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Advanced voltage control for smart microgrids using distributed energy resources

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ABSTRACT

Large scale integration of distributed generation (DG), particularly based on variable renewable energy sources (RES), in low voltage (LV) distribution networks brings significant challenges to operation. This paper presents a new methodology for mitigating voltage problems in LV networks, in a future scenario with high integration of distributed energy resources (DER), taking advantage of these resources based on a smart grid type architecture. These resources include dispersed energy storage systems, controllable loads of residential clients under demand side management (DSM) actions and microgeneration units. The algorithm developed was tested in a real Portuguese LV network and showed good performance in controlling voltage profiles while being able to integrate all energy from renewable sources and minimizing the energy not supplied.

1. Introduction

Large-scale integration of DER, especially DG but also energy storage systems or controllable loads, at the level of the LV distribution grid presents a set of challenges in order to ensure efficient and secure network operation while guaranteeing quality and continuity of service to end-users [1]. Voltage profiles in particular can be severely affected by the integration of decentralized units, namely based on variable RES [2].

Therefore, it is essential to develop tools for grid operation in order to manage the available DER that may help in solving the technical problems caused by a high integration of RES generation, particularly at the LV level [3]. In this context, the microgrid and smart grid concepts appears as an alternative paradigm for distribution networks that will allow integrating distributed resources with increased flexibility for grid operation, taking advantage of advanced control infrastructures and enabling the provision of ancillary services to the system [4,5].

Several studies addressing the issue of renewable integration in LV networks have been recently conducted and published with interesting results. For instance, the authors in Ref. [6] consider the use of a meta-heuristic to minimize the microgeneration shedding and active power losses in order to avoid voltage violations. In fact, this methodology has proved successful at ensuring that voltage was kept within admissible limits but at the expense of some microgeneration curtailment in LV networks.

Other works such as Ref. [7] attempted to overcome this limitation by utilizing storage systems present in the network in order to store excess energy from microgeneration, thus avoiding renewable curtailment that would be required to control voltage values. The results obtained were encouraging as a good geographical distribution of these storage systems across the network provides a good solution to control voltage levels for the Distribution System Operator (DSO). This enables preventing overvoltages caused by high levels of RES-based microgeneration and simultaneously avoids under-voltage problems by discharging the stored energy during periods of high consumption where the voltage profiles are typically low. Alternative measures include the control of the consumption of domestic customers in LV grids. Accordingly, from the scientific literature, some studies in this field have been performed where different researchers have different methods and technologies with the objective of controlling customers' consumption, for instance Refs. [8,9].

From the foregoing, it is understood that there are different alternatives to integrate the increasing penetration of renewable microgeneration, but few alternatives actually include the combination of all these different DER in order to solve that problem. Consequently, a monitoring and control system that considers the coordinated operation of storage systems, loads under active DSM and microgeneration units can constitute an advance towards

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advanced voltage control in LV distribution networks in the future. The proposed approach consists of an algorithm for day-ahead operational planning control that is run at every hour taking advantage of the available DER for voltage control purposes.

2. Control architecture and management architecture

A microgrid can be regarded as an LV network with microgeneration units, controllable loads and storage devices that can be managed as an active cell of the distribution system in an autonomous way, supported by a control and communication infrastructure [10]. This methodology involves a voltage control tool applied to distribution systems to be installed at the level of the MicroGrid Central Controller (MGCC), *i.e.* at the MV/LV secondary substation. This algorithm should be implemented as a software module dedicated to the operation of the microgrid running every hour in order to define the control actions required to maintain voltage profiles within an admissible range.

There is a wide variety of technologies with great potential for voltage control, associated to different DER. In this work, regarding the voltage control scheme, the following systems at the LV level were considered:

- Storage devices (batteries);
- Controllable loads at the domestic level under DSM actions;
- Microgeneration units (photovoltaic – PV – panels).

This requires that a suitable communication infrastructure be available in order to enable the interaction between the different DER and the control centre. This infrastructure could be based on a smart metering infrastructure, for instance, exploiting communication solutions that can be either wired (such as PLC prime) or wireless (such as GPRS).

For the proposed algorithm, there is also the need to rely on short-term load and renewable generation forecasting in order to define the control actions for the following hour. It is also assumed that the system is completely observable. However, in real life context it may not be necessary to have full observability if adequate state estimation algorithms are used, where the availability of a set of measures with sufficient redundancy may allow obtaining the current state of the system. In the scientific literature, new methodologies for state estimation, Refs. [11,12], which can be applied here, are available and reveal show good results in determining unobservable magnitudes in real-time.

2.1. Storage devices

Storage systems are regarded as a distributed resource to be used by the voltage control algorithm and their characteristics are essential for a proper modelling of these devices. The main features that influence the possibility of storage systems supporting voltage control are the storage capacity, the available power and the efficiency [13].

Usually, the battery connection to the network is ensured by power electronic interfaces such as voltage source inverters. With these devices, it is possible emulate the behaviour of a synchronous machine to use the energy stored in batteries and enable voltage or even frequency control in microgrids [10].

2.2. Controllable loads

Loads at the domestic level may also be regarded as an additional resource for the DSO so that an effective control of the customer's consumption can be exploited in order to solve problems in LV distribution networks, particularly in terms of voltage. A good management of this resource may contribute to optimize the use of electricity, reducing customer costs as well DSO costs. According to Ref. [14], it is possible to define a number of categories for the control of various domestic applications classified as follows:

- Uncontrollable load—loads that may present technical difficulties to control, where a drastic change in consumer habits will potentially cause discomfort;
- Load shedding—electrical equipment which can be switched off for short periods of time without compromising the quality of service and consumer habits;
- Shiftable load—loads that can be shifted in time, namely transferring consumption from peak hours to periods with high microgeneration levels that have no relevant impact on the consumer.

These actions should be implemented respecting some restrictions in order to avoid a drastic change in consumption habits, ensuring that there is no significant discomfort for the customers. For example, equipment such as refrigerators can be interrupted only for short periods of time, without compromising their primary function.

2.3. Microgeneration

Renewable-based microgeneration are non-controllable sources and a source of variable power since they depend on the primary source, which is usually wind (in the case of micro wind generators) or sun (in the case of PV panels).

Therefore, in order to control the voltage profiles, it may be necessary to reduce the active power injected by renewable-based microgeneration units. It is assumed that the control system presented in Fig. 1 is used to send pre-defined values of active power from the MGCC to the MC that controls the inverter and the active power that the microgeneration unit injects into the network. Thus, microgeneration curtailment is presented as a last resource to be used by the advanced voltage control algorithm.

2.4. Control actions

The control actions envisaged are defined through set-points that are sent by the DSO through the MGCC to each load controller (LC) to control or change the electric consumption and to each microsource controller (MC) to control the microgeneration (curtailment of renewable energy) and storage systems (charge or discharge a certain amount of energy). Communication and information exchange between these controllers is assumed to be bidirectional such that the smart meters are able to obtain data at the level of the LV domestic customer such as the electricity consumption and send this information to the MGCC, as illustrated in Fig. 1.

It is expected that the use of smart meters will ease the implementation of programs for managing large-scale consumption in the residential sector. From the point of view of the DSO, an intelligent control of consumption prevailing in this sector will reduce peak demand in distribution networks. With the implementation of smart meters it will be possible to analyse in detail customers' consumption and contribute to a better balance between supply and demand. This will also enable increasing security of supply by integrating microgeneration in a more effective way and easier to control.

3. Mathematical formulation

The proposed procedure involves solving an optimization problem. The main objective consists in minimizing the voltage control