The impact of PV orientation in smart grids

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***Abstract*— In the last years it became a practice photovoltaic power plant to be designed and built with south orientation, the main reason for this being maximum generation of clean energy. This economic approach is justified, from the investors' point of view, but it does not take in to consideration, the different aspects energy produced over the distribution network. Considering the process of decentralization of the energy system that is to a great extend provoked by the systematically conducted policy stimulating the construction of new PV, the problem with the PV modules orientations is very significant and from its correct solution depends the efficient dispatching of the distribution network. The purpose of this article is to explore the possibilities of differently oriented PVs connected to the medium voltage distribution network. The focus is on MV network with differently oriented PV battery systems and different loads. It makes a parallel between the options provided by differently oriented photovoltaic power plants with battery systems for dispatching the network. The article explores the relationship between the orientation of the photovoltaic power plants and their optimal allocation in different nodes. The study proves that for the differently oriented photovoltaic power plants the optimal allocation is not always in the same nodes. It reveals the importance of the orientation of the photovoltaic power plants and not just the estimated power, which is the practice until now, for the proper planning of Distribution Company for newly constructed PV power plants. The research proves that in order to achieve optimal coverage of load profile with minimum investment and electrical losses, the optimum orientation for the construction of photovoltaic power plants with storage systems must take into account not only the orientation of the panels / east, south, west / but also the size of the load and its profile. The investors' interest is also important.**

Keywords—smart grid; photovoltaic power plants; storage systems; distribution network covering the load profile; demand response;

I. INTRODUCTION

Preferential purchase prices introduced to stimulate the production of clean electricity in many countries provoked the investors' interest. In a relatively short period of time, were built significant capacities for the production of photovoltaic modules and photovoltaic power plants in different EU member states [1], [2]. The Directive 2009/28/EC [3], says that the renewable energy sources (RES) have to assure both the adequate electricity generation and the economic convenience of the investment [4]. The EU target 20/20/20 led to installation of photovoltaic power plants with impressive for Bulgaria and the EU capacities. This policy resulted in decentralization of the electricity energy system (EES), market liberalization and reduction of the cost of the installed capacity of photovoltaic power plants. During the intensive growth of the installed power from photovoltaic power plants no one registered the impact of this increase on the distribution network. International standard (61727, 2004-2012)[5], which regulates the technical issues related to voltage harmonics, power factor, loss of tension, grounding, voltage protection , voltage drop, and others, does not take into account the capabilities of PV power plants to cover the load profile.

When new PV power plants connect to the distribution network, the decisive criterion is the estimated power. This is legally regulated and respected by the distribution system operator (DSO)[6].

The concrete engineering and economic consequences are not taken into account, when the PV power plants (PV PP) are not south oriented, when the load type and profile is different as this creates significant problems of operational nature related to the dispatching of the network. According to the latest amendments of the Law on renewable energy DSO are required, as a priority, to connect power plants that use renewable energy sources. The law, however, except the installed power does not regulate the principles of their design according to the load and its profile. Therefore, it is an established practice to design PV PPs with south orientation and, depending on the geographic location of the plant to determine the tilt of the solar photovoltaic modules [7], [8], [9], [10], [11], [12]. To follow that approach is appropriate, if not taken into account the impact of PV PPs on the grid but is either intended to pay back the investment costs in the shortest possible period or to enforce innovative photovoltaic technologies. As a result, by mid-2013, a large number of renewable energy generators have been constructed, including PV PPs, in the EU Member States [13]. It can be concluded that this goal has already been achieved. However, the process of building new capacities from renewable energy sources continues. The trend is the price of electricity from PV PPs to become equal to the price of electricity generated by the generators of the electricity mix of the EES. This fact will additionally motivate investors to invest in clean energy, but this time to satisfy their own needs. An important point here is to map one new reality, that regulates the gradual introduction of "smart grids" in the energy system of the EU Member States (EC 2011b).

This work was supported by RSE SpA (Italy) under the contract DERri No. 228449 with the European Commission, within the 7th Framework Programme – CAPACITIES – Research Infrastructures.

978-1-5090-1798-0/16/$31.00 ©2016 IEEE

According to Directive 2010/31/EU[14], from 2017 every new building must independently meet its energy needs. The goal is to reduce the cost of electricity and dependence on external suppliers; electricity is delivered to the consumer with minimal investment costs for transmission and distribution; more efficiently are managed energy flows at greater security of electricity supply to the end user at optimal buying and selling prices. The realization of this objective implies to increase the share of photovoltaic power plants in the electricity mix. Building facade PV PPs requires to take into account the architectural features and building orientation / not every building is oriented to the south, which is particularly relevant for facade PV PPs / orientation of the PV PPs and connection in the same point of PV PPs with south orientation and PV PPs with other orientation. Since the solar resource is not constant, there are problems with the fluctuations of generated electricity and PV PPs dispatching. In this regard are taken unconventional measures for the management of PV PPs such as adjusting the power and turning off the PV PPs , at the discretion of the ESO, which at some point support the electricity distribution company, but in practice the problems with their management remain unsolved. The measures that must be initiated are associated with optimizing the orientation of PV PPs, in line with the specific load pattern. This will improve the forecasting of electricity generation, dispatching of the electricity network and will extend grid connected batteries lifetime [15], [16].

II. Allocation of PV PP in MV network

A. Software used

The effective planning and management of the processes linked to: the penetration of decentralized renewable energy sources in the EES, the change of the structure of the electricity consumed, the rehabilitation, modernization and construction of new facilities requires a new generation computer models. SPREAD[1] helps optimizing a variety of technical solutions that minimize: the capital costs; electricity losses, maintenance and exploitation costs. The optimization process goes along with some technical limitations like voltage profile, maximum distribution capacity of the facilities, quality of the services offered, minimum losses, minimum interruptions and others.

On this basis it is possible to reconfigure the Medium Voltage grid by reducing the investment costs and increasing the quality of services offered.

B. Input data

The technical data for a MV network that is to be optimized with a connection of a RES, are introduced. The technical characteristics of the electrical network and the generating source are used. The existing MV network is examined, Figure 1 and Table I, with 23 nodes, which is supplied by two substations. The data for the substation and nodes are summarized in Table I. The data for the load pattern have an interval of 1 hour and are presented on Figure 2.

[1] The project is financed form the Ministry of Economic Development with the research Fund for the Italian Electrical System

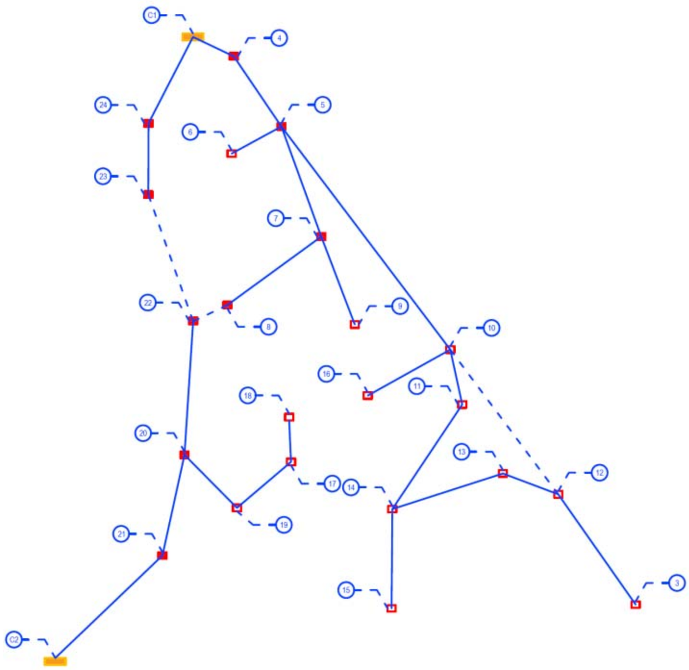

Fig. 1. Existing MV grid

The loads used are according to the area of consumption. The urban loads are in urbanized territories, the agricultural – in areas where there are active agricultural companies and in small towns and villages. The industrial loads are in the areas characterized by strong industry and many administrative buildings.

From node № to node №	Distance, km	Type Overhead line, cable line	mm^2	Current, A
1-4	0,864	Cable line	240	360
4-5	1,52	Cable line	240	360
5-6	1,003	Cable line	95	200
5-7	2,105	Cable line	95	200
5-10	5	Cable line	95	200
7-8	2,051	Cable line	95	200
22-23	2,398	Cable line	240	360
23-24	1,302	Cable line	240	360
22-8	0,668	Cable line	95	200
1-24	1,846	Cable line	240	360
7-9	1,692	Overhead line	16	105
10-11	1,024	Overhead line	16	105
10-16	1,658	Overhead line	16	105
11-14	2,243	Overhead line	16	105
14-15	2,181	Overhead line	16	105
14-13	2,046	Overhead line	16	105
13-12	1,045	Overhead line	16	105
3-12	3,24	Overhead line	16	105
10-12	2,419	Overhead line	16	105
17-18	0,804	Overhead line	16	105
17-19	1,257	Overhead line	16	105
19-20	1,325	Overhead line	16	105
20-21	1,86	Overhead line	35	190
2-21	2,788	Overhead line	35	190
20-22	1,215	Overhead line	35	190

a. Technical characteristics of the analyzed MV network

The loads used are according to the area of consumption. The urban loads are in urbanized territories, the agricultural – in areas where there are active agricultural companies and in small towns and villages. The industrial loads are in the areas characterized by strong industry and many administrative buildings.

The software SPREAD allows identifying an optimal configuration (topology, conductor section, location and number of automatic and sides of backup feed) at minimal cost. The algorithms for the search of optimal configurations are based on Genetic Algorithms

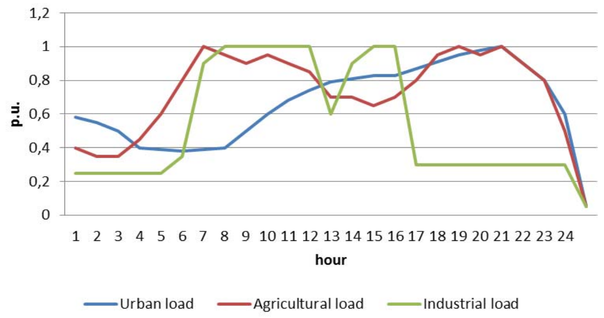

Fig. 2. Loads during simulation

The distribution network supplies electricity to the all three kind of consumers. The approach is to take in to account the most sophisticated situation when each type of consumer has different characteristics. In other studies as [9] the authors consider to apply their methodology on separate areas of services in order to find whether the incentives for continuity of supply should be the same or not depending from the area of customer which is served. In a lot of countries the type of customers are not clearly defined, in such case it is more useful to use combined load curves.

III. Results

The simulations have been done by using SPREAD. They have been done with differently oriented PV PP with battery system in MV network. The goal is:

- To determine whether it is to possible to increase the number of the PV PP to the network if they have a different orientation;
- To determine how the increased number connected to the network PVPP will reflect the option to cover the load patterns;
- To determine what is the impact of the differently oriented PV PP on the MV distribution network

Four scenarios have been developed:

In the first scenario, the simulation is done with PV PP totally south oriented, with optimal power, situated in the network studied.

In the second scenario, the entrance parameters are the same. The difference is in the part of the generators' load pattern. In this case PV PPs are optimally situated with eastern configuration.

In the third scenario, having the same entrance parameters, only the part of the load pattern of the generators is changed. In this case PV PPs are optimally situated with western configuration.

In the fourth scenario, in order to achieve optimal charge and discharge the PV PPs are optimally situated in configuration east, west and south.

In the studied MV network one can install PV PPs with the following orientation: south 14 MWp, east 5 MWp, west 6,5 MWp, east/ west/south 16,5 MWp. The greatest decentralization can be achieved by using PV PPs with an orientation east/south/west, see Table 2. The orientation of the PV PPs has a significant impact on the number of the installed PV PPs and their power. The difference at the different scenarios can be more than 230%. At different PV PPs orientations, the nodes appropriate for their connection are different (see Table II). A node, where it is possible to connect differently oriented PV PPs, is for example, node 6. Here the limiting condition is the installed PV PPs power. Depending on the orientation, it is from 500 kWp to 1500kWp.

TABLE I.

Node №	Power, kVA	PV-south, kWp	PV -east, KWp	PV-west, kWp	PV-e/s/w, kWp
3	100	500	0	0	500
4	750	500	0	0	0
5	1800	0	0	0	1000
6	520	1000	500	1000	1500
7	1700	2000	0	1000	2500
8	880	500	500	0	1000
9	200	0	500	0	0
10	350	1000	0	0	0
11	100	0	0	0	0
12	200	0	500	500	1000
13	260	500	0	0	1000
14	200	1000	1000	0	1000
15	400	1000	0	1000	1000
16	430	500	500	500	1000
17	200	1000	0	0	1000
18	550	0	1000	500	1500
19	300	0	0	500	0
20	70	1000	0	0	0
21	850	1000	0	0	0
22	550	2000	0	1000	2000
23	1700	0	500	0	500
24	1700	500	0	500	0

b. Electricity generation in different time intervals

Some of the major problems that arise for decentralized RES are:

- Fluctuations of the generated electricity;
- Predictability of the electricity generation;
- Synchronization of the electricity generated by the RES and electricity consumption.

One of the most commonly discussed, acceptable from technical and economic point of view solutions, is the application of storage systems. Figure 3 summarizes the losses of the studied MV network, which is characterized by several differently oriented PV PPs and one storage system that is situated in a certain node. The figure 3 shows that the electricity losses are different. They depend on the type of the load pattern of the consumers and the load pattern of the differently oriented PV PPs. Predominantly minimum are the losses covering the loads of south oriented PV PPs. For a mixed load (urban and agricultural) the losses are minimal at the installation of storage system with PV PP west oriented.

The ratio - installed PV PP power to electrical losses - in the network shows that the losses from electricity are minimal when having a combined storage system with PV PPs, where parts of the panels are oriented in the following ratio 1:1:1 east, south and west.

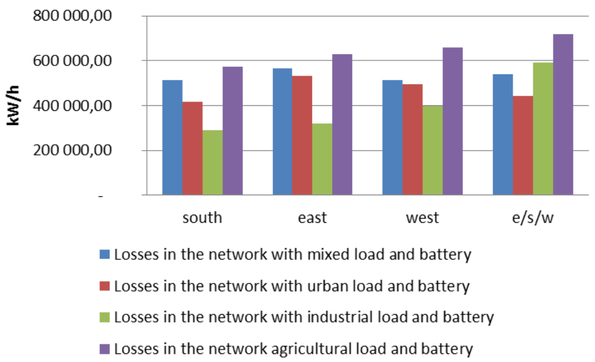

Fig. 3. Losses in the distribution network

Different participants in the energy system have different priority issues to solve. The DSO aim at reducing the electricity losses and increasing the level of decentralization by adding new generating sources from renewables. For the investors, the major priority is the return of their investments. In many cases the expressed investor's interest to build a RES - PV PPs, in a certain node of the electricity network, does not meet the interests of the DSO. In other nodes of the electricity network where there are benefits for the DSO, the investors are confronted with technical problems. For example, inappropriate place for PV PPs installation due to specific architectural and other requirements that leads to reduced productivity and profitability of PV PPs. Practically, it is also possible that DSO has some benefits in a certain node, however there is no investor's interest for renewables. This mismatch in the interests of the investors and DSO can be compensated to a certain extend by designing and connecting PV PPs with different geographic orientation to the distribution network. For example, for a given node, it might be inappropriate to install PV PPs with eastern orientation, however for the same node it might be possible an optimal installation of PV PPs with orientation east/south/west (Table II). If for a certain node, it is optimal to have a western oriented PV PPs, but there is no investor's interest, a possible solution is that PV PPs to be south oriented. These conditions change depending on the load patterns that have to be covered.

Planning the PV PPs orientation is of great importance because of the node where the storage system will be situated (Table III) and the need to estimate the installed power of the storage system (Table IV).

TABLE II.

Allocation of storage system				
Orientation	**Mixed Load**	**Urban Load**	**Industrial Load**	**Agricultural Load**
	node	***node***	***node***	***node***
South	10	14	14	10
East	10	10	7	10
West	7	5	5	5
e/s/w	12	12	14	13

c. Allocation of the storage system depending on the PV PPs orientation and the consumer load

TABLE III.

Installed power, kW/ time for working of battery system, h				
Orientation	**Mixed Load**	**Urban Load**	**Industrial Load**	**Agricultural Load**
South	4000/3	4000/3	3000/3	4000/3
East	4000/2	4000/2	2000/3	4000/2
West	2000/3	4000/2	3000/2	3000/3
e/s/w	4000/2	4000/2	4000/3	4000/3

d. Installed power of the storage system depending on the PV PPs orientation and consumer's load

IV. Conclusion

The study of the impact of the differently oriented PV PP with storage systems and different load to cover the load pattern allows for the following conclusions:

- The effective management of the intermittent power, meaning less electricity losses and high quality, secure and safe electricity supply, requires a connection of PV PP with storage systems that are not only south oriented, but also considering the load pattern, to the distribution network. This way the fluctuations of the electricity generation are overcome, its forecasting and dispatching improved, and the loads covered
- When PV PP are south oriented, the total number of nodes where they can be installed is 15. This number is 8 for eastern oriented, 9 for west oriented and 14 – east/south/west. The installed power is also different - 14 MWp for south orientation, 5 MWp for eastern orientation and 6,5 MWp for western and 16,5 MWp. for east/south/west orientation
- The differently orientated PV PPs have a different optimal allocation in the distribution network. When connecting electro generators to the distribution network, it is very important for the DSO to be familiar not only with the PV PP power, but also with its

orientation in order to be able to estimate its impact on the load pattern. Depending on the European, national and regional goals, DSO can prioritize PV PPs with a specific orientation. The most PV PPs installed are the ones with east/west/south orientation 16,5 MWp. In this case we would witness highest electricity generation

- In order to decrease the electricity losses, DSO have to consider not only PV PPs power as it is the practice now, but also the load pattern of the concrete distribution network where the PV PP will be installed. The ratio electricity losses / installed power shows the losses in the studied distribution network, depending on the PV PP orientation, are 38%.
- The efficient management of construction and modernization of the distribution networks requires DSO to make a forecast for the allocation and orientation of the future PV PPs in order to speed up the entrance of “smart grids” in EES.
- The optimization linked with the PV PPs allocation and orientation requires to be taken into consideration not only the load, but also the load pattern and the investor’s interest.
- In the process of planning the connection of new facilities, DSO should announce tenders for the different nodes where the deposit paid to be a guarantee for the costs made in case the investor withdraws and the PV PPs has to be installed in another node.

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