ANALYTICAL APPROACH OF DISTRIBUTED GENERATION ON DISTRIBUTION SYSTEM FOR VOLTAGE PROFILE IMPROVEMENT

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Abstract- The electricity plays an essential role on economic development in Myanmar. However, in some places, particularly Kyaukse area, the existing power station cannot fulfill the increasing customer's demand of power consumption due to high power loss and voltage drop during distribution. Evaluation of voltage drop and power loss to improve the overall efficiency of the power distribution system is prerequisite issue in power station. Recently, there has been great interest in the integration of distributed generation units at the distribution level. Numerous advantages attained by integrating Distributed Generation (DG) in distribution systems. These advantages include decreasing power losses and improving voltage profiles. Such benefits can be achieved and enhanced if DGs are optimally sized and located in the systems. This paper proposes an analytical expression to calculate the single and multiple DG and an effective methodology to identify the corresponding optimum location for DG placement for minimizing the total power losses and improve voltage profile in primary distribution system of Belin Substation in terms of 36-bus radial distribution system in Myanmar. The analytical expression and the methodology are based on the exact loss formula. Single and multiple DG installation cases are studied and compared to a case without DG, and 36-bus distribution system is used to demonstrate the effectiveness of the proposed method.

Keywords- Distributed Generation, Multiple DG, Power Losses, Single DG, Voltage Profile.

I. INTRODUCTION

Traditionally, electric power system includes three parts, namely generation, transmission and distribution. The bulk of electricity is generated at central station generations, and transmitted through high voltage transmission line to distribution network before supply to consumers. Distribution system provides a final link between the high voltage transmission and consumers.

A radial distribution system has main feeders and lateral distributors. The main feeder originates from substation and passes through different consumer loads. Laterals are connected to individual loads [1]. Generally radial distribution systems are used because of their simplicity. Electrical energy is continuously lost due to resistance in power system networks, and distribution system loss accounts for more compared to transmission system. Moreover, distribution systems are well known for a higher R/X ratio compared to transmission systems and significant voltage drops can result in substantial power and energy losses along distribution feeders. As a result, loss reduction in distribution systems is one of the greatest challenges to many utilities around the world. Reconfiguration and capacitors placement are two major methods for loss reduction in distribution systems [2].

Distribution system provides a final link between the high voltage transmission and consumers. Power loss in a distribution system is high because of low voltage and hence high current [3].One of modern important techniques in electrical distribution systems to reduce losses is to accommodate small scale decentralized generating units known as distributed generation (DG). Since the last few years, the interest in the placement of DG in utility network has increased due to its effective role in reducing the power loss of the distribution networks so as to serve remote loads. In recent years, the power industry has experienced significant changes on the distribution power system primarily due to the implementation of smart-grid technology and the incremental implementation of distributed generation.

II. DISTRIBUTED GENERATION

Distributed generation is an electric power source connected directly to the distribution network or customer side of the meter. It may be understood in simple term as small-scale electricity generation. The definition of distributed generation takes different forms in different markets and countries and is defined differently by different agencies [4].In fact, it is so new, neither a standard definition nor a standard name for it has been agreed upon.

Some researchers define DG by rating DG units, whereas others define DG in terms of the technology used. DG also appears under different names, depending on the country. For instance, in some parts of North America, the term Dispersed Generation is used, while in South America, Embedded Generation has been coined. Meanwhile, in Europe and some Asian countries, DG stands for Decentralized Generation [5]. International Energy Agency (IEA) defines Distributed Generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages [6]. CIGRE defines DG as the generation, which has the following characteristics: It is not centrally planned; It is not

centrally dispatched at present; It is usually connected to the distribution network; It is smaller than 50–100 MW. Other organization like Electric Power Research Institute defines distributed generation as generation from a few kilowatts up to 50 MW [7].The DGs are small scale power generation technologies of low voltage type that provide electrical power at a site closer to consumption centers. Appropriate size and location of DG play a significant role in minimizing power losses in distribution systems.

Decentralized power generation close to rural load centers using renewable sources appears to have the potential to address at least some of the problems of rural electrification [8].There are a few number of DG technologies are still in research & development stage but a large number of DG technologies are available in the market today. Some currently available technologies are reciprocating engines, micro turbines, combustion gas turbines, fuel cells, photovoltaic & wind turbines. Each of these technologies has it's own benefits & characteristics [9]. Employing DG in a distribution system has several advantages as discussed below:

- DG can reduce line losses.
- DG is installed for voltage profile improvement.
- DG is used to reduce emissions of pollutants.
- Overall energy efficiency is increased using DG.
- Enhanced system reliability and security.

This paper is organized as follows: Section II discusses Distributed Generation Definition. Section III includes the methodology to find the optimal DG for power loss reduction and voltage profile improvement. In Section IV used test system is discussed. Section V discusses the performance of proposed technique and at last section VI concludes the paper and followed by the references.

III. PROPOSED METHODOLOGY

In this section 36-bus radial distribution system is used to locate the DG in an optimal place with the proper sizing. The Proposed Approach needs power flow to be run for two times, one for the initial base case and another at the final stage with the DG to obtain the optimal solution.

A. Problem Formulation

The optimal size of DG is calculated at each bus using the exact loss formula and the optimal location of DG is found by using the loss sensitivity factor. The loss sensitivity factor is used for the placement of DG is explained as the real power loss in the system is given by,

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

Where,

$$\alpha_{ij} = \frac{r_{ij}}{|V_i||V_j|}\cos\left(\delta_i - \delta_j\right) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{|V_i||V_j|}\sin\left(\delta_i - \delta_j\right) \quad (3)$$

And

$Z_{ij}=r_{ij}+jx_{ij}$ are the ijth element of [Zbus] impedance matrix.

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right) \quad (4)$$

The sensitivity factor of real power loss with respect to real power injection from the DG is given by sensitivity factor are evaluated at each bus by using the values obtained from the base case load flow. The bus having lowest loss sensitivity factor will be best location for the placement of DG. The total power loss against injected power is parabolic function and at minimum losses, the rate of changes of loss with respect to injected power is zero.

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right) = 0 \quad (5)$$

Then the above equation becomes

$$P_i = \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i + \sum_{j=1,j\neq i}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right] \quad (6)$$

Where P_i is the real power injection at node i, which is the difference between real power generation and the real power demand on that node,

$$P_i = P_{DGi} - P_{Di} \quad (7)$$

P_{DGi} is power injection of generator to the bus.
P_{Di} is the load.
P_i and Q_i are active and reactive power of the buses.

The optimal size of DG at each bus i for minimizing losses is given by equation (8),

$$P_{DGi} = P_{Di} + \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i + \sum_{j=1,j\neq i}^{N}\left(\beta_{ij}P_j - \beta_{ij}Q_j\right)\right] \quad (8)$$

The power factor of the single load $\left(PF_{D_2}\right)$ is given by equation (9),

$$PF_{D_2} = \frac{P_{D_2}}{\sqrt{P_{D_2}^2 + Q_{D_2}^2}} \quad (9)$$

It can be proved that at the minimum loss occur when power factor of DG is equal to the power factor of load as given by equation (10),

$$PF_{DG_2} = \frac{P_{DG_2}}{\sqrt{P_{DG_2}^2 + Q_{DG_2}^2}} \quad (10)$$

B. Computational Procedure for Proposed Approach

Step 1: Start the Process.

Step 2: Run the base case load flow without DG using Newton-Raphson load flow using MATLAB software and calculate the bus voltage, angle, real and reactive power loss respectively.

Step 3: After Load Flow identify the optimum size of DG for each bus using equation (8).

Step 4: Compute approximate loss using equation (1) for each bus by placing DG of optimum size obtained in step 3 for that bus. Add the injection from DG for that bus and use base case values for state variables.

Step 5: Locate the bus at which the loss is minimum after DG placement. This is location the optimum of DG.

Step 6: Stop the Process.

IV. TEST SYSTEM

The test system was applied on an existing Belin substation in Myanmar. This system consists of 36 buses at 33 kV voltage level. The capacity of the system is 400 MW real powers and 350 MVar reactive powers. The full network parameters are given in Appendix A.Fig.1.shows the single line diagram of 36-bus distribution system for Belin Substation in Myanmar.

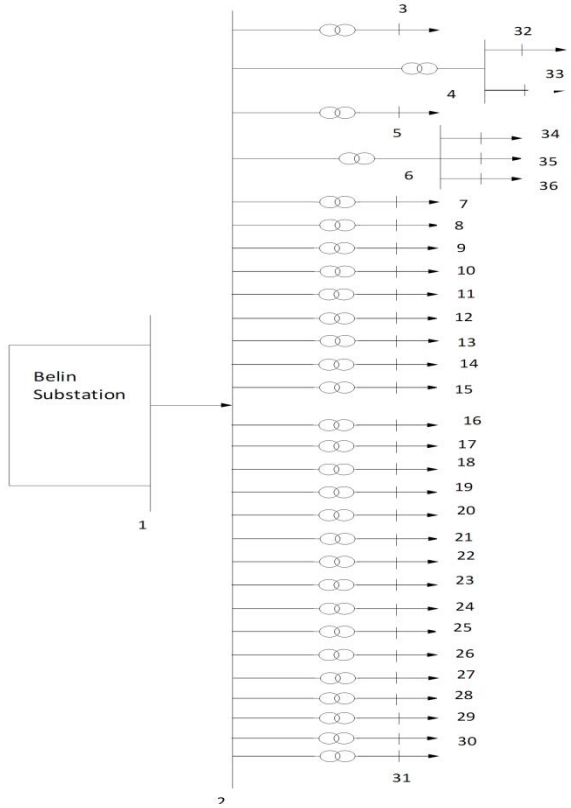

Fig. 1.Single Line Diagram of 36-bus Distribution System for Belin Substation in Myanmar

V. SIMULATION RESULT AND DISCUSSION

36-bus distribution system for Belin Substation in Myanmar is used to test the analytical method in finding the optimal DG size and place. Various scenarios, including single and multiple DG installations 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 the number of DG unit installations.

Case 1: Installing One DG

The proposed method was applied to a 36-bus 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 shows the optimal DG size and corresponding real power losses at all of the system buses .The optimal DG size can get by using equation (8) and the real power losses can be calculated by using equation (1). The optimal sizes and locations of DGs for 36-bus system at various power factors were calculated by using propose method (IA). The power factors of DG varied from zero to 1.00.

TABLE I
RESULTS OF INSTALLING ONE DG

Bus Number	DG size (MW)	P_{loss} (MW)	Power Factor	Loss Reduction%
2	95.07	2.388	0.88	62.17
3	6.75	0.091	0.85	62.9
4	18.87	0.133	0.9	63.6
5	17.81	0.5731	0.92	64.9
6	18.31	0.187	0.8	48.06
7	15.38	0.124	0.86	64.35
8	3.9	0.106	0.83	65.05
9	3.41	0.148	0.81	41.73
10	5.65	0.1904	0.82	52.97
11	7.41	0.193	0.83	41.81
12	7.23	0.188	0.81	46.57
13	10.35	0.277	0.8	46.31
14	9.2526	0.06512	0.91	68.58
15	6.91	0.196	0.8	35.31
16	7.44	0.162	0.85	62.67
17	8.22	0.216	0.79	37.2
18	8.33	0.1228	0.83	51.76
19	4.77	0.217	0.82	28.61
20	7.81	0.215	0.8	36.6
21	7.92	0.213	0.82	37.27
22	7.86	0.217	0.8	34.83
23	8.32	0.122	0.78	50.2
24	4.24	0.168	0.79	39.49
25	4.11	0.253	0.85	66.13
26	17.89	0.178	0.72	57.3
27	6.87	0.212	0.83	42.97

28	6.86	0.112	0.8	57.73
29	4.8	0.138	0.78	47.92
30	91.6	3.595	0.87	11.8
31	53.7	1.982	0.79	40.8
32	5.77	0.093	0.8	45.93
33	5.93	0.092	0.81	55.4
34	5.79	0.1914	0.85	67.83
35	24.38	0.412	0.8	46.04
36	4.32	0.088	0.82	52.94

In 36-bus distribution system, the optimum sizes ranging from 3.41 MW to 95.07 MW as shown in Fig.2. The range of power factor good for minimizing losses at bus 14 is 0.91. Power factor plays an important role in loss reduction.

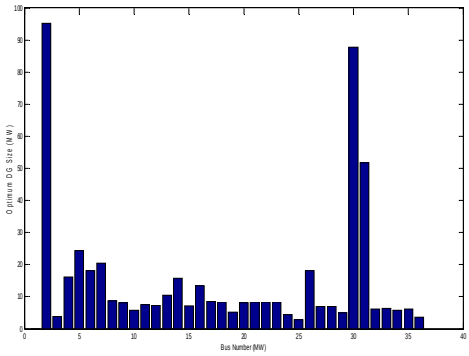

Fig. 2.Suitable DG Size of 36-bus System

Fig.3. shows the corresponding total real power losses for installing the optimal DG size at each bus of the system. From the figure, the best bus for optimal DG allocation is at bus 14. Installing the DG at bus 14 with a size of 9.2526MW caused a reduction in real power losses from 0.2073 to 0.06512 MW, which is about a 68.58% reduction.

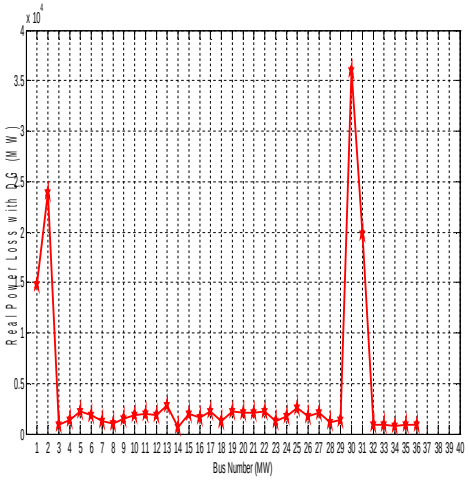

Fig. 3.Total Real Power Losses per DG placement

Fig. 4 shows the improvement in the voltage profile after installing the DG unit at bus 14. The voltage profile of buses is also improved with addition of DG.

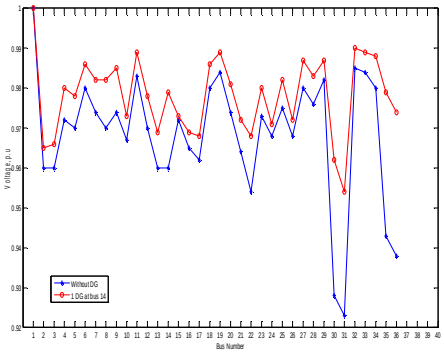

Fig. 4 Voltage Profiles of 36-bus Distribution System

Case II: Installing Two DG

An additional decision variable was added to handle the second DG, and all combinations for allocating two DGs in a distribution system were investigated. The best five solutions for optimal DG allocation are listed in Table 2. It is clear that installing DGs at bus 3 with a 1.25 MW capacity and at bus 14 with 8.94 MW capacities gives the optimal solution. The range of power factor for these location is 0.94.

TABLE II
RESULTS OF INSTALLING TWO DG

DG 1 Bus	DG 1size (MW)	DG 2Bus	DG 2size (MW)	P_{loss} (MW)	Loss Reduction %
3	1.25	14	8.94	43.64	77.33
3	1.25	25	4.26	12.37	75.09
5	4.26	8	2.89	4.075	75.06
7	4.26	31	5.86	13.26	72.82
10	3.98	24	4.65	2.807	70.42

However, other solutions can be taken as alternatives should the DGs be unable to be installed at the optimal location. At the optimal solution, the total real power losses are reduced from 74.39 MW (at no DGs in the system) to 43.64 MW, which is about an 77.33% reduction. This reduction is higher than installing only a single DG; in other words, installing two DGs would give better results in reducing the total real power losses. The voltage profile also improved, as shown in Fig.5.

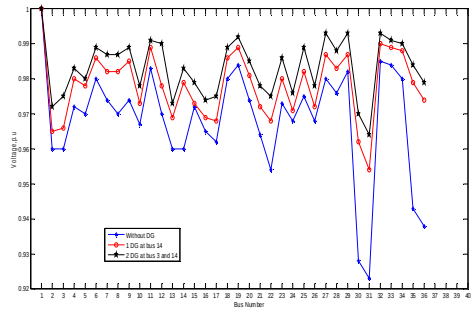

Fig. 5 Voltage Profiles of 36-bus Distribution System

Case III: Installing Three DG

In this test, in addition to the decision variables for the voltage magnitude and its angles, there are three decision variables for each DG. The optimization problem was solved and the best five solutions are provided in Table 3.

The results show that the total real power losses were reduced even more compared to the previous scenarios. The optimal locations for the DGs were at bus, 3,5and 24 with sizes of 5.98MW, 7.47MW and 7.1MW, respectively. The total real power loss for this solution is 9.936 MW, (which is about a 97.16% reduction).

TABLE III
RESULTS OF INSTALLING THREE DG

DG1 Bus	DG1size (MW)	DG2 Bus	DG2size (MW)	DG3 Bus	DG 3size (MW)	P_{loss} (MW)	Loss Reduction %
3	5.98	5	7.47	24	7.1	9.936	97.16
5	7.47	7	17.8	31	23.78	109.8	96.58
14	7.43	24	7.1	25	4.12	150.1	94.61
7	17.8	8	3.91	14	7.43	0.282	89.37
3	5.98	25	4.12	31	23.78	0.065	84.77

In this system, the best power factor found to be closer to unity (i.e., 0.99). Fig.6 shows the improvement in the radial system voltage profiles in this case as well as in previous cases.

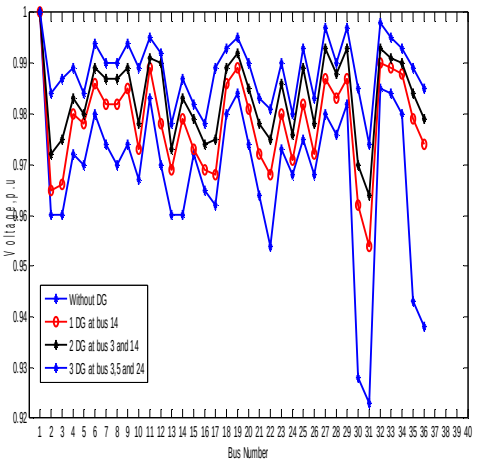

Fig. 6 Voltage Profiles of 36-bus Distribution System

CONCLUSION

In this paper a new emerging method called analytical approach is used to identify the optimal placement and optimum sizing of Distributed Generation in 36-buses Distribution Feeder for Belin Substation in Myanmar. The installation of DG units in power distribution networks is becoming more prominent. These benefits include reducing power losses, improving voltage profiles, reducing emission impacts and improving power quality. Single and multiple DG installation cases were studied using 36-bus distribution system for Belin substation in Myanmar. The results were compared to a case without DG. The proposed methodology for location selection correctly identifies the best location for installing three DG placement in order to minimize the total real power losses.

It has been shown that voltage profile is significantly improved by placing DG in distribution system and the losses have been reduced by 97.16 %.The results also showed that integrating multiple DG reduce real power losses in a system more than by integrating only a single DG. The results demonstrated and emphasized that multiple DG installations decreased total real power losses more than single DG installations.

APPENDIX A
TABLE IV
LINE PARAMETERS AND LOAD DATA OF 36 –BUS DISTRIBUTION SYSTEM

Line Parameters				Load Data		
From Bus No.	To Bus No.	R (p.u)	X (p.u)	Bus No.	P (p.u)	Q (p.u)
1	2	0.0002	0.0003	1.	200	198
2	3	0.0021	0.0039	2.	198	196.99
2	4	0.0195	0.0365	3.	1.19	1.142
4	32	0.1332	0.1540	4.	8	6.5
4	33	0.1332	0.1540	5.	6.17	5.37
2	5	0.0167	0.0313	6.	8.6	6.7
2	6	0.0181	0.0339	7.	2.06	2.045
6	34	0.0444	0.0513	8.	2.06	2.045
6	35	0.3553	0.4109	9.	2.04	2.03

6	36	0.8883	1.0272	10.	2.91	2.75
2	7	0.0017	0.0031	11.	2.71	2.15
2	8	0.0014	0.0026	12.	2.54	2.03
2	9	0.0028	0.0052	13.	2.8	2.6
2	10	0.0003	0.0005	14.	2.4	2.3
2	11	0.0003	0.0006	15.	2.4	2.3
2	12	0.0023	0.0043	16.	2.98	1.59
2	13	0.0006	0.0010	17.	2.84	2.613
2	14	0.0005	0.0008	18.	2.4	2.13
2	15	0.0004	0.0008	19.	2.45	2.338
2	16	0.0119	0.0221	20.	2.45	2.338
2	17	0.0009	0.0016	21.	2.54	2.15
2	18	0.0009	0.0017	22.	2.5	2.037
2	19	0.0047	0.0088	23.	2.39	2.225
2	20	0.0020	0.0038	24.	2.57	2.31
2	21	0.0016	0.0031	25.	4.2	3.15
2	22	0.0017	0.0031	26.	8.4	6.3
2	23	0.0011	0.0020	27.	2.2	2.15
2	24	0.0011	0.0021	28.	2.02	2.015
2	25	0.0181	0.0339	29.	2.01	2.007
2	26	0.0002	0.0004	30.	28.53	23.75
2	27	0.0004	0.0008	31.	25.68	29.613
2	28	0.0021	0.0039	32.	2.6	1.95
2	29	0.0053	0.0099	33.	2.83	2.123
2	30	0.0174	0.0325	34.	4.83	3.623
2	31	0.0178	0.0334	35.	5.83	5.27
				36.	2.53	2.373

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