Influence of PV power stations on the indicators for power supply continuity in Bulgaria

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***Abstract* — The paper presents the results from a study and analysis of the indicators of continuity in the connection of photovoltaic power stations to different types of medium voltage electric distribution networks - cable and overhead. The period of survey is three years, and the number and duration of power supply interruptions are analyzed. The relative share of the SAIFI and SAIDI indicators for the two types of electric distribution network have been calculated.**

Keywords — electric distribution network, quality of electric power supply, continuity indicators, PV stations, interruptions

I. Introduction

The reliability and safety of the electrical equipment of The electric distribution network (EDN) distributes the electric energy to the end customers on medium voltage (MV) and low voltage (LV). Its parameters are calculated so as to provide uninterrupted power supply and quality voltage at the point of connection of consumers.

The renewable energy sources (RES) power plants are divided into the following types depending on the used primary power source:

- Photovoltaic power plants (PVPPs);
- Wind power plants (WPPs);
- Hydropower plants (HPPs);
- Biomass district heating plants (BioPPs);
- District heating plants (TPP) with cogeneration.

The greatest influence is exerted by PV power stations due to the random nature of the power generated by them. The average annual increase of the constructed PV capacities for the period 2009 - 2019 is 31% [1].

The production of electric energy from wind for the period from 2000 to 2020 worldwide, increased by about 12%. Europe is a leader in the use of wind energy. The EU uses various direct economic and administrative preferences for the purchase of wind-generated electric energy. In Germany, for example, direct subsidies for wind energy alone exceeded € 20 billion in 2003. In 2014, Denmark received 39% of its required energy from WPPs, and in windy days by mid-2015 it was able to meet 140% of the country's needs [1, 2].

Nearly 30% of the world's electric energy is generated by various hydropower plants and about 88% of the energy produced from renewable sources is also from hydropower plants [1]. Hydropower plants range from small micro-hydropower plants to huge dams that provide energy to millions of people. The category of small HPPs includes power plants with an installed capacity of 10 MW and less, mini HPPs are power plants with a capacity of 500 to 2000 kW, and micro HPPs - up to 500 kW. In the last decade, small channel hydropower plants have been built on running water. They do not need a pre-accumulated water volume, which is why they are extremely environmentally friendly.

The connection of RES can be done directly to the transmission network, to the MV network or to the LV network. This subsequently affects the operation of the electric power system (ERS) and the EDN of the electric distribution companies.

The type of renewable energy sources used, as well as the size of the connected capacities complicate the management and operation of the network. The distribution network is designed and calculated for energy flows from the power system to the EDN and all customers, when switching on generating capacities at certain points, sometimes the direction of energy transfer is reversed. At certain moments there is a transfer of energy from the EDN to the power system. These cases are not constant around the clock, as well as in certain periods of time and create abnormal, and therefore inefficient operation of the network.

II. Prospects for the usage of RES in Bulgaria

The requirements for the power plants producing electric energy from renewable energy sources are not as strict as for the other producers - they do not have compensating capacities, they do not have a reserve (hot, cold), etc. The obligation to buy 100% of the produced energy leads to unplanned production.

The planned new production capacities, according to the investment intentions, by types of power plants are given in Table I [4, 5]. For the period 2020-2029, a total of 2029 MW of new capacity is planned for construction, of which for the production of electric enenrgy from renewable energy sources, according to the concluded preliminary and final contracts for connection of transmission and distribution

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network levels, have a capacity of 1465 MW (Fig. 1) [4]. These are:

- Photovoltaic power plants (PVPPs) – 659 MW;
- Wind power plants (WPPs) – 673 MW;
- Hydropower plants (HPPs) – 69 MW;
- Biomass district heating plants (BioPPs) – 64 MW.

TABLE I. NEW CAPACITIES FOR ELECTRIC ENERGY PRODUCTION

Type	Year										
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	Total
TPP, MW	69	0	28	269	198	0	0	0	0	0	564
RES., MW	211	48	52	73	151	297	155	158	158	159	1465
HPP, MW	11	7	6	10	5	6	6	6	6	6	69
WPP, MW	109	0	0	7	91	91	91	94	94	94	673
PVPP, MW	80	31	38	51	90	195	53	53	53	53	659
BioPP, MW	11	10	8	5	5	5	5	5	5	5	64
Total, MW	281	48	80	342	349	297	155	158	158	159	2029

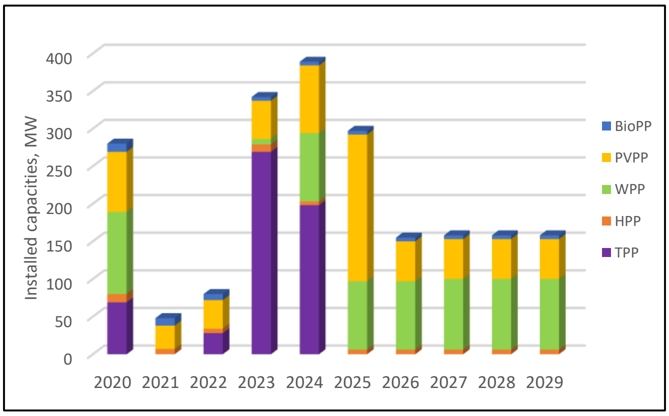

Fig. 1. Capacities for electric energy production for the period 2020 – 2029.

For comparison, the existing RES capacities at the end of 2019 are as follows:

- Photovoltaic power plants (PVPPs) – 1059 MW;
- Wind power plants (WPPs) – 700 MW;
- Hydropower plants (HPPs) – 2347 MW;
- Biomass and biogas plants (BioPPs) – 77 MW.

The planned new capacities for production of electric energy from thermal power plants and from highly efficient combined production of heat and electricity are 564 MW [4, 5].

The country will have a residual availability for production from 4,300 to 10,000 GWh per year. It should be borne in mind that this is mainly due to the gradual commissioning of gas units, as well as the planned increase in the use of renewable energy sources, especially PVPPs. Power balances show a significant disparity in terms of opportunities to cover domestic consumption and possible exports of electric energy (Table II) [3]. The latter is not only impossible in winter conditions, but in some years even implies activation of the slow tertiary reserve and/or import of electric energy. The situation is even more complicated by the combination of prolonged extreme winter conditions, depleted primary energy resources in the system-regulating HPPs and TPPs and increased emergency of the power generation capacities.

TABLE II. AVERAGE ANNUAL USAGE OF THE TYPES OF POWER PLANTS FOR 2019

Type of the power plant	Average annual usage, %
NPP	94,5
TPP	45,2
TPP with cogeneration	44,7
Factory PP	30,4
HPP	11,9
PVPP	15,1
WPP	21,4
BioPP	45,5

During the summer season there is a significant residual availability for production, but the realization of exports is directly dependent on the production of RES, especially PV-PP. Apart from a technical problem, this would also create financial problems for the local condensing plants from unrealized availability for production.

The projected production of electric energy from RES is based on the set installed capacities in the "Draft Integrated Plan in the field of energy and climate of the Republic of Bulgaria", prepared by the Ministry of Energy and is consistent with the average production in recent years under normal climatic conditions. It is reported that the electricity produced by Hydro-pumped storage power plants is not renewable. The forecast is presented in Table III [6].

TABLE III. PRODUCTION OF ELECTRICITY FROM RES AND HPSPPS

Type	Year									
	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
HPP in NEC, GWh	2855	2918	2981	3044	3107	3163	3226	3289	3352	3415
HPSPP, GWh	455	518	581	644	707	763	826	889	952	1015
HPP out of NEC, GWh	1121	1123	1125	1128	1131	1137	1144	1153	1165	1177
WPP, GWh	1467	1488	1509	1530	151	1572	1656	1740	1824	1908
PVPP, GWh	1407	1607	1808	2008	2209	2409	1796	3182	2569	3955
BioPP, GWh	350	370	390	410	430	450	470	500	510	530
Total for RES, GWh	6745	6988	7232	7476	7721	7968	8466	8975	9468	9970
Estimated consuption with HPSPPs, GWh	39600	39040	39330	40920	41180	41390	41590	41780	42010	42250
Share of RES, %	17,03	17,90	18,39	18,27	18,75	19,25	20,36	21,48	22,54	23,60

With the accepted development of electric energy production from renewable energy sources, it is envisaged that by 2029, it will exceed 23% of the projected consumption of electric energy in the country. It should be borne in mind that when realizing electric energy consumption close to the minimum option, the share of RES in the final gross consumption would increase.

The capacities with priority production include the highly efficient power plants for combined production of electricity and heat (cogeneration), as well as the power plants from RES (WPP, PVPP, biomass, etc.). The share of all these capacities is growing and it is becoming increasingly difficult to regulate the frequency and exchange capacities, although to some extent, they are able to follow the round-the-clock load schedule, with the exception of WPPs.

The variations of the primary energy resource of RES leads to problems with maintaining the balance between production and consumption. This requires special attention to the balancing and regulating capacities when planning the power balances.

If by 2029 the designed WPPs and PVPPs are unregulated at a total installed capacity of over 3800 MW, the balancing capacity (flexibility) of the power system will be reduced. Fig. 2 shows the load profile of an EDC. It can be seen that at certain hours the production from RES covers a large part of the consumption in EDN. The energy produced from renewable energy sources in some cases reaches high values, about 47% of the energy consumed in the EDN. During the day there is a large production of electric energy, while at night it is almost absent, which is due to the operation of the PVPP.

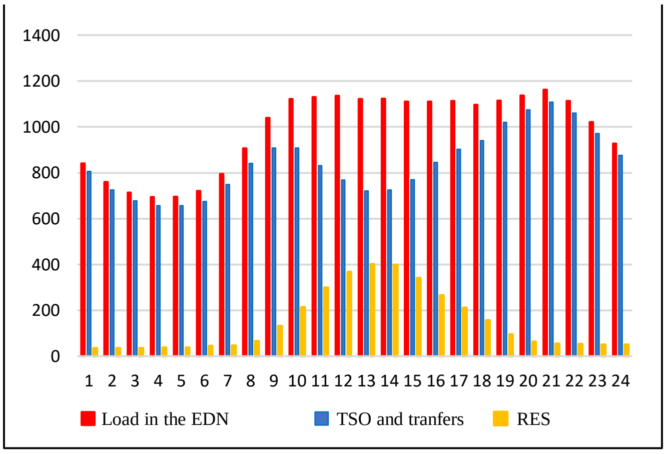

Fig. 2. Load profile of the EDN.

In the electric distribution network of Southeast Bulgaria the connected RES power plants are over 1400 with installed capacity over 670 MVA. For comparison, TPP AES Galabovo has an installed capacity of 660 MVA. In addition, depending on the network load, for a given region the energy produced by renewable energy sources may exceed the consumption and they start to generate energy to the power system. At certain moments there is a transfer of energy from the ERM to the power system, and these features must be taken into account in the management and operation of the network.

The development of the installation of PVPPs is caused by the development of technologies for the production of their main components and, accordingly, the reduction of their cost. They do not have a permanent production regime and have an unpredictable schedule, depending on the meteorological conditions (change of sunny and cloudy weather). Therefore, it is difficult to balance their production.

PVPPs are built in accordance with the RES Act, Art. 30 para. 4, for the construction of remote control and telemetry for connected plants at the connection point [7]:

- In case of an accident, the PVPP switches off automatically and after receiving voltage at the 10th minute it switches on automatically. The reason for this is the lack of permanent operational staff.
- The PVPP is automatically disconnected from the voltage protection when the voltage rises above 22 kV at the connection point.
- The operation of the PVPP in island mode is inadmissible. In the absence of voltage should turn off automatically. This mode is dangerous both for the elements of the EDN and for the consumers a frequency outside the permissible limits, and voltage with a deviation outside the norms of BDS EN 50160 can be obtained [8]. This mode is also dangerous for the operating personnel because it is expected that there will be no voltage and therefore it is possible to obtain an earth fault during actions.
- PVPPs can cause voltage fluctuations at the connection point depending on the meteorological conditions. This creates problems in the regulation of the mains voltage and problems for the normal operation of the powered users.

In case of planned power supply interruptions, there are also peculiarities in the operation of EDN with connected PVPPS, caused by the change of the network configuration. This leads to a complete or partial loss of transmission capacity, due to which the produced energy cannot be delivered to consumers. In these situations, manufacturers should stop working for the duration of the planned interruption.

III. Continuity Indicators in EDN with Connected PVPPs

The indicators of continuity for two regions - Region A and Region B are considered.

Region A has PVPPs that are connected to a MV cable network (more than 90% of its total length is constructed with cable power lines). The cable power lines are laid in collectors and pipe ducts, which also provides protection against damage as a result of uncoordinated construction activities. The region is characterized by a small number of electric energy producers with large installed capacities. There are 18 PVPPs with a total installed capacity of 25,692MW.

Region B has PVPPs that are connected to the MV overhead network (more than 90% of its total length is realised as overhead power lines). The region is characterized by a large number of electric energy producers with small installed capacity. Some of the PVPPs are connected at the end of the power lines. The PV power stations are located at a great distance from the substations.There are 37 PVPPs with a total installed capacity of 11,927 MW. For most settlements in this region, electric energy consumption is low.

Fig. 3 shows the number of planned and unplanned power supply interruptions for 2019, 2020 and nine months of 2021.

It can be seen that the number of interruptions in Region A, where the network is cable, is tens of times smaller than the number of interruptions in the use of overhead network in Region B. The reasons for this are mainly the impact of external factors in the operation of overhead power lines, and namely: bad weather conditions, increased lightning activity, birds, etc. In cable networks, external factors do not have such a strong impact.

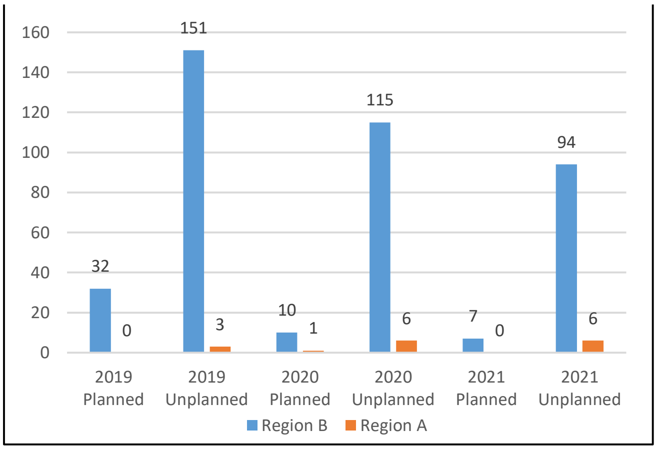

Fig. 3. Number of interruptions for 2019, 2020 and 2021.

The SAIFI and SAIDI continuity indicators for the two regions are determined by years, according to the EWRC methodology [8].

Fig. 4 shows the change over the years of the SAIFI indicator for unplanned interruptions. It can be seen that the frequency of interruptions in Region B is many times (sometimes by orders of magnitude) higher than in Region A. This is due to the type of distribution network and its possibilities for operation. The connection of the PVPP to such a network leads to complexities in the operation of the power lines. The automatic switching on of the power plants also leads to problems in the network and the search for accidents using special devices for indicating the location of the faults in the network.

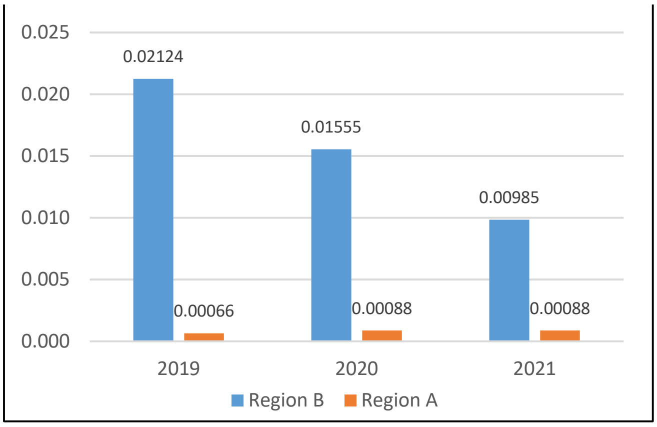

Fig. 4. SAIFI indicator for 2019, 2020 and 2021.

The change over the years of the SAIDI indicator for unplanned interruptions is given in Fig. 5.

The duration of the interruption of the power supply to the customers in the overhead network is much longer than in the cable network. This is due to the strong impact of atmospheric and other external conditions on the network. As a result of these impacts, there are problems not only in the EDN of EDC but also in ESO.

In 2019, in the region with a predominant overhead network, the indicators reach values above 1.16 minutes for SAIDI and 0.02 for SAIFI, for the entire network.

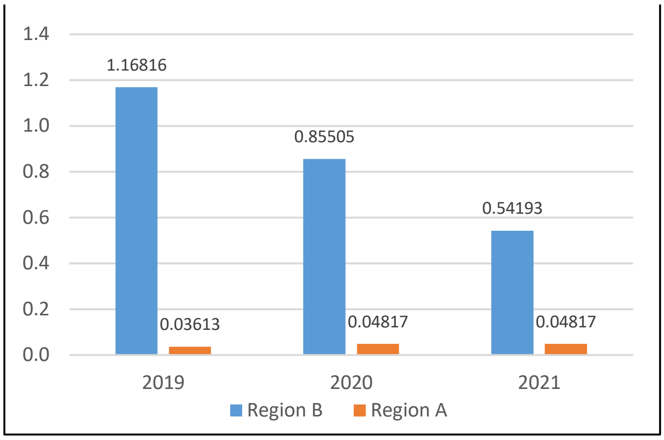

Fig. 5. SAIDI indicator for 2019, 2020 and 2021.

The long overhead network and the small number of places for switching are a prerequisite for a long time interval when isolating the faulted section, as well as eliminating other accidents.

In cases of announced restricted consumption regimes in a given region, the production of electricity from PVPP is suspended.

The connection of PVPP to cable power lines leads to greater security of energy production, and hence the quality of electric power supply. Overhead power lines are not reliable and, accordingly, the energy production of PVPPs is not reliable [8, 10].

It is desirable that the PVPPs to be directly connected to the power system in the substations. Thus, they will not affect the other customers, it will be possible to adequately regulate their production, and hence the energy flows in the EDN.

Measures related to changing the organization of the work of the teams and the available resources of the EDC do not always have a positive effect if the staff/owners of the PVPP are not interested in them.

It is necessary to know very well the resource of the network in order to properly assess its ability to tranfer the required powerflows in the event of an operational need. Wrong decisions would lead to disruptions and sometimes to permanent and prolonged accidents. When planning any interruption, all known circumstances that could affect the manipulation must be carefully taken into account. The design and operation of EDN, especially with connected PVPPs, have the task of minimizing energy losses and ensuring maximum security of production and power supply. Any change in the normal state of the network leads to a decrease in security and an increase in losses, as well as the cessation of electricity production. Due to these features, the main goal of the operational staff is to keep the EDN as close as possible to its normal state. The use of telemechanics to perform switching in EDN, especially in cases of PVPPs with an installed capacity of over 200 kW, improves the quality and safety of processes.

SCADA has become the preferred tool for network management. As a result, high network efficiency is ensured and the duration of switching is reduced to a minimum. The remote-controlled sites improve the quality of the power supply and the continuity of the production of PVPPs. With a reliable connection with the sites, SCADA increases the quality of electricity supply and customer service.

All the above leads to positive financial results, high quality of electricity supply and maximum production of electricity from PVPP.

IV. Conclusion

The analysis of the achieved values for the number and duration of disconnections in the EDN of terminals with and without PVPPs does not show that their presence worsens the accident rate. However, in the case of non-selective switching on of generating capacities, this affects the switch-offs. The presence of PVPPs connected at the end of the power lines, especially in settlements with low consumption, leads to a large difference in voltage, respectively when the PVPP generates electric energy and when it is disconnected. The use of voltage regulator switches in these cases becomes meaningless due to the periodicity in short intervals of the day. The voltage difference reaches several kV.

The values of the indicators for uninterrupted power supply SAIFI and SAIDI in the EDN of the two considered regions A and B show that the use of cable lines increases the security, and hence the indicators in times.

The presence of RES sometimes helps the work of EDN. There are several cases when in case of failure of substations in a given region and shortage of electricity, the inclusion of PVPP, when possible, can lead to improved parameters of this part of the EDN and power supply to customers. The situation is similar with large hydropower plants, which, joining the island regime, supply large areas in crisis situations.

In case of an abnormal scheme of operation corresponding to the designed part of the network, the energy produced by PVPP cannot be guaranteed to be transferred by EDC in terms of quantity and quality. For this reason, in these situations, it is desirable for manufacturers to stop working while the planned interruption is in progress. It is necessary to make a warning about the period of disturbance. This is a requirement of the EA.

The direct connection of the PVPP leads to an increase in the quality of both the operation of the EDN and to the minimization of the disturbances of the consumers and the producers.

Attempts to move to decentralized production of electricity from renewable energy sources have been made in recent years. In Bulgaria, this will reduce network security and increase the cost of providing quality service.

Acknowledgment

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