

# Investigating Reliability of Smart Electrical Grids Considering Self-healing in Presence of Distributed Generation Resources

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**A** *The advent of DG and SEGs has led to fundamental changes in various fields of power system operation. The current*  
**B** *paper is aimed to investigate the reliability of SEGs considering DGRs based on the self-healing concept. Due to the*  
**S** *emergence of new uncertainties in the power system resulted from the presence of DGRs, this paper is dedicated to*  
**T** *comparing network reliability indices before and after the entry of DGRs and analyzing their effect on improving network*  
**R** *reliability. To do so, improving the indices based on customer satisfaction, such as reducing the SAIFI, and SAIDI, is*  
**A** *evaluated. More specifically, the improvement of the most important index based on load and energy, namely energy not*  
**C** *supplied (ENS), is investigated. To do this, the MCS method is used given the pdf of the samples due to the presence of*  
**T** *uncertainty created by the presence of DGRs, demanded load change and network restoration time after the presence of*  
*DG. Also, after providing an appropriate model for problem analysis, results of applying this model to the case study*  
*system are investigated using reliability indices. Subsequently, in order to improve performance of the system, impacts of*  
*the changes of various parameters on the given indices are reported. One of the most important points in this regard is to*  
*investigate the impacts of the changes in the system configuration on the results. It is observed that self-healing positively*  
*affects the reduction of the electrical energy restoration time as well as the system reliability.*

## Article Info

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## I. INTRODUCTION

Distributed generation (DG) is an electric power source which is connected directly to the distribution network or on the customer site of the meter [1]. It refers to generating electrical energy from small resources and is used when the electrical energy is generated at the consumption point, or nearby. Some of the main reasons for using this type of generation include improving voltage and reducing the losses [2]. Although DGR is a novel concept in the economic literature of the electricity industry, its nature is not much new. Since the direct current (DC) networks are the first electricity

networks, they are used as batteries in order to create a balance between generation and load of the storage resources existing in the consumption centers. Later, the advances of technology (such as creation of alternative current (AC) networks) has provided the possibility of electricity transmission to longer distances [3].

On the other hand, power system reliability is one of the most important aspects regarding the service safety. It refers to the probability of its satisfactory operation over the long run and denotes the ability to supply adequate electric service on a nearly continuous basis, with few interruptions over an extended time period [4].

An important feature of the smart distribution grid compared to the traditional one is its self-healing. One of the

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most important issues in power systems is the occurrence of the outage due to weaknesses in infrastructure, human error and natural disasters. Applying new technologies and methods can reduce the rate of outages and interruptions. However, in some cases, it can be prevented by the prediction of the current situation. Generally, the merge between the monitoring system and the recovery/preventive techniques is called self-healing [5]. This issue is one of the important features of the future distribution grid and is expressed as the ability to recognize and fix the defective system and repair the disconnected system to achieve maximum network access.

This property is generally expressed as error recognition, isolation, and auto-restoration in the damaged system [6] and is one of the key functions for increasing the reliability and high-quality power supply, especially in smart distribution grids [7,8].

The most important methods of self-healing of the network include self-healing by reconfiguration [9], self-healing using distributed generation resources, and self-healing by load shedding. The first step in implementing a self-healing SEG is to construct an operator section for each part of a distribution substation, such that each main transformer in the load bus could have a link operator capable of connection to other sections. These operators have permanent information on measurement devices and their information contains the measurement equipment's conditions derived from built-in sensors. Besides, from a wider perspective, they have information such as prediction of future functional conditions of other equipment.

Regarding the concerns on constant and continuous supply of energy for subscribers and minimizing the electricity supply errors, reliability of the DGRs and smart energy systems is highly regarded. In this content, numerous studies have been reported to date.

In 2016, a research was conducted on DGRs to investigate optimal location of switching in a radial distribution network with the aim of increasing the reliability [10]. The islanded distribution system was considered with regard to the distribution method of DGRs. Subsequently, the problem was analyzed via the healing time approach and the optimal location of switching was presented by genetic algorithm (GA) and neural networks (NNs).

Another research conducted in this field was focused on increasing the reliability in distribution network [11]. In this case, it was proposed to use fuel cells as an appropriate choice for supplying power. Subsequently, considerable reduction of interruption duration as well as appropriate efficiency of the proposed method was demonstrated. As for hybridization of the support power unit, some guidelines and instruction were suggested for continuous and constant operation. Finally, a comprehensive solution with appropriate efficiency was described in order to increase the reliability indices. In another study, Li et al. [12] assessed reliability as the main index of

power generation resources for customer satisfaction. By simulating power transmission, they provided an appropriate optimal model.

In the study on generation power of the DGRs in the islanded state, Vahedi et al. [13] separated different accidents by considering various constraints of security and reliable performance of system. They showed that the proposed method with minimum detection time had very high precision in the presence of large noise-signal ratios.

Cortes et al. [14] proposed an iterative procedure for the optimal design of a microgrid topology in active distribution networks by applying graph partitioning, integer programming and performance index. They claimed that the presented approach had the ability to avoid infeasible and non-optimal designs of microgrid structures and provided remedial solutions for enhancing the previous topology design method.

In another study [15], a procedure was proposed for normal mode which minimized the operation costs and provided sustainability using the seamlessness index. The operational planning of emergency mode was integrated into the proposed framework to provide the optimal schemes which could handle the possible abnormal conditions using the available DGRs and guarantee the desired resiliency level. The proposed self-healing strategy could sectionalize the isolated area of the distribution system into islanded sections to provide reliable power supply to the critical loads.

In [16], a methodology was described to solve the multi-period distribution expansion planning problem considering reliability as well as DG, capacitor and switch placement in the SEGs. The proposed model was presented in a mixed integer nonlinear optimization form and solved using a stochastic simulation method based on MCS. The authors defined the main objectives as the best alternative to install power system components and to determine the installation period and size of components to minimize the investment cost and maximize the system reliability. The case study systems were the modified version of the IEEE-RBTS 24 bus and a 90-bus system. The obtained results verified the effectiveness of the proposed method for reducing the operating cost and average interruption time. The work did not conclude different scenarios regarding DGRs, self-healing and reliability analysis, individually.

In [17], a new healer reinforcement approach was introduced based on modeling the plug-in hybrid electric vehicle (PHEVs), through optimal parking lot (PL) placement and sizing, under contingencies. The PL placement and sizing problem was formulated by considering PHEVs participation as both backup and storage units in the self-healing process. As claimed, the PHEVs presence as the storage units could prevent congestion occurrence and enable execution of the best restoration strategy through charging in light load and injecting power to the backup feeding path in the peak load of the repair time.

In [18], self-healing was implied as a key characteristic and goal of SGs. It was highly regarded for classifying the operating states of power system. As there were some essential differences between distribution and transmission networks in terms of the operation states and structural features, these two systems were compared with each other. A new method based on hierarchical classification was proposed to classify the operating states in distribution networks in the presence of DGRs and several important features reflecting the operating conditions of distribution system were regarded as critical attributes, including external stability, reliability, integrity and economy.

In [19], a transformative architecture was proposed for the normal operation and self-healing of networked microgrids, connected by a physical common bus and a two-layer cyber communication network. In the lower layer, the energy management system (EMS) scheduled each microgrid and, in the upper layer, a number of EMSs for global optimization were linked. In the normal operation state, the main objective was to schedule dispatch-able DGRs, energy storage systems (ESSs) and controllable loads to minimize the operation costs. In fault conditions in one microgrid, the model switched to the self-healing mode and the local generation of other microgrids to support the on-emergency loads of the system. Test cases demonstrated the effectiveness of the proposed methodology.

In [20], a strategy was proposed in the area of self-healing distribution networks in the event of a permanent short-circuit, in which a systemic reconfiguration was necessary. The suggested method was based on distributed intelligence and allowed the signals to propagate between the recovery switches. The proposed algorithm was tested in a large distribution network for various operation states.

The majority of the researches in this field has been focused on statistical and case studies on electricity interruption; in some cases, reliability has been investigated. To the best knowledge of the present authors, none of the previous research has discussed self-healing capability and its positive effect on reliability; also no appropriate model has been provided by these studies.

In this paper, self-healing is investigated using DGRs and its effect on improving grid reliability. Using a number of DGRs in the self-healing grid allows these resources to supply the required load in the event of an error in the energy production or transmission system. Also, upon the occurrence of an error in the grid, they can create a deliberate island, so that a part of the system only feeds from the DGRs while accelerating the restorative operation and providing critical and sensitive loads of the grid. Otherwise, due to a permanent error, these loads must endure a long outage; this method is a good option for the end loads of the grid that do not have access to the backup branch.

This study examines the improvement of customer

satisfaction indices, energy-based indices in the SEG and self-healing grid using the MCS method or the same random data replication, and the effect of changing the demanded load and time of grid restoration after the presence of DGRs on the reduction of the ENS index. The reduction of the ENS index has a direct relationship with lower revenue and energy sales for power distribution companies. It is enough to multiply the value of each kilowatt-hour (kW/h) of electrical energy by ENS and the resulting value to the given currency will be the outage loss. Given the uncertainty of the quantities being evaluated due to DGR's presence in the grid, their normal pdf graphs are considered to make the results more realistic. In the previously conducted studies, the ENS index has not been investigated in the presence of uncertainties.

Also, given that the capacity of the DGRs is effective in reducing network loading and error restoration time, it is necessary to fit the power supplied by the DGRs and the network load demand to prevent disruption and instability in the grid in the presence of DG. To do so, the relationship between supply and demand is examined in the presence of DGR and its effects on loading and error restoration time is analyzed, which is rarely considered in previous research on self-healing.

For this purpose, the sample grid was simulated in MATLAB software and the changes in SEGs reliability indices were analyzed in the presence of the DGRs using self-healing context.

The reminder of this paper is organized as follows. Section 2 details the problem formulation. In section three, the solution method is described. Section 4 presents the simulation and case study results. Finally, section 5 describes the conclusion.

## II. PROBLEM FORMULATION

Regarding the simulation-based methods, various methods have been proposed for reliability assessment, which are more or less associated with the MCS method. In this method, the reliability calculations are performed using sequential simulations of a real action with a random behavior in the system. In this method, due to the random nature of the problem, the number of errors, time interval between errors and load marketing time can have any number or level. As was reported, evaluation based on this method requires a large amount of time.

The reliability assessment results of distribution networks are presented in the form of the indices of load points and entire system. The load points' reliability indices include average error occurrence rate  $\lambda$  ( $f/yr$ ), average interruption  $r(h)$ , average annual interruption duration  $U(h/yr)$  and average energy not supplied  $ENS$  ( $kWh/yr$ ). The relevant equations are as follows:

$$\lambda_s = \sum_{i \in A} \lambda_i (f / yr) \tag{1}$$

$$U_s = \sum_{i \in A} \lambda_i r_i \tag{2}$$

$$r_s = \frac{U_s}{\lambda_s} \tag{3}$$

where i determines the relevant section in feeder A,  $\lambda_i$  is error occurrence rate in the  $i^{th}$  mode,  $r_i$  is the time required for restoring the supply to the given load points after occurrence of the error in the  $i^{th}$  mode and  $P$  is the average consumption rate in load point (distribution substation).

In order to have a better understanding of the grid's status, the reliability indices related to the system, which indicate the entire feeder's behavior, are used. These indices include:

*System average interruption frequency index*

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \tag{4}$$

*System average interruption duration index*

$$SAIDI = \frac{\sum N_i U_i}{\sum N_i} \tag{5}$$

*Energy not supplied:* This index presents the energy not supplied. In fact, the main focus of this work is to improve the relevant indexes to unproduced energy sales. As a result, if this index improves, the distribution network profitability will be increased accordingly. The ENS value is obtained by multiplying the system exit time (U) at the average consumption time (L). For the case that there is no DGR in power grid, it is calculated as:

$$ENS_c = \sum ENS_i \tag{6}$$

$$ENS_i = \sum \lambda_i r_i L_c$$

It the presence of the uncertainties, such as the conditions that the DGRs are in the power grid, the above equation would be changed. In this situations, some new indices are needed to be considered. First of all, we should define a parameter known a DGR. It mean the demanded load and generation ratio. In this way, the distribution probability is considered in different modes. The demanded load and generation margin, named M, between the generated load and power is considered and both functions are defined as the normal distribution. The defined density function is defined as follows [21]:

$$G-L=M \Rightarrow \frac{G}{L}-1 = \frac{M}{L} \Rightarrow GLR=1+\frac{M}{L} \tag{7}$$

in which G is the normal distribution function of generation, L is the normal distribution function of load and M is the

margin probability distribution function.

The mean and standard deviation are for depicting the normal density distribution function:

$$\mu_m = \mu_g - \mu_l \tag{8}$$

$$\delta_m^2 = \delta_g^2 - \delta_l^2 \tag{9}$$

For analyzing the energy not supplied in the power grids containing the DGRs, the following formula will be applied.

$$ENS_c = (\sum_{i \in f} \lambda_i r_i + \sum_{i \in \gamma} \lambda_i P L T_a + \lambda_{up} P_M T_a) L_c \tag{10}$$

in which i determines the relevant section in feeder f,  $\gamma$  defines the low voltage feeder sets excluding the feeder f,  $\lambda_i$  and  $r_i$  are the failure rate and repair time for section I, respectively. Also,  $\lambda_{up}$  is the number of interruptions and the unavailability, and  $L_c$  is the load of  $C^{th}$  consumer.  $P_M$  is the probability of the error in isolation process when a fault occurs inside the DG.  $PL$  is the shut-down probability.  $T_a$  is the average time to restore the network by DG.  $T_a$  is the time required for the system to recovery. As this operation is made automatically by the central controller of the DG, it does not depend on the location of the micro generators. If the rules are applied for any fault inside DG, it will result in shut-down which means  $PL=1$ .

In the reliability analysis method, which was introduced in the previous section, first, the error modes that affect each of the load points in the distribution substations are identified. Then, by assessing them, the reliability indices at each load point are calculated. It should be noted that in simulating the error modes, the effects of power grid structure, presence of sectionalizers and possibility of supplying the interrupted loads from the main grid or other resources must be properly modelle.

### III. SOLUTION METHOD

The analysis method for investigating the reliability is composed of several steps, as follows:

*Importing information*

In this step, the primary information, including user data, is determined. This information can be received from the power distribution company's website. Therefore, all the information of the network lines along with other required characteristics can be received and analyzed.

*Calculations*

The above equations are expressed generally and, then, substituted after receiving the data of lines. These computations can be performed by the software. Here, for this purpose, we use MATLAB software.

*Reliability indices*

In this section, the relevant reliability indices of distribution network are investigated in three scenarios: (1) traditional

power distribution grid, (2) smart distribution grid and (3) SEG considering the self-healing of DGRs. Once the reliability indices in these three states are obtained, the improvement procedure of the indices will be compared. The aim is to investigate the effects of self-healing; therefore, the possibility of application of this system will be investigated.

A. Description of elements

Here, the effect of variations of different elements affecting the system's reliability indices in two states, before the presence of DGRs and after presence of DGRs (considering grid's self-healing), will be investigated. Accordingly, the procedure of these variations as well as their effects on the given indices will be analyzed. Such an investigation enables us to recognize that adjusting and controlling of which element have maximum effects on improving the system's reliability. In fact, the key for improving the reliability indices in this states is clear.

E. General results

After investigating the above points, some diagrams are presented for different states, so that comparability of the above-mentioned states would be obvious. It should be mentioned that by comparing some factors, the general results for the reliability improvement methods can be achieved.

IV. SIMULATION AND CASE STUDY RESULTS

Fig.1 shows the single line diagram of the studied system [12]. Also, the grid data are given in Tables 1 and 2.

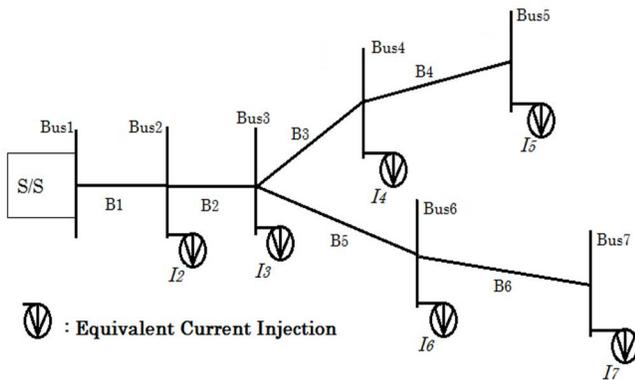


Fig. 1. Single line diagram of case study network

TABLE I  
Grid's load points data

Load points	I2	I3	I4	I5	I6	I7
Load supply probability (%)	0.99	0.99	0.99	0.99	0.99	0.99
Min power (kW)	100	120	15	10	75	25
Max power(kW)	135	160	60	45	95	65
Number of customers	120	140	35	28	85	45
$\lambda_i$ (fr/yr)	0.00	0.001	0.001	0.001	0.000	0.001
r (hr)	1	1	2	8	5	
U (hr/yr)	1.5	1.2	3.3	4.3	2.3	4.6
	0.00	0.005	0.004	0.009	0.004	0.003
	4		3		3	4

TABALE II  
DGR data

DGR	Min Power (kW)	Max Power (kW)
Fuel cell	13	240
Solar panel	0	55
Wind power	0	70
Gas power	0	46

In the first step, the traditional grid must be considered as smart in order to specify the effect of this smartization on the relevant index improvement, followed by applying self-healing on the grid and investigating its effects.

It should be mentioned that the self-healing of the distribution grid is indeed a capability to identify and resolve the system's defects. In order to achieve maximum accessibility as well as higher reliability of the grid, an important point that must be taken into account is the self-healing grid's capabilities for providing adaptive protection. Another important point in the grid is to provide a continuous and constant supply.

Self-healing of a distribution grid can be accomplished through several ways, which include rearrangement and restoration of the system, use of GDRs, load cut-off during peak load conditions and demand response management.

The given scenarios for investigating these states are as follows:

**Scenario-1:** First, the indices are obtained for a traditional grid. In this state, it is assumed that there is no switch or DGR on the studied feeder. Thus, by the occurrence of an error, the feeder is interrupted from its origin.

**Scenario-2:** The smart electrical grid. It is assumed that the feeder's components are automated and each section has a remote disconnection breaker. For this purpose, two sectionalizers are mounted on the two ends of the feeder.

**Scenario-3:** Self-healing by DG. It is assumed that each of the DGRs is installed on the node considering the appropriate location.

Table 3 and Fig. 2 show the details of the obtained results in all the scenarios.

Table III  
The indices calculated in three scenarios

Index	Scenari o 1	Scenari o 2	Scenari o 3
SAIFI (interruptions/customer)	27.63	5.462	4.778
SAIDI (hr./customer)	14.435	2.617	2.263
ENS (kWh)	121.144	18.689	16.427

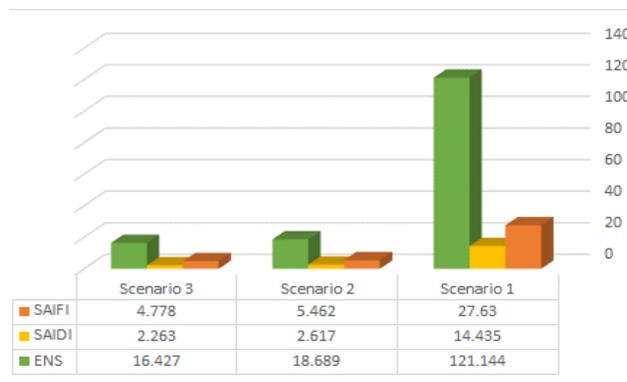


Fig. 2. Reliability parameters in 3 scenarios

The SAIFI index is one of the most important reliability assessment indicators in the power system, which shows how many outages are averagely experienced over the period of study by the customers. The lower value of this index verifies higher reliability of the power network and lower number of customer outages. As depicted in the figures, this index in the second and third scenarios is improved compared to the first scenario.

The SAIDI index represents the average time period, in which the customers do not have access to electrical energy. It shows how long each customer has experienced the outage. The lower value of this index results in higher reliability of the power system. The values of this index in the second and third scenarios are smaller than the first one. So, the SAIDI index is improved in the second and third scenarios.

The ENS index is the most important parameter based on energy and load, which determines the amount of energy that has not been delivered to the customers.

This index is very important for distribution utilities as it has a direct impact on energy bidding contracts. The smaller the index, the more reliable the power grid would be. According to the obtained results, by smartization the power grid in the second and third

significantly. This means self-healing leads to increasing the power grid reliability.

Now, let's investigate the effect of each element on these indices. Considering the equations as well as the experiment performed in this regard, changes in the controllable elements had no significant effect on the ENS index.

Based on the ENS index, it can be concluded that only the elements of consumed load and restoration time can affect this index. So, we investigate the variations of these parameters on ENS.

The failure rate and average repair time for the  $i^{th}$  component are presented by the Committee of Transmission and Distribution of Engineers Association of IEEE as the IEEE-1366 standard in 1998.

The experiment designed for investigating the effects of the  $L_C$  and  $T_a$  elements on ENS index is as follows:

Analyzing The  $L_C$  impact

Generally, using the DGRs in the grid would result in uncertainty; thus, the values of these elements cannot be considered as definite. Therefore, for each of the values of these elements, a normal density distribution function is considered. However, it should be noted that the normal density probability should be considered equal for all the elements in each step of the experiment repetition in order that the obtained results can be compared.

The experiment should be repeated for multiple times; then, the obtained results should be sampled in each step. Finally, the normal PDF diagram should be depicted for the sampling results.

In order to investigate the effects of DGRs, the experiments must be repeated after their presence.

Accordingly,  $L_C$  changes after the presence of the resources. Now, the effects of DGRs on consumed load in different states should be investigated at the end. These states depend on the generation rate of the DGRs as well as load consumption.

However, it should be noted that the unwanted islanding state should be prevented. This condition occurs when after the occurrence of a disturbance, it is impossible to interrupt DG, so it should be immediately detected and eliminated.

Investigating effects of  $L_C$  is demonstrated in the following diagrams.

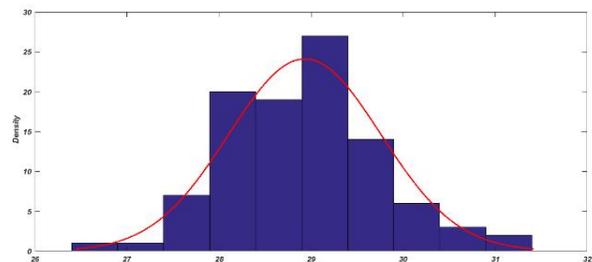
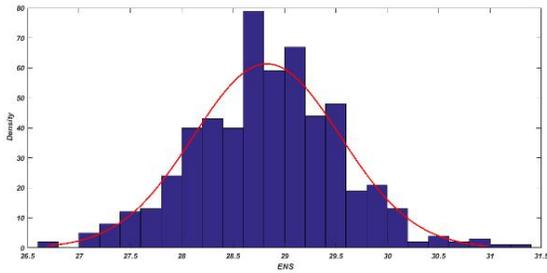
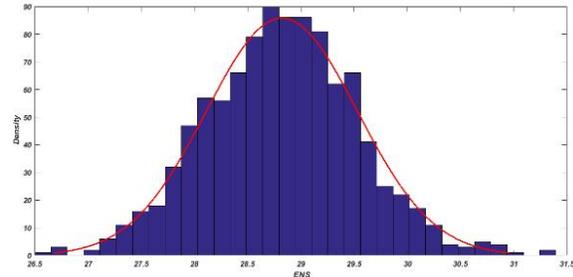


Fig. 3. Effects of  $L_C$  on ENS before DGRs presence (for 100 times)



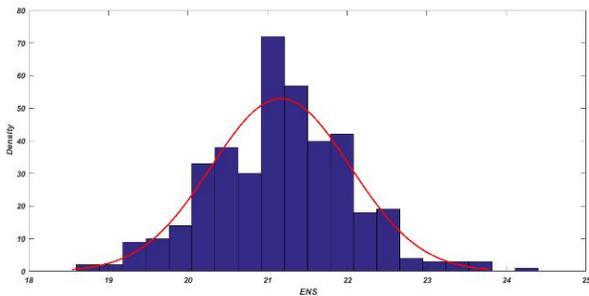
**Fig. 4.** Effects of  $L_C$  on ENS before DGRs presence (for 500 times)



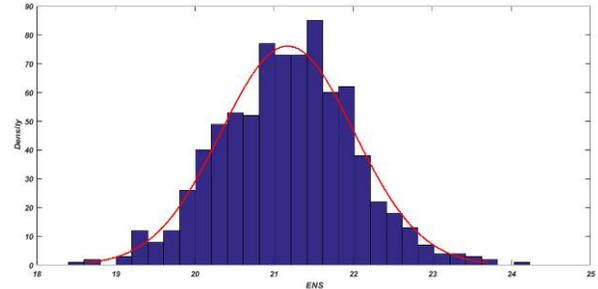
**Fig. 5.** Effects of  $L_C$  on ENS before DGRs presence (for 1000 times)

Since DGRs supply the loads locally, they reduce the grid loading. However, in some conditions, some of the lines might be overloaded. Therefore, investigation the grid in the presence of DGRs in terms of overloaded lines is among the major studies that must be conducted in the presence of DGRs.

Generally, in a traditional power grid, the distribution feeders are usually weakened by getting farther from the substation. In fact, the conductors with smaller cross-sections can be used. Such a design is based on the primary assumption of these grids, in which the grid is radial and single-side fed, and also its feeder is located at the beginning of the substation.



**Fig. 6.** Effects of  $L_C$  on ENS after DGRs presence

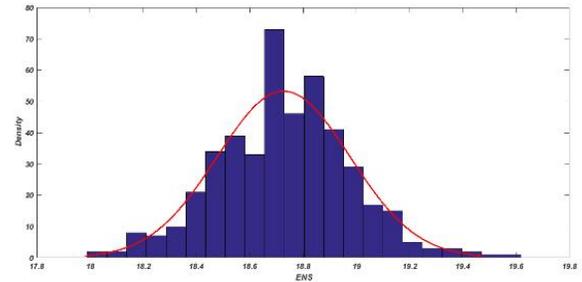


**Fig. 7.** Effects of  $L_C$  on ENS after DGRs presence (1000 times)

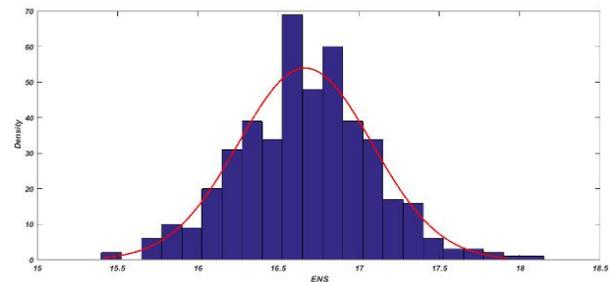
*A. Analyzing the  $T_a$  impact*

Location of DGRs has no effect on  $T_a$ , but appropriate number and size of DGR can reduce it.

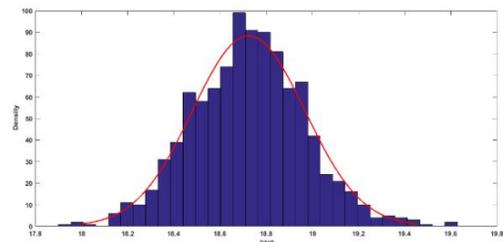
The following figures demonstrate the impact of  $T_a$  on ENS before and after DGRs presence in the network.



**Fig. 8.** Effects of repair time on ENS before DGRs presence



**Fig. 9.** Effects of  $T_a$  on ENS after DGRs presence



**Fig. 10.** Effects of repair time on ENS before DGRs presence

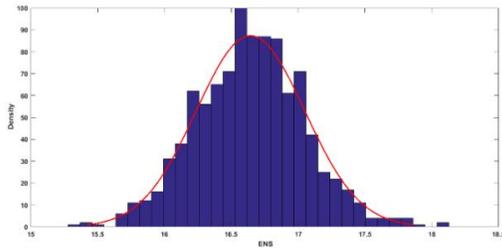


Fig. 11. Effects of  $T_a$  on ENS after DGRs presence

As depicted, the appropriate value of  $T_a$  depends on the amount of DGRs just the same way it affects the value of the given index before and after the entry of the resource.

It can be inferred from the provided diagrams that the reduced restoration time causes the reduced ENS index value. The improvement of this index indicates that the index can be improved by controlling this element.

Analyzing the GLR impact

Investigating the diagrams of the consumed load with and without the presence of DGRs reveals its effect on improving the ENS index.

In the following sections, different states for the DGRs production rate and consumed load rate will be investigated.

The reliability variations are clearly visible, so that they can be discussed. The changes in these parameters imply the importance of reliability. Besides, it is shown that variations of the consumed load and DGRs production rate affect each other.

In this state, the expressed points indicate the standard deviation and mean, and can be also used for determining the reliability indices. Other parameters of DGR have been explained earlier. In the density diagrams, it is attempted to observe the distribution rate in different ratios. Accordingly, the higher the current ratio, the more the movement toward the negative part would be.

The three investigated states include:

- GLR=1: Generation equals demand
- GLR<1: Generation is less than demand
- GLR>1: Generation is more than demand

In the diagrams provided below, it should be noted that if  $M=0$ , then there will be no storage in DGR and the entire generation of the resources will be consumed by internal customers. However, if  $M>0$ , then generation of the resources will be more than the demand and the grid will do the storage (the green color part). Furthermore, if  $M<1$ , some of the DGR loads will be released (red color part).

As explained earlier, the support region or section is indeed the regions where  $M$  is bigger than zero (green) and DGRs whose load is discharged have  $M$  values smaller than zero (red).

Therefore, the logical relationship of the elements and subsections with each other affects the reliability of the entire

system. However, on the whole, it can be said that long sequences of components or subsystems should be avoided in design. While designing, the systems must be scrutinized to detect the components and elements that have a considerable effect on reliability and, accordingly, take necessary measures in order to improve reliability of the entire system. Furthermore, since the after-sale services and repairing are very important parameters in reliability of the components and repairable systems, it must be designed in such a way that the after-sale services and repairing can be provided easily.

According to the diagrams, as expected, ability of DGR to improve reliability of the grid depends on the load generation-demand ratio, so that the higher the DGR rate, the more improved the reliability indices would be.

The power generated by DGR depends on the environmental conditions and also the load demand is dependent on the conditions. Therefore, the DGR's performance is influenced by the load generation-demand ratio. Uncertainty in load demand is an important factor affecting the reliability, which has been investigated.

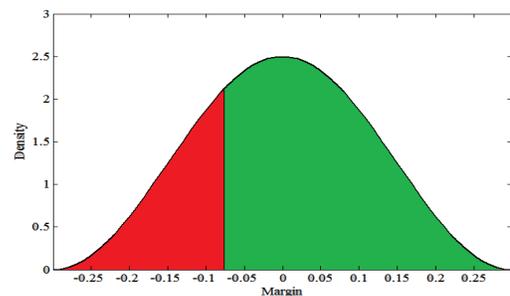


Fig. 12. Density in case of GLR=1

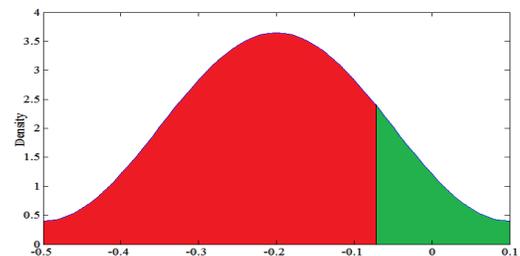


Fig. 13. Density in case of GLR=0.8

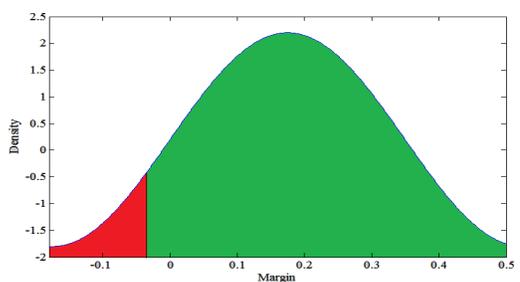


Fig. 14. Density in case of GLR=1.2

The capacity needed to restoration outage sectors as well as the production capacity of the DGR available to the feeder without electricity has a direct impact on the grid restoration time. In the grid restoration by DG, it is tried to restore the highest load with the highest significance in the least time by creating a deliberate island and in the load shedding area. By creating an error in a bus, the upstream switches of the error location are opened and all the downstream loads of switches such as loads between the error location and the breaker switch are unloaded. By opening the two-way disconnecter switch of the error location, the breaker switch is re-closed and the upstream loads of the error location to the breaker switch are re-electrified. In this case, the DGR of the loads that are the loads that are located in the error range remain de-electrified until the problem is fixed.

Investigating the relationship between G and L during the restoration period:

$G > L$ : In the first case, it is assumed that the available capacity of the DGR is capable of feeding all loads of the de-electrified area. In this case, the restoration time of the downstream load is equal to the time required for switching operation ( $T_{sw}$ ).

$G = 1$ : It is assumed that the DGR capacity for all loads in the error area is inadequate. In this case, if the island's range is already specified, when the error occurs, the load end of the feeder is fed by the DGR using an disconnecter switch as an island.  $T_{sw}$ ,  $T_{connect}$  and  $T_{is}$  are the time of switching operation, isolating the island from the main grid and launching the island, respectively.  $T_a = T_{sw} + T_{connect} + T_{is}$

$G < L$ : Another case which is more probable is that the available DGR capacity is not enough for electrifying a non-electrified area. In this case, one has to disregard the electrification of some of the loads in the error area. The duration of the outage for these loads is equal to the full-time of error fixing.

## V. CONCLUSIONS

Generally, with increased demand as well as the need for a sustainable system, high reliability, higher power quality, improved voltage profile and reduced losses and air pollution in recent years, the power systems have tended toward using DGRs. Over time, due to the high system losses and the resulting consequences, the power systems undergo considerable damages, which are not cost-effective for consumers as well as generators in technical and economic terms. DGRs reduce the losses by injecting the current and improving the voltage. Thus, one of the major issues in DGRs is to locate and connect the DGR in a place that can lead to higher benefit for the power grid. In general, one of the important issues in the grid is its load. The grid's load directly affects the current derived from the grid and indirectly affects, through the current, the derived power and losses of line. Particularly, type of the load has a considerable effect on calculating the power loss in power systems. As depicted, the self-healing capability plays a major role in the stability and continuity of current. Furthermore, the presence of DGRs in a limited scale can cause stability of current, but in the large scale, its efficiency must be investigated and discussed. It should be noted that the arrangement optimization of resources can help find the best state of reliability. In the general state, SEGs are capable of providing reliability coefficient appropriately. In this paper, the influence of DGR on the improvement of grid reliability as well as its effect on reducing loading and restoration time of the grid and, as a result, reducing the volume of ENS was evaluated. The point which should be further investigated is providing a strategy that can coordinate the volume of DGR power supply with the grid load demand. Also, in this study, the probability of outage or error in the DGR is not considered, which can be added to make the proposed method richer. Another important point is that DGR reduces grid restoration time by creating a deliberate island. But if an unintentional islanding occurs in the grid, i.e. after removing the error, it is not possible to disconnect the DGR from the grid. Then, a strategy should be designed to quickly detect and remove it from the grid; this issue refers to the exploration of the phenomenon of islanding in the power system.

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