COOPERATIVE CENTRALISED AND DECENTRALISED ENERGY MANAGEMENT SYSTEMS FOR ACTIVE NETWORKS

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ABSTRACT

The paper proposes a hierarchical control for active networks that integrates both centralized and decentralized EMS. One day-ahead, the centralized EMS schedules the dispatching of the active resources for the next day. In real-time operation, the intraday optimization adjusts the day-ahead scheduling for technical (e.g., to relieve voltage contingencies or resolve current congestions) or economical (e.g. losses reduction) reasons with a decentralized EMS. The effectiveness of the proposed procedure has been tested on the Italian representative networks produced by the research project ATLANTIDE.

INTRODUCTION

In active distribution networks, Distributed Energy Resources (DER) share responsibilities for network operation with the Distribution System Operator (DSO). Distributed Generation (DG), storage devices, and active demand can be used to fix distribution network issues such as voltage regulation and power congestions, and to offer high value services to the Transmission System Operator (TSO). In order to achieve these results, modern Distributed Management Systems (DMS) integrate advanced Energy Management Systems (EMS), SCADA and distributed measurements. The debate between centralized and decentralized DMS/EMS is still open even though the vast majority of real applications are based on light decentralized systems with a control system that operates in Primary Substations and controls all resources spread into the supplied system. The major drawback of such systems is represented by the difficulty to operate in quasi-real time systems with storage capabilities (i.e., electric, thermal and mechanical storage) in real scale applications. On the other hand, simulations and experiments proved that decentralized DMS can significantly reduce the amount of information exchange among players and, as consequence, be applied in real time applications.

The paper proposes a hierarchical control for active network that integrates both centralized and decentralized EMS according to the relevant time scale. The centralized EMS schedules the dispatching of the active resources for the incoming day based on medium term forecasts (i.e., resulting from the forecast of local demand and generation). This is called day ahead optimization and aims at coordinating the DER in the system so that the operation cost is minimised while all technical constraints are complied with. This optimization technique, if applied in systems with storage devices, allows planners to find the optimal way to use storage capabilities. Anyway, since predictions have inaccuracies, a correction of the day ahead optimal schedule is normally necessary. This correction is called intraday optimization and involves the real-time operation of the system. The intraday optimization adjusts the day-ahead scheduling for technical (e.g., to relieve voltage contingencies or resolve current congestions) or economical (e.g. losses reduction) reasons. In the paper this function is performed by a decentralized EMS proposed by the authors.

CENTRALISED ENERGY MANAGEMENT

In the centralized EMS (Figure 1), the OPF optimizes an objective function that is the sum of the operational expenditures related to the active management of the distribution system by making all technical constraints (e.g., line thermal limits, nodal voltage, reserve, etc.) complied with. The economical optimization is based on price signals, which coordinate the participation of DER in Volt/VAR regulation, and the use of storage and active demand. A window of one day duration is considered in order to find the optimal operation of electrical storage.

The EMS resorts to the following operation options [1]:

- Tap optimization of the On Load Tap Changer (OLTC) transformer;
- Active power generation curtailment (GC): this option can be useful to face overvoltage conditions. High prices reduce the curtailment of Renewable Energy Sources (RES);
- Active power injection from programmable generators;
- Volt/var regulation with DG and storage;
- Demand Side Integration (DSI), to involve customers that participate to Active Demand (AD) programs in the active management of the network; the effect of

AD is modelled including the payback effect [2]-[3] for a better representation of its real impact;

- Energy losses minimization to improve the total energy efficiency;
- Storage devices charge and discharge used for load levelling and voltage regulation [4].

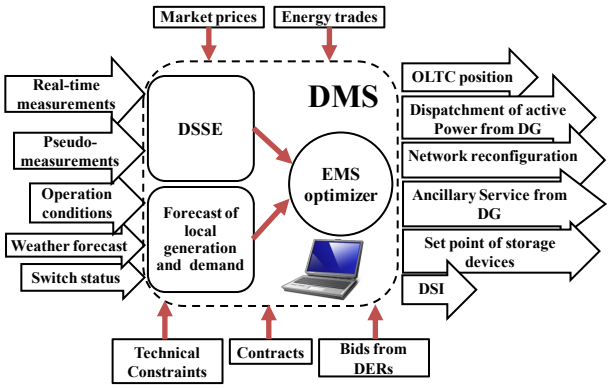

Figure 1. Architecture of the centralized EMS.

The OPF can be solved with several techniques as non-linear programming (NLP), linear programming (LP) or mixed-integer linear programming (MILP). Computing time, reliability and ability to handle many different operating constraints suggest a linearization of constraints. For that reasons, in the proposed application the MILP has been used, where the integer constraints are used to properly model the constraint related to the OLTC position.

DISTRIBUTED CONTROL SYSTEM

The aim of the distributed control strategy adopted for this work is to allow the distributed resources connected to the grid to participate to the network regulation by changing their active power production and reactive power exchange [5], [6].

The hypothesis assumed in this paper is that a suitable communication infrastructure exists in the grid together with some end-user automation, allowing the customers to react to signals coming from the Network Supervisor (e.g. requests for regulation support associated to an economic offer).

In particular, the control inputs are the bus voltages and branch currents since the aim is to secure a safe operation of the network while maintaining the voltage levels within a given allowed band. The strategy eventually includes actions coordinated with the remote voltage measurements by the Primary Substation's OLTC with aim to help the voltage regulation.

To suitably adjust the voltage magnitude at the MV busbar downstream the Primary Substation a sort of voltage compound is acted basically by trying to balance the voltage deviations on the feeders as presented in [6].

The approach used for the distributed regulation consists in defining regulation areas grouping network buses characterized by similar working conditions and therefore having common regulation objectives. This process is made possible by a sensitivity analysis on the network, allowing the definition of the electrical distance between the buses and their influence in solving the contingencies while taking into account the actual operating conditions (i.e. power flows and voltage values) and therefore adapting the selection to the situation. A conceptual scheme of the decentralized EMS is depicted in Figure 2.

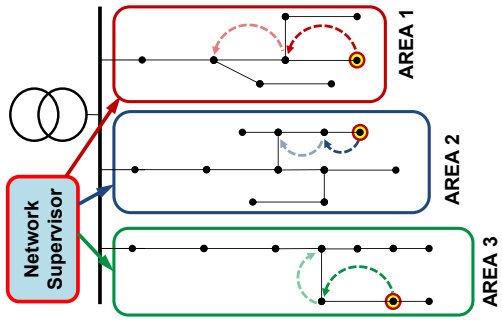

Figure 2. Conceptual scheme of the distributed control strategy.

A central unit, called Network Supervisor (NS), acquires the remote voltage and current measurements and identifies the regulation areas through the sensitivity analysis. At this point the power contribution requests (active and reactive power) are forwarded to each area, starting from a "pilot bus" (circled in Figure 2) which is the more influent one in the process of solving the contingency (i.e. bus with the worst voltage or the closest node to the congested branch). When receiving the request signal, the customers can decide whether to participate or not to the regulation depending on the local availability and convenience.

The message is then forwarded to the next bus and the process continues until the total contribution matches the request or the maximum regulating power availability is reached.

Differently from the centralized EMS, aim of the distributed control system is to enable the participation of DERs to the regulation strategy without a power dispatching but rather through a supply-and-demand mechanism based on the DERs reaction to the NS technical and/or commercial requests. For this reason, assuming different costs for each resource, the DERs will participate or not depending on the economical offer made by the NS.

COOPERATIVE ENERGY MANAGEMENT SYSTEM

The two regulation strategies described in the previous two sections, although differing for the approach in calculating and fulfilling the power contributions from DERs, are similar for what concerns the local costs.

The centralized EMS calculates the DERs active and reactive power contributions by considering the relative local cost and by using it as a variable to weight their

availability in the power flow optimization.

The distributed EMS, differently from the centralized one, relies on the regulation areas procedure described in in the previous section for the request fulfillment but the availability of DGs is still driven by a comparison between the price offered by the NS and the DER's local cost. With this kind of approach, even if not dispatching the power set-points, the distributed EMS still considers the local costs as an availability factor.

With the considerations made so far, the two EMS are then used in a "synergized" fashion, by adopting the centralized EMS with a generation and load forecast in the day-ahead operation and then by applying the distributed EMS as the intra-day control strategy.

CASE STUDY APPLICATION

The case study network is one of the Italian reference distribution networks identified in the ATLANTIDE project [7]. In particular, this network was selected as representative for the rural context, consisting in 103 MV nodes supplied by one HV/MV substation and disposed on 7 relatively long feeders (mostly small cross section overhead conductors for a total extension of about 160 km) the longest being around 25,5 km. One 25 MVA 132/20 kV transformer is located in the Primary Substation, which is also equipped with an OLTC device providing the Automatic Voltage Regulation (AVR) at the secondary busbar (bus no. 2 in Figure 3).

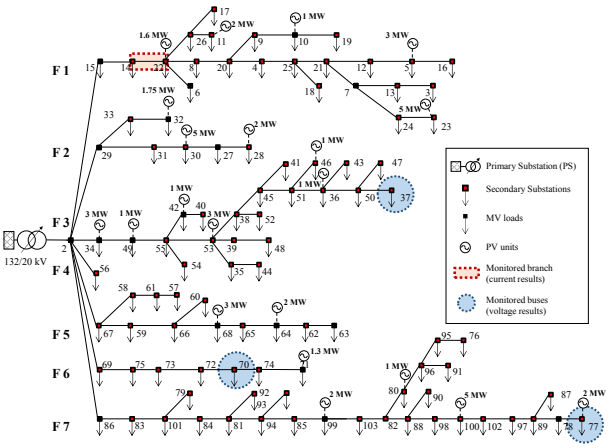

Figure 3. Single-line diagram of the MV case study network. The branch and buses selected to show the results are highlighted.

The scenario chosen for the application has been defined in the ATLANTIDE Project as *Roadmap* and considers an intensive growth in the number of photovoltaic distributed generators [8]: the simulations discussed in the following refer to the year 2020 in which the amount of PV installed power is expected to be around 47.8 MW. The nominal load - a mix of agricultural, residential and small industrial customers - is about 18.8 MW at the peak (with a power factor equal to 0.9 lagging).

As mentioned in the previous sections, since the control strategies presented in the first two sections are complementary, the Centralised Energy Management System (C-EMS) has been employed to calculate, basing on the forecasts, the active and reactive power contributions by DGs. The Distributed Control System (DCS) instead is supposed to run in the intra-day operation, adjusting the active and reactive power flows in order to reduce the current and voltage contingencies deriving from the inaccuracies in the forecast as reported in **Errore. L'origine riferimento non è stata trovata.** and Figure 4.

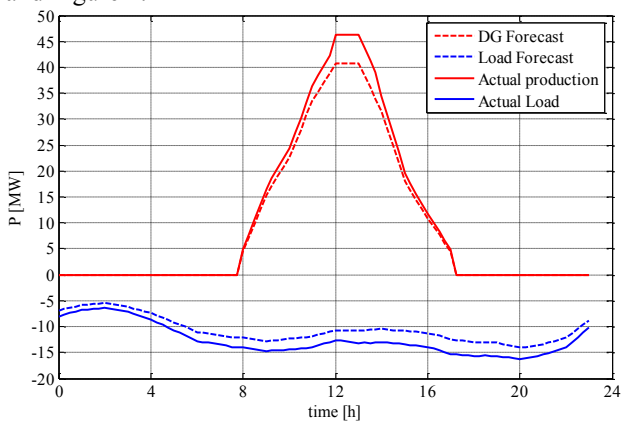

Figure 4. Forecast and actual DG production and load.

Table 1. Comparison between forecasted and real energy.

	Forecast [MWh]	Reality [MWh]
DGs	219	242
Loads	248	293

As a working hypothesis, it has been assumed that the remote voltage measurements are available in real-time for the network operator though a suitable communication system so that in the intra-day operation the OLTC device can be operated through the control logic described in Sec. III. The simulations have been performed over a 24-hours interval, involving three different degrees of control as reported in Table 2:

- Scenario A: only the coordinated OLTC control capability is considered;
- Scenario B: the DG units provide the active and reactive power contributions established in the day-ahead operation;
- Scenario C: the DG units provide the contributions coming from the day-ahead operation and are available for the intra-day distributed control.

Table 2. Definition of the simulation scenarios

	OLTC	Centralised	Distributed
Scenario A	✓	✗	✗
Scenario B	✓	✓	✗
Scenario C	✓	✓	✓

In Figure 5 the total active and reactive power contributions from DGs are shown for all scenarios.

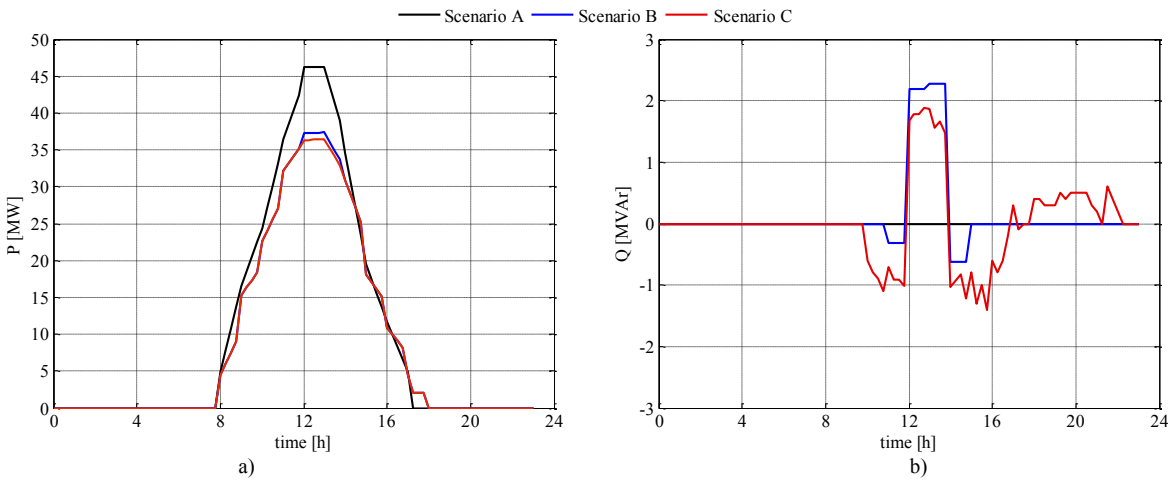

Figure 5. Active (a) and reactive (b) power exchanged by the DG units in the three scenarios.

In Scenario A the active power injection is about 45 MW at the peak hour (around 12:00), while the reactive power production is equal to zero during the entire 24-hour interval. Since Feeder 1 is characterized by the highest active power injection by DGs, the branch highlighted in Figure 3 has been selected to show the line loading results, reported in Figure 6. As it could be seen, in Scenario A the inverse power flow during the high production period lead the line loading to an unacceptable level (more than 75% over the rated current).

The results in terms of the bus voltages of some significant nodes of the network (highlighted in Figure 3) are reported in Figure 8, where the different scenarios are compared with the not regulated situation in which the OLTC is used simply as an AVR based on the secondary busbar voltage. In Scenario A the coordinated action of the OLTC (shown in Figure 7) leads to an improvement in the voltage deviation, but nevertheless is not able to maintain the voltage value in all feeders neither within the objective regulation band (green area) nor within the maximum acceptable band (dashed area).

In Scenario B, the active and reactive power contributions by DGs deriving from the day-ahead operation through the Centralised Energy Management leads to a sensible reduction of the congestions, as could be seen in Figure 6, mostly due to the active power curtailment (reduction of about 10 MW overall during the production peak period).

As shown in Figure 8, the voltage deviation on the feeders is maintained within the maximum acceptable range as a result of the active and reactive power regulation supporting the OLTC control and allowing it to be further exploited as can be seen in Figure 7 in the period 12:00 – 14:00.

It appears clearly that the unpredicted variations in the produced and absorbed power cause the voltage and current values to overcome the ranges adopted as objective.

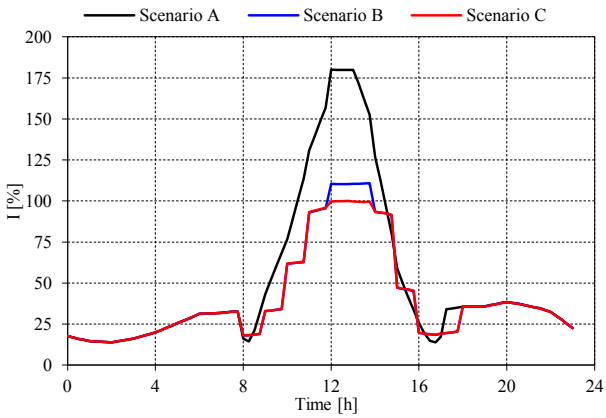

Figure 6. Line loading of the branch between buses 14 and 22.

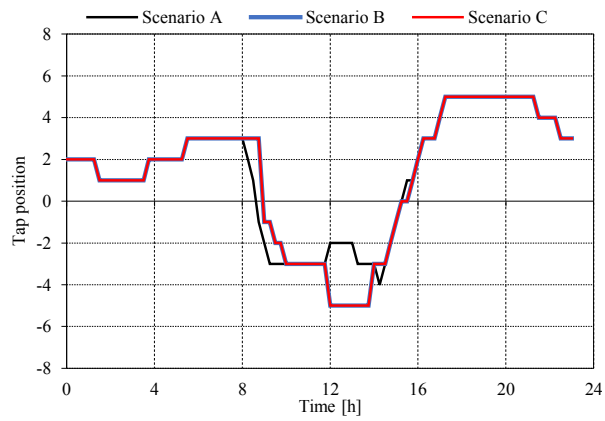

Figure 7. Tap position of the OLTC: Scenarios B and C.

Scenario C considers the participation of the DGs in the intra-day operation too, by allowing facing the unexpected variations in the power flow. As it can be seen in Figure 5, a further small reduction in the active power is required to the DGs in order to reduce the loading of the branches wheareas the reactive power support permits a better regulation of the voltages, allowing the objective range to be respected although not varying the OLTC coordinated action, already depleted in Scenario B.

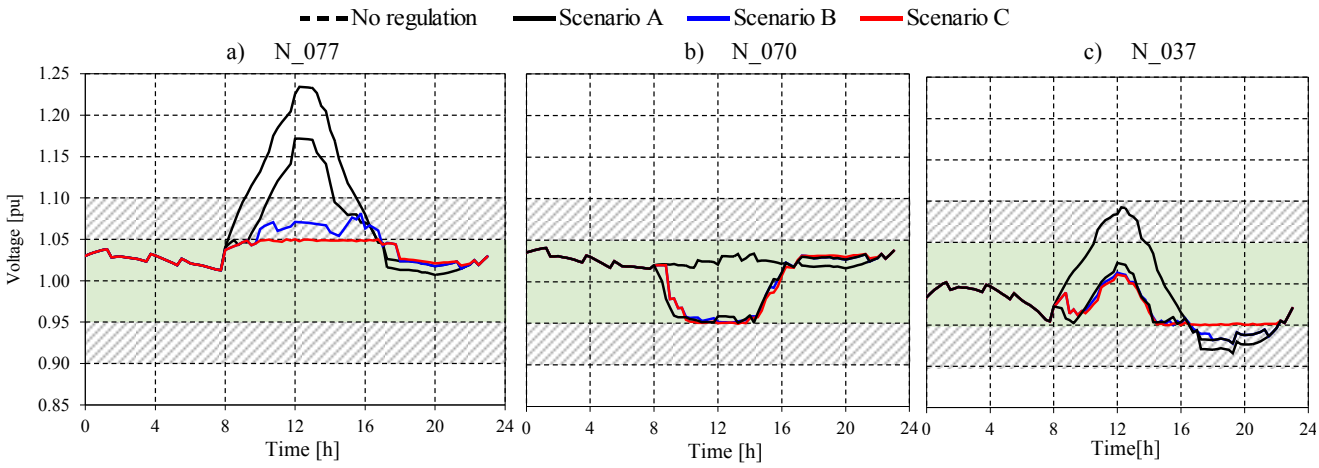

Figure 8. Voltages during the 24-hours interval for buses 77, 70 and 37. The "No regulation" scenario refers to the condition in which the only regulating action is the Automatic Voltage Regulation by OLTC based on the secondary busbar voltage.

CONCLUSIONS

The paper presents a hierarchical control for active network that integrates both centralized and decentralized EMS. In particular, the proposed methodology works on two different time levels. One day-ahead, the centralized EMS schedules the dispatching of the active resources for the next day. The optimization starts from of the expected state of the network (i.e., resulting from the forecast of local demand and generation), aggregates the bids that the DERs owners place in the market, and, subjected to the technical constraints and according to the market rules, finds the optimal scheduling of the active and reactive powers set points of DERs. In the real-time operation, the intraday optimization adjusts the day-ahead scheduling for technical (e.g., to relieve voltage contingencies or resolve current congestions) or economical (e.g. losses reduction) reasons with a decentralized EMS.

The effectiveness of the proposed procedure has been tested on the Italian representative networks produced by the research project ATLANTIDE.

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