THE APPLICATION OF DISTRIBUTION STATE ESTIMATION TO SUPPORT A REAL-TIME VOLTAGE CONTROL ALGORITHM: A PATH TO INCREASE THE INTEGRATION OF DISTRIBUTED GENERATION

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ABSTRACT

Portuguese and European political forces have clearly laid out their intention of increasing the integration of Distributed Generation (DG) into Distribution Networks (DN). The benefits of DG are undeniable, however higher penetration of DG bring new challenges to the secure operation of the DN. These facts associated with the high standards for quality and security of supply lead the Distribution System Operators to consider new cost-effective management techniques. The voltage rise problem is one of the challenges that have limited the integration of DG. This paper presents a centralized voltage control scheme to control the AVC relays set point. The performance of such scheme for the Portuguese Distribution Network is discussed.

INTRODUCTION

The level of Distributed Generation (DG) is expected to increase as the European Union and the Portuguese Government have clearly laid out their intentions to promote energy from renewable sources.

Considering that the Distribution Networks (DN) were originally designed to supply demand that reduced with the distance from the transmission systems and, therefore, are not prepared to accommodate the expected growth of the DG. Normally, the generation requires connecting to the rural DN, which is normally lightly loaded. In addition to this, the demand of Distribution System Operator (DSO) for high quality and reliable power supply is at the highest in the history of electrical power distribution.

These factors brought new technical issues that must be addressed by the DSO and will lead to consider new cost-effective management techniques in order to optimize the distribution networks.

In this paper the authors discuss a possible approach for the voltage control at the HV/MV primary substation in distribution network with generation.

IMPACT OF DISTRIBUTED GENERATION

As described in [1,2] the presence of DG will have a number of significant impacts on the operation of the distribution, such as (i) bidirectional power flow and the potential to exceed equipment thermal ratings, (ii) violation of voltage profiles within admissible limits, (iii) increased short circuit contribution and fault levels, (iv) altered transient stability, and (v) degraded protection operation and co-ordination.

VOLTAGE REGULATION

Current Method

At the present time, the information used to control the voltage regulation is based on real-time measurements only at the primary substation and is implemented in the local Automatic Voltage Control (AVC) relay, which controls the On-Load Tap-Changing (OLTC) transformer.

The AVC relay maintains the voltage at the substation higher to compensate the voltage drop along the network and thus maintain the voltage in the MV network within the technical limits. However, due to the integration of DG into the network, some of the feeders power flows become bidirectional and this voltage control approach may become ineffective [3]. In order to achieve a more efficient voltage regulation, a more extensive real-time monitoring and control is needed which, besides the equipment supervision and control, includes comprehensive real-time voltage measurements and detailed load supervision. Unfortunately, these information are not currently accessible in real-time and historical data is used to estimate the customer loads. However, the accuracy of historical data about the customer loads fails to provide sufficient details for real-time application.

A Centralized Voltage Regulation Approach

Distribution State Estimation coordinated with a MV Network monitoring improvement can be used to increase the accuracy of the estimated load data. In order to do that, the state estimation employs the real-time measurements currently available and few new real-time measurements strategically positioned across the DN. With the available data it is possible to use an iterative process to calculate the optimal voltage at the primary substation that minimizes voltage deviations across the MV network. Although, this solution presents several constraints, as it does not consider the possibility to: (i) control the active and reactive power of the DG units, (ii) store devices, (iii) adjust the load consumption, and (iv) support demand response. Thus, in case of high penetration of DG, this solution would not be effective. However, in an initial phase, while the previous identified controllable devices are not yet available, this method promises to be a possible cost-effective solution.

In order to attain an efficient voltage profile control in a network with high penetration of DG a new approach must be persecuted. In this scenario, where an optimised network operation, power losses minimization and technical limits is intended to be ensure, a decentralised but hierarchical voltage control scheme must be foreseen as proposed in [4]. To become practicable, this solution requires not only the existence of active and controllable microgrids, DG units and MV loads, but also advanced metering, robust and comprehensive communications capabilities, and extensive automation.

This work discusses the application of Distribution State Estimation to monitor a typical Portuguese distribution network with generation. The estimated voltage is then fed into a real-time Automatic Voltage Reference Setting Controller algorithm to actively control the OLTC transformer by changing the AVC relay voltage reference. Both Distribution State Estimation and Automatic Voltage Reference Setting Control Algorithm are expected to bring all the network voltages within the technical network voltage limits. Therefore, more generation can be connected to the network without compromising the quality and reliability of the power supplied to the costumers.

VOLTAGE CONTROL SYSTEM

The voltage control system adopted in this work is a centralised voltage regulation which deals with different variables in the system and has the main purpose of counteract the voltage rise effect in the network. The voltage control problem will be solved with an on-line constraint optimization.

System Architecture

The schematic of the proposed architecture for the automatic voltage controller reference setting is represented in Fig.1.

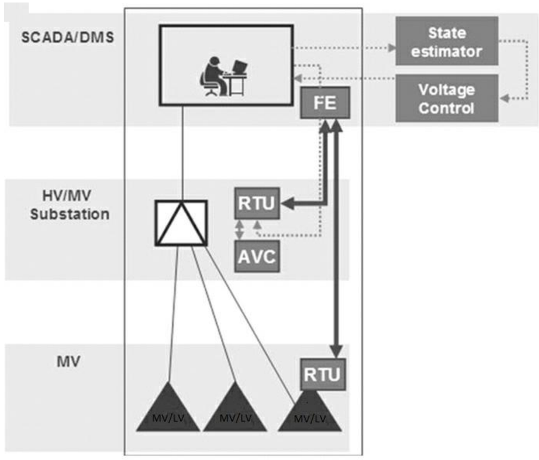

Fig. 1: Automatic Voltage Controller Reference Setting architecture

To interact with the voltage regulation at the substation, it was considered the adjustment of the voltage reference of the AVC relay, which in turns modifies the OLTC transformer tap step.

Automatic Voltage Reference Setting Controller: Software Module

Fig 2 shows a block diagram of the Automatic Voltage Reference Setting algorithm which presents a model of the software to be implemented in the controller.

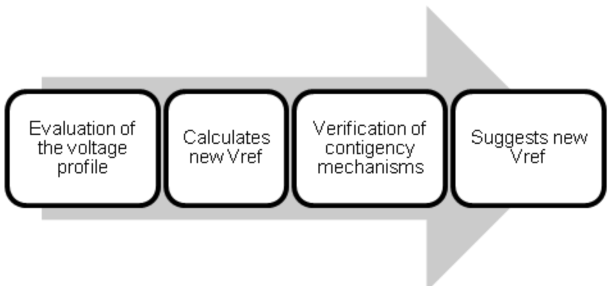

Fig 2: Automatic Voltage Reference Setting Controller Algorithm.

Firstly, the voltage control module requests the State Estimation algorithm to provide the voltage levels on the DN. Then, the voltage estimations provided by the state estimation module are evaluated, considering the nodes type and the uncertainty of the estimations. If the node represents the MV/LV stations busbar, the voltage should be within the technical voltage limits. Otherwise, a new Vref for the AVC relay is determined by estimating the number of taps N necessary to change the voltage in the MV/LV Station. This action could not bring the others MV/LV station voltage outside the technical limits. Before setting the new Vref suggested by the Automatic Voltage Reference Setting algorithm, the Voltage Control System waits for the operator confirmation.

State Estimation Algorithm

The developed distribution state estimation algorithm determines the voltage magnitude and its accuracy at all MV/LV stations. The schematic in Fig. 3 represents the input and output variables of the distribution state estimation algorithm.

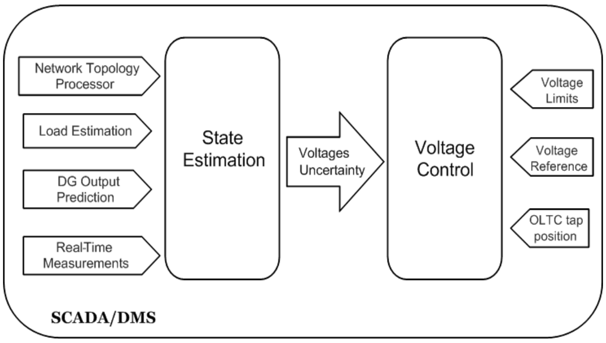

Fig. 3: Input and Output Scheme of the Distribution State Estimation and Voltage Controller.

The distribution state estimation algorithm used is based on the weighted least squares as in [5-7].

SCADA system interface

The Portuguese DSO (EDP Distribuição, EDPD) employs an EFACEC SCADA/DMS for real-time operation and control and in the end of 2009 the EDPD network assets in the HV/MV network approximately consisted of:

400	HV/MV Substations	16,000 MVA
1,000	HV Lines	8,500 km
4,000	MV Lines	71,000 km
62,000	MV/LV Stations	18,000 MVA

All of the 400 HV/MV substations have Remote Terminal Units (RTU), but only few of the MV/LV stations have one (about 1%). At the substation level, the RTU communicates in real-time to SCADA all the operational data necessary for the secure operation of the system. The data relating to the electrical network characteristics is managed by a Smallworld's Geographical Information System (GIS/SW). This is the single point for data entry in the EDPD, providing network configuration data to other systems.

The SCADA/DMS is automatically updated from the GIS/SW with the data of the electric HV/MV network, correlating the real-time data with geographical information and having the real-time state of the network updated.

The voltage control function cycle was defined according to the frequency of the RTU measurement archives that occur every 15 minutes, and which were used as input data to the voltage control function.

In case of network reconfiguration the state estimation module should receive from the SCADA/DMS an update of the network topology. This guarantees an exact representation of the topology of the system to provide accurate voltage estimations. When a new Vref is determined by the voltage controller, the system operator has to authorize sending the information to the RTU of the correspondent substation. Then the setpoint of the AVC relays is changed and the RTU sends back to the SCADA/DMS the new assumed value, confirming the change.

As previously mentioned, the AVC realy at the substation interacts with other automation functions in some contingency situations, such as voltage or frequency load shedding and restoration. In these cases, the AVC relay should send an order to the OLTC transformer to return to a pre-defined reference tap. Also in case of capacitor bank switching (based on time scheduling control) the AVC relay should order the OLTC transformer to reduce to a pre-defined voltage in order to reduce the electrical transients. The AVC relay returns to is normal functioning mode only when the other automation functions become inactive.

EXPERIMENTS AND EXPECTED RESULTS

The Portuguese distribution network used to evaluate the Automatic Voltage Reference Setting Controller has 63 MV/LV busbar stations. This MV network is fed by a 60/15kV substation with 10MVA of total installed capacity and an OLTC transformer with 23 taps. At busbars numbered 58 and 62 two distributed generating plants were considered with the capacity of 500 kW and 2 MW respectively. The state estimation algorithm was applied to the network and tested considering real load scenarios, historical load data from the industrial clients and typical daily load curves for the residential and commercial loads.

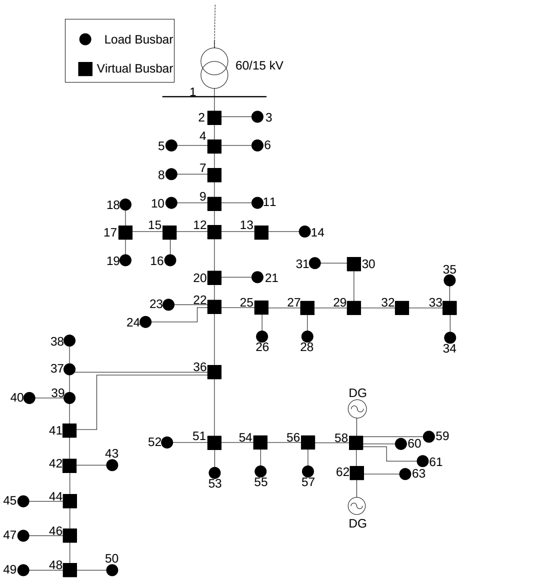

Fig. 4: Portuguese Distribution Network under test

Results have shown that, the average voltage accuracy for the 63 busbars is below 1%. This was obtained running for 500 times the estimation algorithm. For the distribution network under test only one real-time measurement was considered, at the MV busbar of the primary substation.

Fig.5 represents the voltage at MV/LV station 62 where there is a voltage rise effect with the technical voltage limit violated at 40s. When the generation power output increased cause the power flow to change direction and make the voltage went outside of its technical limits. This voltage has not been recognized for the real-time measurement from the MV busbar at the primary substation. However, with the help of the state estimation algorithm, the Automatic Voltage Reference Setting Controller algorithm recognized that the voltage was outside its technical limits and has suggested changing the voltage reference setting for the AVC relay. It was simulated the acceptance by the operator and, as the voltage reference setting changed, it was initiated a tap in the transformer that brought the voltage again into its technical limits. AVC relay voltage reference has been changed from 1.05 pu to 1.029.

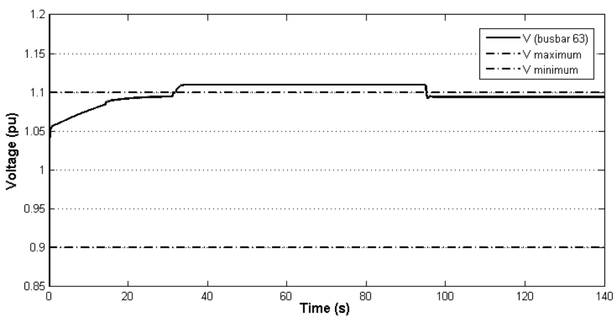

Fig.5: RMS voltage at busbar 63 and its technical limits

CONCLUSIONS

The solution for the Automatic Voltage Reference Setting Controller is based in a centralised voltage control approach. The controller has been simulated in Matlab and confirms that using AVC relays is possible, in some circumstances, to minimize de impact of the connected generation onto the distribution network. Results also show that the use of the voltage controller can increase the DG that may be connected to a feeder as the voltage across the distribution network may be maintain within their technical limits.

Acknowledgments

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