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Optimal Allocation and Sizing of Distributed Generation using Sequential Quadratic Programming

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Abstract : Distributed generation (DG) is becoming more important due to the increase in the demands for electrical energy. Distribution system loss reduction is one of the prime objectives for planning of distributed generation. To minimize the losses, optimal sizing and location of distributed generation (DG) is critically important. In this paper, the optimal DG placement and sizing problem is investigated using single-objective optimization problem, where the systems power losses are considered as the objective to be minimized. These problems are formulated as constrained linear optimization problems using the Sequential Quadratic Programming method (SQP). The proposed method is demonstrated on IEEE-15 bus radial distribution systems. Simulation results with the DG shows improvement in terms of voltage profile enhancement and power losses reduction are obtained satisfactorily.

***Index Terms* - Optimal Location, Distributed Generation (DG), Sequential Quadratic Programming Method (SQP), Voltage Profile Enhancement.**

I. INTRODUCTION

One of the largest consumer markets in the world is the electric power industry. For instance, in the United States, 3% of Americas Gross Domestic Product (GDP) is spent on electric energy purchases, which are increasing faster than the rate of economic growth. The cost of electricity is estimated at around 50% for fuel, 20% for generation, 5% for transmission and 25% for distribution [1]. Distribution systems must deliver electricity to each customer's service entrance at an appropriate voltage rating. The X/R ratio for distribution levels is low compared to transmission levels, causing high power losses and a drop in voltage magnitude along radial distribution lines. Studies [2] have indicated that approximately 13% of the total power generated is consumed as real power losses at the distribution level. Such non-negligible losses have a direct impact on the financial issues and overall efficiency of distribution utilities. Traditionally, distribution power losses are minimized through proper dispatch of reactive power control devices, which can be done by deploying automatic voltage regulators (tap changing transformers) and shunt capacitors installed at low voltage buses [3].

Distributed Generation (DG) also provides an opportunity to effectively exploit the renewable energy, which is produced from replenish able resources available and abundant in nature. To accommodate this new type of generation, the existing distribution network should be utilized and developed in an optimal manner. Several approaches have been proposed in literature to determine the optimal location of EG in the distribution networks. To date, Artificial Intelligence (AI), evolutionary computation and optimization techniques are among the popular techniques that are normally used to solve these problems. The optimal allocation problem can be solved using Ant Colony Search Algorithm (ACSA). This algorithm is inspired from the natural behaviour of the ant colonies on how they find the food source and bring them back to their nest by building the unique trail formation. The property of ACSA or Ant Colony Optimization (ACO) is adapted to solve the optimal location and size of EG. However, the rates of ant colony regulating parameters need to be determined using experimental approach. The complete approach is proposed in [4]. The optimal allocation problem is also solved by using Evolutionary Programming (EP) method. In this, authors use the sensitivity indices as the tools to predict the placement of EG at a particular bus. Sensitive indices are developed from voltage stability index. Buses with highest sensitivity values are selected for the location of the embedded generators [5]. The incorporation of Particle Swarm Optimization (PSO) for distribution generation sizing and allocation is proposed by simultaneously taking losses as objective function along with load flow [6]. The related works on GA for optimal allocation of EG using ET AP software with MA TLAB for solving that problem has been proposed in [7]. However, the implementation of GA is not explained clearly. When Distributed Generation is combined with shunt capacitor placements computation time is more[8].Different evolutionary techniques for optimal operation of distributed generation in terms of cost of Active and Reactive powers are GA, differential evolution, ACO, PSO and tabu search. A comparison of these methods is proposed in [9].

2.1 Problem Formulation

An optimization problem can be mathematically defined as the minimization or maximization of a function (called the objective function) while satisfying a number of equality and/or inequality constraints on its variables [10]. The general optimization problem can be formulated as:

$$\underset{x\in R^n}{Min/Max;} \qquad f(x) \qquad \text{.....(1)}$$

$$subject\ to; \quad h_i(x)=0, \quad i=1,2,......,n \qquad \text{..(2)}$$

$$subject\ to; \quad g_i(x)\le 0, \quad i=1,2,......,m \qquad \text{.....(3)}$$

$$subject\ to; \quad x^{min} \le x \le x^{max} \qquad \text{.....(4)}$$

where

f(x) : the objective function, a function of *x* that we want to maximize or minimize.

h(x), *g(x)* : the vectors of equality and inequality constraints that the unknowns must satisfy.

x : the vector of *n* decision or unknown variables and $x=[x_1, x_2, \cdots, x_n]$.

This kind of optimization is called a single-optimization problem, since *f(x)* is only one objective function. On the other hand, a multi-optimization problem has more than one objective function, as illustrated in the following chapter.

Problem Objective

The objective function to be minimized to solve the optimization problem is the total active power loss of a distribution system.

$$Minimize: P_{Loss}(X) \qquad \text{.....(5)}$$

where is the total real power loss, which can be expressed in the following equation:

$$P_{LOSS} = \sum_{k=1}^{NS} G_k \left(|V_i|^2 + |V_j|^2 - 2|V_i||V_j|\cos(\delta_i - \delta_j) \right) \qquad \text{.....(6)}$$

where

NS: the total number of branches,

Gk: the conductance of the *k-th* branch which connects the sending bus *i* and the receiving bus *j*,

V_i,V_j : voltage magnitude at bus *i* and *j*,

δ_i,δ_j : voltage angle at bus *i* and bus *j*.

Constraints

Equality Constraints: The objective function is minimized subject to various operational constraints to satisfy the electrical requirements for the distribution network and constraints on DG operation. These constraints are discussed as follows:

***Power Balance Constraints**:* Power balance is given by nonlinear power flow equations, which state that the sum of complex power flows at each bus in the distribution system injected into a bus minus the power flows extracted from the bus should equal zero.

$$P_{DGi} - P_{Di} - \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \varphi_{ij}) = 0 \qquad \text{.....(7)}$$

$$Q_{DGi} - Q_{Di} - \sum_{j=1}^{NB} |V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \varphi_{ij}) = 0 \qquad \text{.....(8)}$$

where

P_{DGi}, Q_{DGi}: active and reactive power delivered by DG at bus *i*

P_{Di}, Q_{Di} : active and reactive power demand at bus *i*

$|Y_{ij}|$: the magnitude of the *ij-th* element of the admittance matrix

ϕ_{ij}: the angle of the *ij-th* element of the admittance matrix

NB : the total number of buses

Inequality Constraints

Power Flow Constraints: The power flow constraint is used to ensure that they do not approach their thermal limits. The following constraint checks for the absolute power flow both at the sending and receiving ends of a particular line to be within the upper limit of the line.

$$S_{ij} \le S_{ij}^{max} \qquad \text{.....(9)}$$

$$S_{ji} \le S_{ji}^{max} \qquad \text{.....(10)}$$

where

S_{ji}^{max} : apparent power maximum allowable for branch i j

Sij: apparent power flow transmitted from bus i to bus j

Generation Capacity Constraints*:* Limiting the DG size so as not to exceed the power supplied by the substation and the output power of each DG unit is constrained by lower and upper limits.

$$\sum_{i=1}^{nDG}\left(P_{DGi}+jQ_{DGi}\right)\leq P_{ss}+jQ_{ss} \quad .....(11)$$

$$P_{DGi}^{\min}\leq P_{DGi}\leq P_{DGi}^{\max} \quad .....(12)$$

where and are the minimum and maximum operating outputs of unit *i*, respectively.

Bus voltage limit: Bus voltage magnitudes and phase angles of the radial distribution system are to be bounded between maximum and minimum values, imposed by a system operator. The boundary constraint can by expressed as follows:

$$\left|V_i^{\min}\right|\leq\left|V_i\right|\leq\left|V_i^{\max}\right| \quad .....(13)$$

$$\left|\delta_i^{\min}\right|\leq\left|\delta_i\right|\leq\left|\delta_i^{\max}\right| \quad .....(14)$$

where: $\left|V_i^{\min}\right|$, $\left|V_i^{\max}\right|$, $\left|\delta_i^{\min}\right|$ and $\left|\delta_i^{\max}\right|$ are the lower and upper bounds of the bus voltage $|V_i|$ and the bus voltage angle δ_i, respectively.

Mathematical Models of DG Units

A DG unit can be modeled as either a PV or PQ bus in the distribution system. If DGs have control over the voltage by regulating the excitation voltage (synchronous generator DGs) or if the control circuit of the converter is used to control P and V independently, then the DG unit may be modeled as a PV type. Other DGs, like induction generator-based units or converters used to control P and Q independently, are modeled as PQ types. The most commonly used DG model is the PQ model [11]. In this work, the PQ-DG units are represented as a negative PQ load model delivering active and reactive power to a distribution system. The DG reactive power can be calculated by the following equation:

$$Q_{DGi}=P_{DGi}\times\tan\left(\cos^{-1}\left(PF_{DGi}\right)\right) \quad .....(15)$$

Sequential Quadratic Programming

Since the objective function and its constraints are naturally nonlinear equations, the optimization problem is classified as a Nonlinear Optimization Problem (NLP) [12]. The DG optimization problem is performed using a conventional Sequential Quadratic Programming (SQP) method also known as Iterative Quadratic Programming and Recursive Quadratic Programming, meaning that one Quadratic Programming (QP) sub problem is solved at each major iteration. According to the accuracy, efficiency and percentage of successful solutions of the SQP method over a large number of test problems, it is considered as the best nonlinear programming method for constrained optimization [13].

The main idea of SQP is to model the optimization functions at the current point, x^k, by making a quadratic model of the objective function and linear models of the constraints using Taylors expansion. These are then solved at each iteration to find a new search direction, *d*, with a better solution, x^{k+1}. This method closely resembles Newton's method for unconstrained minimization [14]. By applying Taylors expansion to the general optimization problem, we get:

$$f(x)\approx f\left(x^k\right)+\nabla f\left(x^k\right)^T\left(x-x^k\right)+\frac{1}{2}\left(x-x^k\right)^T\nabla^2\left(x^k\right)\left(x-x^k\right) \quad .....(16)$$

$$h(x)\approx h\left(x^k\right)+\nabla h\left(x^k\right)^T\left(x-x^k\right) \quad .....(17)$$

$$g(x)\approx g\left(x^k\right)+\nabla g\left(x^k\right)^T\left(x-x^k\right) \quad .....(18)$$

where ∇ refers to the gradient of the *f(x)*, and ∇^2 is the Hessian of the *f(x).*

Setting:

$$d=\left(x-x^k\right) \quad .....(19)$$

$$H^k=\nabla^2 f\left(x^k\right) \quad .....(20)$$

Thus, the QP sub problem will have the form:

$$\text{minimize: } f\left(x^k\right)+\nabla f\left(x^k\right)^T d+\frac{1}{2}d^T H^k d \quad .....(21)$$

$$Subject\ to: h\left(x^k\right)+\nabla h\left(x^k\right)^T d=0 \quad .....(22)$$

$$Subject\ to: g\left(x^k\right)+\nabla g\left(x^k\right)^T d\leq 0 \quad .....(23)$$

Satisfying the KKT Conditions

The SQP applies the Lagrange multipliers method to the QP sub problem, starting by transforming the constrained optimization problem to a Lagrangian function and then satisfying conditions (called Karush-Khun-Tuker (KKT) conditions) and solving the unknown variables from the derived equations through Quasi-Newton method in each iteration. The Lagrangian function for this problem can be written as follows:

$$L(x,\lambda,\mu)=f(x)+\lambda^T h(x)+\mu^T g(x) \quad .....(24)$$

Where

λ : the equality Lagrange multiplier,

μ : the inequality Lagrange multiplier.

The KKT conditions state that, at the optimal point solution, the gradients of the Lagrange function are equal to zero, as follows:

$$\nabla f(x)+\lambda^T\nabla h(x)+\mu^T\nabla g(x)=0 \quad .....(25)$$

$$h(x)=0 \quad .....(26)$$

$$g(x)\leq 0 \quad .....(27)$$

$$\mu^T g(x)=0, \mu\geq 0 \quad .....(28)$$

The active set method [15] applies to the inequality constraints to partition it into two groups. The first group is to be treated as active and the second group as inactive. Let A be a set of i, such that . The necessary conditions for the inequality constraints then become:

$$\nabla f(x)+\lambda^T\nabla h(x)+\mu^T\nabla g_i(x)=0 \quad .....(29)$$

$$g_i(x)=0, i\in A \quad .....(30)$$

$$g_i(x)<0, i\notin A \quad .....(31)$$

$$\mu_i\geq 0, i\in A \quad .....(32)$$

$$\mu_i=0, i\notin A \quad .....(33)$$

The Lagrange multipliers for the inactive inequality constraints are set to zero.
Therefore, they will be considered as equality constraints in the Lagrange function.
The QP sub problem is formulated as:
minimize:

$$f(x^k)+\nabla f(x^k)^T d+\frac{1}{2}d^T\nabla^2 L(x,\lambda,\mu)d \quad .....(34)$$

$$Subject\ to: h(x^k)+\nabla h(x^k)^T d=0 \quad .....(35)$$

$$Subject\ to: g(x^k)+\nabla g(x^k)^T d\leq 0 \quad .....(36)$$

where $\nabla^2 L(x,\lambda,\mu)$ is the Hessian of the Lagrange function.

The local convergence of the SQP method follows from the application of Newton's method to the nonlinear system given by the Kuhn-
Tucker-Karush (KKT) conditions:

$$\begin{pmatrix}\nabla L(x_k,\lambda_k,\mu_k)\\ h(x_k)\\ g_A(x_k)\end{pmatrix}=0 \quad .....(37)$$

The QP sub-problem solution is obtained by solving the Quasi-Newton, as follows:

$$\nabla^2 L(x_k,\lambda_k,\mu_k)\begin{pmatrix}d\\ \upsilon_\lambda\\ \upsilon_\mu\end{pmatrix}=\nabla L(x_k,\lambda_k,\mu_k) \quad .....(38)$$

$$\begin{pmatrix}\nabla^2 L(x_k,\lambda_k,\mu_k) & \nabla h(x_k) & \nabla g(x_k)\\ \nabla h(x_k)^T & 0 & 0\\ \nabla g(x_k)^T & 0 & 0\end{pmatrix}\begin{pmatrix}d\\ \upsilon_\lambda\\ \upsilon_\mu\end{pmatrix}=\begin{pmatrix}\nabla f(x_k)+\lambda^T\nabla h(x)+\mu^T\nabla g(x)\\ h(x_k)\\ g(x_k)\end{pmatrix} \quad .....(39)$$

The Newton step from the iterate k is thus given by:

$$\begin{pmatrix}x_{k+1}\\ \lambda_{k+1}\\ \mu_{k+1}\end{pmatrix}=\begin{pmatrix}x_k\\ \lambda_k\\ \mu_k\end{pmatrix}+\begin{pmatrix}d\\ \upsilon_\lambda\\ \upsilon_\mu\end{pmatrix} \quad .....(40)$$

where and are the Newtons steps toward a KKT solution point.

These formulae may be rearranged by moving the term to the left-hand side of (39), giving:

$$\begin{pmatrix}\nabla^2 L(x_k,\lambda_k,\mu_k) & \nabla h(x_k) & \nabla g(x_k)\\ \nabla h(x_k)^T & 0 & 0\\ \nabla g(x_k)^T & 0 & 0\end{pmatrix}\begin{pmatrix}d\\ \lambda_{k+1}\\ \mu_{k+1}\end{pmatrix}=\begin{pmatrix}\nabla f(x_k)\\ h(x_k)\\ g(x_k)\end{pmatrix} \quad .....(41)$$

The Newton-KKT system solves the equations starting by estimated solution points to get the search direction and new values for the Lagrange multipliers in order to be utilized in the next iteration. The process is repeated iteratively until an optimal solution, x^*, is reached or certain convergence criteria are satisfied.

Update the Hessian Matrix

The Hessian of the Lagrangian function in the QP sub problem is to be calculated in every iteration. The Quasi-Newton method approximates the Hessian matrix (B) instead to calculate it. The most widely used formula, and the one considered to be most effective, is the BFGS update formula, named for its inventors, Broyden, Fletcher, Goldfarb, and Shanno . Using this scheme, we set:

$$r_k = \theta_k y_k + (1-\theta_k) B_k s_k \quad \text{.....(42)}$$

$$s_k = x_{k+1} - x_k \quad \text{.....(43)}$$

$$y_k = \nabla L(x_{k+1}, \lambda_{k+1}, \mu_{k+1}) - \nabla L(x_k, \lambda_k, \mu_k) \quad \text{.....(44)}$$

$$\theta_k = \begin{cases} 1 & if \;\; s_k^T y_k \geq 0.2 s_k^T B_k s_k \\ \dfrac{0.8 s_k^T B_k s_k}{s_k^T B_k s_k - s_k^T y_k} & f \;\; s_k^T y_k < 0.2 s_k^T B_k s_k \end{cases} \quad \text{.....(45)}$$

Then we can update B_{k+1} using,

$$B_{k+1} = B_k - \frac{B_k s_k s_k^T B_k}{s_k^T B_k s_k} + \frac{r_k r_k^T}{s_k^T r_k} \quad \text{.....(46)}$$

SIMULATION RESULTS OF IEEE-15 & IEEE-33 BUS SYSTEMS

Software Tools Used

The proposed optimal DG size and placement in the distribution systems was coded in MATLAB® Version 8.5.0.197613 (R2015a). MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Programmers and users of MATLAB can analyze data, develop algorithms, and create models and applications, using the language, tools, and built-in math functions to explore multiple approaches and solve technical computing problems faster than with spreadsheets or traditional programming languages, such as C/C++ or Java.

The system considered is a 15-bus radial distribution system. Various scenarios are analyzed using this system. The following analysis is performed with the test system and presented accordingly:

- Determining the optimal size and placing of DG.
- The effect of DG allocation on a voltage profile.
- The effect of DG allocation on a power loss.

A voltage deviation index was calculated in all tests and cases to show improvements in the voltage profiles.

Radial Distribution System (IEEE-15 BUS)

The first test was applied on an existing rural distribution feeder. This system consists of 15 buses and 14 branches at 12.66 KV voltage level. The capacity of the system is 3802 kW real power and 2694 KVAR reactive power. The full network parameters are given in Appendix-A, Figure 1 shows the single line diagram of the radial distribution system under study, with its lateral branches. The optimization problem is investigated for single DG installation as follows.

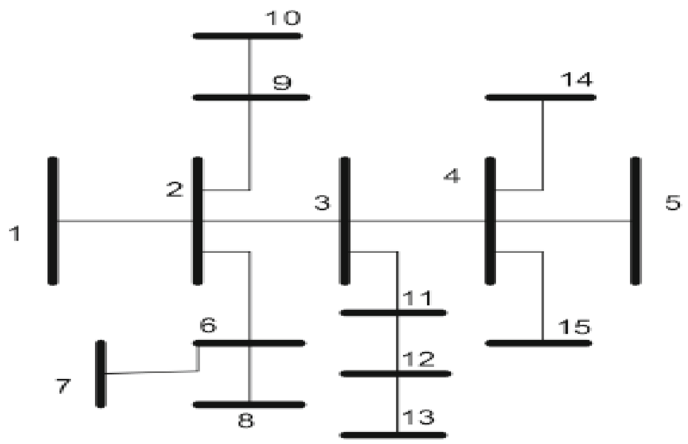

Figure 1: A single-line diagram of a 15-bus radial distribution system

Case 1: Installing One DG

The proposed method was applied to a 15-bus radial distribution system by installing one DG at each candidate bus. All buses are considered as candidate buses in this test and in all subsequent tests. Table 1 and Table 2 shows the corresponding real power losses and voltage deviation at all of the system buses with DG and without DG. It is observed that the best bus for optimal DG allocation is at bus 13. Installing the DG at bus 13 with a size of 467 KVA caused a reduction in real power losses from 671.6 kW to 557.42 kW, which is about a 17% reduction. Figure 4 shows the improvement in the voltage profile after installing the DG unit at bus 13. Here we can see that voltage deviation improved to 1.17%.

Table 1: Real and Reactive power loss comparison Table

BUS No.	P Loss without DG (KW)	P Loss with DG (KW)	Q Loss without DG (KVAR)	Q Loss with DG (KVAR)
1				
2	235.0968	182.4347	229.9539	178.4438
3	70.2140	44.8507	68.6780	43.8695
4	15.1987	6.2080	14.8662	6.0722
5	0.3443	0.3403	0.2322	0.2295
6	0.8798	0.8756	0.5803	0.5776
7	0.2048	0.2038	0.1381	0.1375
8	22.0069	21.9012	14.8438	14.7726
9	5.9019	5.8735	3.9809	3.9617
10	2.9457	2.9316	1.9869	1.9774
11	13.5184	13.3977	9.1183	9.0369
12	3.7304	3.6970	2.5162	2.4937
13	0.4587	0.4546	0.3094	0.3066
14	1.2726	1.4335	0.8584	0.9669
15	4.5046	4.4515	1.8460	1.8243
TOTAL	**376.2777 KW**	**289.0537 KW**	**349.9087 KVAR**	**264.6701 KVAR**

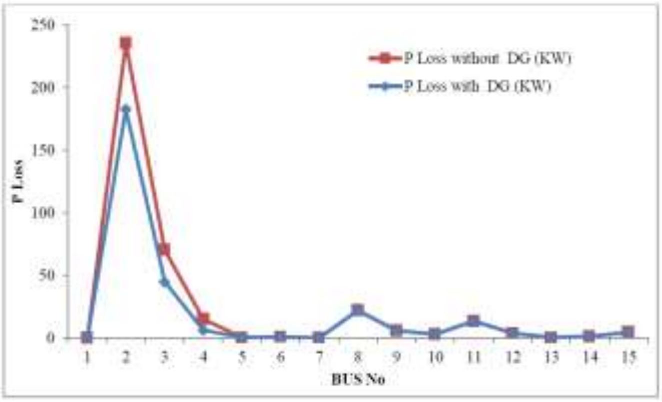

Figure 2: Active power loss with and without DG

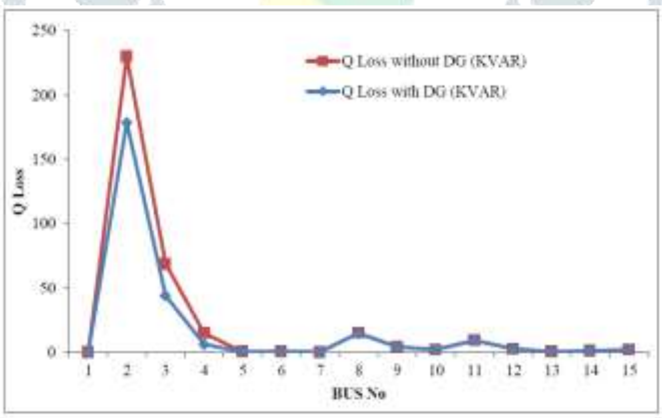

Figure 3: Reactive power loss with and without DG

Table 2: Voltages (P.U) before and after placement of DG

BUS No.	Voltages (P.U) without DG	Voltages (P.U) with DG	% Voltage Improvement
1	1	1	0.00
2	0.9815	0.9838	0.23
3	0.9721	0.9764	0.44
4	0.9684	0.9742	0.60
5	0.9677	0.9735	0.60
6	0.9745	0.9768	0.24
7	0.9721	0.9744	0.24
8	0.9727	0.9750	0.24
9	0.9803	0.9826	0.23

BUS No.	Voltages (P.U) without DG	Voltages (P.U) with DG	% Voltage Improvement
10	0.9797	0.9820	0.23
11	0.9675	0.9718	0.44
12	0.9647	0.9690	0.45
13	0.9638	0.9681	0.45
14	0.9668	0.9759	0.94
15	0.9659	0.9716	0.59

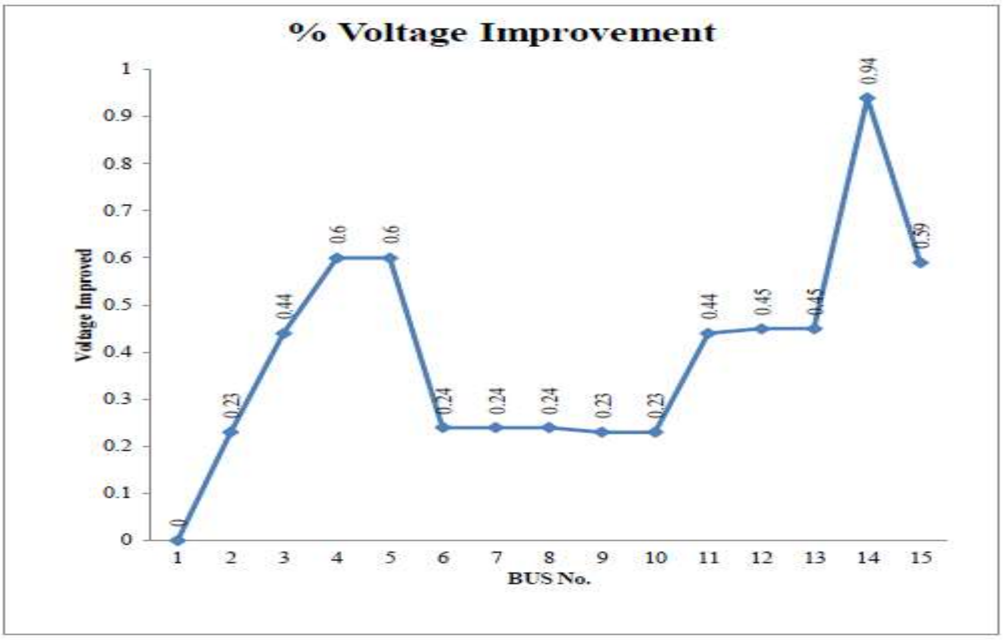

Figure 4: Voltage Profiles of 15 bus radial distribution system

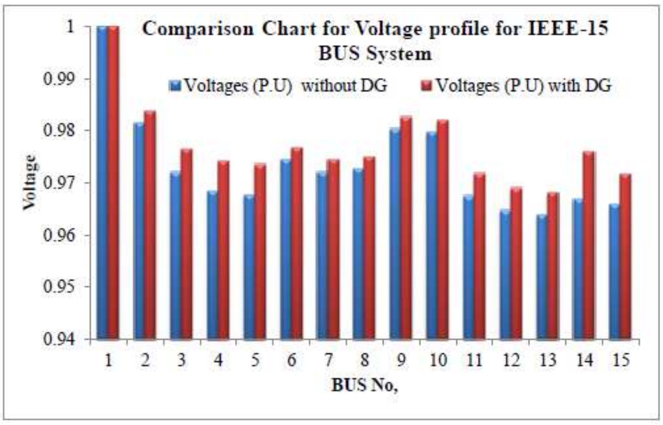

Figure 5: Comparison chart for Voltage profile for IEEE-15BUS System

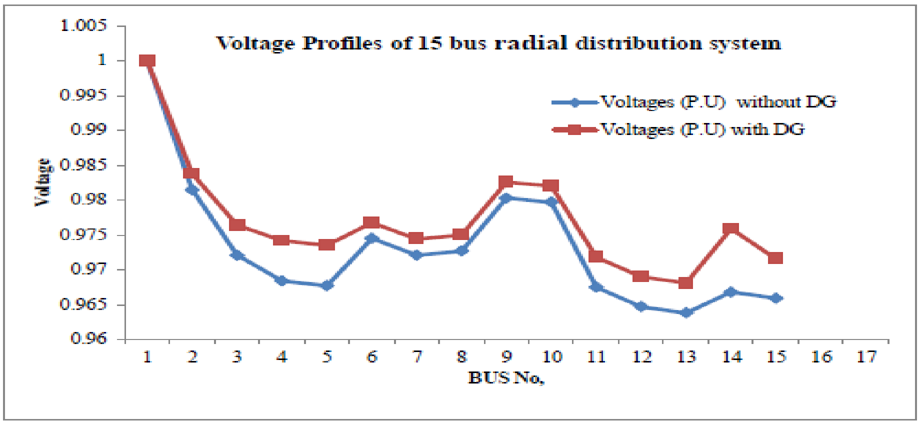

Figure 6: Voltage Profiles of 15 bus radial distribution system

Case 2: Installing Two DGs

The proposed method was applied by installing two DGs. Tables 3 and 4 shows the corresponding real power losses and voltage deviation at all of the system buses with DG and without DG. The optimal location of DG is determined by SQP is at bus numbers 4 and 6. Installing the DG at these buses with a size of 760.062 KW and 466.338KW caused a reduction in apparent power losses from 512.7 KVA to 204.8 KVA, which is about 39.94% reduction. Table 4 shows the improvement in the voltage profile after installing the DG units at bus numbers 4 and 6. Voltage profiles are also improved to 1.84 % and 1.12 % at buses 4 and 6 respectively, the obtained results are verified.

Table 3: Real and Reactive power loss comparison Table

0	P Loss without DG (KW)	P Loss with DG (KW)	Q Loss without DG (KVAR)	Q Loss with DG (KVAR)
1				
2	235.0968	90.22	229.9539	87.23
3	70.2140	9.47	68.6780	9.23
4	15.1987	1.8352	14.8662	1.71
5	0.3443	0.3417	0.2322	0.3328
6	0.8798	0.9260	0.5803	0.9142
7	0.2048	0.2123	0.1381	0.1923
8	22.0069	25.823	14.8438	22.821
9	5.9019	8.797	3.9809	7.917
10	2.9457	3.245	1.9869	2.245
11	13.5184	0.3441	9.1183	0.312
12	3.7304	3.6743	2.5162	3.152
13	0.4587	0.4591	0.3094	0.4423
14	1.2726	1.5679	0.8584	1.32
15	4.5046	2.784	1.8460	2.164
TOTAL	**376.2777 KW**	**149.70 KW**	**349.9087 KVAR**	**139.9826 KVAR**

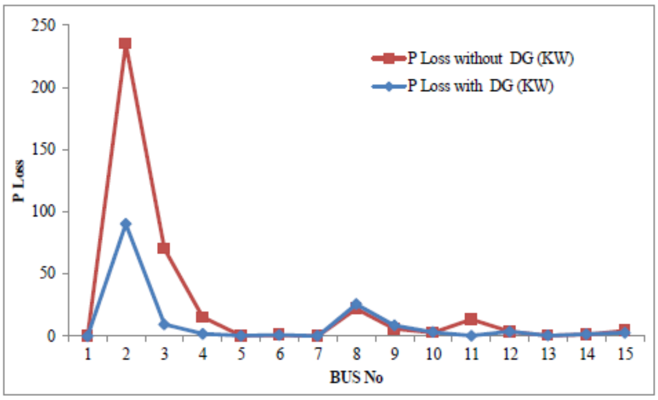

Figure 7: Active power loss with and without DG

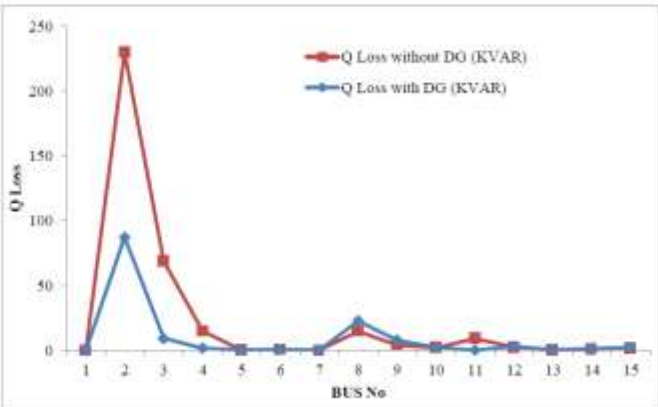

Figure 8: Reactive power loss with and without DG

Table 4: Voltages (P.U) before and after placement of DG

BUS No.	Voltages (P.U) without DG	Voltages (P.U) with DG	% Voltage Improvement
1	1	1	0.00
2	0.9815	0.9852	0.38
3	0.9721	0.9821	1.03
4	0.9684	0.9862	1.84
5	0.9677	0.9812	1.40
6	0.9745	0.9854	1.12
7	0.9721	0.9833	1.15
8	0.9727	0.9833	1.09
9	0.9803	0.9869	0.67
10	0.9797	0.9847	0.51
11	0.9675	0.9812	1.42
12	0.9647	0.9852	2.13
13	0.9638	0.9864	2.34
14	0.9668	0.9884	2.23
15	0.9659	0.9883	2.32

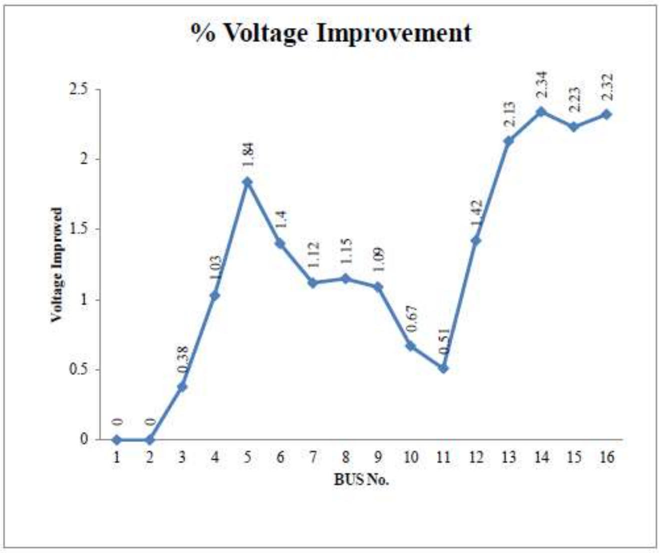

Figure 9: Voltage improvement of IEEE-15 BUS System

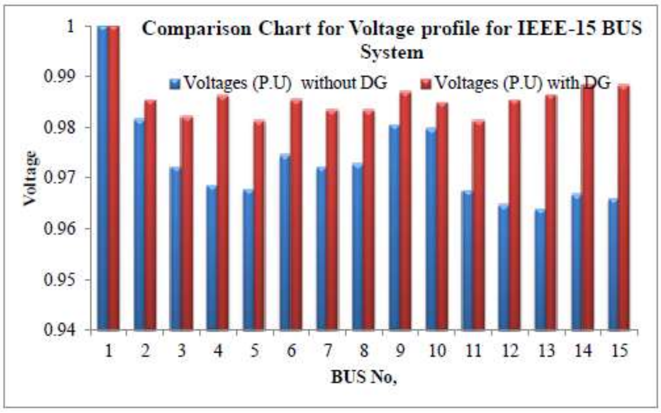

Figure 10: Comparison chart for Voltage profile for IEEE-15BUS System

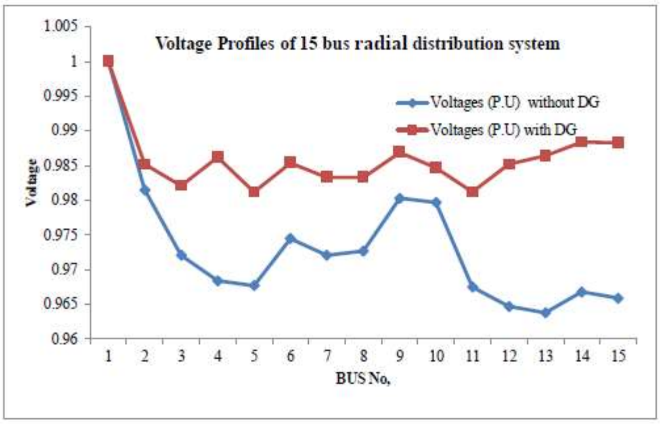

Figure 11: Voltage Profiles of 15 bus radial distribution system

CONCLUSION AND SCOPE FOR FUTURE WORK

Conclusion

DGs are perfect solution of to-days and futures power generation and distribution system which could meet the demanding needs of the consumers economically and environmentally by minimizing the cost, reducing power losses, improving voltage profiles, complexity, interdependencies and inefficiencies associated with onsite power generation, transmission and distribution network.

In this paper, the optimal placement and sizing of DGs within distribution networks was investigated. The single-objective optimization problem attempted to determine a DGs optimal place and size by using total real power losses is an objective to be minimized by using Sequential Quadratic Programming (SQP). Single DG installation cases were studied using a 15-bus radial distribution system. The results are compared to a case without DG. It was shown that choosing proper DG size and place has a significant impact on minimizing power losses and improving voltage profiles.
The following points are the major contributions of this paper:

- Including additional advantages in reducing power losses and improving voltage profile.
- The optimal DG size and placement problem could be investigated using DG with different practical values of power factor, such as 0.9, 0.95 and unity, or using DG with unspecified power factors.

Scope for future work

In this paper, single objective function with minimization of real power losses is considered and constraints were voltage and size of DG. It can be multi objective functions and different constraints with uncertainty included in objective function as well as in constraints. Multiple objective functions may include minimization of cost as well as maximization of profit. Multiple objective functions with constraints in optimal distributed generation plant may include.

Objective function

1. Minimization of total cost of the system
2. Minimization of the energy losses
3. Minimization of the voltage deviation
4. Maximization of DG capacity
5. Maximization of voltage limit liability

Constraints

1. Power flow equality constraints
2. Bus voltage or voltage drop limit
3. Short circuit level limit
4. Power generation limit
5. Discrete size of DG units
6. Limited buses for DG installation

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