Methodology for Reliability Assessment of Distribution Networks with Decentralized Energy Resources Connected

Evgeniya P. Vasileva[1]

Abstract – **The purpose of this article is to propose a new method for assessing the reliability of a RES upgraded electrical power supply system by utilizing an economic indicator - the amount of undelivered electric energy at various DERs schemes connected to the conventional power grid.**

The article discusses three major distribution electricity network variants: one, two, and three power lines connected to decentralized energy sources.

A methodology for calculating the amount of undelivered electricity has been developed and proposed, allowing for accurate calculations and their application in various schemes for connecting decentralized energy sources to the electricity distribution network.

Keywords – **renewable energy sources, decentralized energy resources, reliability.**

I. INTRODUCTION

Electricity is vital for the global economy to succeed in this and future centuries. Energy can be produced from a variety of sources, and it is preferable to generate it from a variety of sources. The increased demand, generation, multiple sources of generation, and reliance on electricity necessitate a high level of reliability and flexibility in the power system [1]. Power networks have been designed for decades with a few major centralized power plants supplying electricity to a vast consumer base via extensive transmission and distribution lines. Increasing the final price of electricity for end users; high requirements and goals set before each member state of the European community; and targeted policies supporting the development and dissemination of renewable energy sources are all factors that have contributed to the rise in the number of decentralized energy resources (DERs) in the European Union (EU) and in Bulgaria so far [2]. Renewable power generation capacity is defined as the maximum net generating capacity of power plants and other installations that generate electricity using renewable energy sources. According to IRENA data [3], there is a continuous increase in the capacity for generating energy from renewable sources. The data show a significantly faster increase in capacity in the European Union countries overall, compared to Bulgaria. The trend for both the European Union and Bulgaria is the same, with a continuous increase in total renewable energy, Fig. 1. Many authors [4–9], as well as the current situation in Europe and Bulgaria, believe that diversification and decarbonization are becoming highly important. There are numerous decentralized power systems in use, such as distributed generation clusters, smart grids, microgrids. That kind of power system can be of great help in the completion of critical tasks such as power system optimization and stabilization. They are also capable of incorporating renewable energy sources (RES) and intelligent control centers. The majority of decentralized power systems are local hybrid power systems that include RES, inverter, storage, and smart control. Depending on the circumstances,

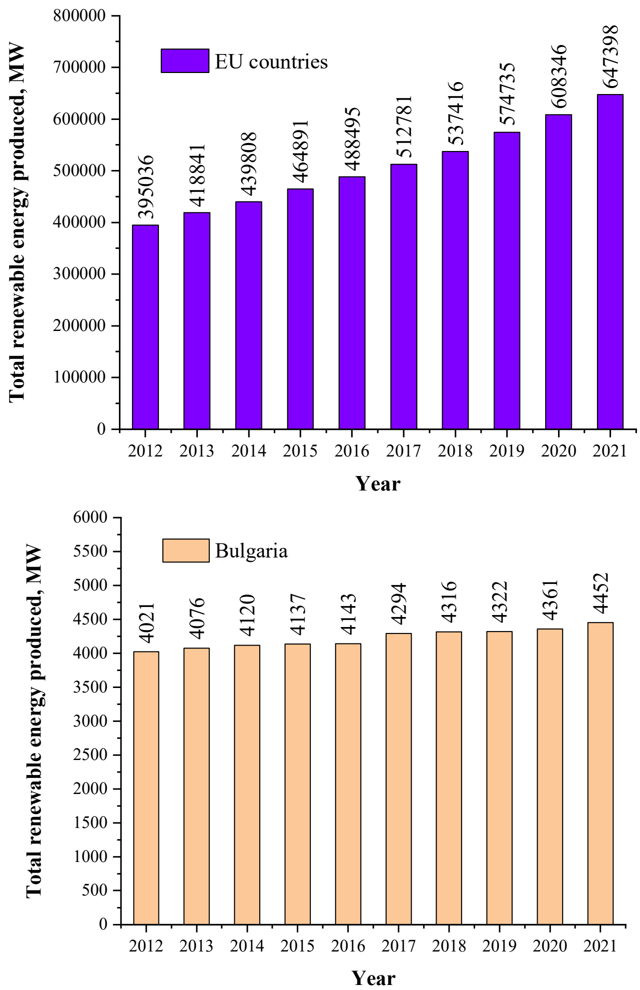

Fig. 1. Growth in renewable generation in the European Union and Bulgaria [3].

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they can be connected to a centralized power grid to sell power for import and export, Fig. 2.

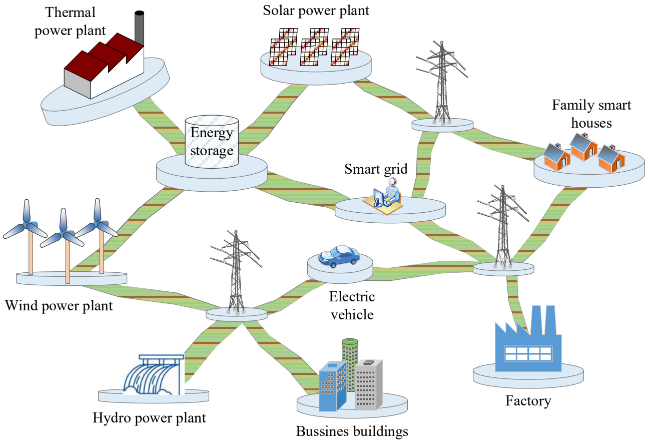

Fig. 2. Example of a decentralized power system.

The brief literature review gives us a reason to consider that in an energy system the size of the decentralized energy sources is of great importance, as well as the way they are connected to the power system. As a result, the primary goal of this article is to present a criterion for evaluating the reliability of the electricity grid at connected DERs.

Akhtar et al [10] propose reliability assessment of electrical grid with incorporated solar and wind renewable energy sources by different models. Case study and risk analysis have been performed based on different risk indexes to show the usefulness of the proposed strategies and assessment framework. The paper and the obtained results prove that the integration of the solar and wind energy systems into the grid enhance overall the reliability of the entire power system.

According to [11] the evaluation of reliability of the power systems is a critical issue in planning, design, and operation. The system is considered to be operationally successful if there is sufficient generation capacity to meet the peak load, i.e. adequate reserve to meet maximum demand. The book concerns the issue of unsold but claimed electricity or the so-called expected energy that is not supplied - ϵENS. The ϵENS index is used to calculate energy sales, which are the true earnings of the electric company.

Many authors have used various methods to assess the reliability of electrical energy systems. The most common methods are mathematical: modeling [12–14], optimization or various algorithms usage [15, 16], stochastic and analytical [17], various strategies [18].

The goal of this article is to propose a new method for reliability assessment of an RES upgraded electrical power supply system using an economic indicator - the amount of undelivered electric energy at various DERs schemes connected to the conventional power grid.

II. Experimental Research

Usually, the important decisions, regarding the connection of DERs to the conventional electricity grid, are made after a technical and economic analysis of the various options. It is necessary to include the reliability assessment for which the discounted cash flow method is used in the feasibility study. It is necessary to consider the undelivered electricity from renewable energy sources when using this method [19, 20]. The optimal level of reliability corresponds to the minimum value of the sum of discounted cash flows and undelivered electricity costs.

It is well known that the reliability of the power supply system in the presence of renewable sources or DERs depends on a variety of factors, including: the reliability of the elements in the connection scheme, operating reserve availability and the presence of sectioning, and the level of automation used.

A. Choosing a criterion for reliability assessment at connected DERs

The reliability criterion may include logical or analytical expressions. The criterion enables the presence or absence of dependability to be determined. The amount of undelivered energy is the most appropriate criterion for assessing reliability in this case.

The average value of undelivered electricity ($\bar{E}$) - equation 1, is determined by complex reliability indicators: readiness factor $k_r = \bar{T}/(\bar{T} + \bar{\tau})$ a nd the coefficient of forced stay $k_s = 1 - k_r$:

$$\bar{E} = \bar{A}\, k_s = \bar{P}\, T\, k_s, \qquad (1)$$

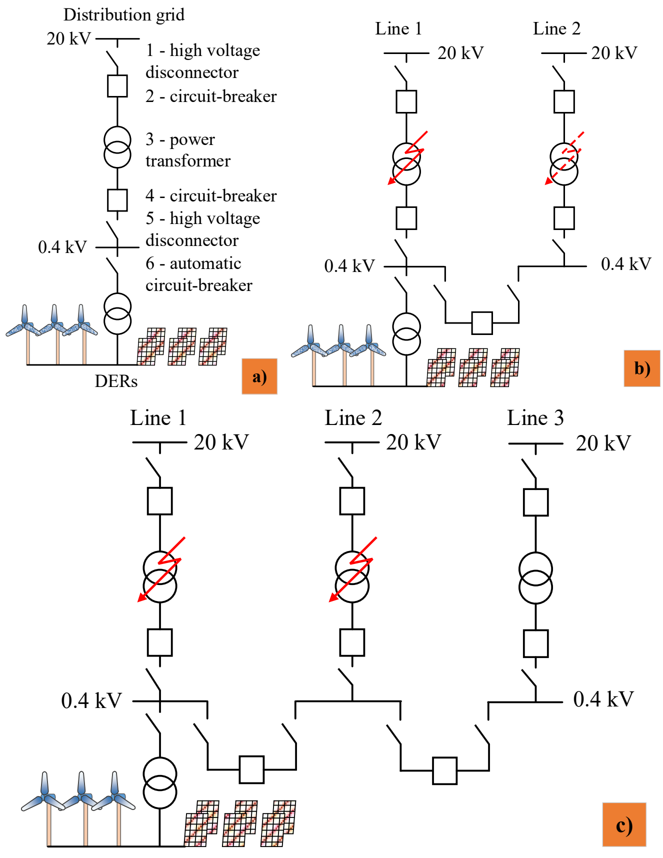

Fig. 3. Decentralized energy system with two substations

where $\bar{P}$ and $\bar{A}$ are the mathematical expectation of power and electrical energy for time T respectively; $\bar{T}$ and $\bar{\tau}$ are the average duration of trouble-free operation and recoveries.

B. Connection of DERs to the power grid via a single, two and tree substations

The distribution grid includes lines, poles, transformers, disconnectors, switching and protection circuits.

The article discusses three main variants of distribution electricity network - with one, two and three power lines, Fig. 3.

For 10 years, experimental data on the operation of a real system containing decentralized sources of electricity located in the Sliven region (Bulgaria), have been collected and processed. As a result of the collected data, Table I is summarized, containing data on the operation of DERs, in terms of: flow of failures for 1 year, duration of refusals, number of recoveries and their duration.

TABLE I
EXPERIMENTAL DATA FOR NUMBER OF FAILURES, REFUSALS DURATION, NUMBER AND DURATION OF RECOVERIES

Element number according Fig. 1.	Number of failures ω for 1 year	Refusals duration τ_b, hours	Number and duration of recoveries $\mu.\tau_r$, hours/year	Break duration $T_{equiv,\,i}$, hours (calculated)
1	0.015	4	6	6.06
2	0.04	10	16	16.4
3	0.01	80	20	20.8
4	0.04	10	16	16.4
5	0.015	4	6	6.06
6	0.1	5	0	0.5

The equivalent duration of the shutdowns $T_{equiv,\,i}$ for each *i-th* element of the schemes of Fig.1a calculated by expression 2:

$$T_{equiv,i} = (\omega.\tau_b + \mu.\tau_r)_i \tag{2}$$

The equivalent break duration is determined by equation 3 where i is the number of elements included in the distribution line (according to Fig. 1a $i = 6$):

$$T_{equiv} = \sum_{i=1}^{6} T_{equiv} = 66.22\ hours \tag{3}$$

The amount of electricity supplied is calculated using the mathematical expression 4:

$$N = \beta.T_{equiv}, kWh \tag{4}$$

where β is the day-time or night-time price of electric energy in €/kWh (or BGN/kWh) respectively.

Figure 1b depicts a case of a distribution grid with two lines and two transformers. There is a chance of a short circuit in either line 1 or line 2. There are two possible cases: the first is the occurrence of a short circuit in line 1 (case 1) and the second is the occurrence of a short circuit in line 2 (case 2). For Case 1, Table II summarizes the experimentally obtained results. Case 2 - In the event of a short circuit in line 2, the results are analogous to those shown in Table I.

TABLE II
EXPERIMENTAL DATA FOR NUMBER OF FAILURES, REFUSALS DURATION, NUMBER AND DURATION OF RECOVERIES

Element number according Fig. 1.	Number of failures ω for 1 year	Refusals duration τ_b, hours	Number and duration of recoveries $\mu.\tau_r$, hours/year	Break duration $T_{equiv,\,i}$, hours (calculated)
1	0.015	4	6	6.06
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5	0.015	4	6	6.06
5	0.015	4	6	6.06
4	0.04	10	16	16.4
5	0.015	4	6	6.06
6	0.1	5	0	0.5

The following scheme, which is discussed in this article, contains three lines of the distribution network.

TABLE III
EXPERIMENTAL DATA FOR NUMBER OF FAILURES, REFUSALS DURATION, NUMBER AND DURATION OF RECOVERIES

Element number according Fig. 1.	Number of failures ω for 1 year	Refusals duration τ_b, hours	Number and duration of recoveries $\mu.\tau_r$,	Break duration $T_{equiv,\,i}$, hours (calculated)
1	0.015	4	6	6.06
2	0.04	10	16	16.4
3	0.01	80	20	20.8
4	0.04	10	16	16.4
5	0.015	4	6	6.06
5	0.015	4	6	6.06
4	0.04	10	16	16.4
5	0.015	4	6	6.06
5	0.015	4	6	6.06
4	0.04	10	16	16.4
5	0.015	4	6	6.06
6	0.1	5	0	0.5

The distribution network is divided into three lines in the following scheme, which is discussed in this article. These three lines determine the existence of the three cases listed below:

- first - in the event of a line 1 short circuit: The case is analogous to a circuit with two transformers, and the results obtained and shown in the table are completely repeated;
- second - the case is analogous to that of Fig. 1a and repeats the table results.
- third - this is the worst-case scenario, in which short circuits occur on lines 1 and 2 of the distribution network at the same time. The same methodology is used in this case to calculate the equivalent shutdown duration T_{equiv} and the amount of undelivered electricity. Table III summarizes and presents the results for this case.

III. Conclusion

The article demonstrates and proves that the connection of decentralized energy sources to the distribution grid with two or more lines, the amount of undelivered electricity is reduced to zero, because the likelihood of simultaneous damage to all connection lines is minimal.

A methodology for calculating the amount of undelivered electricity has been developed and proposed, allowing for appropriate calculations and their implementation in various electrical schemes containing decentralized energy sources to the electric distribution network.

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