Optimal integration of solar photovoltaic distributed generation considering reliability index, voltage stability index and loss configuration

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Abstract. Climate change and environmental issue is a common concern for all of us. On the other hand, energy is essential for our daily life and how to get secure, affordable and environmental sustainable energy becomes global issue. Distributed generation (DG) is one of the solution to mitigate environmental impact and to integrate as a part of the smart grid. Solar photovoltaic can be used abundantly as the small multi-distributed generation system to improve system performance in many ways. According to the previous researches, it is clear that DG can make system performance better. However, choosing location and sizing is a must considerable issue for integration of DG in the distribution network. In some research, the location and size was determined only depended on the amount of loss reduction. In our research, three factors such as reliability index, voltage stability index and loss reduction are going to evaluate to figure out the location and size of the DGs. Using forward-backward sweep method in MATLAB, power loss condition is analysed. Then, loss reduction level is check by installation DG in each bus and the most effective buses or the buses at which the highest amount of loss DG can reduce are assigned as locations for DG. And then the voltage stability index (VSI) is calculated and one of the nominate buses which has highest VSI index is chosen as the designated bus for allocation. In this way, the optimal location of DG can be assigned with the consideration of losses and VSI index. In another way, the location of DG can be determined with the consideration of reliability index. From the concept of reliability, the most effective or optimal location is the bus at which the reliability is the highest. In this research, the location and size of DGs were considered based on combination of three indices such as VSI, loss and reliability index.

Keywords: DG, optimal allocation, reliability, VSI, loss reduction.

1. Introduction

In power system to meet a required power demand and to be reliable as possible is very important. In Yangon, Kamayut Township is not sufficient electricity in radial distribution because interruptions occur frequently. The reliable power supply of Kamayut Township is currently challenging because of
increasing population and economic development. Therefore, the demand for electricity is expected to increase. In Myanmar, electricity depends on hydro power plants [1]. The generating stations mostly are located in the upper country and the load dispatch in the lower country. Therefore, long distance to supply load leads to significant amount of voltage drop and losses across the distribution lines. To solve this problem Distributed Generation (DG) is vital role for distribution network [2]. The planning of DG will require the assessment of several factors such as the number and the capacity of units, best location impacts of DG on the System operation characteristics such as system losses, voltage profile, stability and reliability issues [3]. The integration of DG may affect the operation of distribution network in beneficial and detrimental ways. The positive effects of DG are: voltage support, power loss reduction, support of supplementary services and improved reliability, but negatives ones are protection coordination, dynamic stability and islanding. Furthermore, the interconnection of DG units concerns technical constraints to maximize benefits and minimize problem [4].

DG technologies are classified into two types: renewable technologies (eg, photovoltaic and wind turbine) and non-renewable technologies (eg, mini and micro turbine, combustion turbine and fuel cells). DG technologies have an importance impact on the selection of appropriate size of DG to be connected to the grid or customer loads. At currently DG Technologies in the market: PV cells, wind turbines, Fuel cells, Micro turbines [3]. The problem of DG allocation and sizing is great importance. The installation of DG unit at non-optimal places can result increase system losses and cost. In distribution system, the selection of the best places for installation and the preferable size of DG is complex optimization problem [6]. Optimal placement and sizing of DG using FBSM methods of load flow study at the proper bus location minimizes both losses and cost. The proposed approach has been tested on MRTV3 radial distribution system and created by MATLAB. The result obtains from the test system and explains the optimal sizing and locations of DG there by minimizes of the power losses of the system.

Normally, size and locations of DG were evaluated based on loss and voltage condition. Many researchers have been conducted it. In this paper, reliability index is also considered to check the result obtained with the previous methods. The objectives of the research is to find out the size and location of DGs as economically and reliably as possible with the consideration of three factors such as voltage, loss and reliability.

2. Methodology

2.1. Load Flow Analysis

In radial distribution systems load flow analysis is high R/X ratio, with the distribution network are ill conditions and normal conservative techniques [7]. The Forward backward sweeping method is to analyze the distribution network. This method is not need Jacobian matrix unlike NR methods. However, the conventional backward forward sweep method is not useful for modern useful distribution network. The Forward-Backward Sweep Method (FBSM) is easy to program and run quickly [8]. Therefore, network topology base analysis has been used for finding voltage and the total power loss of RDS under balance operating condition employing constant power model.

The matrix Equivalent Current Injection): This method is based on current injection and shown in (1) and (2.)

\[ S_i = P_i + Q_i \quad i=1,2…N \]

\[ I_i^k = I_{ij}^k (V_i^k) + jI_{ij}^k (V_i^k) = \frac{P_i + jQ_i}{V_i^k} \]

Where, \( S_i \) is the complex power at i-th bus, \( P_i \) is the real power at i-th bus, \( Q_i \) is the reactive power at i-th bus, \( V_i^k \) and \( I_i^k \) are the bus voltage and current injection at the k-th iteration for i-th bus.
2.2. Voltage Stability Index (VSI)
This index will find the most optimum weakest link in the system which could lead to the voltage
stability when the load is increase. Under stable
operation, the value of the VSI should be greater than
zero for all buses. When the values of SI become closer to one, all buses become more stable. The values
of stability index is minimum, is more sensitive to the voltage collapse.

\[ VSI = \sqrt{\left( V_s - 4 \left( P_r x_{ij} - Q_r r_{ij} \right) \right)^2 + \left( P_r x_{ij} - Q_r r_{ij} \right)^2} \] (3)

Where, \( VSI \) is Voltage stability index, \( V_s \) is the sending bus, \( P_r \) is active load at receiving end, \( Q_r \) is the reactive load at receiving end, \( r_{ij} \) is resistance of the line i-j, \( x_{ij} \) is reactance of the line.

2.3. DG sizing and Location
The main analytical approach is to minimize the total system power loss by optimal sizing and location
of DG in RDS. The main function is formulated as expressed

\[
\text{Minimize } S_{\text{loss}} = \sum_{i=1}^{n} (P_{\text{loss}} + Q_{\text{loss}})
\] (4)

The Total active power loss in a RDS is :

\[
P_{\text{loss}} = \sum_{i=1}^{n} (I_i^2 \times r_{ij})
\] (5)

The total reactive power loss in a RDS is :

\[
Q_{\text{loss}} = \min\left( \sum_{i=1}^{n} (I_i^2 \times x_{ij}) \right)
\] (6)

Where, \( N \) is the number of lines at bus i, \( I_i \) is the line current at bus i, \( r_{ij} \), \( x_{ij} \) is the line resistance and
line reactance at bus i. The exact real power losses in an RDS is calculated by using (7).

\[
P_{\text{loss}} = \sum_{i=1}^{n} \sum_{j=1}^{n} \left[ a_{ij} (P_i P_j + Q_i Q_j) + b_{ij} (Q_i P_j + P_i Q_j) \right]
\] (7)

Where,

\[
a_{ij} = \frac{R_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)
\] (8)

\[
b_{ij} = \frac{X_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)
\] (9)

The exact reactive power losses in a RDS is :

\[
Q_{\text{loss}} = \sum_{i=1}^{n} \sum_{j=1}^{n} \left[ c_{ij} (P_i P_j + Q_i Q_j) + d_{ij} (Q_i P_j + P_i Q_j) \right]
\] (10)

Where,

\[
c_{ij} = \frac{R_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)
\] (11)

\[
d_{ij} = \frac{X_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)
\] (12)

Where, \( a_{ij}, b_{ij}, c_{ij}, d_{ij} \) are the function of loss coefficient between bus i and j. According to real and
reactive power flow and characteristics of DG, DG injects reactive and real power and consumes real
and reactive power. The active and reactive power injected at bus i, where the DG located are given by

\[
P_i = P_{\text{DG}} - P_{\text{Di}}
\] (13)

In radial distribution system, the location and size of DG is very importance and produce utmost benefits.
IF the DG size is optimal, the losses are reduced to a minimum value at that location [10]. If the size of
DG is beyond the optimal, the losses start increase. The use of high capacity DG will lead to excessive
power flow through small-sized conductors and hence results in higher losses. This paper aims to reduce
losses and improve voltage profile to optimize size and better location of DG. In this paper real power injected DG type at bus i is used. This type consists of (PV) photo voltaic, (FC) fuel cell, micro turbine (MT) will generate real power. The optimal sizing of DG is given by

\[ P_i = P_{DGi} - P_{Di} \]  

(14)

\[ P_i = \frac{1}{a_{ij}} \sum_{i=1}^{n} \sum_{j=1}^{n} [a_{ij} P_i - b_{ij} Q_i] \]  

(15)

\[ P_{DGi} = P_{Di} + \frac{1}{a_{ij}} \sum_{i=1}^{n} \sum_{j=1}^{n} [a_{ij} P_i - b_{ij} Q_i] \]  

(16)

Where, P is The real power injection at node i, \( P_{DGi} \) is the real power injection from DG placed i. \( P_{Di} \) is the load demand at node i. From above analytical proposed, the optimal sizes are calculated from the losses. The optimal location is considered at minimum losses which DG should be added. As losses reduction is improved with loss coefficient from the base case to DG allocation.

3. Test System and Data

In this paper, the load flow analysis is tested in MRTV3 Radial Distribution System, Myanmar as shown in Fig.1. The total real and reactive power loads are 27.947 MW and 23.063 MVAR. In this system the initial power loss is 0.936 MW and 2.838 MVAR. It has three 30 MVA step down transformer from 66 kV to 11, 6.6 and 33 kV.

![Figure 1. Proposed Test Area of MRTV3 Station](image)
4. Results and Discussion

The test system has three different voltage levels as shown above figure. The three cases are considered in this study for analysis as follow.

Case I: One DG Unit at 11 kV
Case II: One DG Unit at 11 kV and Two DG Units at 6.6 kV
Case III: One DG Unit at 11 kV, Two DG Units at 6.6 kV and One DG Units at 33 kV

In case I, the test system has 25 buses. The minimum voltage point and stability index point at bus 13 shown in Fig. 2 without DG by running load flow. It is noted that the minimum voltage is 0.9764 pu and minimum stability index VSI is 0.9153 pu at 13th at existing condition without DG. After installing DG, the voltage and VSI are increased to 0.9868 pu and 0.9549 pu at 11 kV. From the figure, the minimum power losses at bus 13. Hence, the optimal placement at bus 13 and the optimal size is 1.018 MVA. Installing one DG at 11 kV the voltage is increasing all 11 kV feeders, but voltage is not affected for the whole system because the test system is three voltage levels. But the total loss is reduced for the whole system.

![Figure 2. 11 kV distribution system](image)

![Figure 3. 6.6 kV distribution system](image)

The second case simulation result is shown in Table 1. According to the result, it is found that minimum voltage and stability index point at 6.6 kV is 0.8791 pu and 0.5792 pu at 33th bus without DG. The result of optimal location and sizing is found for two DG units. The optimal placement is at bus 33.
and 57, and the optimal size for two DG units is 2.16 MVA and 1.2 MVA respectively. Without DG unit condition, the voltage profile of 6.6 kV level is the worst condition in MRTV3 RDS VSI at all bus of 6.6 kV level also decreased. After installing DG units, the minimum voltage is reached from 0.8791 to 0.9298 and the minimum stability index is reached from 0.5792 to 0.7473 shown in Fig. 3. In addition, installing three DG at 11 kV and 6.6 kV the voltage is increased all 11kV and 6.6 feeders, but 33 kV feeder voltage is not affected.

Table I shows voltage and stability index in tubular forms. The minimum voltage and stability index are 0.9558 pu and 0.8345 pu at bus 3 as Fig.4. The optimal location is bus 1 with minimum power losses. Although the optimum DG size is of 2.174 MVA is connected at bus1 in 33kV voltage level MRTV distribution system, the voltage improvement is not effective at 33 kV level. Installing all four DG at 11 kV, 6.6 kV and 33 kV, the total system losses are reduced for the whole system. The voltage and stability index are similarly same at 33 kV level before and after installing DG because load demand is least at initial condition. According to result, the voltage improvement is not affected by considering DG at 33 kV level.

![Figure 4. 33 kV distribution system](image)

**Table 1. Comparison Results for Optimal Sizing and Allocation of DG**

| Test System | Optimal location | Optimal DG size in MVA | Minimum Voltage Without DG | Minimum Voltage With DG | Stability Index Without DG | Stability Index With DG |
|-------------|------------------|------------------------|---------------------------|-------------------------|---------------------------|-------------------------|
| 11 kV       | 13               | 1.0183                 | 0.9764 (bus 13)           | 0.986 (bus 13)          | 0.9153 (bus 13)           | 0.9549 (bus 13)         |
| 6.6 kV      | 57,33            | 1.2, 2.16              | 0.8791 (bus 33)           | 0.9298 (bus 33)         | 0.5792 (bus 33)           | 0.7475 (bus 33)         |
| 33kV        | 1                | 2.174                  | 0.79558 (bus 3)           | 0.9598 (bus 3)          | 0.8345 (bus 3)            | 0.8448 (bus 3)          |

In figure 5, comparison of SAIFI can be seen for different cases. Comparing case I and II, SAIFI is clearly decreased by integrating more DG. However, SAIFI is not much decreased in case II even though more DG is installed. In figure 5, expected energy not supply is also compared. The decreasing characteristics is the same as SAIFI and integrating many DG could not be a better solution.
5. Conclusion and Recommendation

In this paper, VSI and optimal allocation and sizing Of DG is investigated by analytical approach. Using FBS method proposed analytical expression the optimal size and location are evaluated on the MRTV3 radial distribution system. The voltage and VSI at all buses are dramatically decreased without DG as load demand is very high at 6.6kV. After considering optimal DG place, the losses are reduced in the system. Moreover, VSI and voltage magnitude are increased significantly. After DG installing, the voltage profile of 11kV and 33kV levels are slightly increased and the voltage profile of 6.6 kV is distinctly increased and satisfied for the acceptable limit compared to the without DG conditions. Although four DG are installed to the system, the losses can be reduced slightly. To conclude the result installing three DG is more suitable than four DG. Therefore, the optimal allocation and DGs size has impact in the MRTV3 radial distribution system.

The main target of our research is to investigate location and size of DG considering three factors power loss, voltage level and reliability. The works will be carried out in future. Moreover, PV DG can not get stable and required output for full time. The next task is to find out PV DG as the source which can available partial time and partial capacity.

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