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An Analytical Approach to Find DG Integration Capacity by Load Analysis

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***Abstract*—** With time the electrical power demand and so the DG penetration has increased highly. As the present conventional power systems structure is not well-suited with these energy generation schemes. Therefore to house this high diffusion of distributed generation proper planning is required. This study offers an analytical approach to compute the optimum site and size of installing DG unit for minimizing power losses. The power injections from DG units deviate the system's power flows, thus effecting voltage steadiness and the system losses. In the proposed mathematical model, the maximum size of integrating DG at each bus is calculated using the load and injecting power at each bus. The given mathematical model is simulated in MATLAB. The maximum size and site of DG integration is found with a decreasing power losses of the system.

***Keywords*—** Distributed Generations, Optimal size, Power injection; Power loss.

I. Introduction

The generation from renewable sources and its penetration in the power system is widening frequently due to the ecological and financial concerns. Mostly renewable energy is integrated to the power system using Distributed Generation techniques. The generation of electrical power/energy by the connection of distributed generating units to the power system at sub transmission or distribution levels is termed as DG [1]. DG units integration help in overcoming the losses that occurs in transmission of electrical energy into remote areas, whereas in DG the electricity is generated at the distribution side where it is mainly consumed. On the other hand increasing the generation capacity may require to upgrade transmission and/or distribution system or even building of new facilities additional to the existing ones to make sure that the supply meets the demand. In DG units integration the weight is shared on the distribution side which results in delaying or even complete removal of such up-gradation making it cost and time effective. DG units integration promote the generation of electrical energy from renewable sources [2].

An electrical power system generally consist of organized processes connected to each other namely generation, transmission and distribution. In Pakistan where there is centralized generation system and the power flow is unidirectional i:e from top to bottom, the generation totally depends on few or minor count of huge power plants. The transmission of power is in the upper voltage level to the far remote load areas in the lower voltage level. Water And Power Development Authority (WAPDA's) power division is organized into distinct commercial units including ten distribution companies (DISCOs), one transmission companies (TransCo) (National transmission and dispatch company NTDC) and four generation companies (GENCOs) [3]. DG integration will decentralize the current system making it more reliable and may lead to bidirectional power flow [4]. It also highly increase consistency of the power system and lower the possibility of disturbance in occurrence of any line failure by providing substitute transmission path [5]. Implementing this system will encourage consumers to initiate their own generation facilities to fulfill their energy requirements, and if they are having enough resources to generate surplus energy they can even be paid by selling it to the grid. Excessive rise in electricity charges and shortfall can be controlled by promoting small or even large scale private businesses.

As the system was not initially designed to house this generation, with DG growing penetration it will cause intense modifications in the network design, maintenance and working of distribution systems. In order to minimize problems and take full advantage of benefits, DG integration requires proper planning to encounter these needs starting from best location to all the way the quantity and capacity of units, use of best technology and network connection type [2].

Bulk electrical energy user (i:e railways and large industries etc.) which takes electrical energy straight from transmission and sub transmission system, and in the same way they could be fed directly by DG.

II. Important Factors of DG System Planning

Following are the few very important and deciding aspects of DG integration, each of them will be briefly discussed.

A. Technical and organizational advantages

DG empowers additional effective management through peak cutting or trimming; it allow the consumers to flexibly manage their energy requirements in maximum demand hours with local electrical energy generation units through appropriate planning of storing energy. This will lower the burden on consumer by reducing electricity cost and also reducing load burden.

DG Integration into electric network offers the essential balancing power sources; it raises the system overall consistency (in tackling of the main generating units outage) and removes the requirement of further funds on spinning reserve units [6].

- Reducing power loss by postponement of huge transmission and distribution (T&D) and rectifying power factor.
- Decreasing the frequency of load shedding and to provide more dependable power sources for crucial practices, by coupling of energy storage system like involvement of uninterruptable power supply (UPS), fuel cells and diesel engines, and
- Steadying the tumbling regularity in electrical power system in occurrence of spontaneous generating unit outage and unexpected load flood [7].

Moreover, nature of DG make installation, constructing and placement simpler and speedy, increased sensitiveness for load deviation pursuing and regulation, and lesser footprint necessity [8].

B. Financial advantages

The financial/economical advantages of DG system are found on both sides of electrical power (supply and demand). On the supply side i:e. load serving entities (LSE) and utility firms, it is attained by neglecting the requirement of investing allot of funds on upgrading and expanding T&D, particularly in far isolated regions. Economic efficiency can also be accomplished by dropping operational rate determined by peak shaving [9].

On the demand side too, DG economic efficiency is established. A financial evaluation found that the electricity costs compulsory on the users is considerably reduced in DG system employment with proper modification in electricity tariff alteration, with accomplishment of LSE co-benefit [10].

Moreover, lesser energy charges of DG system are related to employment of substitute lower prices fuels. Particularly, in areas with considerable economic similarity among conventional fuel (coal, fuel oil, etc.) and gas, highly significant bill reduction towards users can be achieved through fuel exchanging DG system combined with gas based power generating units [11]. Similarly, low-price biogas from landfill can also be used in implementation of DG system.

C. Environmental advantages

Penetration of energy from renewable sources into electric power system in the form of DG can perform a significant role in dropping gaseous toxin discharges and influence on atmosphere changes [12].

Per annum carbon discharges reduction by up to 1.08 million tons was observed in province Jiangxi due to DG integration into power network with the incorporation of power from wind sources at a proportion of 0.16% [13]. Optimal DG system situation with renewables like incorporation of wind power and solar PV systems on buildings with zero-energy indicated that ecological cost can be reduced by 99% [14]. Furthermore, postponement of T&D expansion across the ecologically delicate ranges and jungles is attainable with DG penetration [15].

III. Proposed Methodology

A. DG effect on power system

The overall effect of DG on the system losses and voltage stability is briefly discussed below.

1. System losses without DG unit

The overall effect of DG on the system losses and voltage stability is briefly discussed below.

Eq. (1) commonly recognized as “exact loss formula”, represents the overall real losses (P_L) in a distribution network having N number of buses [16].

$$P_L = \sum_{i=0}^{N}\sum_{j=0}^{N}\left(\alpha_{ij}\left(P_iQ_i + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right) \quad (1)$$

Where $\alpha_{ij} = \frac{r_{ij}}{V_jV_j}\cos\left(\delta_i - \delta_j\right)$, $\beta_{ij} = \frac{r_{ij}}{V_jV_j}\sin\left(\delta_i - \delta_j\right)$

$V_i\angle\delta_i$ represent the complex voltage of the i^{th} bus; and $r_{ij} + jx_{ij} = Z_{ij}$ are the ij^{th} component of (Z_{bus}) matrix with $(Z_{bus}) = (Y_{bus})^{-1}$; the real powers are represented by P_i and P_j while Q_i and Q_j represents the reactive power injected at buses i and j correspondingly.

2. System losses with DG unit

Eq. (2) and (3) correspondingly represents the real power introduction to the system at bus i at the point at which DG unit is situated [17].

$$P_i = P_{DGi} - P_{Di} \quad (2)$$

$$Q_i = Q_{DGi} - Q_{Di} = a_iP_{DGi} - Q_{Di} \quad (3)$$

Here $Q_{DGi} = a_iP_{DGi}$, P_{DGi} & Q_{DGi} are correspondingly the real and reactive power introductions at bus i by DG unit, $a_i = (\text{symbol})\tan(\cos^{-1}(Pf_{DGi}))$ and {symbol = +1 when DG unit is delivering reactive power and for DG unit taking reactive power symbol = -1}; P_{Di} and Q_{Di} correspondingly represents the real and reactive loads at bus i; pf is the DG unit's operational power factor at bus i. Putting P_i and Q_i from Eq. (2) and (3) into Eq. (1) for P_L, we can find the overall real power losses from Eq. (4) when the DG is connected.

$$P_{LDG} = \sum_{i=0}^{N}\sum_{j=1}^{N}[\alpha_{ij}((P_{DGi} - P_{Di})P_j + (a_i P_{DGi} - Q_{Di})Q_j) + \beta_{ij}((a_i P_{DGi} - Q_{Di})P_j - (P_{DGi} - P_{Di})\, Q_j))] \quad (4)$$

Let the power system consist of an overall n number of buses then the current injected at bus i is given as,

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + Y_{i2}V_2 + \ldots\ Y_{in}V_n \quad (5)$$

Here Y is the admittance of the n bus system, where $Y_{ij} = |Y_{ij}|(\cos\delta_{ij} + \sin\delta_{ij})$ and δ_{ij} is the angle of ij[th] component of the Y_{ij} matrix. By simplifying Eq. (5)

$$I_i = \sum_{j=1}^{N}(Y_{ij}V_j) \quad (6)$$

Also $I_i = I_{ai} + jI_{ri}$ where I_{ai} is the real or active part of the injecting current while I_{ri} represent the reactive part of the injecting current at bus i. By knowing I_i and voltage of the i[th] bus P_i and Q_i can be found as follows.

$$P_i = I_{ai}V_i \quad (7)$$

$$Q_i = I_{ri}V_i \quad (8)$$

B. Proposed procedure

Using eq. (1), Eq. (2) and Eq. (3) the active power losses is given by Eq. (9).

$$P_L = \sum_{i=0}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + (aP_i + aP_{Di} - Q_{Di})Q_j) + \beta_{ij}((aP_i + aP_{Di} - Q_{Di})P_j - P_i\, Q_j)] \quad (9)$$

The overall active power losses is minimum if the partial derivative of eq. (9) with respect to P_i becomes zero.

$$\frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{N}\alpha_{ij}(P_j + aQ_j) + \beta_{ij}(aP_j - Q_j) = 0 \quad (10)$$

By simplification

$$\frac{\partial P_L}{\partial P_i} = \alpha_{ii}(P_i + aQ_i) + \beta_{ii}(aP_i - Q_i) + \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) + a\sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}Q_j + \beta_{ij}P_j) = 0 \quad (11)$$

Rearranging Eq. (11).

$$\alpha_{ii}(P_i + aQ_i) = -\beta_{ii}(aP_i - Q_i) - A_i - aB_i \quad (12)$$

Where $A_i = \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)$ &

$B_i = \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}Q_j + \beta_{ij}P_j)$

Using Eq. (2) and (3) to replace P_i and Q_i in Eq. (12).

$$\alpha_{ii}(P_{DGi} - P_{Di} + a(aP_{DGi} + Q_{Di})) = -\beta_{ii}(a(P_{DGi} - P_{Di}) - (aP_{DGi} - Q_{Di})) - A_i - aB_i \quad (13)$$

By simplification

$$P_{DGi}(\alpha_{ii} + a^2\alpha_{ii}) = \alpha_{ii}(P_{Di} + aQ_{Di}) + \beta_{ii}(aP_{Di} - Q_{Di}) - A_i - aB_i \quad (14)$$

Now rearranging Eq. (14).

$$P_{DGi} = \frac{(\alpha_{ii}(P_{Di} + aQ_{Di}) + \beta_{ii}(aP_{Di} - Q_{Di}) - A_i - aB_i)}{(\alpha_{ii} + a2\alpha_{ii})} \quad (15)$$

The optimal integrating DG capacity at bus i is given by equation. (15)

As the power losses is minimum when the DG power factor reaches to power factor of the load, therefore for minimum losses power factor of DG is given by Eq. (16)

$$Pf_{DGi} = Pf_{Di} = \cos(\tan^{-1}(Q_{Di}/P_{Di})) \quad (16)$$

C. Computational procedure

Step-1: Run "base case load flow" to calculate P_L from eq. (1).

Step-2: Find the power injection into each bus using Eq. (7).

Step-3: The DG power factor can be found by using Eq. (16).

Step-4: Using Eq. (15) to find the size of DG at each bus. Reactive power at each bus can be calculated by Eq. (3).

Step-5: Run "load flow with DG unit" and find the losses of the system after DG integration using Eq. (4).

D. Case Study

The recommended technique has been subjected to a test on a 5 bus radial distribution system with various characteristics demonstrated in figure 1. The line impedances and the line charging admittances data of the given system are specified in Table 1. On the basis of the data given in Table 1 the Y_{bus} matrix is formed which is given in Table 2. It is to be mentioned here that the sources and their internal impedances are not taken into consideration in the making of Y_{bus} matrix.

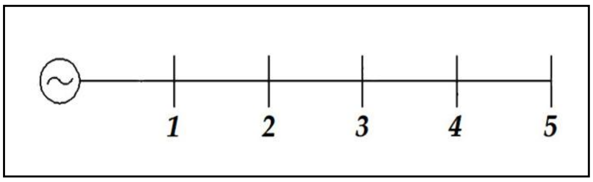

Figure 1. Single line diagram of test system.

TABLE 1. THE LINE IMPEDANCES AND CHARGING ADMITTANCES.

Line (Bus to Bus)	**Impedence**	**Line Charging (Y/2)**
1 - 2	0.02 + j0.10	j0.030
2 - 3	0.04 + j0.20	j0.025
3 - 4	0.05 + j0.25	j0.020
4 - 5	0.10 + j0.50	j0.075

The system initial data including bus voltages and its angles, the active and reactive power generation as well as the load at each bus is given in Table 3. The base value used for active and reactive power given is 100MVA.

TABLE 2. Y_{BUS} MATRIX

	1	**2**	**3**	**4**	**5**
1	1.9231 – j9.5854	– 1.9231 + j9.6154	0	0	0

2	– 1.9231 + j9.6154	2.8846 – j14.3681	– 0.9615 + j4.8077	0	0
3	0	– 0.9615 + j4.8077	1.7308 – j8.6088	– 0.7692 + j3.8462	0
4	0	0	– 0.7692 + j3.8462	1.1538 – j5.6742	– 0.3846 + j1.9231
5	0	0	0	– 0.3846 + j1.9231	0.3846 – j1.8481

The findings of the proposed procedure is given in figure 2, with the reactive power in accordance to the load power factor. The injecting current at each bus along its angle is demonstrated in figure 3. The losses found before and after DG integration is given in Table 4, a significant amount of decrease in the system loses can be noticed. The bus system after DG integration is demonstrated in figure 4.

TABLE 3. SYSTEM INITIAL DATA.

Bus no.	**Bus voltage**		**Power generated**		**Load**	
	Magnitude (pu)	***Angle (deg)***	***P (MW)***	***Q (MVAr)***	***P (MW)***	***P (MVAr)***
1	1.05	0	174.6	72.59	12	3
2	1	0	0	0	96	62
3	1	0	0	0	35	14
4	1	0	0	0	16	8
5	1.02	0	48	0	24	11

The results are compared with another analytical model based on multiobjective index (IMO). The comparison is given in figure 5. It is observed that the same trend has been followed by both methods regarding DG size, however small changes can be noted in the values.

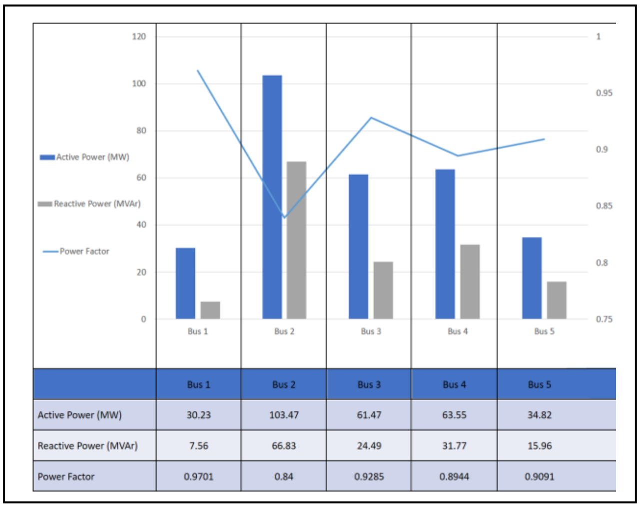

Figure 2. DG capacity found at each bus.

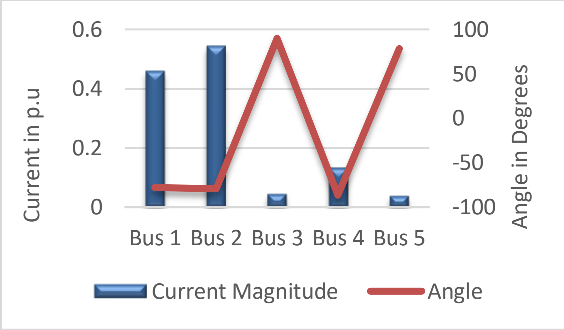

Figure 3. Injecting current at each bus.

TABLE 4. SYSTEM LOSSES.

	Without DG unit	**With DG unit**
System losses	6.6 MW	0.37 MW

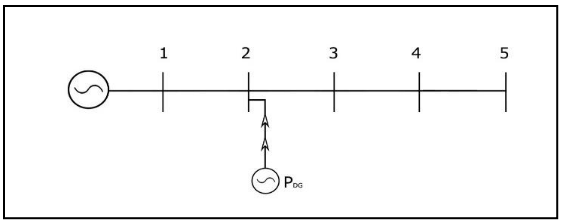

Figure 4. Given system after DG placement.

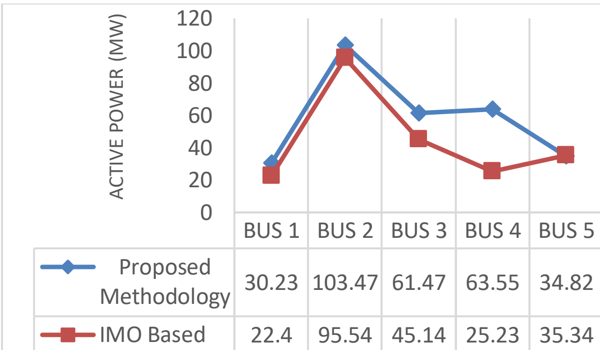

Figure 5. Comparison with IMO based methodology.

CONCLUSION

This study focus on modeling a mathematical prototype in order to calculate the maximum permitted size of a DG unit which is considered to be added into the system at the best suitable location. For a parallel purpose, the study also suggest some other mathematical models. The goal of the study was to find a further fruitful mathematical prototype by considering power losses in the system, before integration of the DG unit into the system. For this objective the exact loss formula is applied, then a general mathematical prototype is attained with the help of equations. The given mathematical prototype is subjected to a 5 bus test system. The maximum permitted DG size is found with the help of given mathematical prototype. This mathematical prototype uses the power injection and the load at each bus in a proper way to enhance the size gained.

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