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Control of Distributed Energy Resources in Low-Voltage micro-grid/Grid Units

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ABSTRACT

This paper deals about the control of low-voltage micro-grids with supplier/consumer architecture. Distributed energy resources (DERs) are interfaced to the grid by means of conventional inverters and a micro-grid supplier controller governs the interaction between the utility and the micro-grid at the point of common coupling with the main grid. The power sharing with the available resources is achieved by the power-based control, a technique which allows to pursue both local (Distributed energy resources level) and global (micro-grid level) optimization goals. The paper focuses on how to attain effective modes of operation in micro-grids for the considered approach can be employed. Simulation results for the proposed approach are finally provided and discussed with the algorithm.

I. INTRODUCTION

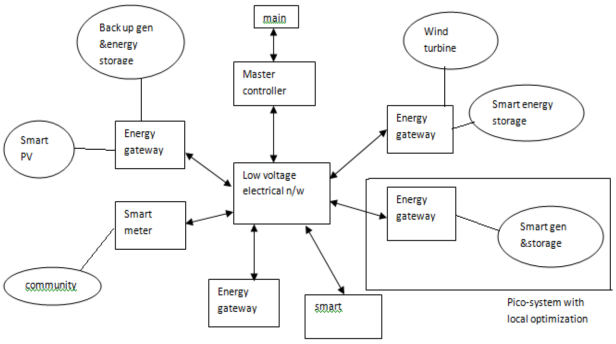
Low voltage micro grid play important role in future smart grids. The presence of distributed micro-generation and energy storage owned by end users results in a new prototype for electrical grids and in a potentially new and energetic market for technology manufacturers, service providers, energy trader, distributors, and regulatory boards.

The main features of a smart micro-grid are highlighted in Fig. 1. Some of the peculiarities of such kind of electrical systems are: high infiltration of distributed energy resources (DERs) connected to a low-voltage electrical network, presence of communication links among resources, and presence of a point of coupling with the main grid (i.e., the mains). In this scenario consumers can aggregate to participate to the operation of the micro grid by deciding to make available part of their resources, for example, to receive, in exchange, economic benefits.

The power electronic converters interfacing DERs to the grid play here a key role, since they enable extensive power control flexibility, as well as the capability of synergistic use of every available energy resource. Therefore, proper control schemes aiming at coordinating the operation of interface converters will guarantee efficient and sustainable integration of green technologies in low-voltage distribution grids. On the other hand, a high penetration of DERs leads to specific technical challenges that include the management of production intermittencies and energy surplus, and the maximization of the return of investment .In this paper two main issues of low-voltage micro-grids are addressed. The first is the regulation of the power flow at the interface between the micro-grid and the main grid. The possibility of regulating the micro-grid power absorption is a valuable feature from the point of view of the distribution system operator. In the proposed control scheme this feature, called dispatch ability, is attained by exploiting DERs on the basis of their availability in contributing to microgrid's needs. To this end DERs are assumed to be able to communicate—to a centralized controller—their flexibility in participating in the control and to accept, as response, some directives on the required power injection. This allows to define a proper sharing of the load among generators and, in addition, to regulate the power flow at microgrid's PCC. These two objectives usually concern, respectively, the primary and tertiary control level of traditional droop control hierarchies.

The second issue addressed herein, that is, the violation of assigned voltage constraint at micro-grid nodes, represents an undesirable operating condition that need to be managed in order to preserve the quality of the voltage delivered to the consumers. Besides, uniform voltage profiles along the feeders indicates an adequate utilization of the distribution lines, which is advantageous in terms of reliability and efficiency . This issue is tackled herein by integrating in the centralized control scheme a dynamic over voltage control technique that allows to coordinately accommodate both the local voltage constraints and the regulation needs at the PCC of the micro-grid. The resulting supplier/consumer control scheme is applied to guide, in a centralized manner, the operation of DERs, while local regulators, embedded in DERs, provide a precise control of active power injection if the measured voltage at the point of connection transcends the nominal operating range.

It is worth remarking that the control approach investigated herein was originally proposed , where it is referred to as *power-based control*. In the present paper, a formal and more detailed description of the underlying algorithm, with a different local control rule, is proposed. In addition the stability analysis of the control is introduced and specifically addressed in terms of local and global properties.



Smart-grid scenario

II. CYBER-PHYSICAL MODEL OF A SMART MICROGRID ARCHITECTURE

The figure highlights the two layers composing the microgrid structure, namely, the electrical layer and the cybernetic layer. The electrical layer represents the electrical infrastructure, comprising, in particular, the mains, the distributed energy resources, and the electrical distribution network. The cybernetic layer represents the information and communication technology (ICT) infrastructure needed for the monitoring and control of the electrical layer, and comprises the sensors, the computation units, and the communication modules and links.

Electrical physical layer

The electrical physical layer can be conveniently modeled as a directed weighted graph $G = (V, E)$ where V is the set of nodes (i.e., the *buses* of the electric grid) and E is the sets of edges representing the power lines. To each edge e we associate a weight that corresponds to the value of the impendance Z_e of the electric line described by e; specifically

$$Z_e = R_e + jX_e,$$

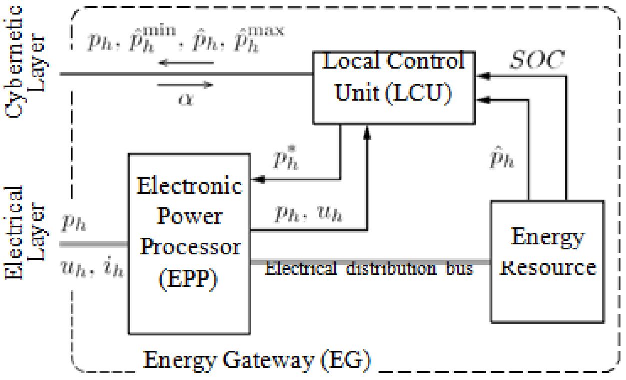
where R_e and X_e are, respectively, the resistive and the inductive component. Because low-voltage grids are addressed herein.

we assume that,

$$R_e / X_e >> 1$$

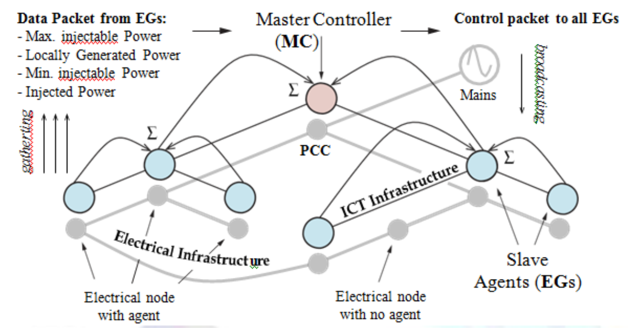
for each $e \in E$, namely, that the interconnection lines are resistive, which is a typical situation in low-voltage grids.

The nodes of the electrical grids can be either *distributed energy resources* or *loads*. A distributed energy resource that can be controlled to contribute to microgrid power needs is herein referred to as an *energy gateway* (EG). The structure of an EG. In addition to the energy resource, which can be a combination of renewable sources and storage devices, an EG is equipped with a local control unit (LCU) and a power electronic processor (EPP). The LCU collects all the quantities needed to determine the state of the local resources and generates the reference set-point of the power to be injected to grid.



Structure of an Energy Gateway (EG)

In this paper a supplier/consumer controller is proposed to supervise the operation of a microgrid. We assume that the *supplier controller* (MC) is located at the PCC of the microgrid and that the EGs, which are geographically distributed, play as consumer units. Both the MC and the EGs are provided with some computational capability and with some sensing capability; specifically, they can sense the electrical quantities of interest (i.e., power and voltage magnitudes) at their point of connection within the electrical layer. Finally we assume that the supplier unit (i.e., the MC) can communicate with the consumer units (i.e., the EGs) via a communication channel, which may be, for example, the same power lines.



supplier/consumer microgrid architecture the with power-based control algorithm

III. A MODEL-FREE POWER-BASED CONTROL ST-RATEGY

In this section we propose an algorithm which regulates the power injection of each EG so that:

- the power flow at the microgrid's PCC (i.e., the PCC power flow) follows a pre-assigned profile
- the voltage magnitudes at the point of connection of the EGs are below a given threshold U_{max} (usually given as a percentage of the nominal voltage magnitude).

For the sake of clarity, only the control of the active power is considered in this paper. A similar approach can be employed also to regulate the reactive power injections from EGs, as outlined in [9].

We assume that each EG regulates the injection of active power every T seconds and we refer to the time interval$[(\ell - 1)T, \ell T]$ as the ℓ-th cycle of the control algorithm.

To the end of regulating the PCC power flow, the interaction among the MC and the EGs takes place in two phases. In the first phase, the supplier controller *gathers* from each EG a data packet that conveys the information of its local energy availability; in the second phase, the supplier controller *broadcasts* to all the EGs a common control packet that is finally translated by each EG into a particular power reference.[2]

In this paragraph, the details on how the proposed algorithm operates are explained more formally. For $h \in \{1, . . . , m\}$, where m denotes the number of EGs in the microgrid, let EG_h denote the h-th EG. Then, for $h \in \{1, . . . , m\}$, at the beginning of the $(\ell + 1)$-th cycle, that is, at time instant ℓT, EG_h sends a data packet to the supplier controller containing the following information:

- the measured active power $p_h(\ell T)$, namely, the active ower injected by EG_h, at time instant ℓT; (For convenience quantities are denoted in the following simply by indicating the relevant control cycle, therefore, for example, by using $p_h(\ell)$ in place of $p_h(\ell T)$.)
- the estimated active power $\hat{p}_h(\ell + 1)$ that will be generated by the local renewable source in the current control cycle, namely, during the time interval $(\ell T, (\ell + 1)T)$—this estimate can be done on the basis of the status of the adopted renewable source

(e.g., irradiation measurements for photovoltaic modules);

- the estimated minimum active power $\hat{p}^{min}(\ell + 1)$ and maximum active power $\hat{p}^{max}(\ell + 1)$ that the EG can inject during the current control cycle by taking into account all the local constraints, including the maximum power that can be delivered ($\hat{p}^{out}_{Sh}$) or absorbed ($\hat{p}^{in}_{Sh}$) by the local energy storage unit; in particular:

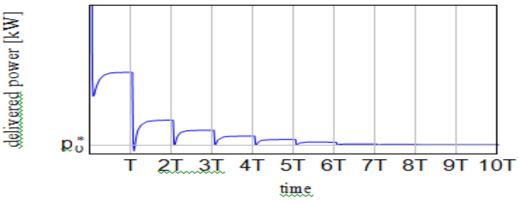
  – if $|u_h(\ell)| < U_{max}$ (i.e., no voltage violations), then

  $$\hat{p}^{max}_h(\ell + 1) = \hat{p}_h(\ell + 1) + \hat{p}^{out}_{Sh}(\ell + 1) ,$$

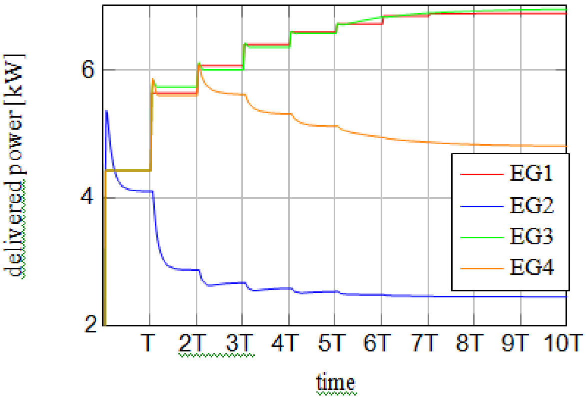
IV. SIMULATIONS

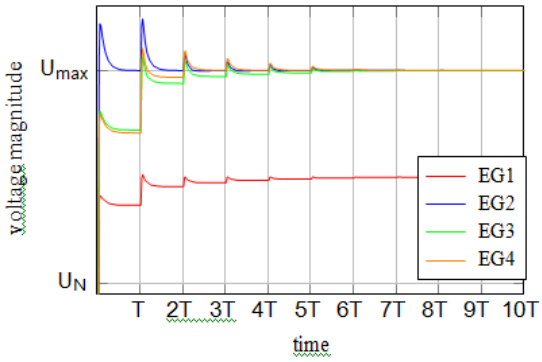
In this section, we simulate Algorithm I on a realistic low- voltage network, sketched in Fig. 4. It represents an actual distribution grid located in Brazil. The network interconnects ten nodes, which represent ten houses. Four of them are equipped with an EG (see Fig. 3) and a load, while the others behave like passive loads. The MC gathers the data from the EGs and sends them back the coefficient α_p every T = 5 seconds, while the EGs measure their voltage magnitude every 0.1 s and possibly perform the local voltage control.

Clearly the simulation test bed does not satisfy the sim- plifying assumptions we made for the algorithm description (e.g., the linear relation between voltages' magnitudes and powers), being the electrical grid a highly non-linear system. In spite of that, Fig. 5, Fig. 6, Fig. 7, show the effectiveness of this realistic scenario.



Finally, we report the values of the sequence α(ℓ) generated by the MC; we can see that α(ℓ) converges to a limit value $\bar{\alpha}_p$ as predicted in Proposition 1.





V. CONCLUSION

This is a simple approach to the control of low voltage on micro-grid by using distributed energy resources was presented and analyzed. The centralized controller, in turn, broadcasts active power set- points for all the active nodes.

The power flow control which is taking place mainly, at microgrid PCC and in the local overvoltage control which is performed distributedly, at each Energy Gateway co-operate so that both the voltage magnitudes at the point of connection of Energy Gateway and the power flow at microgrid PCC and can be simultaneously regulated.

The controller was tested by simulations referring to a realistic application scenario. The results have shown that the power-based control strategy succeed in controlling the active power exchanged at PCC and avoids local microgrid based on this paper algorithm is under progress.

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