APPLICATIONS OF DMS IN THE ATLANTIDE PROJECT: MODELS AND TOOLS

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ABSTRACT

The paper presents some significant results of an exstensive modelling activity being carried out within ATLANTIDE, an on-going Italian Research Project, for studying the active distribution networks under different evolutionary scenarios. The attention is focused on the DMS and its integration with Active Demand side integration with particular reference to urban distribution networks. The results confirm that the developed models, which will be soon made available to the ATLANTIDE community for use with common power flow software packages, are well suited for simulating the operation of modern distribution management systems

INTRODUCTION

ATLANTIDE is a three years research project funded by the Italian Ministry of Economic Development under the framework of the Italian Research Fund for the development of the Italian Power System. ATLANTIDE aims at realizing a repository of reference models for both passive and active LV and MV distribution networks, specifically tailored to the Italian distribution system. The models of reference networks, generation units and loads, and other equipment (e.g., switchgear and relays, Distribution Management System (DMS), etc.) are stored in a database containing their typical characteristics. References models constitute a comprehensive dataset to be used for studying medium and long term predictable scenarios, taking into account the development of the distribution system originated by the load consumption evolution, the widespread integration of distributed and renewable generation, and distribution storage devices [1, 2, 3]. The predictable evolutionary scenarios for the distribution system may require high rate of capital expenditures if faced with traditional network solutions. The use of operation techniques at the distribution level allows the system to increase the hosting capacity of a distribution system without jeopardizing reliability and minimizing both capital and operational expenditures [4, 5]. The original ATLANTIDE technical-economic models for the optimal coordination of Distributed Energy Resources (DER), Distribution Energy Storage (DES) and Active Demand (AD) demonstrate the capability to be a suitable alternative to massive network investments in various predictable scenarios. These models are part of the Distribution Management System (DMS) chain that can be easily simulated in ATLANTIDE with different software packages.

The DMS optimizes an objective function that is the sum of the operational expenditures related to the active management of a given distribution systems. The terms of the objective function can be user-defined to match with the specific features of rural, industrial and urban networks. For instance, in the rural networks, characterized by long overhead lines with high X/R ratio, the participation of the generators to the Volt/VAR regulation is a valid opportunity that might be effective to reduce the curtailment of the renewable power production for overvoltage. In urban networks, the participation of the final users to AD programs for load levelling and peak shaving leads to an increase of hosting capacity with less capital expenditures (e.g., deferment of investments for the addition of a second transformer in the substation). In industrial networks, energy storage might be a much easier to implement option and the DMS can take benefit from an optimal operation of storage for both energy and regulation services.

In this paper the attention has been focused to the integration of AD in the optimal operation of Active Distribution Systems. Firstly, the AD models used in ATLANTIDE are described with particular reference to the true response of loads to aggregators and DSO request of participation to the operation of the system. Secondly, the models for taking into due account the increasing of load demand subsequent to demand side action are also described. Thirdly, an urban network available in the ATLANTIDE database is also described. This network shows the typical characteristics of urban systems that can obtain the highest benefit from the exploitation of demand side integration. Finally, the ATLANTIDE model of a centralized DMS has been applied to the selected urban network to demonstrate the worth of the participation of AD in active management.

ACTIVE DEMAND MODEL

In ATLANTIDE, following the experiences made by other EU projects, the AD is expressed as a variation of load with respect to a reference profile representing the load without any participation to demand side integration [5]. The model introduces the concept of flexibility that is the power an active user makes available to a DMS expressed as a power reserve provision (downward or upward) related to a specific price/volume bid. An example is reported in Fig. 1, where the case of differentiated rates, day/night tariffs, that encourage end-users through a price signal to concentrate consumption in bands with lower price, is considered. For a residential customer, the price difference between the two main bands is 2 c€/kWh.

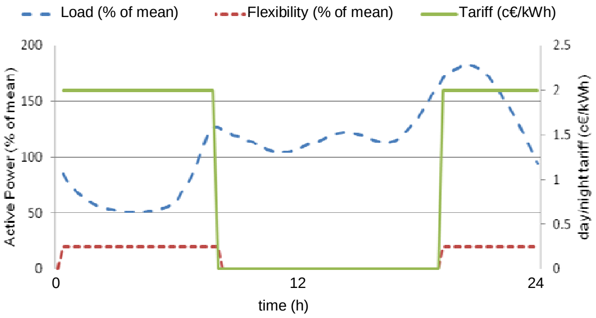

Fig. 2. Flexibility profile of a residential customer with day/night tariffs.

For a given area, basing on the concept of flexibility, the DMS or the aggregator sends the request of AD to the final customers expressed in terms of power, AD^{req}. Usually, the response of the loads involved in AD, AD^{true}, does not perfectly match the request because customers have to be free to decide if and how much contribute to the operation of the distribution system. For these reasons, in the presence of AD, at a certain time interval *k*, the load energy consumption will be the summation of the base load, $b(k)$ and the effective contribution to demand side management, AD^{true}, (1).

$$y(k)=b(k)+AD^{true}(k). \qquad (1)$$

The simplest way to model AD^{true} is with Finite Impulse Response (FIR) filter, as showed in (2).

$$AD^{true}(k)=\sum_{i=0}^{2} f^{i} AD^{req}(k-i)+n(k) \qquad (2)$$

The weights f^0, f^1, and f^2 are the model parameters, which take into account the customer's level of willingness to accept the request to curtail the consumption (f^0), but also the effect of precedent curtailments (f^1, and f^2) that can reduce the amplitude of the true action (*payback*). The term $n(k)$ is white noise with null mean value.

Figure 2 reports the comparison between the AD^{req} (dashed blu) and the AD^{true} (solid green) evaluated with (2). It is clear that the power actually supplied in response to the request of AD is different from the request itself. This trend includes the phenomenon of payback, i.e. the load increasing as a result of a previous reduction caused by the active management of loads.

THE URBAN NETWORK

The urban network was selected from the analysis of a wide multitude of different networks [3]. In order to

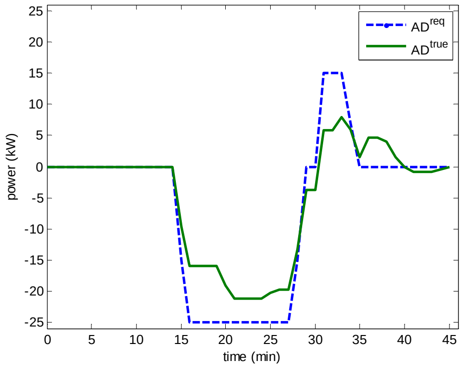

Fig. 1. Comparison between the AD^{req} (dashed blu) and the AD^{true} (solid green).

reduce the computational burden of studies that do not need the highest level of detail the network used in this paper is obtained by suitably clustering the network data, thus, a smaller size equivalent network (132 MV nodes) with the same electrical behaviour as the original one was provided. The main data summary of the test network are reported in Table I where it is possible to observe that it is composed by 5 feeders a low total loading, due to the large amount of LV residential users and 14.42 MVA of installed generating power due to the presence of three PV systems.

TABLE I

DATA SUMMARY FOR THE URBAN NETWORK

	Extension [km]	*Load [MVA]*	*LV Inst. Power [MVA]*	*% LV Power*	*Pot. Gen. [MVA]*
F_1	2.7	1.33	1.10	82.90	0.20
F_2	17.8	2.36	1.07	45.28	8.67
F_3	15.3	5.50	3.58	65.09	5.55
F_4	20	2.30	1.70	73.84	0
F_5	17.9	2.17	1.48	67.95	0

The single line diagram of the considered urban network is reported in Fig. 3, where the nodes that partecipate to AD programs are indicated by stars.

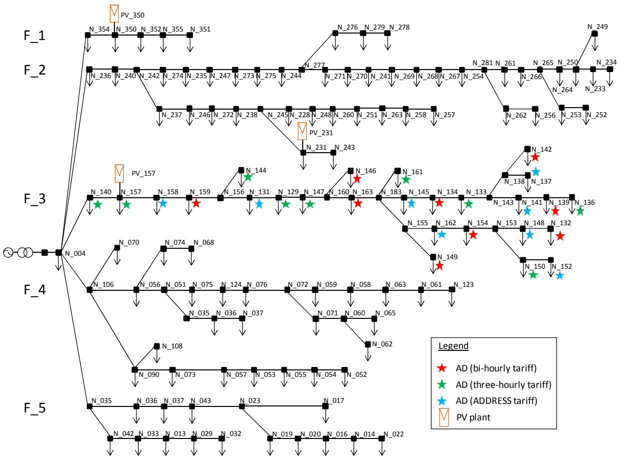

Fig. 3. Schematic representation of the test urban network.

CASE STUDY

The ATLANTIDE DMS model has been applied to the urban network (Fig.3) extracted from the ATLANTIDE dataset, in order to highlight the impact of AD in active operation. The scenario of development for urban network leads to particularly critical conditions. In fact, following the ATLANTIDE evolutionary scenarios [4], it is assumed that in a future year (e.g., 2030), during critical hours of a typical summer day, the PV power production and the load demand cause over-voltages in the most active feeder and under-voltages in the most loaded feeder of the test urban network. In particular, in Fig. 4 and Fig. 5 the voltage profiles for the nodes of the feeders F2 and F3 are shown. The voltage of the F2 nodes closest to the PV generator (PV_231 in Fig. 3) arises beyond the technical limit (i.e., 1.05 p.u.). The farthest nodes from the substation of the heavily loaded feeder F3 suffer to unsustainable under-voltages (Fig. 5).

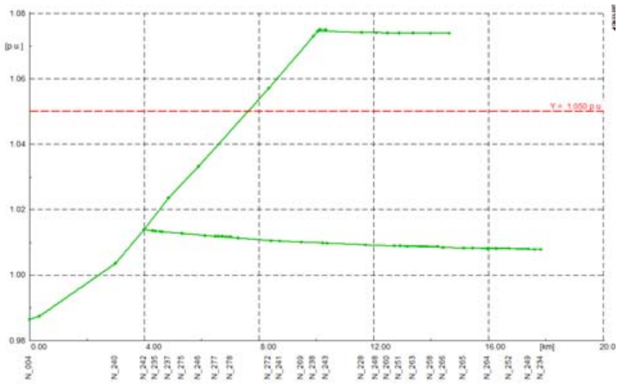

Fig. 4. Voltage profile of MV nodes in F2 feeder at noon of a typical summer day.

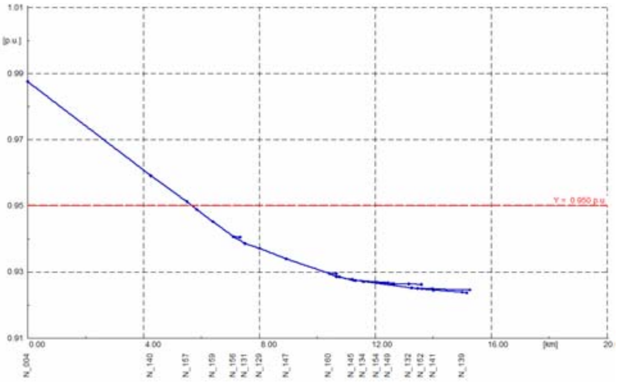

Fig. 5. Voltage profile of MV nodes in F3 feeder at 7:00 pm of a typical summer day.

In such situations, without operation in place, the active power from RES would be totally curtailed (i.e., generators will be switched off) during the overvoltage contingencies and capital expenditures to upgrade the network branches and cope the increased demand would be necessary. With the operation of network and the inclusion of customers in operation policies through the AD less or no upgrades are necessary and RES are not penalized. In order to show such possible benefits to the system different active management policies have been simulated:

1. the DMS resorts to the active and reactive power generation control for dispatchable generators;
2. the AD is included in the active management and integrated with DER optimal coordination;
3. the DMS coordinates DER and AD but no reactive support from DG is available.

In the paper, it is assumed that the DSO pays for their support to the network operation the DG owners and the final users that participate to AD programs. The costs of the active management are assumed strictly related to the hourly energy price $p(h)$ [€/MWh] that is subdivided into three time bands during the day to take into account the peak and off-peak hours. B1 and B2 are two off-peaks hour bands, with prices p_{B2} greater than p_{B1} and the B3 band represents the peak hour time band ($p_{B3} > p_{B2} > p_{B1}$). Therefore, the price of AD support has been considered dependent on three tariff models named *bi-hourly*, *three-hourly* and "*ADDRESS*" tariff model (Fig. 6) [6]. In order to discourage the resort to Generation Curtailment (GC) (in the network only RES is present) the price for varying the DG scheduled active power production has been assumed three times the energy price at the same hour of the day. On the contrary, to favour their Volt/VAR support, the reactive power from DG is paid half the price of energy at the same hour.

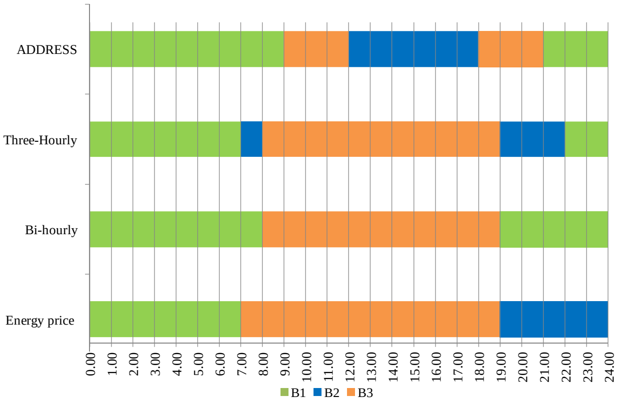

Fig. 6. Hourly energy and AD tariff models bands.

Furthermore, the DG is supposed to give a total support to the DSOs (i.e., the generators offer the 100% of their active power production to be curtailed and the maximum reactive power that their inverters can exchange, during all the day). The active customers, depending on their contract and according with the tariff model in Fig. 6, offer different percentages for varying their scheduled load demand (typically 10% in B1, 30% or 40% in B2, and 70% in B3).

RESULTS AND DISCUSSION

In Fig. 7 the scheduled active power from DG and the total load demand are represented. During the examined day, the total scheduled energy produced by the three PV is equal to 50.11 MWh and the total energy delivered to the customers is equal to 130.57 MWh.

Over-voltage states

Between the 11.00 and 15:00 the total generation overcomes the total demand and in some nodes of feeder F2 over-voltages occur. The simplest action to take is the curtailment of the nearest generation (PV_231 in Fig. 3) when the voltages is beyond the limits. If, as generation control, only the curtailment (GC) is applied and the generators do not participate to the Volt/VAR regulation, the DMS will curtail the active power generated by the PV_231. Whereas, if DG participates also to Volt/VAR regulation, the injection of reactive power in those hours when the voltage overcomes the limits will help to relieve the contingency with less active power curtailment. In the energy produced by the PV_231 in the different examined cases is reported.

TABLE II

ENERGY PRODUCED BY THE PV_231 GENERATOR OF Fig. 3

		GC	GC and Volt/VAR support
	Expected Energy [MWh]	Curtailed energy [MWh]	Curtailed energy [MWh]
PV_231	30.13	27.18 (-9.76%)	28.25 (-6.21%)

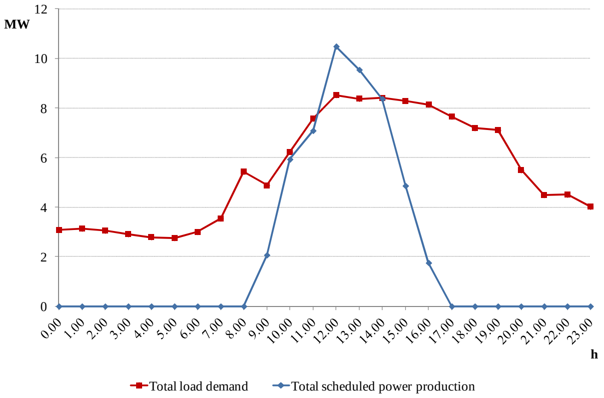

Fig. 7. Scheduled active power from DG and the total load demand.

It is worth noticing that in the test network only PV generators are installed. Even though generally the production of reactive power can seldom limit the production of active power from DG, it has been supposed that the power converters can inject reactive power also when the PV are producing the rated active power. To involve such type of generators in the network operation the interface power converters have to be oversized with an extra cost for DG owners that should be compensated by a fair regulatory mechanism.

Under-voltages conditions

On the contrary, in the feeder F3 the main problems are the under-voltage conditions between 15:00 and 20:00 that occur in the farthest nodes from the primary substation. In order to relieve this contingency, the DMS can resort to the reactive power from the generator connected to the same feeder (PV_157 of Fig. 3) and/or to AD. If the DMS can only dispatch the DG (no AD), the PV_157 will produce the (inductive) reactive power necessary to partially compensate the one requested by the loads. The total reactive energy delivered by the PV_157 during the considered day would be in this case equal to 9.28 MVARh.

To investigate the impact of the AD in the active management, it has been then supposed that all F3 customers participate to AD programs, accordingly with the aforementioned tariff models. Thus, the DMS shaves the peaks of the F3 load demand by minimizing the total cost of the active management. In this case the resort to the reactive support from the generator is still useful but it is reduced more than the previous case (6.43 MVARh). Finally, if the PV generators are unavailable to participate to the Volt/VAR regulation, and AD will be the only option to reduce under-voltages, the load power curtailment will also increase, with extra operation costs. In Fig. 8 the active power produced by the PV and the scheduled and modified power demand in the different examined cases are shown. The differences between the curtailed power curves (required and true) are related to the AD model. In fact, in real applications the behavior of the customers that participates to AD programs, following a request from the aggregator to curtail their power, does not correspond perfectly to the request. Thus, the power that will be effectively curtailed will be smaller than the required, as it is shown in the Fig. 8. In addition, in it is represented the phenomenon of payback (PB) related to, for instance, the load connected to the node N_139 of Fig. 3, which is one of the nodes most involved in the active management. The PB effect leads to an increase in the load as a consequence of a previous reduction caused by a DMS request. The payback effect, in this particular example, is extremely emphasized to better explain the phenomenon (the solid line that represents the power demand taking into account the PB effect is definitely greater than the scheduled dotted one).

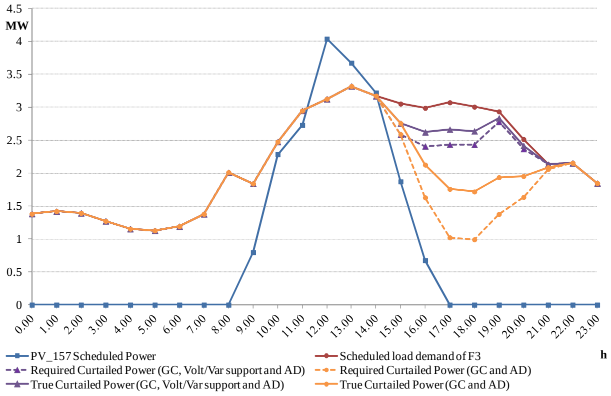

Fig. 8. Power demand of the F3 loads: scheduled and curtailed (required and true) in the different examined cases.

Finally, TABLE III reports for the three examined optimizations the values of the Objective Function (OF), which represent the operational expenditures related to the active management of the given distribution system in the considered day: the minimum cost has been obtained when the AD is included in the active management and integrated with the complete DER coordination (GC and Volt/VAR support from DG).

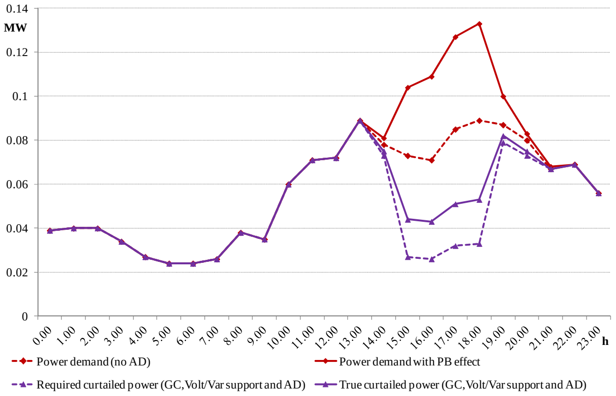

Fig. 9. Load profile: scheduled, true (taking into account the PB effect) and curtailed, required and true, of the load connected in the N_139.

TABLE III

COSTS OF THE ACTIVE MANAGEMENT IN THE EXAMINED CASES

	GC and Volt/VAR support	GC, Volt/VAR support and AD	GC and AD (no Volt/VAR support)
OF value	380.53	335.24	504.92

CONCLUSIONS

ATLANTIDE is an ongoing Italian research project that aims at developing a dataset of reference distribution networks and models for studying the active power distribution under different possible scenarios. Among the different models that ATLANTIDE partners are currently developing, the paper shows the integration of the DMS technical-economical optimizer with the model of active demand that takes into account the true response of customers as well as the impact on a current hour of previous actions. Since active demand is of particular interest in urban areas, the example of application has been tailored for urban networks. The results showed that active demand can easily be included in the DMS with positive effects on both regulation and costs.

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