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A multi indexed performance assessment function to facilitate efficient installation of Renewable Energy resource

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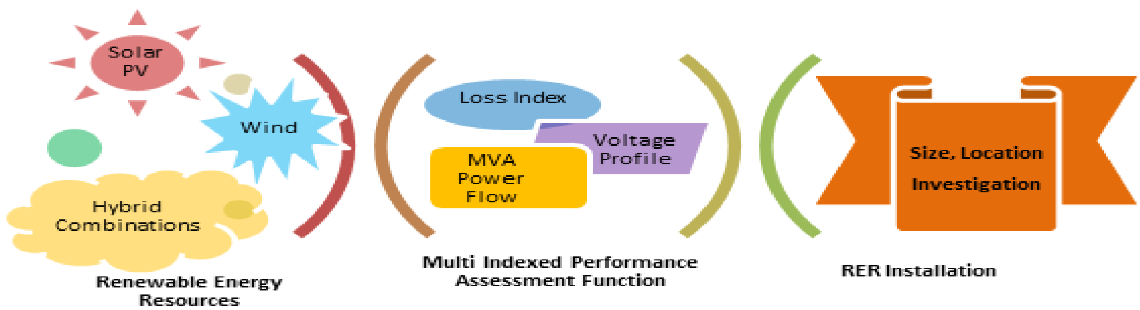
ABSTRACT



Investigating the exact location and design parameters of Renewable Energy Sources (RERs) before actual installation is an important step in Renewable Energy Resource (RER) installation planning. Many RER installation methods are available in the literature, but most of them focus only on investigation of optimal installation location. Very few define bus types for inappropriate locations or RER installations which may degrade system performance. Reviewing the available literature in this field many lacunas are observed to fulfill the requirements of altered network parameters after installation of DGs in the system. To bridge the gap between available approaches and activities, this method describes a novel Multi-Index Performance Assessment function (MIPAF) which provides unique feature of reveling information about apt as well as inapt locations both for RER installation for installing RER in transmission and distribution systems. It is observed that a thorough study of the impact of these often-underestimated RER or Distributed Generation (DG) installations can improve the system's ability to enhance load expansion without a network overhaul. This would provide a tool to reduce the efforts of researchers in this field to find suitable nodes on large networks by reducing the size of candidate locations.

Keywords: Renewable Energy Resources, Performance Parameters, Distributed Generator, Inapt locations, *Loadability*

INTRODUCTION

A power system with RER and DG introduces a different set of network performance issues that can be ideal or worse depending on the network structure.[1-6] Ideal working conditions enrich the energy system with an improved operating environment and cost-effective system management. On the other hand, adverse operating conditions can degrade system performance and reduce reliability levels, thereby imposing penalties on power system operators in terms of low system output power, poor power supplies, system losses, declined stability etc.[1-3] These adverse conditions require hard efforts to minimize the impact of DG implementation on system efficiency.[7-10]

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NOTEWORTHY CONTRIBUTIONS

Installing systems and equipment to harness energy from renewable sources is referred to as renewable energy installation. The move to a more ecologically friendly and sustainable energy system depends on these installations. RER installations support a more resilient and sustainable energy future by lowering greenhouse gas emissions, improving energy security, and lessening the effects of climate change. The installation procedure frequently entails site evaluation, equipment selection, engineering design, permitting, construction, and commissioning. Incentives and rules from the government frequently play a big part in supporting the installation of renewable energy systems since they can lower the initial costs and promote the usage of clean energy sources. Researchers are putting in the sweat and effort for a efficacious Renewable Energy Installation (RERI) from long back. W. Wang at al.[1], has presented cohesive Electricity-heat Energy System with Flexible for RER mixing. Z. Shi et al.[3] synchronized optimization of RER and relative storage capacity by using hierarchical control. Y. M Atwa et al.[4] has shown effective method of effecient renewable resources mix. R. Bansal[5] handbook revealed tharough analysis of DG, their types, definations, planning prose and cones etc. theirafter R. O. Bawazir[6] has also given a detailed servay encompassing the important issues relavant to the planning of DG installation. Discussion of optimal managing of energy storage systems integrated virtual civic[7], RER installation in single area load frequency control,[8] transmission parameters modification for siting and sizing of RER and DG[9] are some of the noticible strategies employed by researchers. Very fine analysis of Leagel model set up of micro and mini-generation distributed of Brazil are presented in E. T. Correia[10]. All of them have utilised novel techniques but some shows the eterative approches, wheras some lacks the accuracy, ease of evaluation can be an issue to be adressed. These issues are tried to overcome in the method presented in this paper. It describes a novel approach using the Multi-Index Performance Assessment Function (MIPAF) to ensure optimal performance for some RER parameters, which can be incorporated into any grid with declined performance. The methodology focuses on assessing the impact of RER allocation on the distribution system, power profile development and critical nodes in the systems, and MVA power output due to generation supplies. Multiple Metric Performance Assessment (MIPA) simplifies the evaluation of appropriate DG design parameters to include in the DS. It also allows the system to receive premium downloads and inappropriate locations. These useful resources help to extend the system with a rich solution environment.

Overview

There are many technical and commercial impacts of DG installation on the overall power system and its delivery patterns that need to be addressed when considering the installation of generators in the power system. The significant impacts are as follows;

The impacts accounted under technical group are[11-17].

- Power loss reduction
- Energy loss reduction
- Voltage profile correction
- Environmental impacts
- Efficiency improvement
- Reliability improvement
- Security requirement
- Transmission & Distribution congestion management

The key economic impacts are[11-17]:

- Deferred investments for line up gradation
- Negligible operational and maintenance cost of some renewable DGs
- Peak shaving
- Reserve supply requirement reduction

In this study, a multi-index criterion was developed to evaluate the performance of the system, taking into account the efficiency and economy of the use of RER after it was placed in the electrical network. These measures are derived from the correlation between performance measures compared to the same network with and without RER[18]. The maximum value of the index will represent the optimum of the trait and in case of execution of the impact of it, the sign of the indicator will show its positive or negative value.

Flow of Work

The improved load carrying capacity of the system and Inapt location investigated after installing DG at the optimal location obtained by applying the MIPAF are studied in this work. The proposed method is illustrated in the flowchart in Figure 1. It shows the method used to find the optimal node and unsuitable locations for DG insertion in the power system.

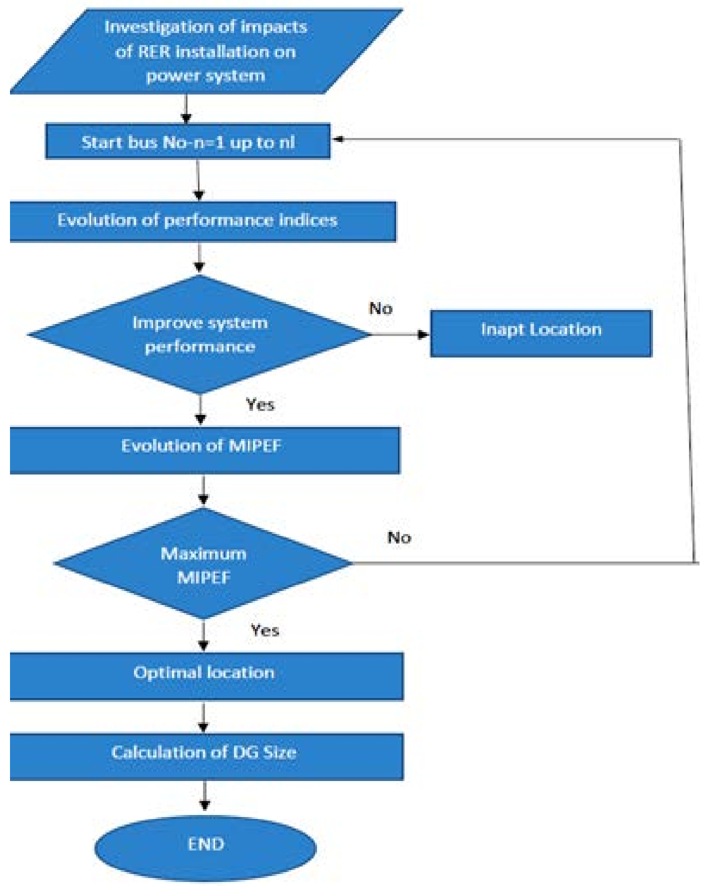

Figure 1. Flowchart of MIPAF

Associated Terms

This work describes two auxiliary uses of the investigated method. The first application finds the loading capability of the power network after the installation of the RER according to the proposed methodology, while the other shows that the buses excluded from the discussion are the best place for the distribution of DG or RER units.[19] Therefore, it can be argued that the parameters recommended as per this method will help to increase the capacity of the system to support load scaling without network modification and evaluation, and reduce the selection of DGs called "Inapt Locations".

PERFORMANCE INDICES

To show the performance of the system after the addition of DG, four main indicators and two secondary economic indicators were prepared by assigning weight fraction to each indicator. These weight fraction values are designed to give a relative weight to each of the impact indicators placed by DG. The use of reliability may refer to certain characteristics depending on the location of the DG and the type of load received from the distribution[9]. Using this model, the best value of the MIPA function obtained will indicate the optimal size of the DG that can be installed in the system. It also helps to control areas that are suitable and unsuitable for additional DG. These indices are explained as:

1. **Voltage regulation Index (V_{RI})**

It is the difference of j^{th} bus voltage without DG and with DG (installed at bus i) to the voltage of j^{th} bus without DG.

$$V_{RI,i} = \sum_{\substack{i=1 \\ j=1 \\ i \neq j}}^{nl} \frac{V_{i,w/oDG} - V_{i,j}}{V_{i,w/oDG}} \quad (1)$$

Where,

$V_{i,j}$	i^{th} bus voltage with installed at bus j
$i_{j,w/o}$ DG	i^{th} bus voltage without DG
i	load bus at which DG is installed one at a time
nl	total load buses

$i \square L_1, L_2, \cdots L_{nl}$

Thus,

$j \square L_1, L_2, \cdots L_{nl}$

Highest value of V_{RI} obtained after DG installed at certain i^{th} location ensures the stable system operation.

2. **Power Loss Index (P_{LOSSI})**

It is the ratio of the difference of active power loss occurred in the system (with same configuration) without and with DG (installed at bus i) to the loss without DG.

$$P_{LOSSI,a} = \frac{P_{LOSS,w/oDG} - P_{LOSS,wit\square DG,a}}{P_{LOSS,w/oDG}} \quad (2)$$

Where

iA∀L_1,L_2,⋯L_nl

$P_{LOSS,\ withDG,i}$	power loss with DG installed at bus i
$P_{LOSS,\ w/oDG}$	power loss without DG

Location Analysis

Optimal location	:	Maximum P_{LOSSI}
Apt location	:	Positive P_{LOSSI}
Inapt location	:	Negative P_{LOSS}

3. **PCC Share Index (PCC_{SI})**

It is the ratio of difference of load share of Point of Common Coupling (PCC) with DG (installed at i) and without DG (with same configuration).

$$PCC_{SI} = \frac{PCC_{\cdot S\square are,w/oDG} - PCC_{\cdot S\square are,i}}{PCC_{\cdot S\square are,w/oDG}} \quad (3)$$

$PCC_{w/o\ DG}$	load shared by point of common coupling without DG
PCC_i	load shared by point of common coupling with DG installed at bus i
Therefore,	$PCC_{SI,i} \leq 1$

4. **DG Capacity Index (DG_I)**

Definition: It is the inverse of optimal capacity of DG calculated in MVA for bus i causing optimum power loss.

$DGI,i = 1/ DG_{capacity,i}$

Where, $i \forall L_1, L_2, \cdots L_{nl}$ (4)

MULTIPLE INDEXED PERFORMANCE ASSESSMENT (MIPA) FUNCTION

MIPA function explored here provides the optimum output for the system by assessing an entire performance after putting DG at each load bus. In this work four major techno-economic indices are proposed. For enhancing its degree of impact on the specific trait a specific weight fraction (wf) has been assigned to each index. Weight fraction is selected as per the degree of implication of respective index. To improve the voltage stability the higher weight fraction can be assigned to V_{RI}, lower loss can be achieved by giving higher weight fraction to P_{LOSSI}, system load carrying ability can be enhanced by assigning higher weight fraction to PCC_{SI}, optimal DG share can be decided by giving appropriate weight fraction to DG_{MVAI}. Thus an appropriate weight fraction can be assigned as per the requirement.

Thus, the Multiple Indexed Performance Assessment Function is given by

$$\text{MIPAF}_i = wf_1 V_{RI,i} + wf_2 P_{LOSSI,i} + wf_3 PCC_{SI} + wf_4 DG_{MVAI,i}) \quad (5)$$

Where, $i \forall L_1, L_2, \cdots L_{nl}$

$$\sum_{i=1}^{4} wf_i = 1 \wedge wf_i \in [0,1] \quad (6)$$

STUDIES PERFORMED

To execute the efficacy of planned MIPAF is applied on standard 33-bus[20] and 69-bus[21] test distribution systems.

EXAMINATION OF VARIOUS INDICES

Figures 2 shows voltage correction attained after installing the RER at the location suggested by proposed MIPEF for 33 bus system. It indicates that buses 2 and 19 fails to provide any possible feasible solution whereas buses 3 to 18 and 19 to 33 offer possible output. Though, buses 14 to 18 and 25 to 33 display maximum degree of attenuation i.e. above 60% of the previous voltage profile.

Similarly the active-reactive power loss indices evaluated for 69 bus system are shown in Figure 3. These figures clearly indicate information regarding practicable and impracticable candidate locations for DG insertion. The power loss indices for buses 2 to 6 and 29 to 51 are very trivial indicating unfeasibility for RER installation with regard power loss minimization. However, a noteworthy loss reduction is observed at 7 to 28 and 52 to 69. It indicates the feasibility of these nodes for RER installation. Systematic analysis of these outputs recommends buses 58 to 65 as the viable options indicating approximately 70% to 80% of reduction of power loss. Similarly, Figure 4 shows all 4 performance parameters intended for 33 bus system. It specifies no probable solution is attained for buses 2 and the buses from 19 to 25. However, a possible result is gained for buses 3 – 18 and 26 –

33 screening important reduction power loss percentage. Whereas buses 6, 7 and 26 to 30 show maximum fraction of reduction of power loss i.e. about 60% and above. Thus, it can be suggested as feasible node for RER installation.

Figures 5 depicts overall MIPEF output evaluated for 33 bus system. Specific formulation of indices enables the identification of optimum, appropriate and inappropriate nodes for RER installation. This noteworthy attribute of the MIPAF is demonstrated by these figures.

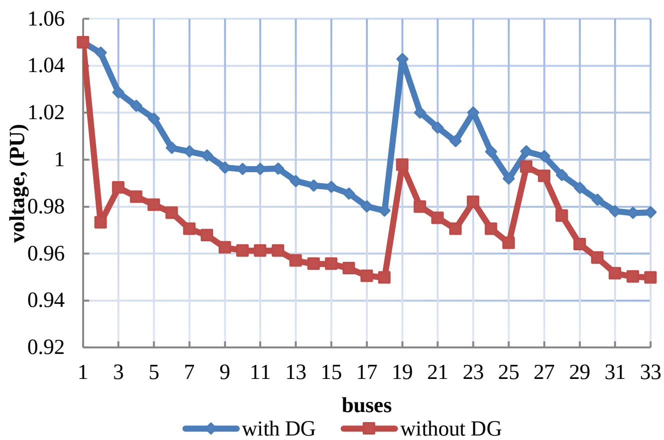

Figure 2. Voltage correction attained after installation of RER as per MIPEFF

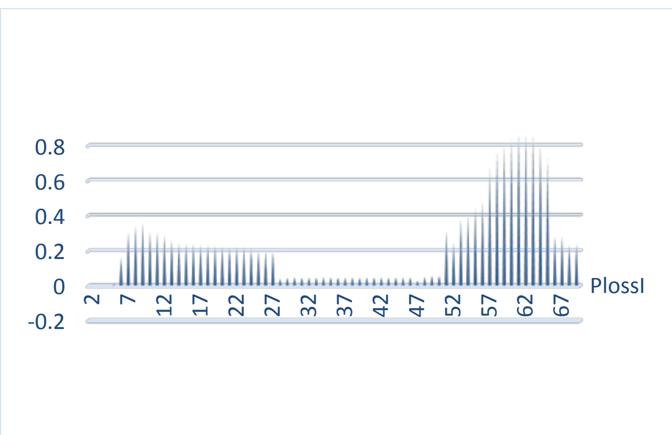

Figure 3. Power loss indices evaluated for 69 bus system

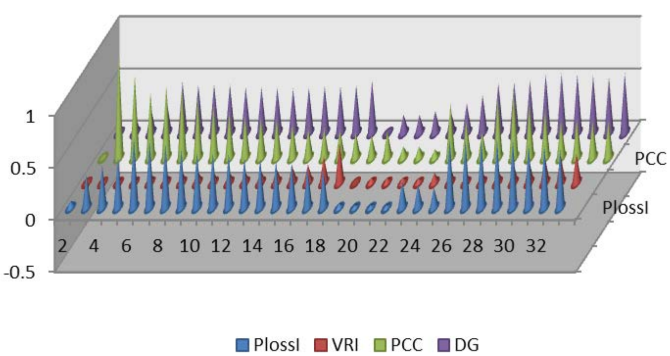

Figure 4. Performance indices evaluated for 33 bus

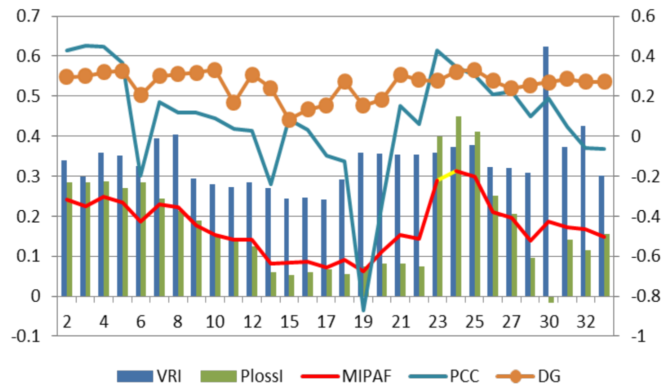

Figure 5. MIPAF output evaluated for 33 bus system

The RER accumulation influence on the performance of network as per the certain optimal node varies for 33 bus system. Table 1, indicates that for 33 bus system, with evaluated optimal location, maximum parameters for RER planning also vary. At bus 6 RER of 3.21 with OPF_{DG} 0.85 is required whereas at bus 29 DG of 2.22 with OPF_{DG} 0.79 is required. Differences with the designated optimal site for 33-bus are given in Table 2 which shows slightly higher indices of power loss whereas voltage upgradation indices are pointedly lower for bus 6 as compared to bus 29. Correspondingly in case of economical indices, since RER size essential at bus 29 is lower than the grid capacity relief which is also moderately lesser than that from bus 6 location. Thus, later the overall MIPAF found for bus 29 is advanced than the bus 6 demonstrating improved degree of performance attained after RER insertion.

Table 1: Optimal location evaluation for RER by using MIPAF and Load Flow Analysis method

System	Method	Optimal location	DG size	OPFDG	Type
33 bus	**Load Flow Analysis**	**6**	**3.21**	**0.85**	**3**
	MIPAF	**29**	**2.22**	**0.79**	**3**
69 bus	**Load Flow Analysis**	**61**	**2.47**	**0.83**	**3**
	MIPAF	**61**	**2.44**	**0.83**	**3**

Table 2: Performance parameters calculated by Load Flow Analysis and calculated by MIPAF

Indices	bus 6 (Load Flow Analysis)	bus 29 (MIPAF)
V_{RI}	0.593	0.804
P_{LOSSI}	0.675	0.660
PCC_{SI}	0.670	0.466
DG_I	0.318	0.4712
max(MIPAF)	0.486	0.547

This function shows that MIPAF offers improved optimal parameters. In this part of study, it can be seen that the similar optimal solution is obtained in 69-bus system by using both methods (MIPAF and load flow analysis) while the output varies slightly for 33 bus system.

System Loadability

Voltage stability is the ability of the power network to keep the voltage amplitude within the limits of the system after static or dynamic disturbances[22-25]. One of its main effects is voltage degradation, which can lead to sudden power cut-off or system-size abnormal voltages. It occurs in heavy load, fault and/or reactive power interruption configurations that do not meet the reactive power generation, transmission and distribution limits. The transmission or the stability of the transmission can be defined by its current carrying capacity. It can be defined as static loading or additional loads beyond the base case that the system can support before it crashes. The place and suitable size of a RER that modifies level of reactive power and streams in a radial distribution power system can have a considerable impact on it.

Enhanced Loadability

Improvement of load carrying capability of the network depends on the active power support provided to the system. Active power support is compatible with system voltage and bus power adjustment[26-28]. Placing the RER at the right size in the right place can reduce the flow of energy on an important part of the system. As a result, it reduces I^2R losses associated with major improvements to the system's power profile and sensitive bus. The proposed method incorporates indices, indicating the percentage of electricity and the improvement of bus power through the installation of RER[29-35]. Therefore, the installation of RER in the appropriate location with the appropriate size and type proposed in the proposed manner can provide a high voltage profile adjustment of the system and a sensitive bus, which ensures the advanced power support provided in the system. Therefore, system loading is increasing with the increase in operational capacity obtained with the addition of DG. Solid electrical power in the energy system can be analyzed using a P-V curve[12]. The power drop point on this curve represents the maximum loading of the system. To investigate improvements in high-performance system loading with the addition of RER, the PV curve is obtained by gradually increasing the operating and updating load of the system as given the following statistics,

The real power attained is compatible with system voltage and bus power alteration. Placing the RER in the right place and the right size can reduce the energy flow in the main area of the network. As a result, it reduces the I^2R loss associated with significant improvements in the power system and main bus. The planned method includes indices, demonstrating the fraction of power and the upgrading of bus power through RER connection[12,14]. So, investigating appropriate location with the suitable size and type of RER as per the explored method can provide a high voltage profile modification of almost all system nodes including a sensitive bus, which ensures the enhanced stability of the system. Thus, loading of the system is increasing with the upsurge in effective size obtained with the adding of RER. The stability of the power network can be analyzed in the power system by using a P-V curve[33]. The low power notch on PV curve signifies the thoroughgoing loading of the network. To examine expansions in high-performance system loading after adding of RER, the P-V curve is gained by progressively adding the load of the system as per the following statistics,

$$P_{Load,i} = P_{L0,i}(1 + \alpha \Delta P_{Load}) \quad (7)$$

$$Q_{Load,i} = Q_{L0,i}(1 + \alpha \Delta Q_{Load}) \quad (8)$$

Where, α 0, 1, 2, 3, 4………upto power outage point

i sensitive bus

$P_{Load,i}$ operating point of active load at bus i, p.u.

$Q_{Load,i}$ operating point of reactive load at bus i, p.u.

ΔP_{Load} addition of active load, p.u.

ΔQ_{Load} addition of reactive load, p.u.

As per equation (1) and (2) the load is added in the system. Adding a DG unit with correct size can power outage point extend the point of a power outage due to the network power limit[1].

Improved Load Carring capability obtained after adding DG at optimal location with parameters suggested by explored method

The load of the sensitive bus of the system is gradually increased without the DG until the voltage of the node reaches the breakdown value called $V_{CRw/oDG}$, where any further load addition may unstable the system. Breakdown voltage, V_{CR} is a minor allowable load after which the system will break down. A load at which the power system become unstable is defined as critical load $P_{CRw/oDG}$.

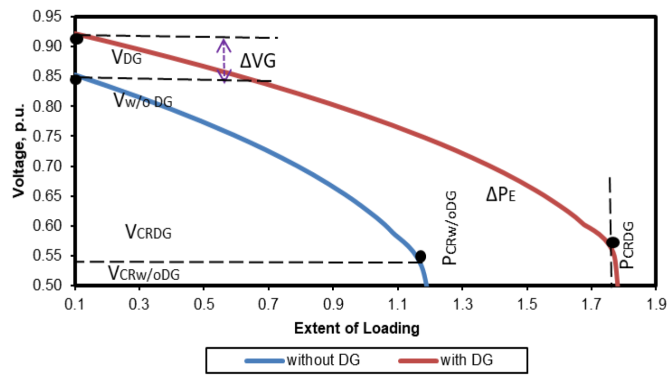

Figure 6. P-V Curve for 33-bus system

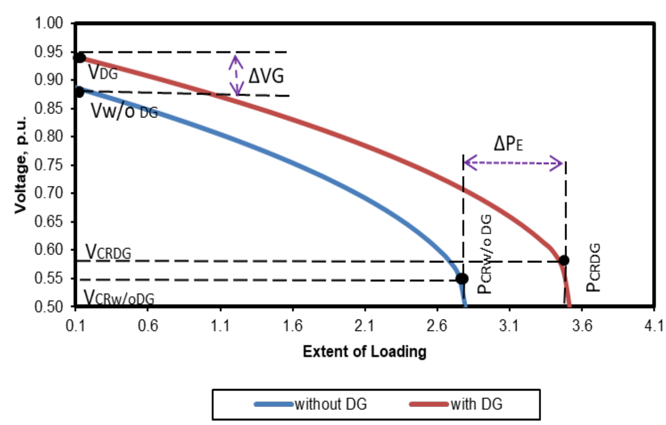

Figure 7. P-V Curve for 69-bus system

As per the Load Flow Analysis method, Type 3 DG of 3.21 MVA with 0.85 pf (Power factor) is installed on bus 6 of the 33 system buses and Type 1 DG of 2.22 MVA with 0.79 pf is installed on bus 61 of 69 bus system. Afterward the load of the sensitive bus is gradually increased up to the critical value, the PCRDG where the voltage reaches the critical area, the VCRDG. Subsequently the difference between PCRw/oDG and PCRDG indicates the maximum load expansion indicated by ΔPE. Similarly, the difference between Vw/oDG (working voltage of PV curve without DG) and VDG (operating voltage of PV curve and DG), indicates Voltage Gradation, ΔVG (in respective working area) obtained after the effective and beneficial addition of DG to the system.

Figures 6 and 17 indicate that in both structures a important upsurge in load is possible with the DG placed in the accurate place with the planned parameters entitled by the explored method as shown in Table 3. In the 33-bus system, 53.7% of increment in load with 8.33% of voltage progression is observed after adding the RER unit and in the 69-bus system 25.67% of the load extension is found with 6.92% of the progression of voltage.

Table 3: Summarized parameters showing enhanced system loadabilty

Syst em	$P_{CRw/oDG}$	$P_{C RDG}$	ΔP E	% Load expa nsion	$V_{CR\,w/oDG}$	$V_{CR\,w/oDG}$	$V_{w/oDG}$	V DG	Δ V G	% Volta ge grad ation
33 bus	1.15	1.7 8	0. 63	53.77	0.54	0.57	0.8 5	0. 92	0. 07	8.33
69 bus	2.78	3.4 9	0. 71	25.67	0.55	0.58	0.8 8	0. 94	0. 06	6.92

Inapt Locations

Choosing the best location for the installation and size of the DG unit in a large network is a common problem[1,5-7]. Most of the best ways to solve this difficult problem can be found in the literature[8-10, 11-22]. Most of the operations have to repeat or go through the computational process, which ultimately leads to a long and complex problem. Also, these models[9,12,17,22] can provide noise for small and medium power systems, but complex systems can create proper or correct integration problems. Such cases indicate investigation location for new functional tools that can reduce the complexity of the system or the number of options available, for example the number of competitors of the system. The plan not only checks for available points, but also provides information about unsuitable locations for DG processing, called Unsuitable Locations. This useful information can help searchers narrow their search for this site.

Prominence of Inapt Locations

Inapt places are defined as network nodes where the installation of unit of RER can develop unwanted operating situations such as monotonous flow of power, reverse current flow etc. In this work such nodes are classified into two types such as;

- **Adverse Impact Areas (AILs)** - nodes in which the unit of RER is installed, lead to a reduction in the performance of power network due to adversative impacts levied on the network by growing system losses, condensed power strength and output of low percentage of the main source location.
- **Concurrent bus (CB)[9]** - a bus near the main station.

Adversative Locations (ALs)

DG cannot be installed on every busbar in power distribution. Some busbars can be considered as bad DG inputs, as inconsistent choice of position and size of DG may result in greater physical loss or lower stable power than outside DG[20, 21]. Integrating DGs into Apt areas can have a negative impact on the power distribution system. The MIPAF developed in this study is used to evaluate these areas. The function can define parameters in the whole system. A negative or zero reading in a candidate region indicates conflict with DG in that direction. The negative index indicates the severity of the adverse effects of DG placement in the appropriate area.

Successive Bus (SB)

If a RER unit is placed after a node of sub-station the power shared by it is zero and the entire power supply will be supplied by RER unit only. Thus, a high size of DG unit is required to cope up power requirement when placed at Successive Bus even for a trivial increment.

Results and Discussions

After application of the Load Analysis method and the MIPAF the suitable place adding RER unit and adversative locations can be inspected. For examining this trait of the explored method it is applied on both the considered systems and after obtaining the outputs the summary results are given in Figures 8 and 9.

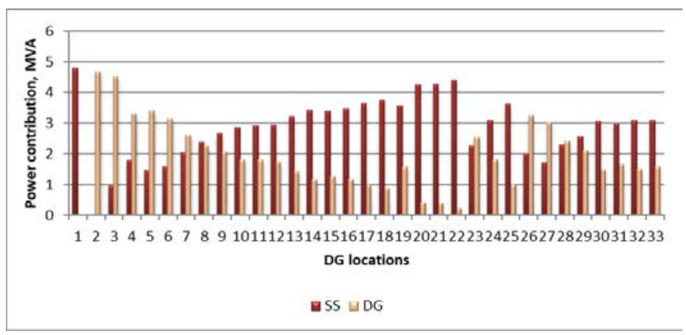

Figure 8. Power shared by substation and the installed RER unit in 33 bus system

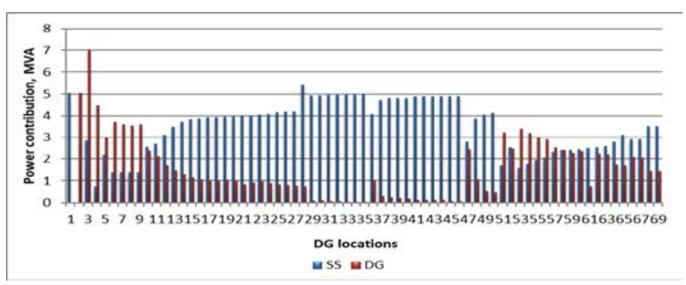

Figure 9. Power shared by substation and the installed RER unit in 69-bus system

Figures 8 and 9 show the power contribution from both the sources that produces a burden on the network from the corresponding area viewing the bus near the sub-station i.e. the next node which may be considered as the Successive Bus. It can be observed that addition of unit of RER at this node will lead to zero contribution from the station as the entire power is now supplied by unit of RER only. High-Capacity unit of RER is thus required to stream power once placed at this node. Except for that very small amount of loss reduction is found in this area. Therefore, it can be suggested that Sequential Bus is the preferred location for RER installation. In the 33-bus system with a total load of 4.38 MVA, bus 2 is CB where a RER of 4.52 MVA is required which will result in a 7.16% reduction in losses. While in the 69-bus system with a load of 4.31 MVA, bus 2 is CB where the DG of 4.18 MVA is required which will result in a 2.07% reduction in loss this leads to the conclusion that Successive Bus is the the worst location for RER placing.

CONCLUSION

Cited research papers encompassing the information, strateges, givernment policies promoting the RER installation revels the rapid growth in the global awareness of public as well as government to in DG/RER planning in the power network. Though it is showing blooming future in the energy scarced scnerio, it is not compitible in many contests with traditional resources. This offers a wide area to be covered for researchers to make it acceptible in all respects. Many methodolgies were reviewed but very few were found to be sound and efficient in providing optimum and abosolute solution for DG installation and if any method could offer appropriate results certainly accompanied by compramised service situations. After analysing all these lacunas observed tiil time, this paper tries to cover maximum possible requiremnts and presents solution with satisfied network constraints. It presents a multi-indexed performance assessment function which marks two supplementary uses such as increased load carrying capability obtained after placing unit of RER and investigation of inappropriate i.e., INAPT node of power network for DG installation. It also demonstrates the effect of consideration of load pattern on load expansion. It is obvious that the load extension of the system is possible after placing DG with the parameters planned as per method at an appropriate site provided by the accurate predictions of load expansion. Obtained outputs are analysied and validated by investigating all possible aftereffects of installtion executed through explored method.

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