Optimal siting and sizing of solar power sources in interconnection grid system

S.Yogendra Reddy, Daka Seshi Reddy, Dr.G.Kesava Rao

Department of Electrical & Electronics Engineering
KL University
Guntur, India
s.yogendra.eee@gmail.com, dseshireddy@kluniversity.in

Abstract— Growing concerns electrical power demand in need and necessity of daily livelihood of life. Impacted over addition power demanded there is climate impacts, environmental conditions due to conventional power generation resulted in improvement of cheaper solar power generation in the whole distribution system network, and programs offered by governments have contributed to an increment in the number of distributed energy resources (DERs) system in commercial and domestic electrical power output. It is well known that fact the non-optimal size and non-optimal siting system may lead to high power losses, bad voltage profiles and high losses of profit margins of DISCON’s end. Therefore, this paper to determine the location best siting and filler of multiple DERs generators supported power loss, generation units, and cheaper power transfer demonstrated through IEEE 30 bus standard test system with help of Power World Simulator Package and single line drawing of 2MW solar PV power plant added to APDISCOM.

Keywords— Distribution system; grid Connected; optimal power flow (OPF); optimal siting; optimal sizing; Power World Simulator; IEEE bus test system; voltage profile; generation unit coefficient; distributed energy resources (DERs).

I. INTRODUCTION

Distributed energy resources are decentralized power generation by small generating units to distribution system. Nowadays DERs technology is gaining wide spread interest because of new constraints placed in India like economical, political, voltage level rating, power loss, growing demand and environmental factors modern trends in electrical power system planning and operation have to push existing power system to capable to fulfill maximum demand will lead to power loss, trapping, and power cut. Centralized Electrical congenital generation (coal, thermal, hydro, and nuclear) fails to meet maximum demand and power loss.

Due to low voltage level LV and high voltage level HV in distribution network system largest power loss is occurred in three stage of power system i.e. power generation, power transmission and power distribution network power losses in line a distribution end will constitute in range of 6%-15% of the compared with power generation system.

Distributed energy resources to an electrical power grid is very complex integration of plug and play problem due to added exiting electrical system consideration of power loss, power quality, protection, stability, reliability etc. It very important to determine the optimal siting and sizing solar power generation before interconnect with exiting electrical power grid.

Present power system integration of solar power system to electrical grid has been rapidly increasing over the past few decade as a result of growing load most demand. To develop efficient expansion optimal power flow algorithms in computational optimizing network and generation. Power losses could be minimized by placing DER in proper place.

This paper is approaches analytical method and numerical method to setting up solar power plant in India. Paper organized as follows. Problem description minimizes the power loss in the network section II. Next the Optimal distributed energy resources sizing and location solar in IEEE 30 bus system section III. Proposed method is verified the simulation results and practical implemented system in 33 kV Nagaladine feeder, Andhra Pradesh, India. Result are obtained clearly explains minimization the power losses in electrical grid section IV. Finally, the conclusion is given in section V.

II. PROBLEM FORMULATION

In Electrical power system load forecasting is done based on demand at distribution network here is a brief description of reduction Method in Network as follows

1. Initial outline rating of station in kilovolt all the buses that within that have similar properties.
2. Ignore all lines connecting buses that belong to same space buses.
3. Lines interconnecting buses that belong to same space can aggregative.
4. Power flow is computed in reduced network.
5. Placement of solar power generation based on constraints.

Power loss is reduced network with speed up computational time. OPF studies significant importance in economical factor and also finding feasible generation that will impact by considering constraints. Power injected from sending end in the buses is equal to the receiving end bus is balanced system.

If power unbalanced occurred in receiving end will generate power loss in network. Power injection with help of solar power at receiving end will reduce the power loss in network. Buses are connected with generation units is Generation Area. Buses are connected with load is Load Area.
as shown in Table.1 planned to interconnect solar energy generator IEEE 30-bus system.

![Diagram of IEEE 30-bus system](image)

Fig.1. Planned to interconnection of solar energy generator IEEE 30-bus system.

Objective function feature proposed version is to decrease the power strength loss within the network by means of standard optimal siting and sizing of solar power electricity assets in grid network. The primary goal function is mathematically formulated as shown in Equation below (1)

Minimize \( f(x) = \sum_{i=1}^{n} P_{loss} \) (1)

Where,

\( P_{loss} \) power loss in network;
\( n \) number of nodes.

Power loss in network is given by

\[ P_{loss} = \min \sum_{i=1}^{n} \sum_{j=1}^{n} I_{ij}^2 Z_{ij} \] (2)

Impedance between the sending end node bus node and receiving end node bus is given by

\[ Z_{ij} = R_{ij} + jX_{ij} \] (3)

Where,

\( I_{ij} \) line current magnitude at node bus i \(^{th}\) to j \(^{th}\);
\( Z_{ij} \) line impedance at node bus i \(^{th}\) to j \(^{th}\) in ohms;
\( R_{ij} \) line resistance at node bus i \(^{th}\) to j \(^{th}\) in ohms;
\( X_{ij} \) line reactance at node bus i \(^{th}\) to j \(^{th}\) in ohms.

Branch current magnitude between two buses nodes given by

\[ I_{ij} = \frac{V_i - V_j}{Z_{ij}} \] (4)

Where,

\( I_{ij} \) Branch current magnitude \( ij \) \(^{th}\) amperes;
\( V_i \) Voltage magnitude at node bus i \(^{th}\) in volt;
\( V_j \) Voltage magnitude at node bus j \(^{th}\) in volt;
\( Z_{ij} \) Branch impedance at node bus \( ij \) \(^{th}\) in ohms.

The real power loss in a system is given by Equation. This is popularly referred to as the "exact loss" formula. Power loss is given by

\[ P_{loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}(P_i P_j + Q_i Q_j) + b_{ij}(Q_i P_j - P_i Q_j) \] (5)

Where,

\[ a_{ij} = \frac{Z_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \] (6)

\[ b_{ij} = \frac{Z_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \] (7)

Where

\( a_{ij}, b_{ij} \) function loss coefficient in network at node bus \( ij \) \(^{th}\);
\( P_i \) Active power flow kW at node bus \( i \) \(^{th}\);
\( Q_i \) Reactive power flow kVAR at node bus \( i \) \(^{th}\);
\( V_i \) Voltage magnitude sending and receiving end at bus in Per Unit.

The sensitivity factor of power loss with respect to a power injection from solar generator is given by

\[ \frac{\partial P_{loss}}{\partial P_i} = 2\sum_{i=1}^{n} \sum_{j=1}^{n} \left( a_{ij} P_j - b_{ij} Q_j \right) \] (8)

Objective function is to satisfy constraints. The constraints are mathematically formulated as follows in Equation below:

**A. Equality constraints**

Power flow constraints related to the non-liner equation to balancing constraints

\[ P_i = P_{solar} - P_{load} \] (9)

Where,
In fig.5, the electricity flow depends on the quantity of power furnished from electrical substation and solar power. In practical electrical power system generating plants are located far away from the consumer distribution network as result in large transmission network is estimated to transfer that power to load side end hence lead to Power loss in the network. Connection of solar electricity power can slight power losses if their right sittings are region. To decide the optimal sitting of solar power generator in IEEE 30-bus system used.

In sensible electric energy device producing plants are positioned a long way far away from the client distribution community as bring about massive transmission network is predicted to switch that energy to load side stop consequently lead to power loss in the community. Connection of sun electricity flowers can slight power losses if their right sittings are region. To decide the highest useful solar electricity generator in IEEE 30-bus system running power flow.

As show in Fig.1 planned interconnection of IEEE 30-bus test system using optimal siting and sizing generator. Now examine two power flow models with respect to generator or load. These two cases are shown in fig.2 power flow go with the power generator to various power loads and fig.3 power go with the flow from various power generators to single power load, respectively. The associated constraints are described as follows:

B. Inequality constraints

Bus voltage limitation profile is maintained within acceptable operating limits the in voltage in bus limit is given by

\[ V_{tr, \text{min}} \leq V_{tr} \leq V_{tr, \text{max}} \quad (10) \]

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\( P_{\text{gen}} \): Electricity provided with the aid of the \( P_{\text{gen}} \) in electrical power network.
\( P_{\text{load}} \): Power fed on via the \( P_{\text{load}} \) in electrical power network.
\( P_{\text{gen},i} \): Electricity strength flowing from power generator to power load.
\( P_{\text{load},i} \): Electricity consumed by numerous power loads.

In a mixture of above two instances defined for fig.1 can be conveyed with the aid of fig.4 single line simplified power flow model only power generators and loads. In fig.4 Node buses i and j can be symbolized with the single line diagram of each buses as show in fig.5. Then total power losses in overall power system can be calculated by way of summing the losses of all the nodes every time the solar power generator is interconnected to buses.

As a fig.5 is that specialize in the connection among solar generator and load. In same manner, the whole power electrical network fig.1 can also be resolute by means of making an allowance for about network electrical power losses. In fig.5 is used as an equivalent arrangement in fig.1 from the point of view of solar power generator. \( P_{\text{load},i} \) equivalent load consumed from \( j \) node bus.

In fig.5, the electricity flow depends on the quantity of power furnished from electrical substation and solar power

\[ P_{\text{solar}, \text{min}} \leq P_{\text{solar}} \leq P_{\text{solar}, \text{max}} \quad (11) \]

Where, 
\( P_{\text{solar}, \text{min}} \) And \( P_{\text{solar}, \text{max}} \) minimum and maximum reactive power generated in solar power kW.

### III. MODELING OF OPF PROBLEM

To decide the highest useful solar electricity generator in IEEE 30-bus system running power flow.

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In fig.5, the electricity flow depends on the quantity of power furnished from electrical substation and solar power.
generator. Then power loss among each bus calculated with the aid of eq.2.

\[
\sum P_{\text{load}_1} + P_{\text{load}_n} + P_{\text{load}_{n+1}} + P_{\text{gen}}
\]

Fig.2. power goes with the flow from generators to the numerous power loads.

\[
\sum f(\cdot)\quad P_{\text{load}_1}, \ldots, P_{\text{load}_n}, P_{\text{load}_{n+1}}, P_{\text{gen}}
\]

Fig.3. electricity float from numerous power generators to power load.

\[
\sum f(\cdot)\quad P_{\text{gen}_1}, \ldots, P_{\text{gen}_n}, P_{\text{gen}_{n+1}}
\]

Fig.4. simplified power flow only power generators and loads.

\[P_{\text{solar}} = I_{\text{solar}} \times (\pm V_j)\] (12)

\[P_{\text{inj}} = P_{\text{solar}} - P_{\text{load}}\] (14)

\[
\frac{\partial P_{\text{loss}}}{\partial P_i} = 2\sum_{j=1}^{n} \sum_{j=1}^{n} (a_{ij} P_j - b_{ij} Q_j) = 0
\] (13)

\[
P_{\text{loss}} = \frac{1}{a_{ij}} \sum_{j=1}^{n} \sum_{j=1}^{n} (a_{ij} P_j - b_{ij} Q_j)
\] (15)

\[
P_{\text{loss}} = \frac{1}{a_{ij}} \sum_{j=1}^{n} \sum_{j=1}^{n} (a_{ij} P_j - b_{ij} Q_j)
\] (16)

B. Optimal distributed energy resource’s sizing and location:

The fact the non-optimal size and non-optimal siting system may lead to high power losses, bad voltage profiles and high losses of profit margins of DISCOM’s end.

DEG’s will generating power will be identified by optimal sizing constraints in eq(9)

\[
P_{\text{inj}} = P_{\text{load}}\] (14)

\[
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\[
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\[P_{\text{loss}} = \frac{1}{a_{ij}} \sum_{j=1}^{n} \sum_{j=1}^{n} (a_{ij} P_j - b_{ij} Q_j)
\] (15)

The above equation is solved as

\[P_{\text{solar}} = P_{\text{load}} + \frac{1}{a_{ij}} \sum_{j=1}^{n} \sum_{j=1}^{n} (a_{ij} P_j - b_{ij} Q_j)
\] (16)

The DEG’s units at non-optimal size and non-optimal siting system may lead to high power losses. Thus power loss is a function of loss coefficients. After installation of solar power system to network loss coefficients will change depending injection of power. Load flow calculation is required for updating Ploss. Finally the optimal size is calculated from the basic case IEEE 30 Bus system.

IV. PROPOSED ALGORITHM FLOW CHART

This paper, IEEE 30 bus test system N=30, and number of DEG’s interconnected is 5 by dividing into Areas. In this case, the maximum losses in node bus number are selected for DEG’s installation. Each time power flow is evaluated to find Power loss and voltage is updated. Both cases are compares with voltage difference at each node bus graph is plotted in fig. 6.
In the 30-bus IEEE system, is ranging from 2MW-150MW as shown in table.3. Solar power system will interconnected to electrical grid. For the IEEE 30 bus system 33/11 kV and 132/33 kV rating is selected. The range of DEG’s system is sited at various locations of node buses as show in fig.1. If the proposed DEG’s is inserted it will reduce 87 MW losses. Solar power step of MW to each DEG’s, the initial power loss is obtained by a power flow computation.

**Table 3**

| Interfacing grid substation | Injection voltage level | Injection capacity at substation |
|-----------------------------|-------------------------|----------------------------------|
| 33/11 kV                   | 33 kV                   | 2 to 8                           |
| 132/33 kV                  | 33 kV                   | 6 to 15                          |
| 132/33 kV                  | 132 kV                  | 11 to 50                         |
| 220/132 kV                 | 132 kV                  | 11 to 50                         |
| 220/132 kV                 | 220 kV                  | 41 to 100                        |
| 400/220 kV                 | 220 kV                  | 51 to 150                        |

A. **Per Unit voltage selection:**

Fig. 11. Optimal sizing and sitting of DEG’s show before and after installations of solar at various node buses. The results are in agreement with the result with previous work. Notice at Load area 1 will installation of 50 MW is best location to reduction of power losses. Similarly load area 2, load area 3 and load 4 installation of 8MW respectively as show in table.4.

**Table 4**

| Area           | Highest load bus | Lowest load bus | Highest loss | Lowest loss |
|----------------|------------------|-----------------|--------------|-------------|
| Load area 1    | 5                | 28              | 6            | 8           |
| Load area 2    | 12               | 13              | 15           | 13          |
| Load area 3    | 21               | 9               | 20           | 9           |
| Load area 4    | 29               | 27              | 29           | 27          |

Though in reality the sizes will be fixed and power factor can be allowed to vary to observe the impact of DEG’s on power loss. It is interesting to see in table 7. Per unit are system is improved. Comparison of voltage level in PU at each bus before and after installation of solar power plotted in graph.

**Table 5**

| Generators | MW     | Load MW | Loss MW |
|------------|--------|---------|---------|
| Before solar | 477.16 | 381.01  | 96.15   |
| After solar  | 493.76 | 485.6   | 8.16    |
Fig.7 MW loss load area 1

Fig.8 MW loss load area 2

Fig.9 MW loss load area 3

Fig.10 MW loss load area 4

VI. PRACTICAL TEST SYSTEM

Technical feasibility for new and renewable energy (NRE) generation unit Bhavsat solar energy Pvt Ltd approved by central power distribution company of AP limited to connecting to power transformer capacity 5MVA with voltage rating 33/11 kV. Substation is anticipated maximum demand 2.25MVA, as show in fig.11 single line diagram EHT SS 33/11 kV with solar power plant will generation capacity of 2MW. Difference between load and generation capacity is 4.25 MW. In 33kV line is feasible to transmit the power with load and generation capacity 4.25MW with power transformer.
Fig.11. single line diagram EHT SS 33/11 kV with solar power plant.

Rated capacity 5MVA. Power transformer will able to load and generation capacity 0.75MW after installation of solar to existing 33 kV feeder. 33 kV feeder percentage of Regulation before installation of solar power plant %5.25 and after installation of solar power plant %5.55 show in table

| BUS No. | Per Unit Volt before solar | Per Unit Volt after solar | BUS No. | Per Unit Volt before solar | Per Unit Volt after solar |
|---------|---------------------------|--------------------------|---------|---------------------------|--------------------------|
| 1       | 1                         | 16                       | 0.54378 | 0.96417                   |
| 2       | 0.83857                   | 17                       | 0.53353 | 0.94363                   |
| 3       | 0.70691                   | 18                       | 0.46756 | 0.93325                   |
| 4       | 0.66299                   | 19                       | 0.46309 | 0.92724                   |
| 5       | 0.70736                   | 20                       | 0.47276 | 0.93005                   |
| 6       | 0.64045                   | 21                       | 0.51254 | 0.91427                   |
| 7       | 0.65471                   | 22                       | 0.51058 | 0.91050                   |
| 8       | 0.63523                   | 23                       | 0.47092 | 0.89506                   |
| 9       | 0.59912                   | 24                       | 0.45178 | 0.83503                   |
| 10      | 0.54247                   | 25                       | 0.38238 | 0.79281                   |
| 11      | 0.67326                   | 26                       | 0.30945 | 0.76983                   |
| 12      | 0.58732                   | 27                       | 0.37776 | 0.77815                   |
| 13      | 0.63983                   | 28                       | 0.60157 | 0.95348                   |
| 14      | 0.53833                   | 29                       | 0.18268 | 0.94405                   |
| 15      | 0.51818                   | 30                       | 0.19125 | 0.92968                   |

VII. CONCLUSIONS

This paper has proposed optimal sitting and sizing of multiple solar power system gird interconnection in distribution system network by using nonlinear constrains equations. OPF based on power loss and power margin was developed to pick up point optimal sitting location.

After connecting multiple solar powers system to an electrical network system, this paper will be used to making decision in minimizing power losses and maximizing profit margin to increasing regulation and performance of the system.

Simulation results show economical dispatch of final siting solar power system in IEEE 30 bus system within limits of operating section of voltages and currents ratings

Practical result is verified the implemented system in 33 KV Nagaladinne feeder show the improvement in power regulation and minimizing losses.

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AUTHOR PROFILE

S. Yogendra Reddy, received B.Tech from Acharya Nagarjuna University Guntur, India. Presently he is pursuing M.Tech from K.L University, Guntur, India. He has published more than two journals and conferences recent trends in power system. His current research interests include solar power systems, power system planning, and renewable energy sources and micro grids.

D. Seshi Reddy, received B.E and M.Tech from Andhra University college of engineering and National Institute of Technology Calicut, India in 2002 And 2004,respectively. Presently he is pursuing Ph.D from JNT university, Hyderabad. Since 2007, he has been with the department of electrical and electronics engineering, K.L. University, where he is currently an associate professor. He has published more than ten journals and conferences recent trends in power system. His current research interests include measurement of power quality problems, Flexible AC transmission systems, and renewable energy sources and micro grids.

Dr. G. Kesava Rao, obtained his PhD from Moscow Power Engineering Inst. Moscow, U.S.S.R. He worked in Institute of Technology at Banaras Hindu University, Varanasi, India in various administrative and academic positions. Currently, he is working as professor in K.L. University, Guntur, A.P., India. His fields of interest are power system deregulation and renewable energy sources.