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# LOCATION OF DG'S IN RESTRUCTURED POWER SYSTEMS USING LOCATIONAL MARGINAL PRICE (LMP)

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## ABSTRACT

Distributed or decentralized generation refers to electric power generating on a small scale, often between a few kilowatts (kW) and one hundred megawatts (MW), typically located within distribution networks or on the client side of the network. The major reasons to put in DG are to make the electric power market more efficient, to lower electricity rates for customers, and to have clean energy sources close to where the loads are. The auxiliary service it provides is voltage support at the distribution level. Power quality, voltage consistency, and reliability are all boosted by DG's contributions to these areas. To figure out where exactly DG should go up, we look at the Locational Marginal Price (LMP) at the load buses. Using MATLAB, we conduct penetration tests on the suggested technique for the IEEE 9, 14, and 57 bus systems.

**Keywords:** Distributed generation; Locational marginal price; Optimal power flow; Electricity market; Social welfare.

## 1. INTRODUCTION

Distribution organisations face their primary problems in the form of growing load demand and increased competitiveness in the electricity market. Moreover, increasing the capacity of the transmission and distribution network might not be a viable option because to the high cost involved. Because of these issues, distribution companies have been pushed to come up with solutions to meet the demand for power through careful planning and design of the network [1,2]. Distributed generation is a realistic and desired option since it can serve both densely populated and dispersed rural locations. The challenge of meeting this demand can be overcome with the help of distributed generating. Distributed generators (DGs) can be integrated into the distribution network or connected locally for a consumer who is disconnected from the network entirely. In situations where it is not viable to have central generating and when there are problems in the transmission network, distributed generation (DG) can be beneficial for both consumers and utilities. Numerous studies have demonstrated that 10-15% of the maximum load may be supplied by distributed generation (DG) by simply inserting it into the existing system with no need for major structural alterations [3]. It improves upon conventional electrical power sources while providing advantages to residential, commercial, and industrial consumers. Utilities investigate this option because they are looking for the best way to handle the issues posed by the supply of electric power [4,5]. In addition to this, investments in DG have the potential to create a market that is competitive.

Distributed generation is also sometimes referred to as on-site generation, embedded generation, scattered generation, or decentralised generation. The term "decentralised generation" can be used to refer to distributed generation. It is the renewable or nonrenewable electric power source that is linked to the distribution network or the consumer location. Both forms of energy meet the criteria for this definition. Businesses that supply electric service can reap economic, technological, and ecological benefits from adopting this system. However, power distribution systems have typically been built to only allow for one-way power transmission [6, 7, 8]. However, by incorporating DG, a bidirectional flow of power is made possible in spite of a variety of difficult operating situations, such as increased terminal voltage level, fault current, harmonic distortion and stability, and reverse power flow [9,10]. Therefore, the research community is still faced with the open-ended task of planning the installation of DG in order to give actual and reactive electricity to the system. Location, sizing, and control of DG facilities in relation to the various types of power grids must all be carefully considered. The necessity of choosing a suitable strategy for DG prompted the search for mathematical optimisation methodologies that can aid in the design and planning decision-making process [11,12]. These techniques can be of assistance in the design and planning phases.

Despite the many advantages of DGs, they add a considerable deal of complexity to the distribution system's operational procedures due to their seemingly random location and sizing. When DG is installed, power flows in both directions, even though the distribution system was designed to carry a unidirectional current [13]. As a result, there are a number of technical issues to worry about, such as power loss variations, voltage fluctuations (during transmission and reception), and disruptions in power supply stability and reliability. Power invertor-based DGs would increase harmonics and transients in the system, and bidirectional power flow could trip the protective devices. Also, renewable energy sources like wind turbines and solar photovoltaic panels can only produce as much energy as the materials put into them. It is anticipated that this may cause the system's reliability and stability to be compromised, as they are of a stochastic nature and are dependent on the speed of the wind and the solar irradiance. It is important to keep in mind that the integration of DG into distribution networks is not as straightforward as simply plugging in a few cables. The distribution network operator needs a trustworthy model to guide their choices on where to install DGs, what kind to use, and how big to make them. As a result, there has been a rise in interest in the practise of applying optimisation approaches, which are used to minimise the problems and maximise the advantages while simultaneously addressing many contradictory objectives.

## 2. LITERATURE REVIEW

In 2020, Memarzadeh, G.; presented a new analytical index to find and decide the right size of DG. The proposed index incorporates the voltage stability index, the loss sensitivity factor, and the reliability factors. This article provides the DG placement index (DGPI) as a weighted sum of the indicators stated above to help find the best location for installing DGs. The highest DGPI value bus in each of the examined networks was selected as a possible site for DG installation. When determining the optimal DG size, care is taken to select a value for the DGPI that is as much as possible.

According to Selim, A.;(2020), an innovative technique known as Harris Hawks optimisation was implemented in order to best position dispersed generation units in a radial distribution network and calculate their capacity. This method's efficiency was measured against that of other, analogous heuristic optimisation strategies. The authors' goal was to minimise lost power using this method.

Suresh, M.C.V. ; (2020) used a novel hybrid technique to identify and establish the optimal size of DG with the goal of reducing power loss. The combined strategy involved the constant execution of both the grasshopper optimisation algorithm (GOA) and the cuckoo search (CS). Using the CS approach, the authors of this research were able to improve the GOA optimisation behaviour.

In order to find and estimate the ideal size of DG, the modified moth flame optimisation (MMFO) was proposed by Elattar, E.E. ; (2020). It was hoped that by minimising things like active power losses, bus voltage changes, DG operating costs, and emission costs, the overall cost of running the network could be kept to a minimum.

Paterakis NG, (2016) presents a multiobjective approach to the DNR problem, with the aim of minimising power loss while simultaneously increasing dependability indices. For multiphase active distribution networks, Jabr RA (2017) proposes a real-time optimum reconfiguration as an extension of the conventional reconfiguration strategy. This approach of reconfiguration is suggested as a superior alternative. The issue highlighted by Jazebi S., (2014) is addressed by employing an optimisation technique based on the shuffling frog leaping algorithm and the imperialist competitive algorithm. In the presence of harmonic loads, DNR can be resolved.

To ensure that Distributed Generation (DG) owners make as much money as possible while keeping power loss to a minimum, Ehsan Azad-Farsani's (2021) Distribution Company (DISCO) implements a number of price-based rules. Meanwhile, DNR (Distribution Network Reconfiguration) helps keep the network downtime to a minimum. In this study, we present a hybrid market-based DNR approach for determining the best network architecture and Locational Marginal Prices (LMPs) at DG-connected buses simultaneously. The Firework Algorithm (FWA) is paired with an Iterative Game-Based Algorithm (IGBA) to determine the optimal network configuration for minimising power loss. To find the optimal setup, the IGBA is run in parallel with the FWA search in the hybrid technique. By applying game theory to the problem of loss reduction, the IGBA can determine the LMPs for individual DG units. In addition, the FW algorithm is inefficient if the coefficients are chosen incorrectly. As a result, we present a self-adaptive framework for determining coefficient values as the algorithm develops. A real-world system is used to test how well the given methodology works.

## 3. METHODOLOGY

The initial step in the base case OPF is to determine multiple power prices at each network node for a specific set of supply and demand bid curves. These values are then compared to one another. The non-linear equality constraints are used to derive the lagrangian multipliers, which are then used to calculate the nodal prices. Both rising functions for supplier bids and falling functions for customer bids are factored into the marginal cost or benefit of the bidder. The disparity in costs is due to losses in the gearbox system as well as active line limitations.

Two different rankings are defined: one is based on LMP, and the other is based on consumer payment (CP). Using these ratings, potential DG deployment nodes can be found.

### 3.1. Locational marginal price (LMP) based ranking

LMP stands for the lagrangian multipliers related to the active power flow equations on each bus in the system. At any node in the system, the local maximum probability (LMP) is the dual variable for the equality constraint [13]. The marginal performance profile, or LMP, is often composed of three sub-profiles: congestion, marginal loss, and marginal energy. Every bus has the same minimum performance requirements. The LMP can be determined using the following formula, which factors in the real power spot price at bus i:

$$LMP_i = \lambda + \lambda \frac{\partial P_L}{\partial P_i} + \sum_{ij=1}^{N_L} \mu L_{ij} + \frac{\partial P_{ij}}{\partial P}$$

$$LMP_i = \lambda + \lambda_{L,i} + \lambda_{C,i}$$

where λ is the marginal energy component at the reference bus which is same for all buses, λL,i = λ(∂PL/∂Pi) is the marginal loss component and λC,i = μLij (∂Pij/∂Pi) is the congestion component. As a result, the spot pricing at each bus stop is dependent on both the loss component and the congestion component in its own special way. This location-specific cost is identical, in theory, to the optimal market value of electricity at that specific location, given all system constraints.

A higher LMP indicates that the node's active power flow equations have a bigger impact on the system's aggregate social welfare. If the LMP is high, then the demand for power at that node is also high. To maximise social welfare, this finding shows that infusing active power at that node will boost net social gain. Since it is expected that DGs will inject real power at the node with the highest LMP, that location will be prioritised for DG installation. As a result, the load buses are sorted based on LMP, with the top node representing the optimal location for the DG.

$$LMP = \begin{bmatrix} LMP_1 \\ LMP_2 \\ LMP_3 \\ . \\ . \\ . \\ LMP_n \end{bmatrix}$$

where n is the number of load locations.

Best location = index {max(LMP)}

### 3.2. Consumer payment based ranking

Potential DG installation nodes can be differentiated by CP, which is the product of LMP and load capacity. So, the combined power at load bus i is the LMP plus the load.

$$CP = LMP_i \times Load_i = \begin{bmatrix} CP_1 \\ CP_2 \\ CP_3 \\ . \\ . \\ . \\ CP_n \end{bmatrix}$$

Best location = index {max(CP)}

The CPi value represents the sum of all electricity costs borne by the consumer at node i. Due to the market for DG placement being viewed from two perspectives, the rankings are altered. Two outcomes are possible: one with high price but low load, and another with cheap price but heavy load. In the second scenario, when nodal payments are prioritised over high prices, the ranking is determined by the amount paid by consumers. Overall, the ranking will lighten the system's most pressing burdens. In practise, LMP decreases and the dominant customer benefits because the amount they must pay is lower than in a no DG circumstance.

The potential candidate nodes are chosen through a series of iterations. Multiple assumed DG cost characteristics are used in the placement. Since the goal of the placement method is to reduce the LMP, DG whose operating costs are already lower than the LMP will see no benefit from using the method. Penetration is predicted to be greater for the DG whose operating costs are lower than those bid by the supplier, and lower for the DG whose costs are higher.

## 4. SIMULATION RESULTS

### 4.1 IEEE 9 BUS:

| DG Size = 5MWRANK | BUS NUMBER | LMP BEFORE DG | LMP AFTER DG |
|---|---|---|---|
| 1 | 5 | 14.1 | 13.7 |
| 2 | 6 | 13.58 | 13.24 |
| 3 | 8 | 13.5 | 13.21 |

| POWER LOSS BEFORE DG | POWER LOSS AFTER DG |
|---|---|

| | |
|---|---|
| 4.641 | 4.5 |

- Here, the DG is placed at one bus i.e, Bus 5.
- The LMP is decreased after the DG Placement.
- Hence, the cost payed by the consumer.

### 4.2 IEEE 14 BUS:

| RANK | BUS NUMBER | DG Size in MW | LMP BEFORE DG | LMP AFTER DG |
|---|---|---|---|---|
| 1 | 14 | 1.14 | 60.1 | 56.7 |
| 2 | 13 | 3.09 | 59.2 | 55.9 |
| 3 | 3 | 2.165 | 58 | 55.0 |

| POWER LOSS BEFORE DG | POWER LOSS AFTER DG |
|---|---|
| 13.593 MW | 12.78 MW |

- Here, the DG is placed at one bus i.e, Bus 14, 13, 3
- The LMP is decreased after the DG Placement.

### 4.3 IEEE 57 BUS:

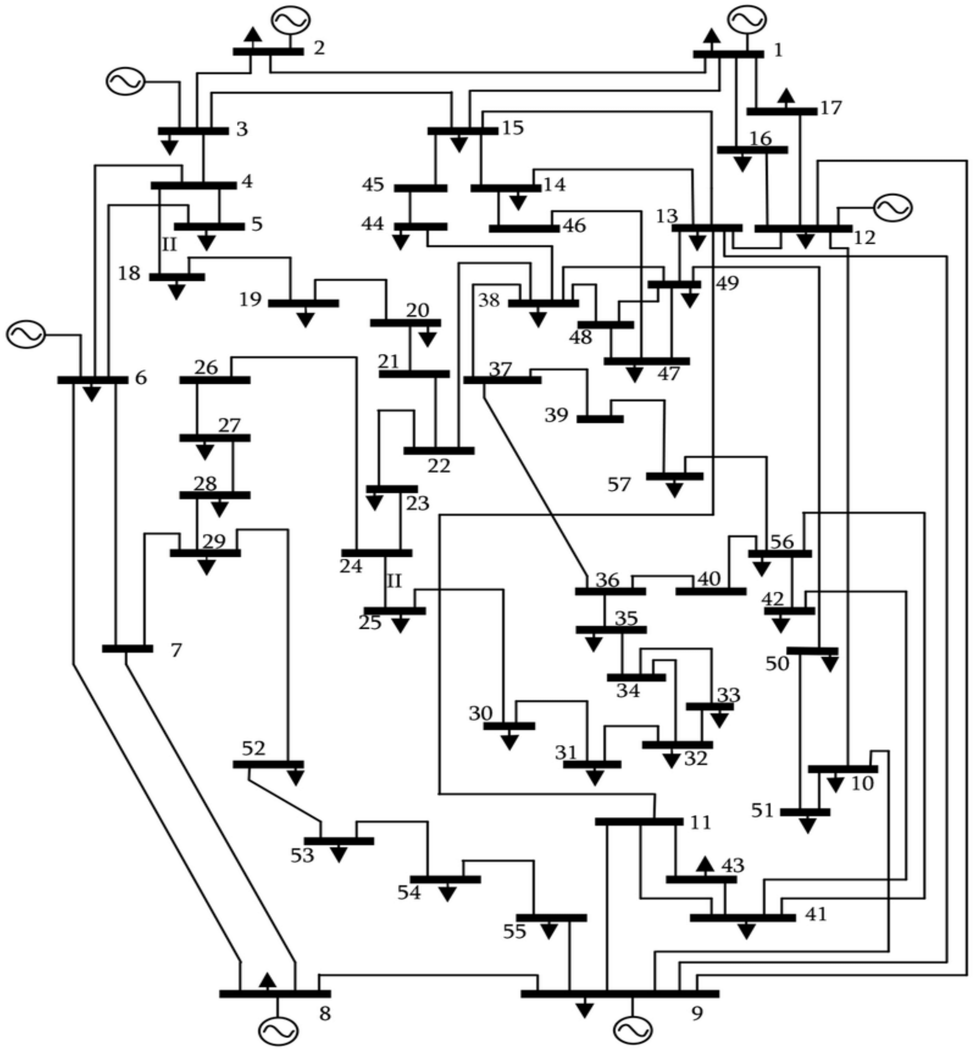
| RANK | BUS NUMBER | DG Size | LMP BEFORE DG | LMP AFTER DG |
|---|---|---|---|---|
| 1 | 31 | 3.41 | 135.8 | 116.1 |
| 2 | 33 | 1.6 | 134.13 | 114.64 |
| 3 | 32 | 10.65 | 133.0 | 114.0 |

| | | | | |
|---|---|---|---|---|
| **4** | **35** | **5.54** | **132.4** | **112.8** |
| **5** | **57** | **2.40** | **131.2** | **111.5** |

| POWER LOSS BEFORE DG | POWER LOSS AFTER DG |
|---|---|
| **27.08** | **23.01** |

- Here, the DG is placed at one bus i.e, Bus 31, 33, 32, 35, 57
- The LMP is decreased after the DG Placement.

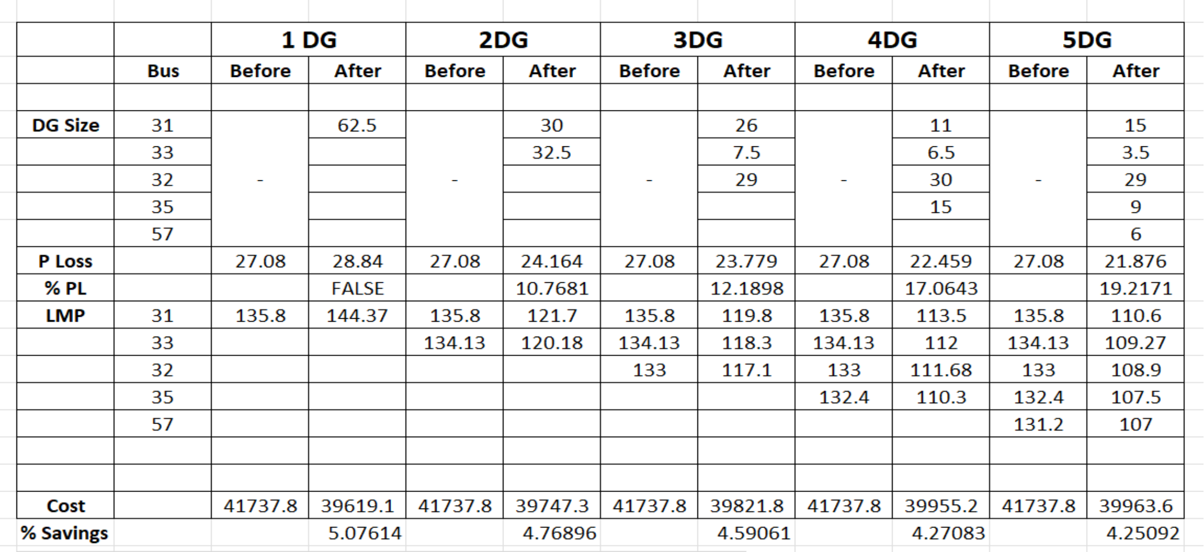
### 4.4IEEE 57 BUS:



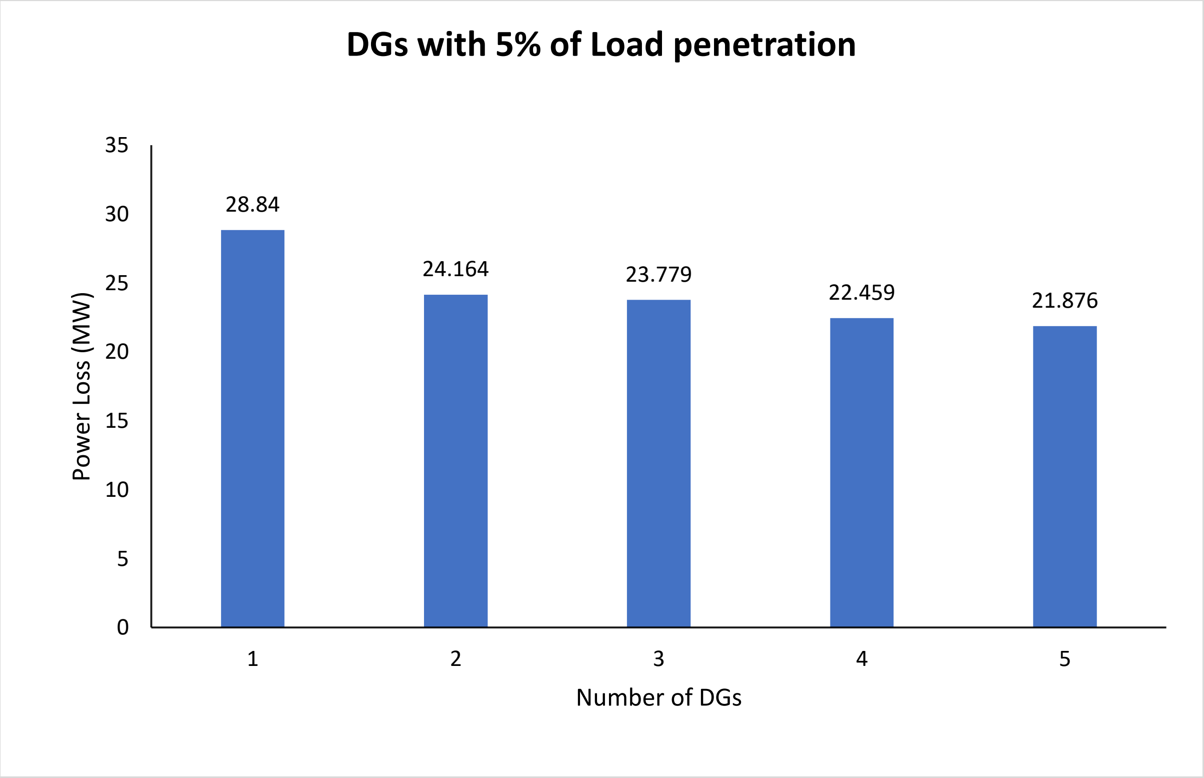
- 57 buses
- 7 generators

- 42 loads

- 5% Penetration (62.5MW) IEEE 57 Bus

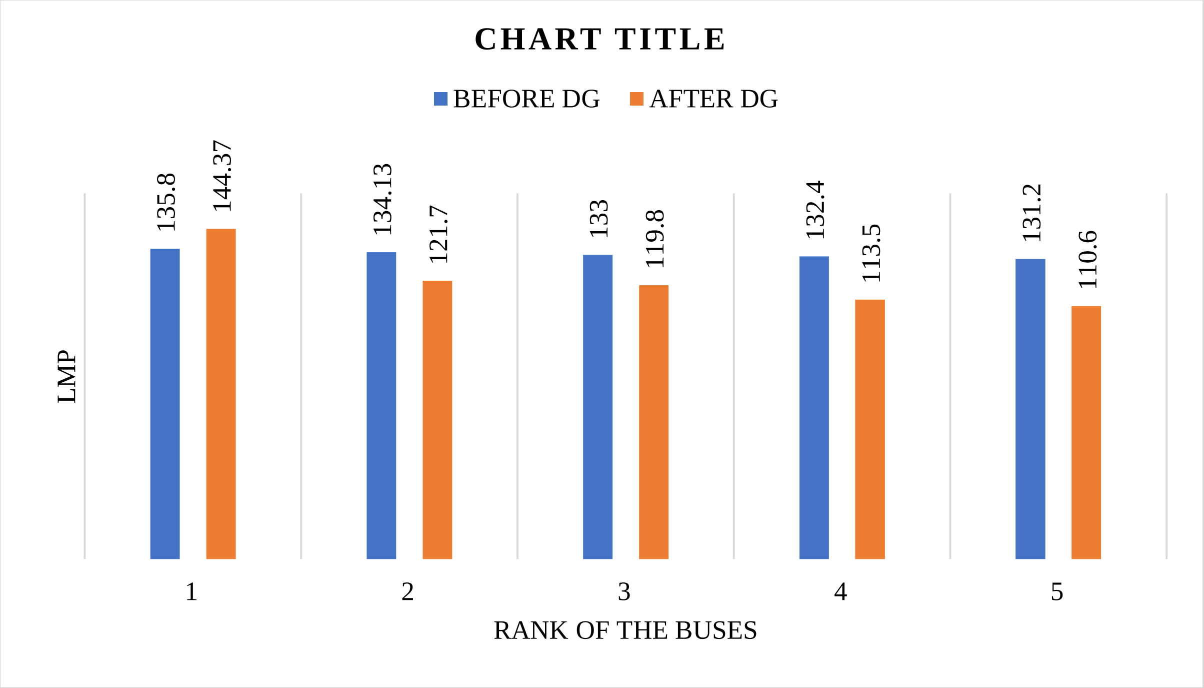


| | | 1 DG | | 2DG | | 3DG | | 4DG | | 5DG | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Bus** | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** | **Before** | **After** |
| | | | | | | | | | | | |
| **DG Size** | 31 | - | 62.5 | - | 30 | - | 26 | - | 11 | - | 15 |
| | 33 | | | | 32.5 | | 7.5 | | 6.5 | | 3.5 |
| | 32 | | | | | | 29 | | 30 | | 29 |
| | 35 | | | | | | | | 15 | | 9 |
| | 57 | | | | | | | | | | 6 |
| **P Loss** | | 27.08 | 28.84 | 27.08 | 24.164 | 27.08 | 23.779 | 27.08 | 22.459 | 27.08 | 21.876 |
| **% PL** | | | FALSE | | 10.7681 | | 12.1898 | | 17.0643 | | 19.2171 |
| **LMP** | 31 | 135.8 | 144.37 | 135.8 | 121.7 | 135.8 | 119.8 | 135.8 | 113.5 | 135.8 | 110.6 |
| | 33 | | | 134.13 | 120.18 | 134.13 | 118.3 | 134.13 | 112 | 134.13 | 109.27 |
| | 32 | | | | | 133 | 117.1 | 133 | 111.68 | 133 | 108.9 |
| | 35 | | | | | | | 132.4 | 110.3 | 132.4 | 107.5 |
| | 57 | | | | | | | | | 131.2 | 107 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| **Cost** | | 41737.8 | 39619.1 | 41737.8 | 39747.3 | 41737.8 | 39821.8 | 41737.8 | 39955.2 | 41737.8 | 39963.6 |
| **% Savings** | | | 5.07614 | | 4.76896 | | 4.59061 | | 4.27083 | | 4.25092 |

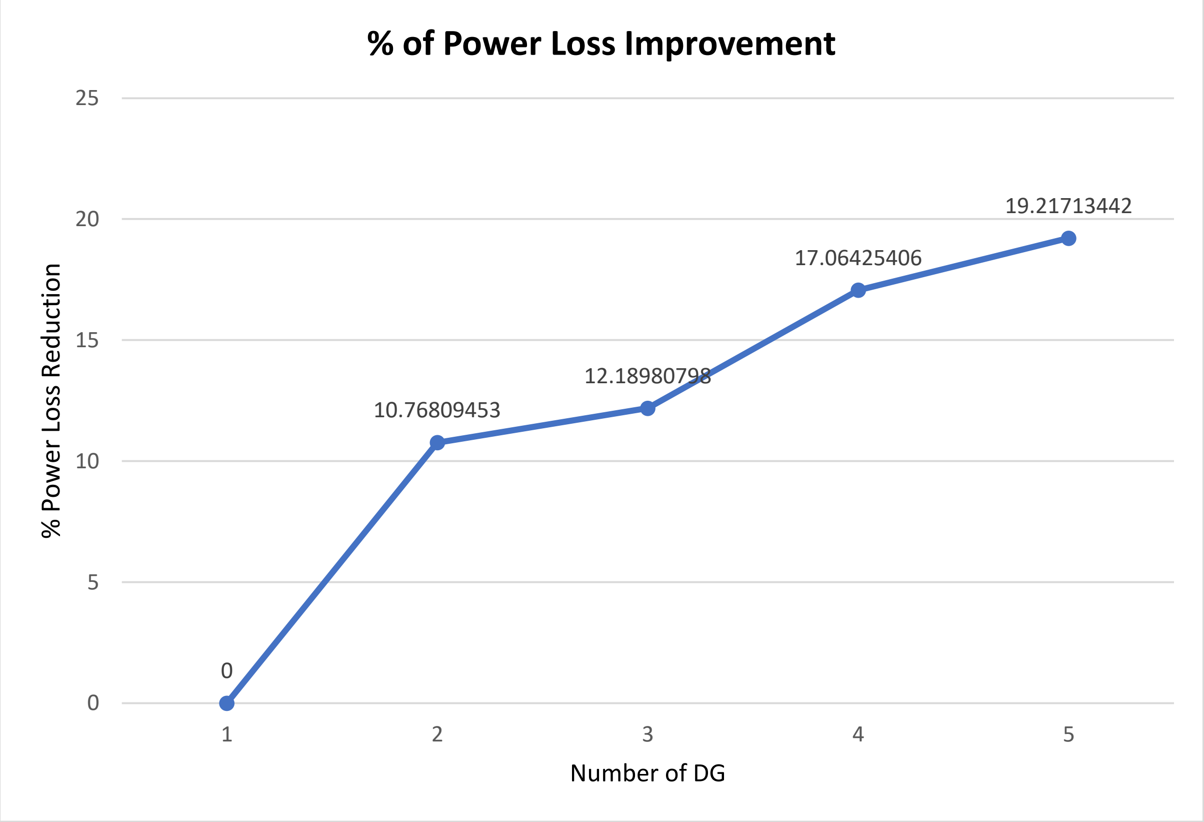


- As the number of DG's increase, the active power loss is reduced.

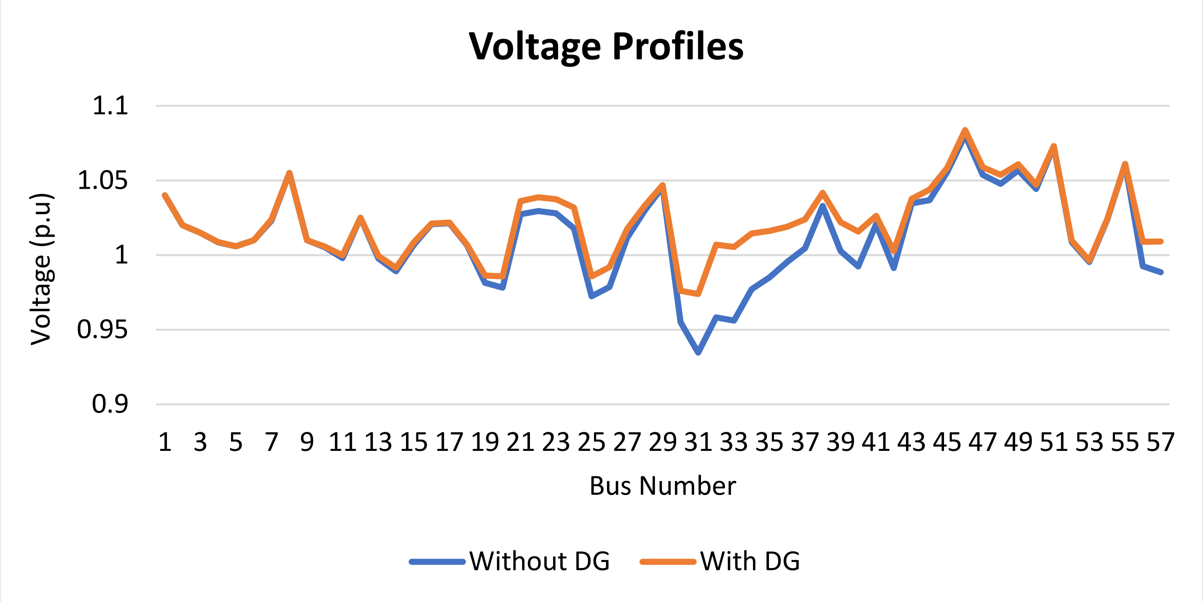
- For placement of 5DG's in the system, the losses has reduced from 27.08 MW to 21.87 MW



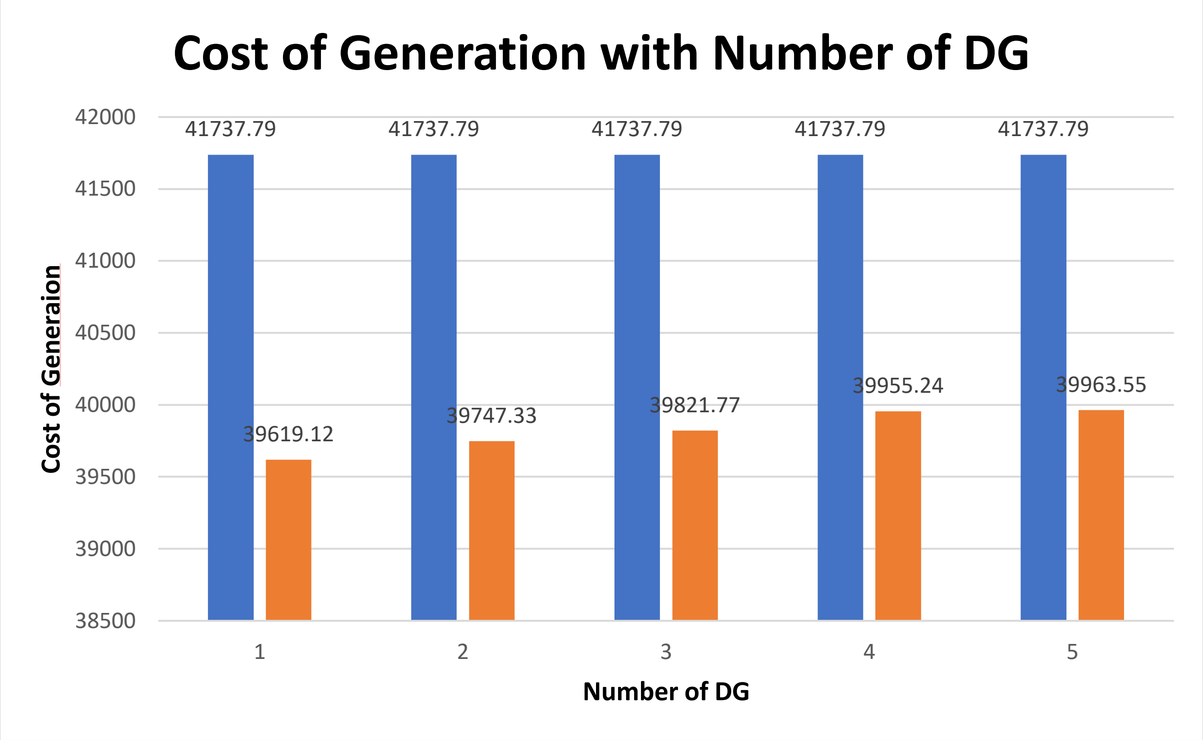
- The LMP of the bus is reduced because of the placement of DG



- There is an improvement in the reduction of power loss.
- The power loss can be improved upto 19.21%.



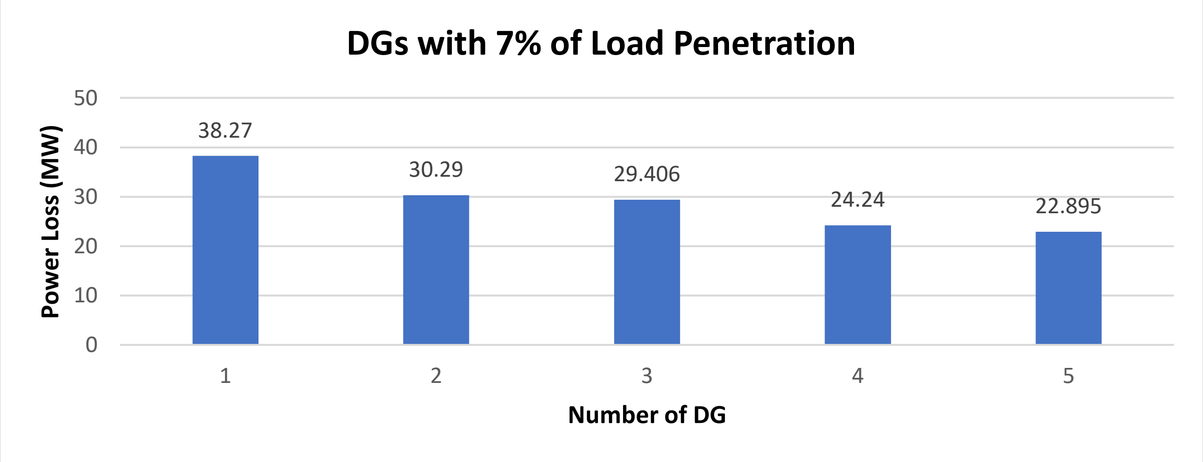
- Voltage profile at the buses where DG's are placed, the voltage is increased.



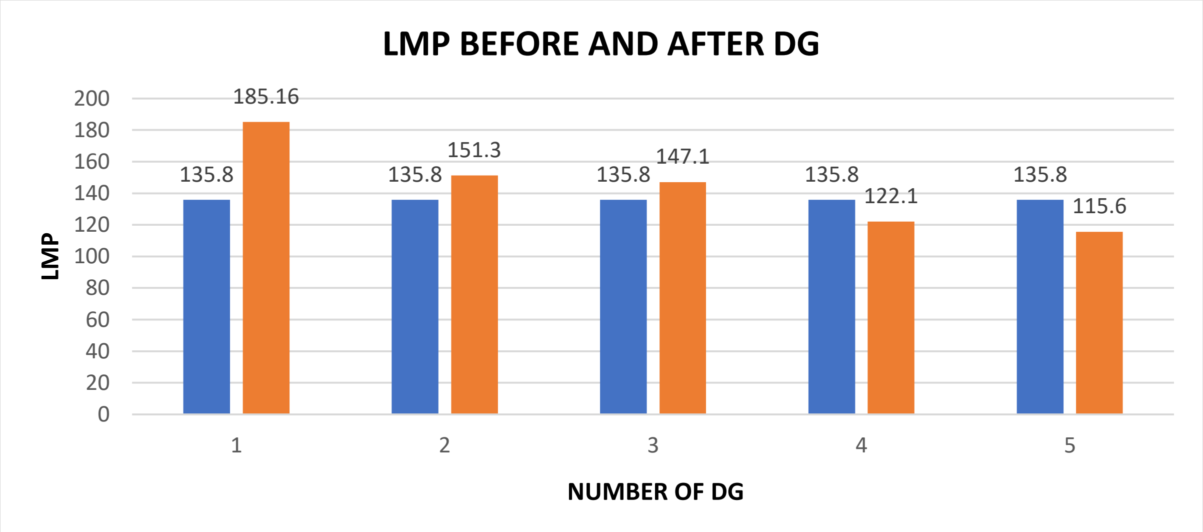
- The cost of generation is reduced.

- 7% Penetration (87.5 MW) IEEE 57 Bus

| | | 1 DG | | 2DG | | 3DG | | 4DG | | 5DG | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bus | Before | After | Before | After | Before | After | Before | After | Before | After |
| | | | | | | | | | | | |
| DG Size | 31 | - | 87.5 | - | 47.5 | - | 42.5 | - | 32.5 | - | 32.5 |
| | 33 | | | | 40 | | 10 | | 10 | | 10 |
| | 32 | | | | | | 35 | | 25 | | 20 |
| | 35 | | | | | | | | 20 | | 15 |
| | 57 | | | | | | | | | | 10 |
| P Loss | | 27.08 | 38.27 | 27.08 | 30.29 | 27.08 | 29.406 | 27.08 | 24.24 | 27.08 | 22.895 |
| % P Loss | | | -41.322 | | -11.8538 | | -8.58936 | | 10.48744 | | 15.45421 |
| LMP | 31 | 135.8 | 185.16 | 135.8 | 151.3 | 135.8 | 147.1 | 135.8 | 122.1 | 135.8 | 115.6 |
| | 33 | | | 134.13 | 149.4 | 134.13 | 145.2 | 134.13 | 120.5 | 134.13 | 114.1 |
| | 32 | | | | | 133 | 144.75 | 133 | 120.1 | 133 | 113.7 |
| | 35 | | | | | | | 132.4 | 118.6 | 132.4 | 112.3 |
| | 57 | | | | | | | | | 131.2 | 111.8 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| Cost | | 41737.79 | 39178.13 | 41737.79 | 39333.73 | 41737.79 | 39431.19 | 41737.79 | 39555.51 | 41737.79 | 39429.1 |
| %Cost | | | 6.132716 | | 5.759912 | | 5.526407 | | 5.228547 | -5.51701 | 5.531414 |



- As the number of DG's increase, the active power loss is reduced.
- For placement of 5DG's in the system, the losses has reduced from 27.08 MW to 22.895 MW
- But, one DG placement is not feasible.



- The LMP of the bus is reduced because of the placement of DG
- Three DG placement is not feasible.
- Hence, more the penetration of DG, it is not feasible.

## CONCLUSION

The research proposes two new methods for DG placement in a wholesale power market based on OPF. Maximum social good and economic benefit can be achieved by determining the best site(s) and population(s) size(s). Each type of DG expense has an optimum site and capacity at which net social benefit is maximised. This is confirmed to be the case for profit maximisation as well.

The LMP value for DG deployment at a node is lower when maximising social welfare is the goal rather than profit. To put it another way, the optimal size of a DG to maximise profits is smaller than the optimal size to maximise social welfare. Social welfare prioritises both the surpluses of consumers and producers, while profit is primarily concerned with the surplus to producers, which will acquire high value as prices rise. When the LMP is high, consumers are more likely to pay more, which boosts revenue for the DG owner.

Hence we can conclude that

- As the number of DG's increase, the active power loss decrease.
- Because of the reduction of locational marginal price at the buses, the customers are benefited. Thus, achieved Global Welfare Maximization
- But, as the penetration level increases the power loss reduction is not that satisfied and also increases the cost of the generation.
- The voltage profiles are also increased, thus acting as a voltage supporter.

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