Influence of Distributed Power Generation from Renewable Energy Sources on Reliability of Distribution Networks

Case Study

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Abstract *– The paper deals with the impact of renewable energy sources on reliability of distribution networks. It is determined through four case studies in which reliability indices are calculated. Island mode operation in the network is allowed with several assumptions. The authors assumed that the reliability of the system can be improved by islanded operation of distributed generation and showed an advantage of proposed islanding in relation to supply availability.*

Keywords *– distributed power generation, islanded operation, reliability, renewable energy sources, supply availability.*

1. INTRODUCTION

Increasing amounts of electrical energy are being produced from distributed renewable energy sources (RES). If failure occurs anywhere in the grid, power plants that are not affected by the failure cannot continue to supply consumers if they are in island mode operation. The reasons for that are the negative effects of island mode operation. This is the operating mode that renewable distributed energy sources would have to ensure availability of supply after failure. Negative effects of islanded operation can be significantly reduced due to the advancement of technology. Considering that fact, power sources distributed in the network could improve reliability of distribution networks. The influence of distributed power generation from renewable energy sources on reliability will be considered by calculations. The calculation consisted of four case studies. The goal of this paper is to show how distributed generation can improve reliability indices in distribution networks.

The first case determines fundamental results, while distributed generation (DG) from renewable energy sources are not included therein. In the second case, five renewable energy sources power plants are added to the network at the end of every feeder and reliability indices are analyzed assuming that distributed generation can supply customers in the feeder with required power. In the third case, switches at the beginning of every lateral are replaced by circuit breakers and reliability indices are analyzed. In the fourth case, switch Rz1 on the main overhead feeder is replaced by a circuit breaker, biomass power plant DGz4 is added and reliability indices are analyzed.

2. RELIABILITY INDICES

Power supply quality is determined quantitatively through reliability indices [1]. Reliability indices are directly associated with profit accomplished by power distribution and with costs of supply interruptions. They play an important role in future planning and development of the power grid. Reliability indices are divided into two groups depending on which kind of information they provide [1], i.e.,:

- customer-oriented indices, and
- load- and energy-oriented indices.

Reliability indices are calculated by summing up all contribution indicators of the consumer or consumer nodes per individual feeder and then by summing up contribution indicators for the whole distribution network [2]. Currently, there are large numbers of indices in use. Only most commonly used ones are presented here [3]:

- *SAIDI* - System Average Interruption Duration Index (h/year),
- *SAIFI* - System Average Interruption Frequency Index (1/year),
- *CAIDI* - Customer Average Interruption Duration Index (h/interruption),
- *ASAI* - Average Service Availability Index,
- *ASUI* - Average Service Unavailability Index,
- *CAIFI* - Customer Average Interruption Frequency Index (1/year),
- *CTAIDI* - Customer Total Average Interruption Duration Index (h/consumer, year), and
- *AENS* - Average Energy Not Served (kWh/year).

3. CASE STUDIES

3.1 FIRST CASE STUDY

Calculation is performed on the test system taken from [1]. The scheme does not present a real network used in practice; nevertheless, it has all important characteristics for this calculation. The system shown in Figure 1 consists of two main feeders. The upper and the lower feeder are a cable feeder and an overhead feeder, respectively. The cable feeder presents an urban environment, whereas the overhead feeder presents a rural environment. The cable feeder has switches at both the beginning and the end of every section.

Those feeders provide isolation of the faulted part of the grid and consequently allow an uninterrupted power supply to the rest of the network. That is not case in the rural area because there are no switches at the beginning and the end of every section. Therefore that power outage will affect a larger number of consumers. Another great difference between the rural and the urban area shown in this example is the inability to supply customers from multiple directions in the case of a rural network. DG must be optimally placed and sized in the grid considering network configuration [4].

Fig. 1. Single-line network diagram - first case

3.2 SECOND CASE STUDY

In further cases, it is assumed that all renewable distributed generation facilities can provide nominal power constantly. Distribution network reliability considering weather and distribution generation is described in [5]. In the second case, shown in Figure 2, five renewable energy sources (RES) power plants are added to the network at the end of every feeder and it is assumed that distributed generation can supply customers in the feeder with required power. If failure occurs on the main feeder, consumers in the lateral feeder will be resupplied with electricity after switches separate laterals from the main feeder.

3.3 THIRD CASE STUDY

In the third case, switches at the beginning of every lateral are replaced by circuit breakers. A single-line diagram of the third case is shown in Figure 3. The circuit breaker allows almost a momentary separation of the laterals from the main feeder in the case of failure on the main feeder. In the previous case studies, switches required a longer period of interruption. In this situation, consumers and distributed generation will enter the islanded mode almost instantly. Other specifications in the test system are identical to previous cases.

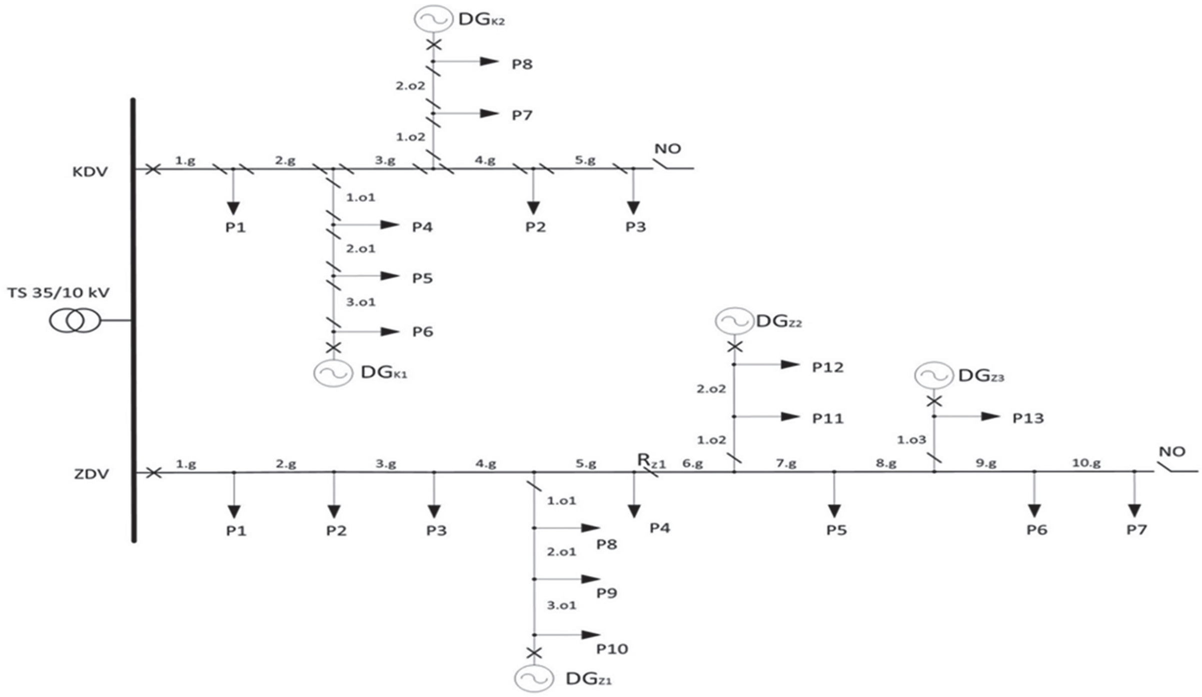
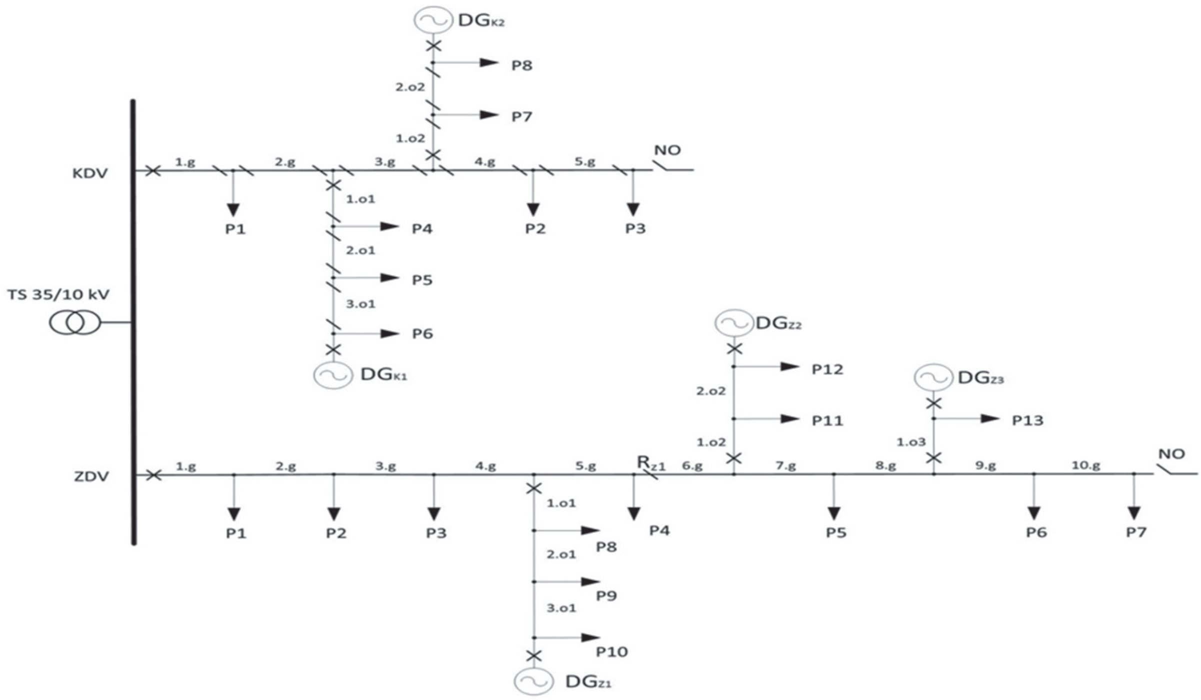


Fig. 2. Single-line network diagram - second case



3.4 FOURTH CASE STUDY

A single-line diagram of the fourth case is shown in Figure 4. In this case, switch Rz1 on the main overhead feeder is replaced by a circuit breaker. Also, biomass power plant DGz4 is added. If failure occurs between TS 35/10 kV and circuit breaker Rz1 on the main overhead feeder, consumers positioned in the newly formed isolated grid will be supplied from the DG after circuit breaker Rz1 opens its contacts. Other specifications in the test system are identical to previous cases.

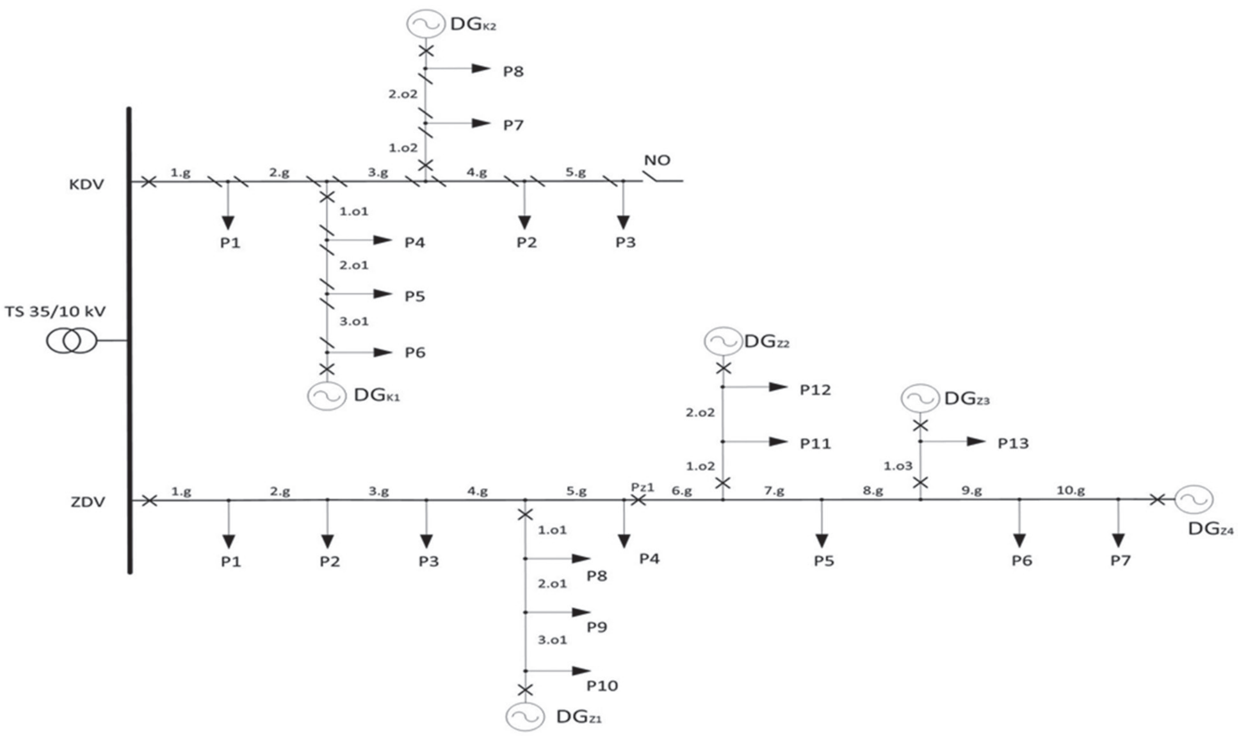


Fig. 4. Single-line network diagram - fourth case

4. CALCULATION RESULTS

In this chapter, calculation results are presented for all four case studies. To calculate reliability indices, we used an analytical method. Results are shown in graphical form. Figure 5 and Figure 6 present *SAIDI* for the cable feeder and for the overhead feeder, respectively. Figure 7 presents *SAIDI* for the entire distribution system calculation is performed on.

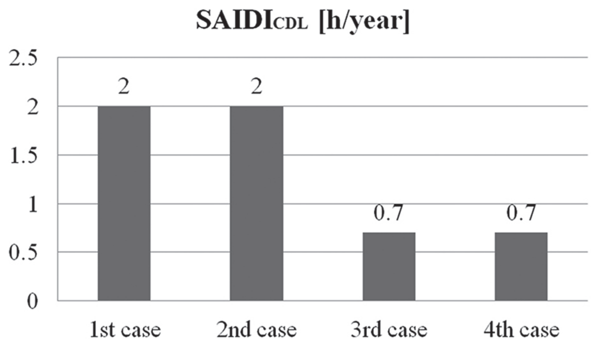


Fig. 5. *SAIDI* of the cable distribution line

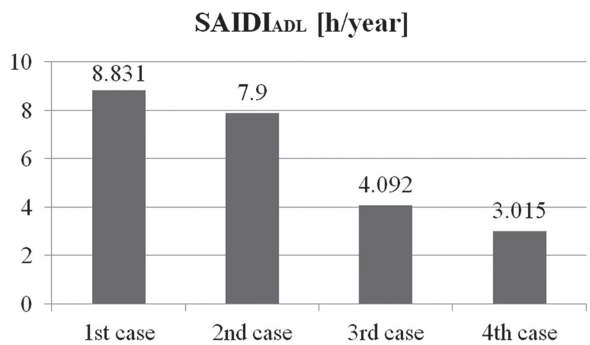


Fig. 6. *SAIDI* of the overhead distribution line

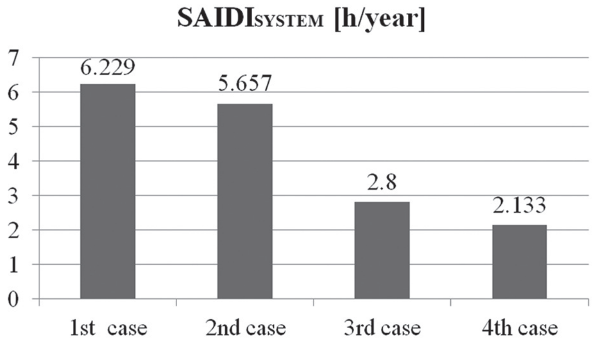


Fig. 7. *SAIDI* of the distribution system

The system average interruption duration index decreases through cases. It can be noticed that there is no change between the first two cases regarding *SAIDI* reliability index for the cable feeder. Implementation of DG in this situation does not affect the system average interruption duration index. As the cable feeder is in the urban environment, there is a large number of circuit switches and any failure can be isolated to a small area of the network. Other consumers can be supplied from the other end of their lateral. In the second case, distributed generation is positioned at the end of every lateral and it replaces a normally opened component. In the third and the fourth case, we can notice reduction of *SAIDI*. The reason for that is installation of circuit switches that are responsible for shortening interruption duration. However, in the case of the overhead feeder representing the rural area, the system average interruption duration index is significantly reduced thanks to distributed generation. As mentioned previously, if an interruption occurs in a rural area, a large number of customers will be affected. Implementing distributed generation and allowing islanded operation in branches improves *SAIDI*. Improvement continues with installation of circuit breakers in the third and the fourth case.

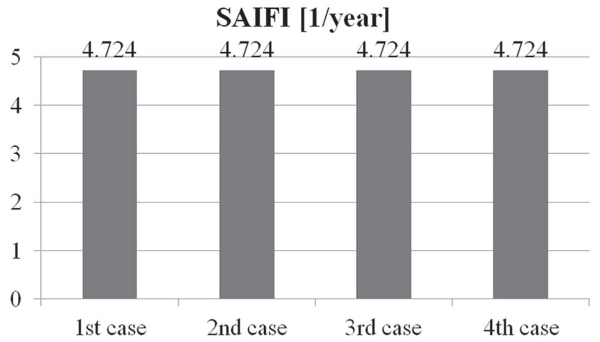


Fig. 8. *SAIFI* of the distribution system

As shown in Figure 8, the system average interruption frequency index is constant through all four cases. Distributed generation is considered ideally reliable in this paper so it does not influence the frequency of interruptions. A similar situation is shown in Figure 9. The customer average interruption frequency index is constant through all four cases for the same reasons as *SAIFI*, because installation of DG will not affect the number, i.e. the frequencies, of failure occurrence, only the duration of power supply restoration.

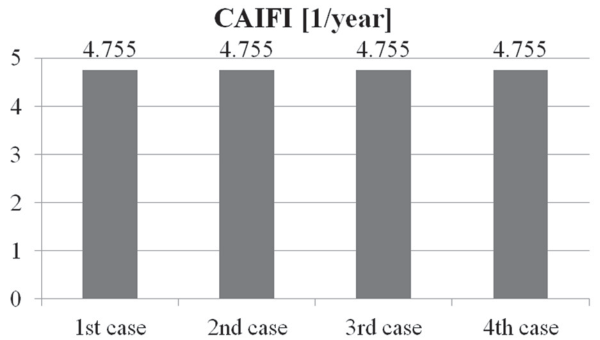


Fig. 9. Customer average interruption frequency index

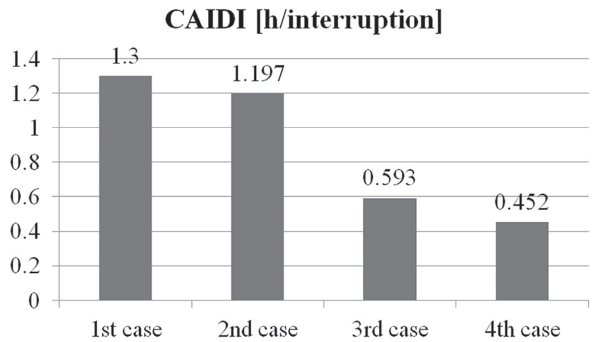


Fig. 10. Customer average interruption duration index

By analyzing results of calculation shown in Figure 10 we can come to a conclusion that distributed generation is responsible for reducing the customer average interruption duration index (*CAIDI*) through cases. A significant effect of reducing *CAIDI* that can be seen in the third case compared to the second case is achieved by replacing switches by circuit breakers. They allow branches to be detached faster in the case of failure on the main feeder, enabling supply of customers by DG in island operation. A positive effect on *CAIDI* increases in the fourth case when the switch on the main overhead feeder is replaced by a circuit breaker. In the first case, *CAIDI* is 1.3 h/year, while in the fourth case it is 0.452 h/year, total reduction of *CAIDI* is 65.23 %.

Supplying customers from distributed generation in the islanded mode during failure on the main overhead feeder enables the average system availability index, *ASAI*, to increase. Its complementary index, *ASUI*, decreases through cases. Figure 11 and Figure 12 show *ASAI* and *ASUI*, respectively. All these previous indices lead to the conclusion system availability increases with island operation and DG.

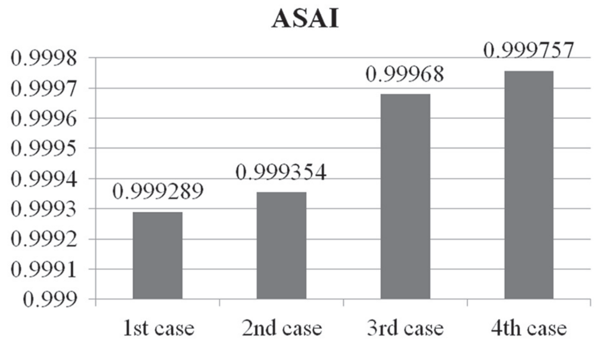


Fig. 11. Average system availability index

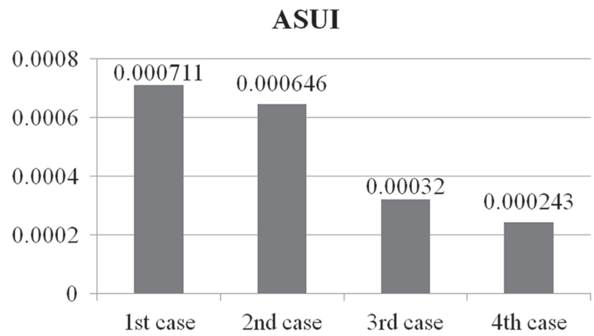


Fig. 12. Average system unavailability index

The value of the customer total average interruption duration index *CTAIDI* reduces through cases. The difference between the first and the second case indicates that interruption duration reduces because of implementation of distributed generation allowing it to supply consumers in the islanded mode in the case of failure in the network. That same reduction of *CTAIDI* will have a greater effect if switches at the beginning of the lateral are replaced by circuit breakers, cf. Fig. 13. Total reduction of *CTAIDI* between the first and the fourth case is 65.75 %.

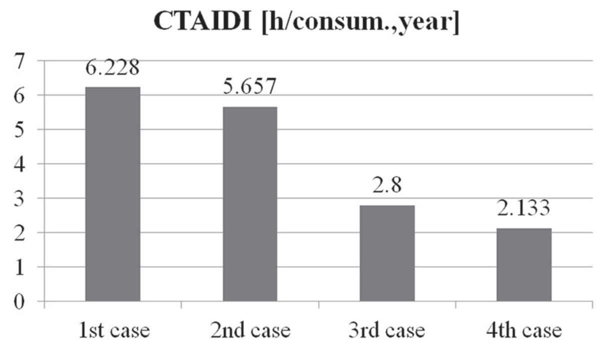


Fig. 13. Customer total average interruption duration index

The last reliability indicator considered in this paper is *AENS*, i.e., average energy not served. This indicator is significant from the economic point of view. The reason for that is a direct connection with profit generated through energy distribution. Results in Figure 14 show a significant decrease in the amount of energy not served. Managing a power distribution system by propositions made in this paper enables a network operator to sell more electricity thus achieving larger profit.

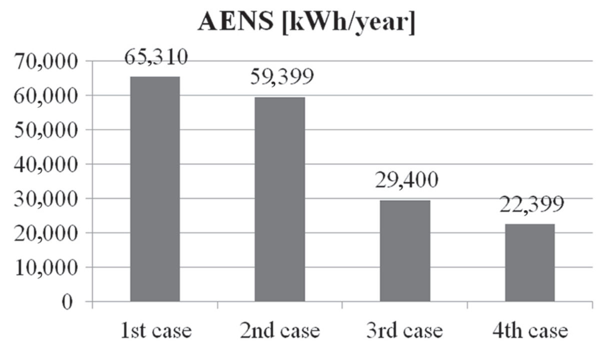


Fig. 14. Average energy not served

5. CONCLUSION

Islanded operation is not allowed in large networks due to unwanted effects it might create in the power system, such as bad effects on voltage quality, the problem with synchronizing separated networks, etc. [6]. The advancement of technology enables us to reduce most of negative effects, in some cases even to eliminate them entirely. In this way, distributed generation from RES power plants can be used for improving reliability of the power system.

In this paper, it is assumed that all consumers can be supplied from an associated distributed power plant. In practice, the islanded mode area must be determined first. In this area, consumers can be supplied from a nearby distributed power plant. The results of calculation indicate better reliability indices after installing switches or even circuit breakers at the beginning of the laterals. These elements separate the island operation area from the rest of the grid in the case of failure. Before any recommendations given in this paper are applied in practice, some issues have to be solved, e.g., the existing protection devices must be programmed for operation in two different network configurations. The first one works in normal mode or the whole system, and the other works in island operation. Network components shall guarantee protection constantly. After clearing the fault in the network, the system must return to the original operating state. The problem regarding reconnecting the islanded mode area and the rest of the network is how to avoid voltage differences at the moment of reconnection if equalizing currents appear and damage equipment. Another obstacle is the cost of additional equipment needed to manage the power system in this way.

Calculations in this paper show many positive impacts on the network. One of them is significant improvement of system reliability. Also, reliability indicator AENS shows that additional profit will be achieved by shortening the duration of power outages. A contract between a customer and an electricity provider guarantees a certain number and duration of power outages will not be exceeded. In some areas, mostly rural, that duration can often be exceeded, and the electricity provider is penalized. Managing the system by recommendations proposed in this paper can help us solve that problem.

6. REFERENCES:

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