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# A Command Governor Approach for the Voltage Control in Smart Grids with Distributed Generation and Storage Devices

**Alessandro Casavola, Francesco Tedesco and Maurizio Vizza**

*Dipartimento di Ingegneria Informatica, Modellistica, Elettronica e Sistemistica, Università degli Studi della Calabria, Via Pietro Bucci, Cubo 42-c, Rende (CS), 87036, Italy,*
{casavola,ftedesco,mvizza}@dimes.unical.it

**Abstract:** High penetration of Distributed Generation (DG) plants in Medium Voltage (MV) / Load Voltage (LV) power grids may lead to abrupt voltage raises. Typical critical scenarios are represented by either low demand conditions or high power production from renewable sources. Traditional approaches used to face such a situation involve both the disconnection of the distributed generators and the curtailment of the generated power leading to several disadvantages. However, new technologies allow an active orchestration between some controllable devices of the grid, e.g. distributed generators, MV/HV transformers, storage devices in order to maintain relevant system variables within prescribed operative constraints in response to unexpected adverse conditions. This work addresses the online management of distributed generators and storage devices. The approach is based on Command Governor (CG) ideas and is based on the resolution at each time instant of an optimization problem containing explicit constraints related to voltage bounds and operational limits of adopted devices.



Keywords: Voltage Regulation, Smart Grids, Distributed Predictive Control, Command Governor, Storage devices.

## 1. INTRODUCTION

The increasing of small-scale distributed generation plants based on renewable energetic sources paves the way to new applications (e.g. electrical vehicle recharge stations) whose developments would have otherwise required strong investments for further power lines. Anyway the scatter along power grids of local generators gives rise to a number of technical challenges related to their safe exploitation. An important issue induced by the higher and higher level of penetration of DG systems is the voltage rising levels along the distribution feeders. Several approaches have been presented in the literature to cope with this issue. Standard methods foresee an active action of an on-load tap changer (OLTC) in a feeder transformer (Ferry *et al.* [2007]) in order to manage the voltage on the main bus of the MV/LV network. Nevertheless, when a large number of buses are connected to the distribution network, it may become virtually impossible to maintain the buses voltage profiles within their nominal ranges by only acting on the OLTC tap positions, especially when the DG production is high and reverse power flow occurs. A conventional expedient adopted in this case would be the immediate disconnection of the DG sources that cause the voltage limits violation. Unfortunately, many disconnections represent an economic loss for the network and the DG plants would result unusable.

Nowadays DG devices come equipped with inverters capable to control their active and reactive power. This aspect has inspired alternative and more effective approaches for the voltage control that are based either on the active power curtailment (Reinaldo and Lopes [2011]) or on reactive power injection/absorption (Bletterie *et al.* [2012]) or both reactive and active power regulation. All previously mentioned methods carry out a decentralized action on local generators and do not foresee any sort of coordination among them. From one hand this aspect avoids the need of communication infrastructures, on the other hand, without system-wide coordination, sound algorithms are difficult to design. In fact, because control actions are computed on the basis of a partial knowledge of the network, only suboptimal performance can be achieved.

The introduction of advanced power electronic and ICT systems into modern smart grids opened to new communication facilities involving DGs and OLTC and gave rise to several more effective control strategies mainly based on the presence of a central controller (Casavola *et al.* [2011]) capable of monitoring and managing the entire MV/LV grid.

More recently the use of storage devices in the grids, usually exploited to increase self-consumption, quite often represents a new degree of freedom with respect to the voltage control problem. In fact, without any storage facility, the possibility to transfer reactive power exists only when the generators are able to inject active power too. On the contrary, the presence of storage devices allows one to inject/absorb reactive power also when the local


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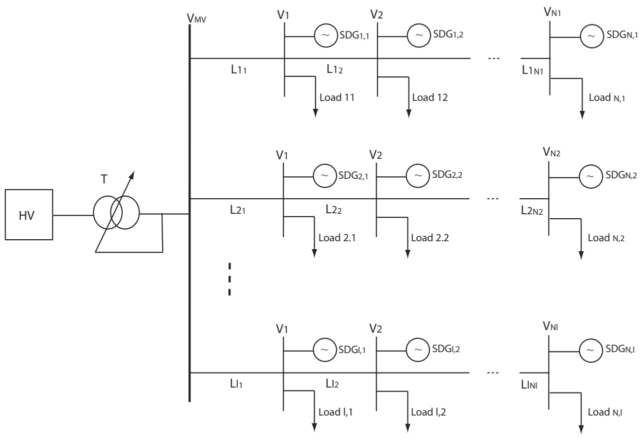


Fig. 1. Distribution Network Scheme

generators are not able to transfer active power, moreover they can be controlled to minimize the curtailment of DC source during overvoltage conditions.

This paper proposes a Command Governor (CG) (Bemporad *et al.* [1997]) supervision scheme for the online coordination of OLTC, DGs and storage devices for the optimal active power loss reduction and minimization of voltage deviation from nominal conditions in the presence of time-varying loads. In particular, here we extend the work presented in Casavola *et al.* [2017] to the more challenging case where storage units are present at generator sides.

The CG is an effective methodology for supervising a system within pointwise-in-time set-membership constraints on relevant variables. It can be used to modify the set-points of the controlled devices of the grids in such a way that input/state constraints are satisfied while maintaining tracking performance (Gilbert *et al.* [1995]).

Following the same lines of Casavola *et al.* [2017], the CG based strategies will be introduced and shown to be effective in accomplishing the voltage control problem.

The paper is organized as follows. The problem of the voltage control for MV power grids is stated in Section II. In Section III, the CG design scheme is presented for the problem at hand. Computer simulations are finally presented in Section IV and some conclusions end the paper.

## 2. PROBLEM STATEMENT

### *2.1 Control Oriented Modeling*

Power grids under analysis can be described through the general scheme depicted in Figure 1 that represents a generic radial distribution network operating in medium/low voltage (MV/LV). There $l$ feeders are supplied through the main MV bus by an HV/MV transformer equipped with *on-load tap changers* (OLTC). The $j$-th feeder consists of $N_j$ nodes to which small size generators and/or loads are connected. Both loads and generators, the latter supposedly consisting of small-size renewable energy generators (wind, sun, hydro, etc.), are characterized by a high degree of uncertainty because they follow the customer behavior and the primary source availability. It is assumed that distributed generators are endowed with "smart" functionalities in the sense that it is possible to specify, within certain limits, the desired amount of active/reactive power to be provided/absorbed with respect to the grid. For this reason in the paper they will be denoted as Smart Distributed Generators (SDG). Moreover, it is assumed that each generator has a direct link with a local storage device. Without loss of generalities the voltage at the secondary sides of the HV/MV transformer can be modeled as an ideal voltage source ($\bar{E}_{MV}$), whose amplitude can be controlled by the OLTC tap positions. In order to present a mathematical model of the above described network, it will be assumed the presence of balanced loads only, symmetrical generation and a linear network behavior. Under such assumptions the network of Figure 1 can be represented by the single-phase equivalent circuit depicted in Figure 2 (see Casavola *et al.* [2011] for details), where the set of $N = N_1 + N_2 + ... + N_l$ nodes is highlighted.

The following notation will be adopted

$$\begin{aligned} &\dot{Z}_{L_i} \triangleq R_{L_i} + jX_{L_i}, i = 1, ..., N, \\ &\dot{Z}_{C_i} = R_{C_i} + jX_{C_i}, i = 1, ..., N, \\ &\bar{E}_i(t) \triangleq E_{D_i}(t) + jE_{I_i}(t), i = 1, ..., N, \\ &\bar{E}_{MV}(t) \triangleq E_{MVD}(t), \end{aligned} \tag{1}$$

where the electrical parameters: $\dot{Z}_{L_i}, R_{L_i}$ and $X_{L_i}$ denote respectively the line impedances, resistances and reactances, $\dot{Z}_{C_i}, R_{C_i}$ and $X_{C_i}$ the nominal load impedances, resistance and reactances, $\bar{E}_i(t)$ and $\bar{E}_{MV}(t)$ complex numbers representing respectively the voltages on the $i$-th node and on the HV/MV transformer secondary side. For

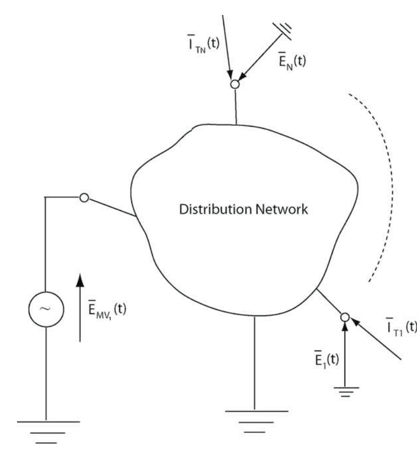


Fig. 2. Equivalent circuit

the same reason, also each SDG unit will be assumed to consist of linear subsystems and represented as a current generator, namely

$$\bar{J}_i(t) \triangleq J_{D_i}(t) + jJ_{I_i}(t) \tag{2}$$

Also in this case the currents $\bar{J}_i(t)$ drawing into $i$-th node are represented in complex form. In particular, notice that the $i$-th generator, being a smart device, allows the manipulation, within certain limits, of its generated complex power $\bar{S}_i(t) \triangleq \bar{E}_i(t)\bar{J}_i^*(t) = P_i(t) + jQ_i(t)$, where $P_i(t)$ and $Q_i(t)$ denote active and reactive power respectively.

In the proposed setting, each SDG is provided with a local storage device that is modeled via a quasi-kinetic