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DISTRIBUTION NETWORKS MANAGEMENT WITH HIGH PENETRATION OF PHOTOVOLTAIC PANELS

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ABSTRACT: The photovoltaic solar panels penetration increases significantly in recent years in several European countries, mainly in the low voltage and medium voltage networks supported by governmental policies and incentives. Consequently, the acquisition and installation costs of PV panels decrease and the know–how increase significantly. Presently is important the use of new management methodologies in distribution networks to support the growing penetration of PV panels. In some countries, like in Germany and in Italy, the solar generation based in photovoltaic panels supply 40% of the demand in some periods of sunny days, mainly in the weekends. In the present work are technically analysed three different approaches to improve the number of PV systems in a distribution network, namely the use of inductors/capacitors, the use of storage systems and the control of reactive power injected by inverters of PV systems.

Keywords: Distributed Energy Resources, Distribution network management, Photovoltaic panels, Voltage stability

1 INTRODUCTION

The Distributed Generation (DG) use increasing, mainly based on Renewable Energy Sources (RES), and other Distributed Energy Resources (DER), like the electrical storage systems and electric and plug-in hybrid vehicles (EV) poses new challenges to Power Systems (PS) [1, 2].

Supported by governmental policies and incentives, the photovoltaic solar units increase rapidly in few years (Italy is the most recent case), mainly in Low Voltage (LV) distribution network. At the present, some plants with large dimensions are also installed in medium and less in high voltage levels.

In this sense, a new approaches and methodologies are necessary to improve the benefits of the distributed generation connected in the distribution networks. The inclusion of storage systems can be very useful in the Energy Resources Management (ERM) process. These units increase the consumption in generation surplus cases (charge batteries) and increase the energy generation in shortage generation cases (discharge batteries) [3, 4].

Several approaches have been developed in recent years considering different perspectives. The smart grids context include some of this approaches trying aggregate the new management and operation methodologies and the new equipment's, providing solutions to be used in the power systems industry.

This work contributes to overcome this situation conceiving, developing and implementing methodologies adequate for Energy Resource Management (ERM) in a medium voltage (MV) distribution network, considering intensive penetration of photovoltaic panels. The proposed work intends to evaluate the maximum penetration of photovoltaic panels considering the injection of active power (without any control), the controllable injection of reactive power by capacitors bank and by the PV panels, and the use of storage systems.

In this paper are shown the maximum capacity of photovoltaic plants connected to the distribution network considering different energy resources management perspectives namely, the injection only the active power, the injection of reactive power with and without control, and finally the consideration of existence of storage units in the distribution network. Some works in literature address this topic. For example, Lin *et al.* [5] proposes an optimization methodology to photovoltaic penetration in distribution systems considering annual duration curve of solar irradiation considering real scenarios.

The proposed methodology considers the typical generation profiles of photovoltaic (PV) solar units in Portugal, the typical consumption profile also in Portugal, the technical constraints of the solar panels and of the storage systems. An AC power flow was also considered including, the bus voltage limits, the lines thermal limits and the MV/LV power transformers. In the presented work was considering the TAPs regulation in HV/MV power transformer and the possibility to inject 1 MW in HV network. The developed algorithms were implemented in GAMS/MATLAB and use a deterministic approach (Mixed-integer non-linear programming) to obtain the optimal solution (maximum penetration of photovoltaic panels connected to each MV/LV power transformer).

The main contribution of present work is determining the impact of new distribution network management methodologies used in distribution network considering the high penetration of photovoltaic panels.

2 IMPLEMENTATION

The implemented simulation is based on a distribution network with 33 buses proposed in [6], considering the load evolution prediction for the year 2040. This distribution network is connected to the 60 kV network through a HV/MV substation in the point (bus 0 in figure 1) where an existing external supplier provides energy and try to schedule the existing distributed generation.

The main objective of the proposed methodology is to maximize the penetration of photovoltaic solar units in each MV/LV power transformer (equation (1)) considering the technical operation limits of the medium voltage distribution network (voltage constraints and lines thermal limits). In this problem was considered the existence of a PV system in each medium voltage bus (power transformer) and the main goal is to maximize the installed power of this PV system. In practice this system represents the sum of all PV systems connected in low voltage distribution network. This value is limited by the MV/LV power transformer and by technical constraints of MV network.

$$max\ Z = \sum_{PV=1}^{N_{PV}} \left(P_{PV(PV)} \right) \tag{1}$$

Figure 1 shows the distribution network used in the present case study. The blue values represent the MV/LV power transformers capacities and the maximum value of active power of loads in each bus (reactive power consumption is equal to 30% of active power). The red values represent the lines thermal limits. In this case study was considered only 95% of the maximum capacity of MV/LV substation capacity. The remaining 5% are considered as operation reserve to prevent future network evolution.

In Figure 2 are presented the typical power consumption profile and the typical PV solar generation profile during 24 hours. In these profiles are considered the maximum consumption in off-peak hours and the minimum consumption in peak hours. In the PV generation profiles was considered the maximum generation in each hour of the day during a year. With these assumptions is possible to obtain the scenarios with maximum power demand (maximum consumption and minimum generation) and the scenarios with maximum generation (minimum consumption and maximum generation).

An important aspect to determine the maximum penetration of PV solar units is the fulfilment of the voltage magnitude limits in each bus. In the present case study was considered the limits of ± 5% in each bus (0.95 to 1.05 pu). In the response to power flow direction variations is necessary adjust the transformer tap of HV/MV substation transformer. In this simulation was considered the existence of an automatic TAPs adjustment in HV/MV power transformers.

a) Simulation 1 – Active Power Injection

In simulation 1 A was determined the maximum penetration of PV solar panels considering only the injection the active power. The total penetration of PV solar units in simulation 1 is 4 894 kWp. Considering the proposed PV generation profile (Figure 2) the generated energy is 53 345 kWh. Figure 3 shows the obtained results.

In Figure 3 is possible to verify that in the periods 11 to 18, considering the results of PV solar units penetration, the distribution system is auto-sufficient to supply all demand and can export energy. It is also possible to verify the increase of power losses in the periods with high PV generation.

b) Simulation 2 – Controlled Capacitors Bank

In simulation 2 was determined the maximum penetration of PV solar panels considering the controlled injection of reactive power less than 30% of maximum of active power. This method needs the control of injected reactive power in each PV system. The reactive control allows a more efficient management of resources and consequently more penetration of PV solar panels. The total penetration of PV solar units in simulation 2 is 4 933 kWp and the total generated energy is 53 777 kWh. Figure 4 shows the obtained results.

c) Simulation 3 – Controlled Reactive Power Injection in inverters of PV Systems

In simulation 3 was determined the maximum penetration of PV solar panels considering the injection of reactive power controlled in the inverters of PV systems. Each PV system has extra PV panels to be used to injected reactive power in distribution network.

This solution requires the connection to the inverter to control the active and reactive power injection set point. This control can be made using the smart meter or other advanced solution. In each unit is considered the maximum use of 20% of reactive power related to the injected active power. The total penetration of PV solar units in simulation 3 is 4 960 kWp and the total generated energy is 54 064 kWh. Figure 5 shows the obtained results.

d) Simulation 4 – Storage Systems

In simulation 4 was determined the maximum penetration of PV solar panels considering the controlled injection of reactive power less than 30% of maximum of active power and the existence of storage units. In this case study was considered the existence of 10 storage units in the distribution network. The total penetration of PV solar units in simulation 4 is 5 128 kWp and the total generated energy is 55 897 kWh. Figure 6 shows the obtained results.

e) Results Analysis

Analysing the results of simulations 1, 2, 3 and 4 is possible to conclude that the control of reactive power increase the maximum quantity of PV solar systems penetration. Comparing the use of capacitors bank (simulation2) and the control of PV systems inverters (simulation 3), is possible to verify that the results are similar.

However, the solution adopted in the simulation 3 can be cheaper and easier to implement in real systems. In simulation 4, with storage units the penetration of PVs increases significantly. This solution have several advantages to the distribution system, however the actually cost of the storage units makes this solution very expensive.

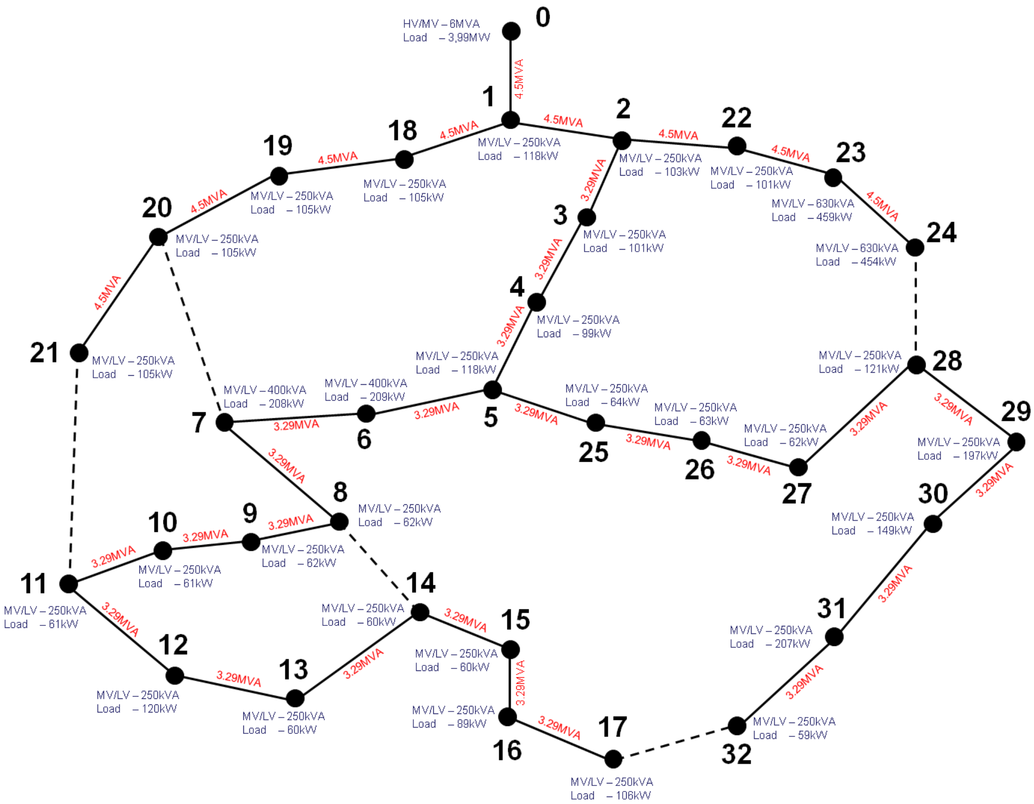

Figure 1. 32 Distribution network [8]

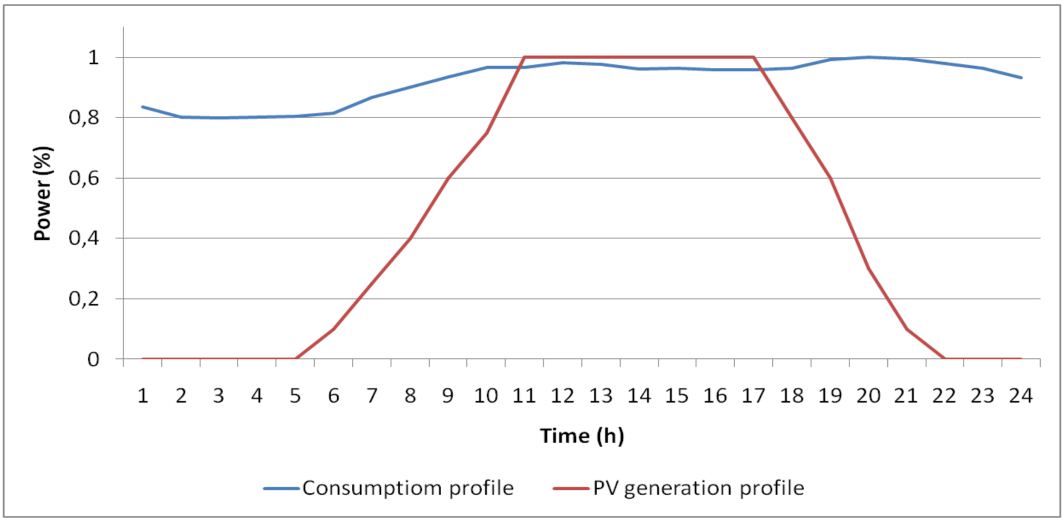

Figure 2. Consumption and PV generation profiles

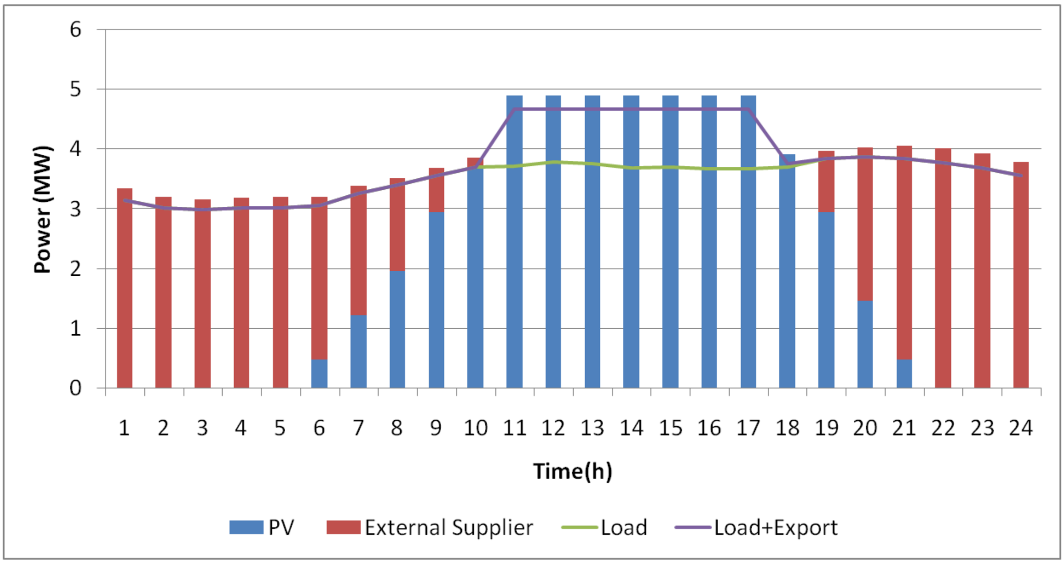

Figure 3. Energy Resources Scheduling in Simulation 1

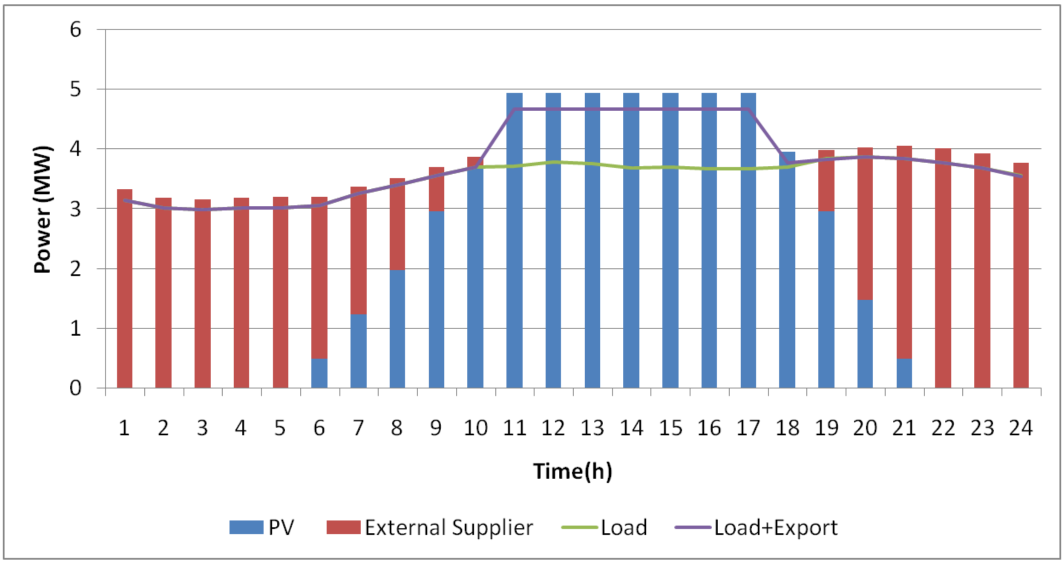

Figure 4. Energy Resources Scheduling in Simulation 2

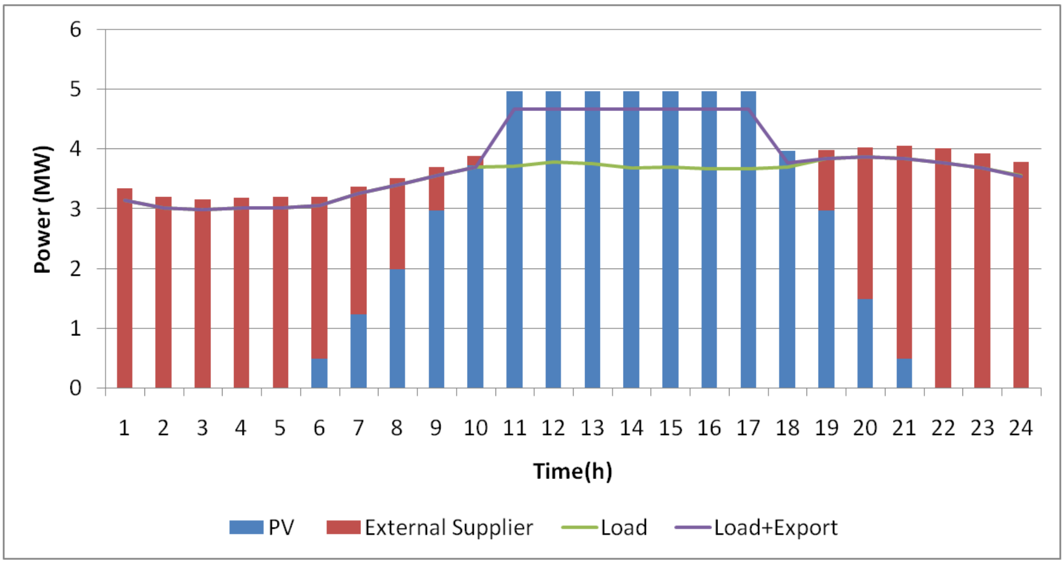

Figure 5. Energy Resources Scheduling in Simulation 3

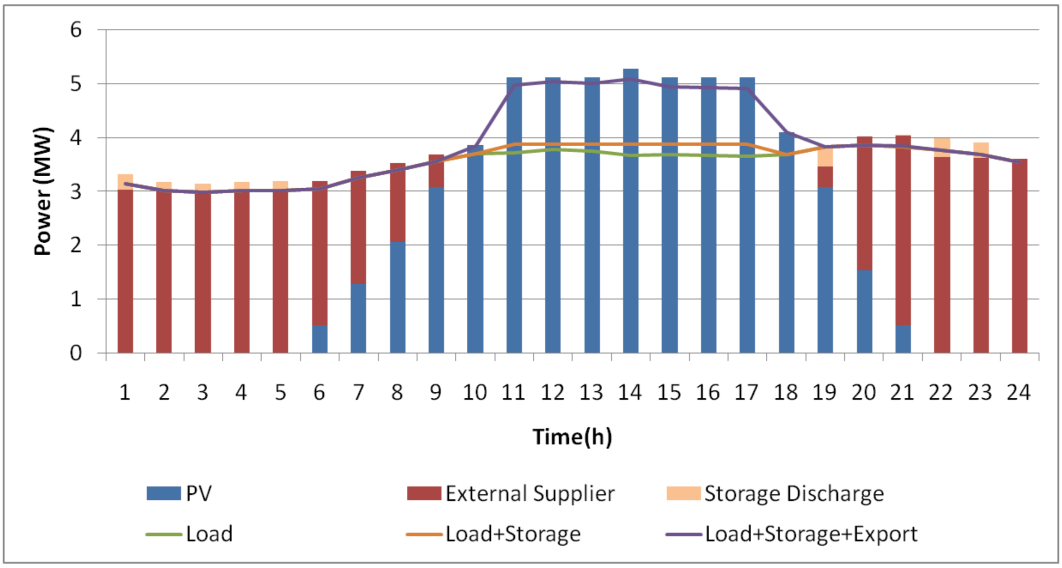

Figure 6. Energy Resources Scheduling in Simulation 4

3 CONCLUTIONS

The present work proposes a methodology to determine the maximum penetration of PV solar units in a distribution network. The high penetration of distributed generation in low and medium voltage levels, arise new challenges to the systems operators. In this sense is important determine the maximum quantities of penetration of distributed generation in the voltage levels.

A case study considering a 32 bus distribution network was tested considering the normal operation of PV panels (injection of active power), the existence of controllable capacitors bank, the capacity to inverters of PV systems inject reactive power, and the inclusion of storage units. The use of storage units provides good results. However, this technology is very expensive. The control of reactive power can be an suitable solution in a near future to improve the penetration of PV panels in distribution network, allowing some control in voltage magnitude in each MV/LV power transformer.

4 ACKNOWLEDGEMENTS

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