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Impacts Assessment of DG Unit in Distribution Networks Based on Technical-Environmental Indices

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ABSTRACT

In this paper, a Multiobjective index is presented to investigate the efficiency of distributed generation (DG) units in distribution systems. In this index, factors such as active and reactive losses, voltage drop, voltage regulation, lines capacity, three-phase short circuit, single-phase to ground short circuit, and the index of pollution emission decrease are investigated. In order to study and calculate the defined factors, the modified Newton-Raphson method, and BIBC and BCBV matrixes are used to calculate power flow and to calculate the fault current for different symmetric and asymmetric short circuits calculation, respectively. A program is provided to assess the impact of DG units on the distribution systems Using MATLAB software and based on the mentioned calculative tools. Finally, the impact of DG units on IEEE standard 34-bus system is investigated and several combinations of them are assessed by the assist of provided program and using multiobjective index.

KEYWORD: Distributed Generation, Multiobjective index, Distribution systems, Technical-environmental indices

1- INTRODUCTION

Recently, the manufacturing and maintenance costs reduction of DG units and applying them in distribution networks have provided a group of advantages, such as, economical, environmental and technical. The economical advantages are reduction of transmission and distribution cost, electricity price and decreasing in consumption of fuel. The most environmental advantage is reduction of emission of green house gases. Technical advantages cover wide varieties of benefit, like, network losses reduction, voltage profile improvement, system reliability increasing and peak shaving [1].

This discussion is important since no power generation is usually considered in distribution network design. Therefore, installing small sized generation units maybe changes such as losses increase or decrease, interference with operation of devices used to control network voltage, and fault current increase are some of the affects must be considered in studies accomplished before applying DG units. Therefore, the investigation on the effects of utilizing DG units accomplished considering several aspects such as investment deferral in network capacity [2], active loss reduction [3], reactive loss reduction [4], reliability improvement [5], improving the system's voltage profile [6] and reduction in the transmission line congestion [7].

In [8], separate indices are defined to asses the effects of issues such as installation place and output power of DG units on voltage index of medium and low voltage networks. Considering a unified index among the presented indices to investigate the impact of DG units on technical parameters of the system is impossible and meaningless.

In [9], the benefit index is considered in order to DG issue related multiobjective index introduce by presenting a simple definition for indices. In this paper, where the DG units are considered just for the transmission systems, the foundation of determining benefit index stands on parameters such as active power losses, voltage profile, and environmental impacts. The type of the tools used to calculate the system parameters such as buses voltages and fault currents is the other important issue in assessing the impact of DG units on distribution networks. Due to unbalance characteristics of the system load in the distribution systems, applying single-phase and balance methods for network parameters determination decreases the accuracy of calculations and in consequence, the results obtained for the modality of DG impact would face with considerable errors despite of defining proper indices [10, 11].

A multiobjective index is defined in [12], which considers several technical factors such as voltage profile, active and reactive power losses, fault current level of the system, and the capacity of network lines, in order to determine the efficiency of DG units in the distribution system. In this paper, the forward-backward sweep technique with the assistance of current adding is used in power flow calculations and the asymmetric component method is applied in fault calculations while the system parameters are investigated in three-phase mode. Applying the methods mentioned above improves the results in compare with the previous investigation despite it causes some limitations in network modeling process. The capability of considering just a single model (constant power) for network loads and considering without mutual impedance

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and current angles in fault current calculation process are some of the existing limitations.

In this paper, a multiobjective index is presented to assess the efficiency of DG units in distribution networks. In this index, the impact of DG units in pollution emission factor is investigated in addition to the factors mentioned in [12]. In order to study and calculate the defined factors, the modified Newton-Raphson method, and BIBC and BCBV matrixes are used to calculate power flow and to calculate the fault current for different symmetric and asymmetric short circuits calculation, respectively. A program is provided to assess the impact of DG units on the distribution systems Using MATLAB software and based on the mentioned calculative tools. Finally, the impact of DG units on IEEE standard 34-bus system is investigated and several combinations of them are assessed in scenarios format by the assist of provided program and using multiobjective index.

2- problem formulation

In this paper, the disadvantages of installing DG units in distribution networks are considered beside its advantages, in order to make a comprehensive assessment. This is accomplished by introducing several indices and the calculation process of each is presented. It is assumed that in determining all indices that the DG generated power and the network demanded power are in the maximum point. The minimum power demand is also considered in order to exact calculation of the voltage index.

Unbalance issue is one of the distinctive characteristics of the distribution system, which is caused of the topologies and special type of its loads. Therefore, it is necessary to calculate the desired indices separately based on a, b, and c phases and the null line (if exists). This approach can be applied for the symmetric systems according to its capability. Therefore, the indices considered in this paper are introduced as follows for the k^{th} combination of DG and distribution system:

2-1- Active and Reactive Power Losses Indices

Usually, system losses are considered as a key parameter in efficiency discussions and technical and economical utilization. In general, the DG units can decrease the losses by cutting off or reducing the load of a part of network lines. It should be noticed that if DG unit generated power in a particular position, is more than the required power rate, the power flow direction in the network would be reversed, which might increase the total lines power losses. Therefore, the first and the second indices of the presented method are LI_p and LI_q, which respectively indicate the active and reactive power losses of the network lines. Relations (1) and (2) well show how these indices are considered:

$$LIp^k = 1 - \frac{Re\{Losses^k\}}{Re\{Losses^0\}} \tag{1}$$

$$LIq^k = 1 - \frac{Im\{Losses^k\}}{Im\{Losses^0\}} \tag{2}$$

Here, $Losses^k$ is the complex form of total power losses for the k^{th} combination of DG and the system while $Losses^0$ is the overall losses value considering without DG in the system.

2-2- Voltage Drop and Voltage Regulation Indices

Optimizing the voltage profile and maintaining the consumer side buses voltage level in an acceptable level is one of the reasons DG units are defined and installed in a power system. Properly installing (size and location) a DG unit in the network, a part of load required reactive and active power is provided and consequently the line current decreases which results in voltage profile improvement at the consumer side buses.

In continuous, VDI (voltage drop index) index is defined which numerically assesses the impact of DG unit in improving the voltage profile.

As mentioned before, the three-phase system is investigated here and naturally, the maximum voltage drop between each phase of any nodes of the grid and the base node is under consideration. Relation (3) shows how this index is calculated. According to the definition, the DG unit shows better performance as the numerical value of the index tends to one.

$$VDI^k = 1 - \max\left(\frac{|\bar{V}\phi_0| - |\bar{V}\phi_i^k|}{|\bar{V}\phi_0|}\right)_{i=1}^{NN-1} \tag{3}$$

where the parameters are defined as follows:

ϕ : a, b, and c phases.

$\bar{V}\phi_0$: the base node voltage (the amplitude of phases are assumed similar).

$\bar{V}\phi_i^k$: three-phase voltage in the i^{th} node for the k^{th} combination of DG and system.

NN: the number of nodes (accompanied by the base node)

According to VDI definition, this index investigates the network voltage profile under maximum load demand condition considered as the advantages of utilizing DG unit. In order to assure unwanted impacts of DG on the network efficiency, the system voltage profile is also investigated under minimum load demand condition during maximum DG power generation interval. This is considered as a critical situation for the system. Therefore, the forth index is the voltage regulation index (VRI) shows the voltage value difference of a particular node under maximum and minimum load demand conditions. The desired condition occurs when the voltage difference between minimum and maximum load demand conditions is small and consequently the VRI value closes to one. Relation (4) shows how VRI is calculated:

$$VRI^k = 1 - \frac{\sum_{i=1}^{NN-1} \max\left(\left\| \frac{\left|\bar{V}\phi_i^k\right| - \left|\bar{V}\phi_i^{k\,\min}\right|}{\left|\bar{V}\phi_i^{k\,\min}\right|} \right\| \right)}{NN-1} \tag{4}$$

where $\bar{V}\phi_i^{k\,\min}$ is the i[th] node voltage in the k[th] DG combination with system considering the minimum load demand.

2-3- Network Lines Capacity Index

The reduction in lines current of some parts of the system and releasing their capacity is one of the consequences of utilizing DG units. It should be noticed that in some cases, utilizing DGs would reverse the current flow direction in the lines and the transmitted power might cause current increase exceeding the maximum permitted level. Therefore, the impact of DG unit on the distribution system lines capacity is one of the issues should be assessed before utilizing them.

On this base, the fifth index is presented as current capacity index (CCI). By the assistance of this index and according to the maximum current capacity of distribution system lines, valuable data are achieved about the effects of DG application on the network current level. It should be noted here that this paper does not aim to change the size or optimize the lines. It is aimed here to investigate the DG and system combinations possessing positive CCI. Relation (5) shows how this index is calculated. Similar to the previous indices, the optimum condition is the CCI value tends to one. This means that there would be more reserve capacity for further expansion and load increase.

$$CCI^k = 1 - max\left(\frac{\left|\bar{J}\phi_m^k\right|}{CC\phi_m}, \frac{\left|\bar{J}\phi_m^k\right|}{CCn_m} \right)_{m=1}^{NL} \tag{5}$$

where $\bar{J}\phi_m^k$ and $\bar{J}n_m^k$ are respectively the phase and null currents passing through *m* branch for the k[th] combination of DG and system.

Parameters $CC\phi_m$ and CCn_m are respectively the current capacity of conductors in phases and the null line and *NL* is the number of network lines.

2-4- Single-phase to Ground and Three-phase Faults Indices

The sixth and the seventh indices are related to the protection issues and selecting the proper devices allocated considering fault level in two DG installed and not installed conditions. These indices assist the planner to investigate the impacts of DG units on the performance of the protection devices of the systems designed with no DG unit. The three-phase and single-phase to ground faults are investigated here because of their more importance in compare with other fault types [13]. Therefore, according to the targets of the presented approach, it is sufficient to assess these faults. Relations (6) and (7) show how these indices are assessed. According to the assessment manner, as the indices are closer to one, the impact of DG on the network fault level and consequently on the protective devices is low.

$$SCI3^k = 1 - \frac{\max\left(\frac{I_{SC\,abc_i^k}}{I_{SC\,abc_i^0}} \right)}{\frac{I_{SC\,abc_*^k}}{I_{SC\,abc_*^0}}} \tag{6}$$

$$SCI1^k = 1 - \frac{\max\left(\frac{I_{SC\,\phi_i^k}}{I_{SC\,\phi_i^0}} \right)}{\frac{I_{SC*}^k}{I_{SC*}^0}} \tag{7}$$

In the above relations, the followings are valid:

$I_{SC\,abc_i^k}$: the three-phase fault current in i^{th} node for the k^{th} DG and system combination.

$I_{SC\,abc_i^0}$: three-phase fault current in i^{th} node with no DG unit.

$I_{SC\,abc_*^k}$: the maximum three-phase fault for k^{th} DG combination with system.

$I_{SC\,abc_*^0}$: the maximum three-phase fault with no DG.

$I_{SC\phi_i^k}$: the single-phase to ground fault current in the i^{th} node for the k^{th} DG and system combination.

$I_{SC\phi_i^0}$: the single-phase to ground fault current in i^{th} node with no DG.

$I_{SC_*^k}$: the maximum single-phase to ground fault for the k^{th} DG combination.

$I_{SC_*^0}$: the maximum single-phase to ground fault current with no DG.

2-5- The Environmental Impact Index

Another important advantageous of utilizing DG in power system is the lower greenhouse gases and other pollutions emission for power generation in compare with the conventional energy generation approaches. This is important since the public concerns about the greenhouse gases emission is rapidly increasing. The greenhouse effect is caused by CO_2 and other greenhouse gases increase results in planet heating and climate changes. Using DG can reduces new capacities installation necessity for two major reasons. The first one is producing active power by DG's and the second is losses reduction.

The basis of defining environmental impact reduction index (EIRI) is the aim to compare the particular environmental pollution emission amount with and without applying DG units is calculated as (8):

$$EIRI_i^k = \frac{PE_{iw/DG}^k}{PE_{iwo/DG}} \tag{8}$$

where i indicates the type of pollutant such as CO_2, SO_2, NO_x and etc. Parameter $PE_{iw/DG}^k$ and $PE_{iwo/DG}$ are respectively the i^{th} pollution emission rate with and without applying DG unit, which are defined as (9) and (10):

$$PE_{iw/DG}^k = \sum_{j=1}^{B}(EG)_{Aj}(AE)_{ij} + \sum_{k=1}^{H}(EDG)_k(AE)_{ik} \tag{9}$$

$$PE_{iwo/DG} = \sum_{j=1}^{B}(EG)_j(AE)_{ij} \tag{10}$$

where,

$(EG)_j$, $(EG)_{Aj}$: the MWh of electric power generated by conventional j^{th} plant with and without utilizing DG, respectively.

$(AE)_{ij}$: is the amount of i^{th} environment pollutant emitted by the j^{th} conventional plant based on its generated power amount.

$(AE)_{ik}$: is the amount of i^{th} pollutant gas emitted by the k^{th} DG unit.

$(EDG)_k$: is the MWh of energy generated in kth DG unit.

B and H are the total number of conventional power plants and the total installed DG units respectively.

In practice, power plants emit several pollutants. Therefore, it seems so practical to define a combined index to investigate the total pollution emission rate. Relation (11) illustrates the way; mixture of gases is calculated for the k^{th} DG and system combination. It is clear that less pollution is emitted as this index tends more to one.

$$EIRI^k = 1 - \sum_{i=1}^{NP}(EI)_i(EIRI)_i \tag{11}$$

Here, parameter $(EI)_i$ is the weight factor for the i^{th} pollutant and NP is the total investigated pollutant number. In addition, (12) and (13) depict the constraints of defining these factors.

$$0 \le (EI)_i \le 1 \tag{12}$$

$$\sum_{i=1}^{NP}(EI)_i = 1 \tag{13}$$

In (11), weight factor is considered for each pollutant gas in order to make it possible to determine and select the importance ratio of pollutant gases and their impact value on the environmental index. These factors can be selected and quantified according to each one caused danger and pollution regarding the (12) and (13) constraints.

Due to not existence of power plant in the distribution systems, the reference bus is considered as a pollution emitting conventional power plant. Therefore, the number of conventional plants is considered one plant in this paper, which is the combination of plants stand at the upstream, high voltage level side of the system.

All indices presented in this section are quantities of system efficiency show better performance of the system as tend more to one. It should be noted here that if the mentioned indices equal to one, it is not meant that the number of DG units certainly increases.

2-6- The Multiobjective Index

In this section, a general index called the multiobjective index (MOI) is presented according to the previously mentioned indices. It is aimed defining such index to investigate and calculate the efficiency of an electric power distribution system with installed DG unit. Therefore, a weight factor is allocated for each mentioned index through which they can be normalized in addition to their importance determination. In this technique, the weight factors fall between zero and one (unit) are considered as a dimension less quantity. Relation (14) shows how MOI is calculated for the k^{th} combination of DG and network. Considering the definition of indices and the normalization process by the assist of weight factors, each DG-system combination, MOI numerical value of which is closer to one, shows better performance and more efficiency.

$$MOI^k = \{w_1 ILp^k + w_2 ILq^k + w_3 IVD^k + w_4 IVR^k + w_5 IC^k + w_6 ISC3^k + w_7 ISC1^k + w_8 EIRI^k\} \quad (14)$$

In (14) following is valid for the weight factors:

$$\sum_{i=1}^{8} w_i = 1.0 \quad \wedge \quad w_i \in [0,1] \quad (15)$$

As mentioned before, main reason of using weight factors is to determine the importance of each index, which would differ, based on the time and the aim of DG installed network company issues such as planning and utilization under normal and emergency conditions. The importance and the value of indices is not a constant quantity and can be unique for each network according to the viewpoint and desire of the system applier. Therefore, it is generally difficult to determine these weight factors properly due to which, the experience of the engineers could be valuable for determining these factors. Table 1 shows examples of determining the above factors.

Table 1. An example for indices weight factors determination

LI_p	LI_q	VDI	VRI	CCI	SCI3	SCI1	EIRI
0.4	0.1	0.05	0.05	0.1	0.05	0.05	0.2

According to the quantities mentioned in Table 1, network losses have the maximum value of the weight factors, which shows the importance of this issue in DG utilization. In addition, due to the importance of environmental concerns, the value of EIRI is considerable between the weight factors. As it shown, other network aspects such as protection, constraints, and are ranked in the next places. It should be noticed that, the quantities are selected for the system's normal condition and they might change according to operator interests.

3- RESULTS AND DISCUSSION

A program is provided by MATLAB software to investigate the impact of DG units on the distribution networks. This program based on a modified Newton-Raphson power flow calculations which can consider the DG units in asymmetric and unbalanced distribution networks. Also for fault calculation in this condition, BIBC and BCBV matrixes technique is used which can be able to bring into account the null wire and ground return wire in system fault current calculations. More details for power flow and fault calculation are presented in [13] and [14] respectively.

The impact of all combinations of one or more DG unit(s) on a particular network can be investigated and the desired indices can be calculated through this program. The multiobjective index can be determined using the defined MOI relation through which all indices can be assessed. It is obvious that the most proper place for DG unit installation is the combination for which the MOI index tends more to one (unit).

In this paper, the 34-bus standard IEEE network is considered to investigate the impact of DG units on the distribution system. The considered network is illustrated in Fig. 1, with voltage level of 24.9 kV where the transformer and voltage regulator are replaced by line impedances to obtain single voltage level and to maintain the voltage of all 34 buses. The detailed technical data are shown in [15].

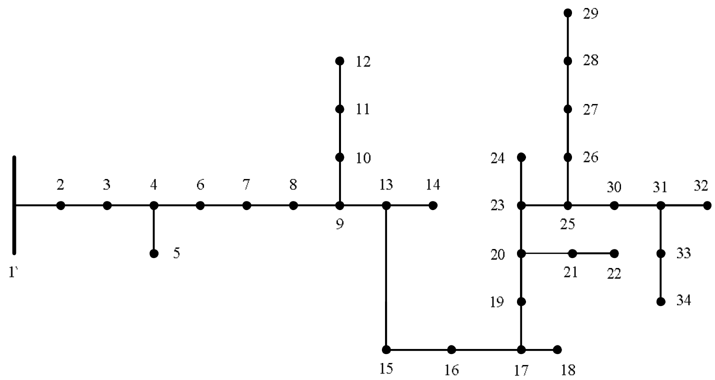

Figure 1. The standard 34-bus IEEE network

Two different states are considered in continuous to investigate the impact of DG on the distribution system by the assist of defined indices. In each state, different DG and network combinations are evaluated in addition to emphasis on the capabilities of the provided program.

3-1- The Impact of the Place and the Size of DG Unit on the Indices

In this section, a DG unit with 500 kW output is added to the system shown in Fig. 1 and the ratio of each index and their variations is calculated for all possible DG and network combinations. The results are shown in Fig. 2.

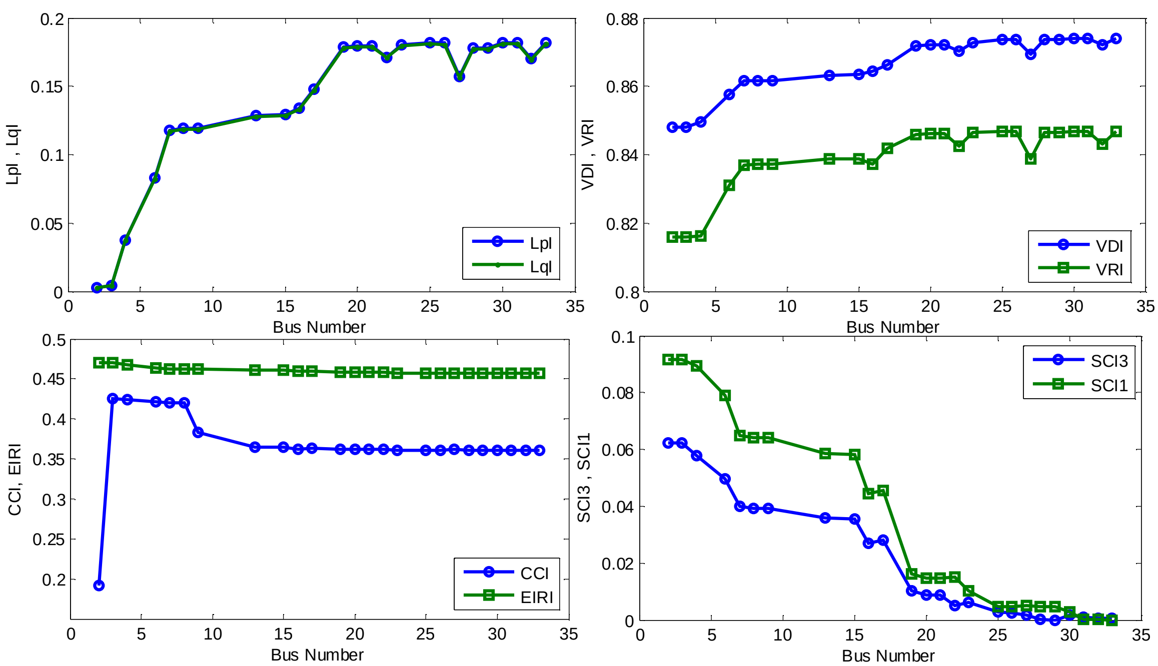

Figure 2. The impact of placing 500 kW DG on mentioned indices.

According to the results shown in Fig. 2 obvious that the CCI, VDI, VRI, LIp and LIq, and EIRI which respectively indicate the cables capacity, voltage drop, voltage regulation, network losses, and the environmental index, would obtain more proper values if DG unit stands close to the loads (far from buses).

This shows the importance of installing DG units close to the loads and is considered as a distinctive advantageous of applying DG in the system. It should be noted that results are obtained for DG unit power factor, which leads to face with similar behavior of active and reactive power losses indices. In protection section (SCI3 and SCI1), as the DG units are closer to network loads, the indices variations are in appose with that of the other sections. In other words, the indices related to the single-phase and three-phase faults are decreased. In fact, as DG unit reaches to the terminative buses, the voltage magnitude is considerably improved and in consequence, the fault current is distinctively increased. The similarity of how the fault indices are normalized, leads to similarity of their behavior under different combinations conditions.

In order to investigate the impact of DG output power on the indices, the DG output power is increased to 1200 kW and the rate of indices and their variations are calculated for all possible DG and network combinations. Fig. 3, shows the results of this investigation.

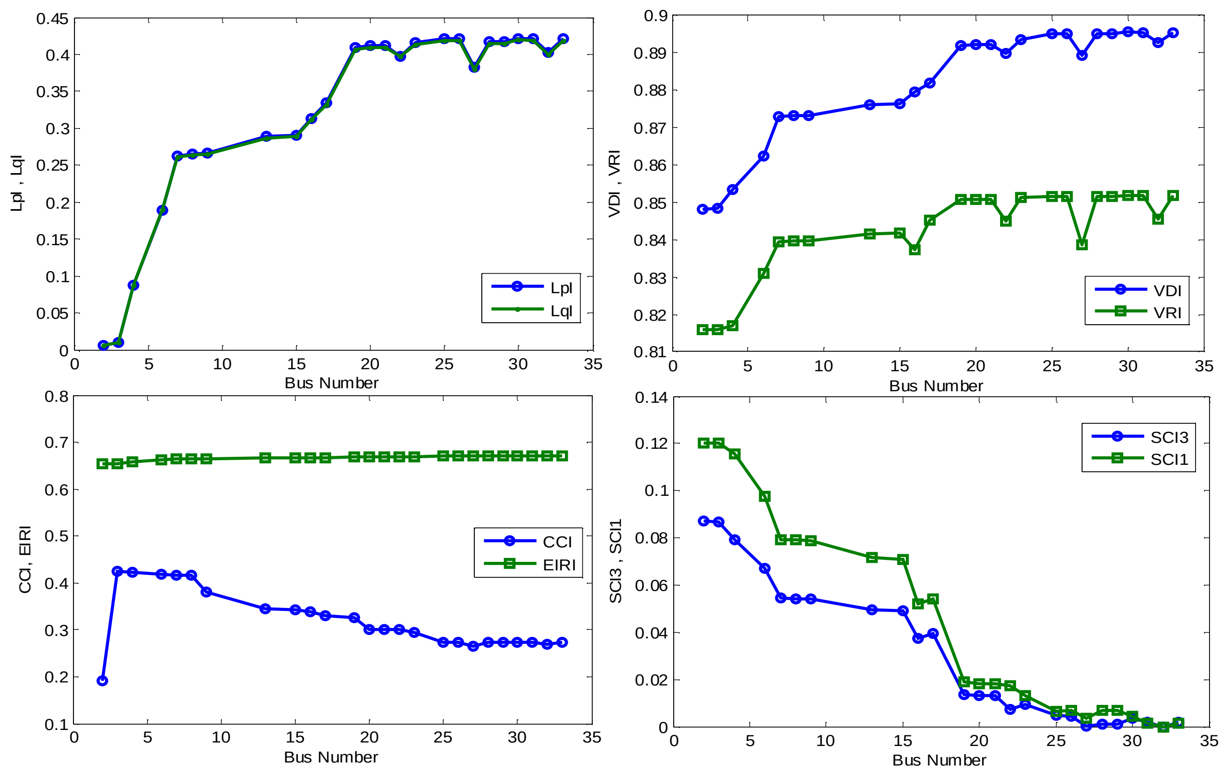

Figure 3. The impact of placing 1200 kW DG unit on mentioned indices

The results well show that as the same as the previous state, placing DG unit in terminal buses, the indices behavior improves in voltage profile, constrains, and environmental parameters aspects and the fault indices are deteriorated. By comparing Fig. 2 and Fig. 3 it can be concluded that the losses indices are considerably improved as the DG power generation ratio is increased. In addition, the environmental index is distinctively improved which is well resulted due to clean power generation by the use of distributed generation. It should be note that the best location for DG in this situation is bus no. 30 and the multiobjective index would be 0.4597.

If the indices were investigated separately, it would be difficult to decide on applying DG units because of the dispersal behavior of them. Therefore, it is necessary to use an efficient multiobjective index to evaluate all indices in a general behavior considering special worries. Based on such fact, this index value for three 300, 600, 1200 and 1500kW DG units and for all possible DG and network combinations is calculated in continuous and the results are illustrated in Fig.4.

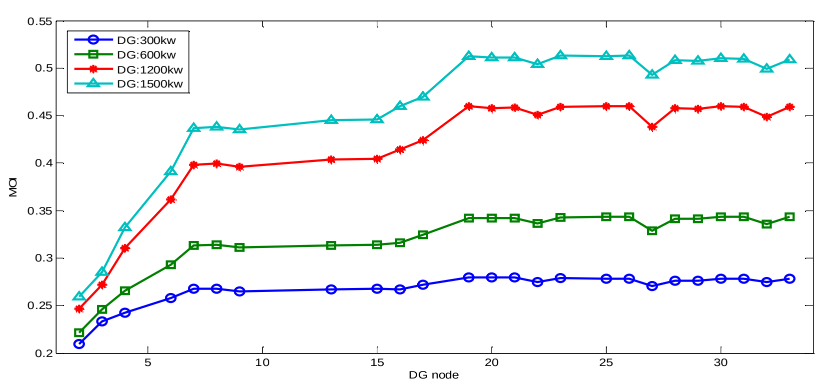

Figure 4. The impact of installing different DG units with 300, 600, 1200 and 1500 kW on the multiobjective index

The obtained values shown in Fig. 4 depict that the multiobjective index value is improved in proportion with generator power increase. This is justified by total system power losses decrease for more DG generation. The maximum MOI value is obtained for 300kw generation on bus 21. Also bus 30 has better MOI for 600 and 1200 kW DG production. In addition, the 23th bus is the most proper bus to install 1500 kW DG unit which results the maximum multiobjective index value.

3-2- The Impact of the Place and the Size of DG Unit on the Multiobjective Index Value

In this part, the MOI values are evaluated for all possible DG and network combinations and the results are illustrated in Fig. 5. It should be noticed that the generation amount variation is as the same as the previous state and the results are achieved based on the counting buses one by one.

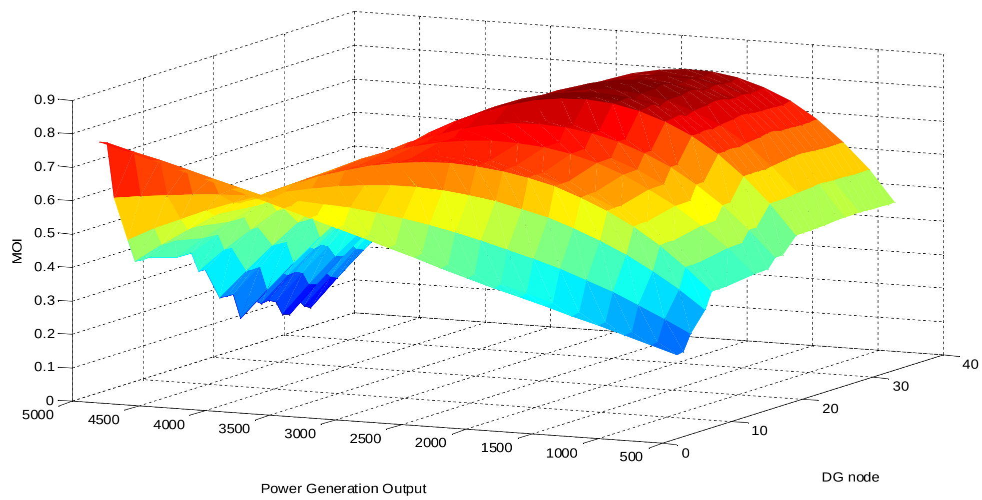

Figure 5. The impact of DG output power rate on the network losses amount.

According to Fig. 5, placing DG unit on the primary buses have no sensible impact on MOI and the most proper place of installing them is the buses stand close to the load (far from buses). In addition, the DG output power increase would not necessarily decrease the system losses and the losses would even increase if it exceeds the network consumption value. Therefore, the MOI value is decreased when DG capacity exceed from 3000 kw. It can generally be concluded that the best combination is achieved installing a 2100 kW DG unit on the 26th bus.

4- Conclusion

Various impact indices such as system losses, voltage profile, lines capacity, fault current, and the environmental were addressed in this work, aimed at characterizing the benefits and negative impacts of DG in distribution networks. In addition, a multi objective performance index using weighted sum approach was proposed to determine the efficiency of the DG unit.

According to the obtained results, applying DG in the distribution network greatly affects all technical parameters of the network. Results have shown that a DG if properly planned will have positive technical impacts such as network loss reduction, voltage improvement, lines capacity increasing and pollutant gas emission minimization. However the short circuit currents will be increased when a DG is installed. In addition, the size of the DG as well as its location distinctively plays roll in indices variation which the network losses index has the most dependence among the others. Consequently, the proposed methodology would be suitable as a tool for finding the most beneficial sizes and places that DG may be located, as viewed from an electric utility technical perspective.

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