. 8, whereby the voltage range becomes up to 4% smaller compared to when the WPP has the voltage control disabled. The effect of the WPP on the voltage made as well possible to reduce the setpoint of the OLTC transformer at Dahlem by 1.5%, as the voltage control of the WPP can raise this voltage above this value if necessary.

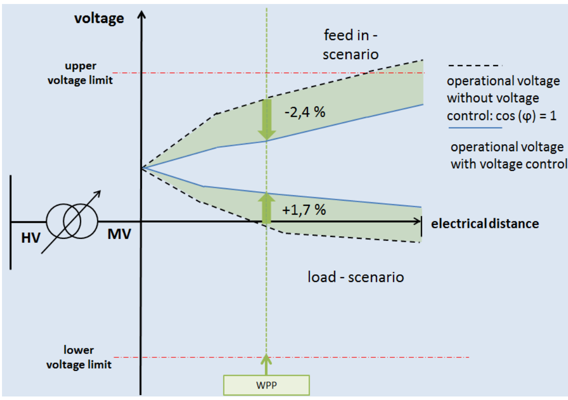

Figure 8. Maximum influence on the operational voltage.

CONCLUSIONS

The increasing cumulative capacity of embedded renewable generation is leading to an emerging complexity of network operation. This paper has focused on one aspect, the challenge of optimising steady-state voltage profiles within the applicable operational limits. Voltage and reactive power support from distributed generation is attracting growing interest by DSOs, as shown by the quantity of effort being put in to develop not only regional or national connection conditions, but also to try to establish a harmonised, Europe-wide common ground.

The sample of the experiences presented here from the pilot project in the area of Westnetz illustrate that the combination of WTGs with STATCOM-like properties and a suitably tuned WPP controller affords an extensive steady-state reactive power capability, thus enabling DSOs to effectively and efficiently manage the voltage quality in their network. Such capabilities do not only make capital and operational expenditure on standalone reactive power compensation equipment redundant, but also allow a meaningful reduction in the time and the cost required for connecting the embedded generating plants and can even postpone the expensive and lengthy reinforcement plans. So long as the capacity of a network is not reached, the contribution of these capabilities by the WPP shall furthermore positively impact the connection of future embedded generation.

Close collaboration between the involved parties is, however, necessary and voltage control / power flow studies need to be performed in order for the DSO to better accommodate the capabilities of a WPP.

Such pilot projects once more prove the type IV WTG technology's robustness and adaptability and reveal how DSOs with forward thinking can develop strategies that optimise system operation in a highly challenging environment.

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