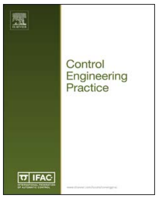
Control Engineering Practice 59 (2017) 100–110

Contents lists available at ScienceDirect

Control Engineering Practice

journal homepage: www.elsevier.com/locate/conengprac



Transmission support using Wind Farm controls during voltage stability emergencies

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ARTICLE INFO

Keywords:
Voltage stability
Converter controls
Wind generation
Reactive support
Maximum power transfer

ABSTRACT

This paper investigates the effect of reactive support by Wind Farms (WF) on the maximum power transfer, and thus the voltage stability limit of a transmission system. An insecure snapshot in a weak area of the Hellenic Interconnected System is examined, as well as a simpler test system. MV feeder characteristics and substation controls (feeder resistance and reactance, switched capacitors, LTC controls) are modelled in detail. Most importantly, the converter current limits, as well as the overvoltage limitations on the MV feeder, are taken into consideration in assessing the effect of the WF support.

1. Introduction

1.1. Harvesting reactive support from distributed resources

Variable speed wind generators maximize the energy harvested from the wind and are thus widely utilized in power systems (Pourbeik, 2007). Due to their power electronic converters these generators have an independent control of reactive power that is usually applied to regulate local voltage, or to minimize losses by keeping a unity power factor (Erlich, Kretschmann, Fortmann, Mueller-Engelhardt & Wred, 2007; Kayikci & Milanovic, 2007; Opila et al., 2010; Zhai & Liu, 2014). This reactive support feature, however, can be used to provide a valuable service to the main transmission system (Aristidou, Valverde & Van Cutsem, 2015; Rather et al., 2012; Zali & Milanovic, 2013; Zerva & Geidl, 2014), especially in case of severe contingencies threatening system stability, or even leading to voltage collapse.

This potentially vital reactive reserve cannot be efficiently utilized before solving several technical problems. A non-exhaustive list of challenges follows:

1. Distributed reactive resources need to be fitted for reactive power control (not a major problem as electronic converters inherently have control capabilities).
2. Investors need incentives for providing the reactive support, i.e. enabling their devices to perform the required control.
3. As several resources may share the same feeder, it is important to coordinate their responses. For instance, if one device is injecting maximum reactive power and the other is regulating voltage, the net effect is cancelled out.
4. Coordination is needed also with existing feeder controls, such as automatic Load Tap Changers (LTC) on distribution transformers, switched capacitor banks, etc. to avoid adverse interactions.
5. Finally, a major problem is the electrical and physical distance between the control objective (transmission grid voltage) and the control means (distribution side resources), which implies communication costs and efficiency problems.

Possible answers to the above challenges are proposed and discussed in the paper for the case of Wind Farms (WF) connected through dedicated MV feeders:

1. Available reactive power is assumed only in cases of reduced active generation. This is not a severe constraint, since in case of a high active generation from distributed sources, less power transfer from the main grid is necessary, rendering reactive support less valuable. On the contrary, for converter controlled loads oversizing of converters is necessary to provide reactive support at full load, when it will be most valuable.
2. It is assumed that TSOs can offer compensation to reactive support providers based on the added value to the transmission system. In this paper reactive support is quantified as added MW transfer capability in a congested corridor. This can be easily expressed in financial value at the stage of remuneration.
3. One single controlled reactive injection per feeder is assumed at the WF connection point that represents the combined supervisory control of the WF.
4. Both automatic LTC and switched capacitor controls are considered in the paper. A standard automatic LTC controlling the secondary

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http://dx.doi.org/10.1016/j.conengprac.2016.11.007
Received 21 April 2016; Received in revised form 3 October 2016; Accepted 11 November 2016

(MV side) of the distribution transformer is assumed. On the other hand, automatically switched capacitors are considered to control reactive power coming from the distribution feeder (Vournas et al., 2006) and are thus implicitly coordinated with the reactive support.

5. The electrical distance is directly taken into account by modelling the MV feeder and the HV/MV transformer leakage reactance. An intelligent way to deal with the telecommunication problem, avoiding the need for telemetering and complex communication channels is discussed in Section 4.4.

1.2. The case of Peloponnese in the Hellenic system

In previous work (Vournas & Anagnostopoulos, 2015), it was seen that the maximum power transfer in the weak area of Peloponnese in the Hellenic Interconnected System (HIS) can be significantly increased by using reactive reserves of seven WF converters.

In this approach it was considered that the reactive power is injected directly on the HV bus and thus the effect of the MV feeders connecting the WFs to the HV grid was accounted approximately. In this paper the limitations of the above approach are further examined using a detailed MV feeder model, as in Vournas and Souxes (2016), where the effect of WFs in increasing maximum power transfer of a weak transmission corridor is closely investigated.

The control mechanisms that have to be coordinated, in order to achieve acceptable operation are described in Section 2. These include the LTC regulating the secondary (MV side) transformer voltage, the switched capacitor banks on the MV substation bus, and finally the reactive power control of the WF converter. For the wind generators both Doubly Fed Asynchronous Generators (DFAG) and Full Converter Wind Generators (FCWG) are modelled as controlled active and reactive power injectors at their AC terminals (Pourbeik, 2007). The active power of the WF is considered equal to that provided by the wind and is thus an input to the system. The resistance and reactance of MV lines are also represented, whereas the WF is considered as a single generator connected to the end of the MV feeder through an equivalent impedance added to that of MV lines. Particular emphasis is given to the limits of the WF converters, as well as the effect of feeder overvoltage constraints.

The HIS snapshot analysed in Section 3 is the same as in (Vournas & Anagnostopoulos, 2015) and corresponds to the operating conditions of June 15, 2010 (Lambrou et al., 2013). This snapshot was labelled insecure by the on-line Voltage Security Assessment (VSA) tool that is installed in the Energy Control Centre of HIS (Van Cutsem, Kabouris, Christoforidis, & Vournas, 2005). The contingency causing the insecurity is the loss of a generating unit in Peloponnese, which, as shown by simulation, results in a cascade of events leading to voltage instability, first in the area of Peloponnese, and then spreading to the Athens area and the rest of the system.

It should be noted that in the snapshot examined in Section 3 the WFs in Peloponnese are injecting very little active power. This is typical, since in Greece the annual load peak is normally in the hottest summer day. Thus in the examined case the available reactive reserve from the WF converters is practically equal to their rated apparent power due to the very small active generation; provided, of course, that all individual converters remain in operation. The availability of converter support is taken as granted in this paper, which aims at demonstrating the advantage in terms of voltage stability enhancement by the proposed WF reactive support.

1.3. Modelling limitations and further analysis

The analysis of the Hellenic System is performed in this paper using the Quasi-Steady-State (QSS) long-term simulation program WPSTAB developed in NTUA that is a part of the software of the on-line VSA (Van Cutsem et al., 2005). However, in the current version of the software the MV feeders are not represented, rendering the analysis of HIS approximate. This limitation is explained in Section 2.2, where a tuning method is presented to avoid an optimistic estimate of the available reactive support by suppressing the overvoltage occurring immediately after a disturbance in the actual feeder. In all cases the results of the HIS simulation are checked again using the detailed feeder model.

Since the representation of the HIS without the MV feeders remains approximate even after the correction of overvoltage, a further step forward is taken in Sections 4 and 5 of the paper, where two actual detailed WF feeders of existing WFs in Peloponnese are used to analyse a test system comprising a weak transmission corridor. The effect of reactive support through HV bus control by the WF is assessed and it is compared with a simpler intelligent control scheme based on a single command requesting maximum reactive support, issued when the transmission voltage falls below a specified threshold. The increase in maximum active power transfer is computed for each of the two distribution feeders both for low and high wind generation conditions and the single command reactive support is seen to be equally effective with the continuous voltage control of the HV transmission bus.

2. Distribution feeder model and controls

2.1. Detailed MV feeder model

The single-line diagram of the typical MV feeder connecting a Wind Farm to the transmission system is shown in Fig. 1. As seen, it is a radial system consisting of the HV/MV substation including a transformer with load tap changer (LTC), switched capacitor banks on the MV substation bus and a distribution line connecting the substation to the equivalent generator representing the WF. It is assumed that the WF and individual wind generator controllers are able to regulate the injection of reactive power to this equivalent WF bus, whereas the injection of active power P_w represents the total wind generation of the WF.

In the system of Fig. 1 three independent controls are assumed (LTC, automatic switched capacitors, WF reactive power), which require some form of coordination, so as to avoid adverse interactions. The following control strategy is adopted for these three controls:

1. The LTC is a discrete-time, discrete-data system controlling the secondary side (MV) voltage V_2 within a narrow deadband (V_2^{min}, V_2^{max}) by varying appropriately the transformer tap ratio r.
2. The reactive power controller of the equivalent WF is assumed to regulate the HV voltage V_1 of the substation, or equivalently to provide maximum reactive support to the transmission system, subject to physical limitations.
3. As both the primary and the secondary voltage of the HV/MV substation are regulated by controls 1 and 2, the switched capacitor bank controller needs to regulate a different quantity to avoid adverse effects such as hunting. Thus the switched capacitor controller regulates the reactive power flow from the MV feeder within a relatively wide deadband between 0 and ΔQ (Vournas et al., 2006).

In order to avoid oscillations due to multiple control actions, the above three controls have a relatively wide time-scale separation.

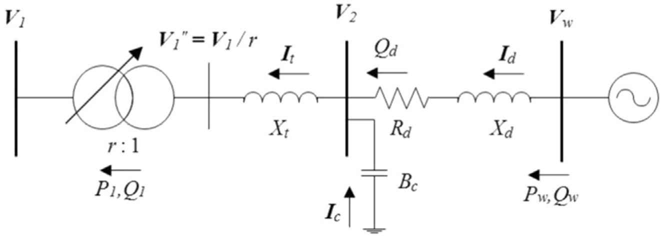

Fig. 1. Wind Farm feeder and substation model.