Influence of the type of electrical distribution network on the indices of continuity of the power supply

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***Abstract* — Results for the indicators of power supply continuity in the electrical distribution networks (EDN) of two typical regions in the Republic of Bulgaria. The purpose of the study is to analyze and evaluate the impact of the type of electrical distribution networks on the indicators of quality of electricity supply in medium voltage distribution networks and to determine the possibilities for reducing the indicators of power supply interruptions.**

Keywords — electrical distribution network, quality of power supply, indices, interruptions, consumers

I. INTRODUCTION

The analysis of the achieved results establishes the dependence of the values of the indicators for continuity of electric power supply SAIDI and SAIFI on the ratio between the share of the overhead and cable network in the different countries. The cable network is less dependent on the impact of external factors, such as the influence of third parties or "force majeure". The presence of a cable network directly affects the quality indicators of the power supply. The use of overhead power lines leads to a higher number of interruptions and hence higher values of the SAIFI and SAIDI indicators. On the other hand, the construction of cable networks is associated with large initial investments.

From the above said it becomes clear that when building new and reconstructing the existing parts of the electric distribution networks, it is necessary to find a balance between the security of the network (power supply) and the value of the initial investments (the price of the facilities). In addition to the feasibility study for the appropriateness of these investments, they must be approved by the regulatory authorities and recognized as operating costs of the electricity distribution company concerned.

A detailed examination of the current state of the electric distribution networks, for low voltage (LV) and medium voltage (MV), for the countries of the European Union shows that a kind of leader in the share of cable network as part of the overall electricity network is the Netherlands, where about 90% from the medium voltage network is implemented through cable lines [1]. This fact explains the extremely low values of the indicators for the continuity of electricity supply, which are realized in the electricity distribution network of the Netherlands. For comparison, in Bulgaria, the share of the cable network is approximately 22% for medium voltage networks and 30% for low voltage networks.

The medium voltage electric distribution network in the Republic of Bulgaria is constructed mostly of overhead and cable lines. The analysis of the emergency conditions of the two types of power lines allows to distinguish the following features:

- For overhead lines
  - Possibility for self-restoration of the insulation after switching-off the short circuit. This feature creates prerequisites for reducing the duration of interruptions by using appropriate means for system automation. On the other hand, there is a possibility of damage expansion as a result of the short-time thermal and dynamic effect of the fault current in unsuccessful attempts for auto-reclosing.
  - Quite often the duration of the restoration of the serviceability is long due to the passage of the power lines through hard-to-reach areas.
- For cable lines
  - Many factors are influencing the insulation characteristics. Hence even a slight violation of the integrity of the insulation is a prerequisite for the occurrence of permanent accidents.
  - The possibilities for visual assessment of the condition are limited, this leads to difficulties in detecting faults.
  - Much more resources are needed for the repair.

Currently, a hybrid version of EDN is often used - as overhead lines with insulated wires. The application of this option allows to realize some of the advantages of both cable and overhead power lines.

In the electricity distribution networks MV in our country there are several values of the nominal voltage, respectively 6, 10 and 20 kV. The 10 kV and 6 kV networks are built mainly of cable lines and are found in large cities. They actually make up a small part of the whole EDN. For this reason, parts of the electricity distribution network with a voltage of 20 kV will be considered in detail in the paper.

II. CHARACTERISTICS OF THE OBJECT OF STUDY

The study covers the influence of the construction type of the electric distribution network on the quality indicators of the electricity supply, calculated according to the EWRC methodology [2, 3] for two regions:

- Region “A” with predominant cable network;

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- Region “B” with predominant overhead network.

The medium voltage distribution network in Region "A" is built predominantly with cable power lines, as the share of cable lines is 90% of the total length of the network. In reality, this is a large city with typical infrastructure - many facilities close to each other with many consumers and high consumption of electrical energy. The cables are mainly mounted in collectors and pipe ducts, which protects them from damage due to uncoordinated construction activities.

In order to increase the reliability of the power supply, the condition of the cables in the collectors and the routes along which they pass are periodically checked. The condition of the cable fittings is visually checked and detours of the transformer stations, which are connected in this network, are tested out. Planned preventive maintenance is carried out in order to prevent accidents. The physical condition of the cable network is monitored, and cables and cable fittings are replaced according to the factory instructions according to the factory operating instructions. A large number of circuit breakers and power disconnectors have been installed in this region in order to ensure switching without disturbing customers [4].

In Region B the medium voltage network has been built, mainly with overhead power lines, which account for over 90% of the total length of the network in the respective region. This is a region located in pronounced mountainous terrain, with small villages located at a great distance from each other, with few consumers and low electricity consumption. In some of the settlements in the autumn-winter period, the number of customers using electricity is units. The constructed power lines pass through wooded terrains with tall trees.

In order to maintain the serviceability of the power lines, the condition of the clearings is periodically checked, according to the allowed distances. In some cases, this is not always enough, especially in regions where the height of the trees is several times greater than the height of the pillars. Then, in combination with bad weather conditions and terrain, trees outside the clearing fall on the power lines and cause accidents. A peculiarity of this type of network is the presence of sectioning disconnectors for large sections in order to locate the fault.

III. Analysis of Results in Different Regions

The study examines the indicators for the quality of electric power supply for the period from 2012 to 2019 in the two typical regions of the electricity distribution company (EDC).

The results for the achieved values of the indicator for the number of unplanned interruptions SAIFI for the considered regions are presented in Fig. 1.

The results show that for the region with a large share of overhead network, the SAIFI indicator has many times higher value than the region with a predominant cable network. Also, in the region with a large share of the overhead network, there is a significant change in the SAIFI indicator over time, as the minimum value is 2.48 and was achieved in 2017, while in 2019 a value of 5.71 was reached, which is the largest for the time interval under consideration. In the region with a large share of cable network, the SAIFI indicator remains almost unchanged, with a maximum value of 0.7 being reached at the beginning of the survey period.

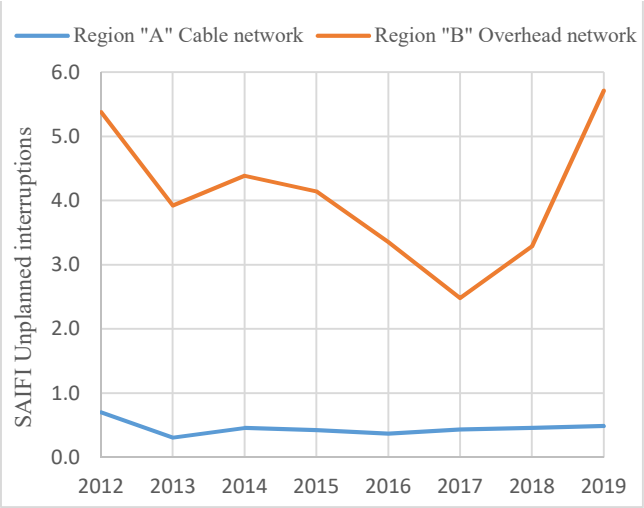

Fig. 1. SAIFI from unplanned interruptions for the regions

Fig. 2 presents the results for the realized values of the indicator for the duration of the unplanned interruptions SAIDI for the two regions.

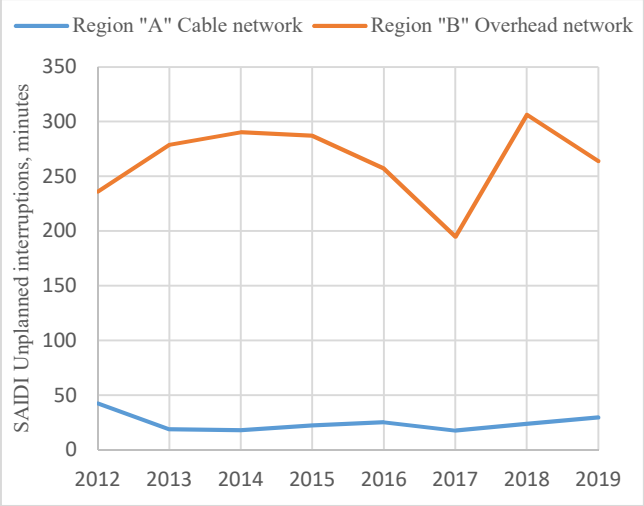

Fig. 2. SAIDI from unplanned interruptions for the regions

The obtained dependences show that for the region with a large share of overhead network the SAIDI indicator has a much higher value (up to 10 times) compared to the region with a significant share of cable network. In the region with a large share of cable network, the SAIDI indicator remains almost unchanged with an average duration of the interruption of 25 to 30 min, as the maximum value of 42 min was realized in 2012. In the region with a large share of overhead network, a significant change of the indicator SAIDI in time is observed, with a minimum value of 194.95 minutes and was achieved in 2017, while in 2018 a value of 306.3 minutes was reached.

The main reasons for the much higher values of the quality indicators of the power supply in the networks built mainly of overhead lines are:

- Poor maintenance and insufficient dimensions of the clearings;
- Human activity - uncoordinated construction activity, vehicles (accidents, high-size equipment, etc.);
- Birds;

- Landslides;
- Force majeure - fires, high atmospheric activity (strong wind, lightning, icing, etc.).

These factors affect individually, and sometimes in a combination of two or more factors simultaneously. In most cases, their impact cannot be predicted. Therefore, actions are taken ex post facto, after the passage of their impact and the occurrence of permanent faults. Where prior information on expected impacts is available, the necessary measures shall be taken to limit their impact where possible or to prepare for a rapid and adequate response to their impact [5].

Looking at the results achieved for the different countries, the report of the European Regulatory Commission shows the trends for change of the indicators in the different countries [7, 9]. This report clearly shows that the division of the exclusions into two types (those caused by "force majeure" and others) gives a clearer picture of the events on the network.

In order to take into account the influence of unforeseen circumstances on the indicators of power supply continuity in the different types of EDN, the values of SAIFI and SAIDI due to the presence of force majeure have been calculated.

The change in time of the indicator for the number of interruptions SAIFI caused by force majeure is presented in Fig. 3.

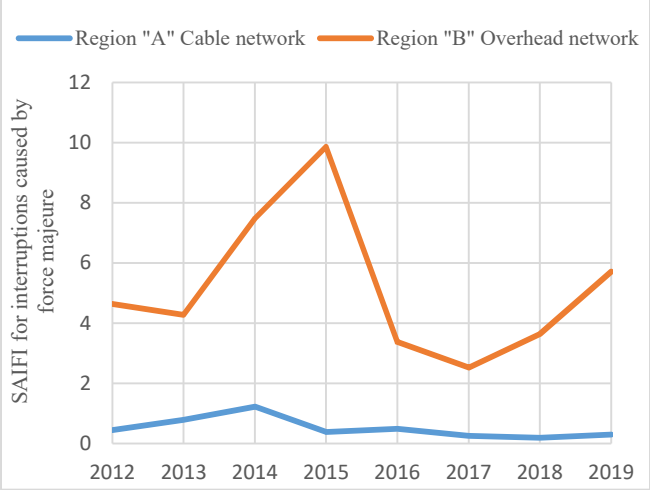

Fig. 3. SAIFI for interruptions caused by force majeure for the regions

The obtained results confirm the significant influence of the type of the electricity distribution network on the indicator for the number (frequency) of interruptions. There is a strong correlation between the trend of change of the SAIFI indicator for unplanned interruptions (Fig. 1) and the trend of change of the SAIFI indicator caused by force majeure, which should show that unforeseen circumstances are the main reason for power outages in overhead networks.

The results for the values of the indicator for the duration of the interruptions SAIDI caused by force majeure circumstances for both regions are presented in Fig. 4.

The results show that for most of the study period the SAIDI values for the two regions are close, with the exception of 2014 and 2015, when the SAIDI value reached 37500.4 minutes. The large SAIDI values in 2014 and 2015 are due to severe weather conditions during the winter season. As for the territory of region 'B', these severe weather conditions often lead to partial or complete disruption of all infrastructure services.

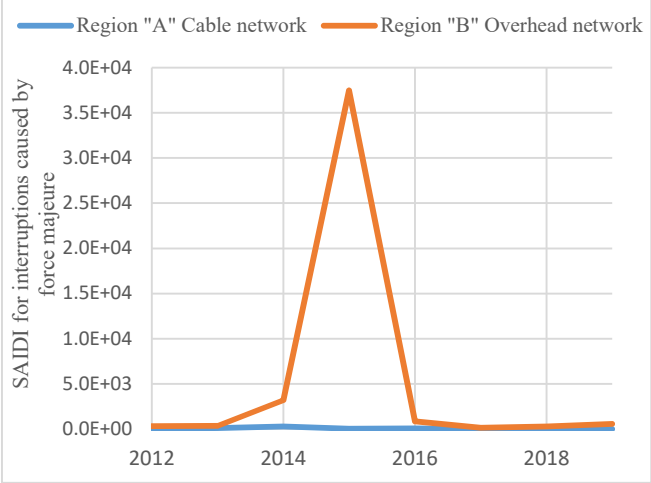

Fig. 4. SAIDI for interruptions caused by force majeure for the regions

The absence of a correlation between the trends of change of SAIDI from unplanned interruptions and force majeure should indicate that the presence of unforeseen circumstances does not have such a significant effect on the interruption duration index.

What is seen as a sustainable phenomenon is the influence of external factors on the overhead network fault in region "B". In this case each worsening weather conditions or other impact causes a sharp increase in the number of unplanned (emergency) interruptions. From this it can be concluded that a careful and regulated separation of the factors influencing the interruptions must be made and measures to increase the security of power supply must be prepared and implemented [6].

IV. Measures to Improve Continuity of Power Supply for Networks of Different Types

The measures that can be implemented are a set of actions to improve the quality indicators of the electric power supply. Depending on the need for changes in the technology of work or the application of new technical solutions, the measures are: organizational and technical.

Organizational measures are primarily related to changes in the organization of work groups and management of available resources. The main purpose of these measures is to keep the network as close to normal as possible, as any change in the state of the network reduces security and increases losses. The operational staff of the respective electricity distribution company is responsible for the implementation of these measures. The main prerequisite for the implementation of these measures is a good knowledge of the resource of the network, which helps to make a proper assessment of its capabilities for load-transfer capacity, in case of operational need [8].

Unlike organizational measures, the applicability and impact of technical measures on the quality indicators of electricity supply depend on the type of electricity distribution network.

The analysis of the results for the indicators for the quality of the electric power supply in regions with different types of

the electric distribution network clearly shows the dependence of the quality of the electricity supply on the external factors. Therefore, for each of the two types of power lines it is necessary to provide adequate protection from external influences.

Technical measures for networks with high-share of overhead power lines include complex solutions that directly affect quality indicators. The idea that is followed when making these technical decisions is in case of disturbances to separate a section with an increased probability of a fault, in which a minimum number of customers will remain without power for a minimum period of time. Some of these technical measures are:

- Installation of power disconnectors or reclosers switching certain parts of the lines;
- Implementation of modern systems for telemechanics and dispatch control with a high degree of automation;
- Expansion and maintenance of the clearings along the route of the power lines;
- Control for construction works in the easement of the air lines;
- Installation of surge arresters in order to limit the effect of overvoltages;
- Installation of protective equipment that does not allow the breach of the isolation distances from the birds (Fig. 5).

Fig. 5. Installation of protective equipment against birds

Another technical measure influencing the quality indicators of the power supply is the management of the earthing mode of the neutral. The installation of an arc-suppression coil with an increase in the active component of the ground fault current is a new solution. With it, we have no real disturbance of consumers in the event of an accident with a permanent earth fault. These devices are equipped with regulators for automatic adjustment of the fault current compensation. When an earth fault occurs in the power line, it doesn't turn-off automatically, but remains supplied. Operational personnel locate the accident under voltage, observing the necessary safety requirements. The advantage of this measure is that consumers have power throughout this process.

The replacement of the overhead electrical network with cable leads to an improvement in the quality indicators of the electricity supply. Sometimes in places with frequent accidents it is economically feasible for the network of a given section to be a cable line, even when this investment is greater than for the construction of overhead power lines. The costs of repeated repairs of faults and the costs of work of employees and equipment are many times higher than the costs of building a cable line.

In the case of cable lines, the same volume of technical measures are carried out in order to ensure a minimum number and duration of interruptions. Some of the measures that are being taken are:

- Taking into account the territorial and geodetic features of the route when designing the cable lines;
- Installation of surge arresters at the transitions from cable to overhead line;
- Control for construction/excavation works and planting of trees in the route of the cable power lines.

V. Conclusion

The analysis of the achieved values of the indicators for continuity of electric power supply SAIFI and SAIDI in regions with a pronounced overhead and cable network shows that the regions in which we have a large share of overhead network accident rate is significantly higher than regions with developed cable network.

Proper implementation of organizational and technical measures can lead to significant improvements. The balance between good power quality and the costs for its achievement is fundamental to network development i.e. new measures must be taken to improve quality at the expense of a new type of investment based on a balance between security, quality and price.

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

The development of generating capacities and their connection to the EDN will lead to a reduction of losses and increase of the security of the power supply by creating a nodal security.

The introduction of monitoring, control and management systems at a new higher technological level (smart grids) will optimize the number of affected users at each interruption. At the moment, this is an expensive investment, which does not allow it to be implemented in Bulgaria yet.

The high percentage of the share of the overhead network in the EDN of the Republic of Bulgaria will determine the relatively low indicators of the quality of power supply for the years ahead. A solution with a sensitive replacement of the overhead with a cable network would lead to colossal costs, which will affect the final price of electrical energy.

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