Optimal Placement and Sizing of DER’s with Load variations using Shuffled Frog Leap Algorithm

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Abstract— This paper presents an algorithm for optimal placement and size of the Distributed energy resources (DERs) considering system loss minimization and voltage profile improvement as objective functions. DERs are the energy resources which contain renewable energy resources such as wind, solar and fuel cell and some artificial models like micro turbines, gas turbines, diesel engines, sterling engines, and internal combustion reciprocating engines. Combinations of DER studies and for every combination, indices, active and reactive losses and voltage profiles are studied. The work is tested on 37-bus distribution system with different % of loading like 90%, 100% and 110% of Base load condition. The simulation technique based on shuffled frog leap algorithm is studied. For all cases current injection based distribution load flow method is used.

Keywords-Distributed Energy Resource (DER); % of Loading; Loss minimization; Optimization Algorithm; Shuffled frog leap algorithm;

I. INTRODUCTION

The Distributed Energy resource (DER) is the electricity generated at consumer end and thereby reduces the problem associated with transmission and distribution losses, costs, saving of the fuel, reduction of sound pollution and green house gases, unreliability of the grid and the problem of remote and inaccessible regions [1]. Other benefits include peak shaving, better voltage profile, relieving of transmission and distribution congestion then improved network capacity, protection selectivity, network robustness, and islanding operations [2-3]. DER technologies are encouraged in the electrified villages where, many are dissatisfied with the quality of grid power.

The more common DER technologies include Micro Turbines, Wind Turbines, Biomass, and Gasification of Biomass, Solar Photovoltaics and Hybrid systems. However, most of the plants are based on Wind Power, Hydel Power and Biomass and Biomass Gasification. The technology of Solar Photovoltaics, wind power are costly and nature dependent. The Fuel cells and Micro turbines are yet to be commercialized.

The maximum benefits of DER and the impact of DER on power losses is not only affected by DER location but also depends on the network topology as well as on DER size and type [1,8]. For better understanding, efficient and robust operation, the load flow studies incorporating DERs, Distribution Automation and Demand Side Management, the mathematical modeling is very essential. For different type of DERs separate mathematical modeling is required. Literature in [4-7] is available for different DER models in Distribution system load flow. Influence of DER on transmission congestion also depends on location of DER in distribution system. Strategically located DER units may utilize the upstream transmission system less, if opportunely operated, and thereby helping to relieve congestion in the transmission network.

Akorede et al.[1] presents a review of different optimization techniques for optimal placement and size of the DER. In the papers [4-8], DERs are modeled as constant power injection source and multiple DERs are not considered. Singh et al.[9] have discussed the size and location of the DER for ‘different load models’, but offered no details about the multiple DER placement and size and type of DERs. Further, the DER is modeled as unity Power factor source with fixed rating at 0.63p.u for all studies. In this present work, the objective is to optimize DER location and size, while minimizing system real, reactive losses and to improve voltage profile. The renewable DERs Wind and Solar are modeled as constant power factor (p.f) model and variable reactive power model in current injection based load flow.

The new shuffled Frog leap technique is used for optimization. Yammani et al.[10] implemented the Shuffled frog leap algorithm for placement and sizing of DERs, but the modeling of the DERs is not included. The SFLA is a real coded population based meta-heuristic optimization method that mimics the mimetic evolution of a group of frogs when seeking for the location that has the maximum amount of available food [11]. It is the combined algorithm of the local search tool of the PSO and mixing information from Parallel Local Searches to move toward a global solution. The whole work is done for % of loading of Base load 90%, 100% and 110% of the Base load is considered and implemented.
II. IMPACT INDICES AND OBJECTIVE FUNCTION

A. Impact Indices

1) Real and Reactive loss indices (ILP and ILQ)

The active and reactive losses are greatly depending on the proper location and size of the DGs. The indices are defined as

\[
ILP = \left( \frac{TPloss_{DER}}{TPloss_{WODER}} \right)
\]

\[
ILQ = \left( \frac{TQloss_{DG}}{TQloss_{WODER}} \right)
\]

2) Voltage profile Index (IVD)[12]

\[
IVD = \max_{i \geq 2} \left( \frac{|V_i| - |V_{i-1}|}{|V_i|} \right)
\]

The voltage profile of the system is depending on the proper location and size of the DGs. The IVD is defined as.

3) MVA capacity index (IC)[12]

The IC index gives the important information about the line of MVA flow through the network regarding the maximum capacity of conductors. The IC can be defined as

\[
IC = \max_{j=1}^{n} \left( \frac{|S_j|}{|C_j|} \right)
\]

This index penalizes the size and location pair which gives higher flow deviation of the line from the MVA capacity of the line, hence make the uniform line flows in the system without congestion.

B. Objective function

The main objective of this paper is to study the effect of placing and sizing the DG in all system indices given previously. Also observe the study with renewable bus available limits. Multi objective optimization is formed by combining the all indices with appropriate weights. The multi objective function is defined as

\[
OF = (W_1 \times ILP + W_2 \times ILQ + W_3 \times IC + W_4 \times IVD)
\]

In this paper the weight are considered [12] as \( W_1=0.4, \ W_2=0.2, \ W_3=0.25 \) and \( W_4=0.15 \) and by taking into account constraint

\[
\sum_{k=1}^{4} W_k = 1 \quad \text{where} \quad W_k \in [0,1]
\]

The weights are indicated to give the corresponding importance to each impact indices for the penetration of DGs and depend on the required analysis. In this analysis, active power losses have higher weight (0.4), since the main importance is given to active power with integration of DG.

The least weight is given to the IVD, since the IVD is normally small and within permissible limits. The OF(5) is to minimize with equality and inequality constraints.

Equality constraints

\[
P_{gs} + \sum_{DER=1}^{m} P_{DER} = P_{load} + P_{loss}
\]

Inequality constraints

\[
V_{i_{min}} \leq V_i \leq V_{i_{max}}
\]

Where, OF is the Objective function, IC is line flow Index, IVD is Voltage Profile Index, \( V_i \) is Reference bus voltage, \( V_i \) is Voltage of \( i^{th} \) bus including \( DER \), \( V_{i_{max}} \) is the Maximum bus voltage at bus \( i \), \( V_{i_{max}} \) is the Maximum bus voltage at bus \( i \), \( n \) is Number of busses, \( S_l \) is the Substation Bus Power, \( m \) is Number of \( DER \), \( P_{gs} \) is Active power generation by \( DER \), \( P_{load} \) is the Total system load, \( P_{loss} \) is the Total system active power loss, \( n \) is the Number of lines, \( P_{DER} \) is the Injected \( DER \) active power at \( i^{th} \) bus, \( TPloss_{DER} \) is the Total Ploss with \( DER \), \( TQloss_{DER} \) is the Total Qloss with \( DER \), \( TPloss_{WODER} \) is Total Ploss without \( DER \), ILP and ILQ are the Ploss and Qloss Indices, IVD is the Voltage Profile Index. The IVD is the Voltage Profile Index. The IVD is the Voltage Profile Index. The IVD is the Voltage Profile Index. The IVD is the Voltage Profile Index.

III. SHUFFLED FROG LEAP ALGORITHM (SFLA)

The SFLA is a real coded population based metaheuristic optimization method that mimics the mimetic evolution of a group of frogs when seeking for the location that has the maximum amount of available food. It is based on evolution of memes carried by the interactive individuals and a global exchange of information among themselves [11]. In essence, it combines the benefits of the local search tool of the PSO [13] and mixing information from Parallel Local Searches to move toward a global solution [14]. PSO is an Evolutionary Optimization method which is based on the metaphor of social interaction and communication such as Bird Flocking and Fish Schooling. PSO is initialized with random solutions (swarm), every individual or potential solution, called Particle, flies in the dimensional problem space with a velocity which is dynamically adjusted according to the flying experiences of its own and its social group [15]. In the SFLA, the population consists of a set of frogs [16] with the same structure but different adaptabilities. Each frog represents the feasible solution to optimization problem and is partitioned into subsets referred to as memeplexes. The different memeplexes are considered as different cultures of frogs, each performing a local search.

A. Overview of SFLA

Assume that the initial population is formed by generating \( F \) frogs randomly pop (i), \( i = 1,2,\ldots, F \). Evaluate the fitness \( fit(i) \) of \( i^{th} \) frog by a know method and arrange the frogs in ascending order of their fit values. This goes as initial step before forming the memeplex as shown in Fig.1 [17]
In each memeplex assume n-frogs for m-memeplexes. Then, F frogs will be equal to ‘mn’. The entire population [17] of F frogs is partitioned into m memeplexes according to their fitness values. If F=30, m=5 then n equals to 6.

In Fig.1, the Fth frog will have the highest fitness value and 1st frog will be with lowest fitness value. For each memeplex, the best value will appear as the last entry and is named as ‘imbest’. Among those imbest values of all m-memeplexes, the best will be taken as global best and termed as ‘best’.

IV. MODELLING OF DERS IN LOAD FLOW STUDIES

In system with DERS, the generation of Photovoltaic systems, Fuel cells, Micro turbines and some Wind turbine units are injected into the power grid via power electronic interfaces. In such cases, the model of a DER unit in load flows depends on the control method which is used in the converter control circuit. The DERS which have control over the voltage by regulating excitation voltage (Synchronous generator DERS) or by the ‘P’ and ‘V’ independently controlled converter circuit, and then the DER unit may be model as PV type. Other DERS like Induction generator based units or ‘P’ and ‘Q’ independently controlled converter are shall be modeled as PQ type. Using these models for DERS, Current injection based load flow method is employed for Distribution system studies.

A. Current Injection Based Load Flow (CILF)

The traditional load flow methods like Gauss-Siedel, Newton-Raphson and Fast Decoupled techniques are inefficient to solve Distribution networks due to the radial structure and wide range of resistance with low X/R ratios. Several methodologies have been proposed to solve the power flow problem in Distribution Systems like Vector based Distribution load flow, Primitive Impedance Distribution load flow and Forward & Backward Sweep Distribution load flow. But all the methods have limitations like, not applicable for meshed distribution systems and implementation become complex when control devices are present in the system. The CILF [18] can used for both radial and mesh systems and easy to implementation of control devices.

B. DER modeled as PQ node

A DER unit can be modeled as three different ways in PQ node mode as illustrated below:

1) DER as a ‘negative PQ load’ model of PQ mode

In this case the DER is simply modeled as a constant active (P) and reactive (Q) power generating source. The specified values of this DER model are real (PDER) and reactive (QDER) power output of the DER. It may be noted that Fuel cell type DERS can be modeled as negative PQ load model. The load at bus-i with DER unit is to be modified as

\[ P_{load,i} = P_{load,i} - P_{DER,i} \]  \hspace{1cm} (10)
\[ Q_{load,i} = Q_{load,i} - Q_{DER,i} \]  \hspace{1cm} (11)

2) DER as a ‘constant power factor’ model of PQ mode

The DER is commonly modeled as constant power factor model [19]. Controllable DERS such as synchronous generator based DERS and power electronic based units are preferably modeled as constant power factor model. For example, the output power can be adjusted by controlling the exciting current and trigger angles for synchronous generator based DERS and power electronic based DERS, respectively [19]. For this model, the specified values are the real power and power factor of the DER. The reactive power of the DER can be calculated by (12) and then the equivalent current injection can be obtained by (13)

\[ Q_{DER} = P_{DER} \tan^{-1}(PF_{DER}) \]  \hspace{1cm} (12)
\[ I_{DER} = I_{DER}(V_{DER}) + jV_{DER} \left( \frac{P_{DER} + jQ_{DER}}{V_{DER}} \right) \]  \hspace{1cm} (13)

3) DER as ‘Variable Reactive Power’ model of PQ mode

DERS employing Induction Generators as the power conversion devices will act mostly like variable Reactive Power generators. By using the Induction Generator based Wind Turbine as an example, the real power output can be calculated by Wind Turbine power curve. Then, its reactive power output can be formulated as a function comprising the real power output, bus voltage, generator impedance and so on. However, the reactive power calculation using this approach is cumbersome and difficult to calculate efficiently. From a steady-state view point, reactive power consumed by a Wind Turbine can be represented as a function of its Real Power [7], that is

\[ Q_{DER} = Q_0 - Q_1P_{DER} - Q_2P_{DER}^2 \]  \hspace{1cm} (14)

Where Q’iDER is the Reactive Power function consumed by the Wind Turbine. The Q0, Q1 and Q2 are usually obtained experimentally. The reactive power consumed by the load cannot be fully provided by the distribution system, and therefore capacitor banks are installed for power factor correction where induction generator based DERS is employed.
C. DER modeled as PV type

The DER as a PV node is commonly Constant voltage model. The specified values of this DER model are the real power output and bus voltage magnitude. For maintain constant voltage the, change in voltage $\Delta V_i$ should maintain zero by injecting required reactive power.

V. SFLA IMPLEMENTATION FOR OPTIMAL PLACEMENT AND SIZING OF DER

In this paper SFLA based optimization technique is used to find the optimal placement and size of the DER by minimizing the losses and voltage improvement. The SFLA contains 80 frogs divided into 4 memeplexes, each memeplex contains 20 frogs. Here binary coded frog is taken and it contains 20 bits 8 are for placement of the DER and remaining 12 are for Size of the DER. The information about the DERs is taken by decoding the frog. The fig.2 shows the flow chart of optimal place and size of the DER. Maximum numbers of iterations is limited to 500.

VI. RESULTS AND VALIDATION

For testing the proposed algorithm, the test data of 38 Bus Distribution systems is considered. In the test data, given load is taken as base load. System data of Distribution system is available in paper [20]. The 90% and 110% of the base load is taken for optimal placement and sizing of DERs at all load variable conditions. Table I shows the optimal Placement and sizing of DERs with base load condition. Single DER integration and various combination DERs are also presented in tables. With the maximum number of DERs integration the active power losses is decreased from 0.20221 to 0.02890 and Reactive power loss from 0.13484 to 0.02054. Table II shows the Impact indices of base loading condition, the lower the indices represent the best performance of the system. The Fuel cell integration is shows the least performance than the other DERs because it is modeled as constant voltage model. In this constant voltage model, the required p.u voltage at optimal bus is maintained. Table III shows the optimal Placement and sizing of DERs with 90% of base load. With the maximum number of DERs integration the active power losses is decreased from 0.161277 to 0.02485 and Reactive power loss from 0.1075 to 0.0174. The placement of the single DERs are almost same of the base case but in case of multiple DERs the bus numbers are changing in sensible busses like 7,11,13,14,28,29,30,31 and 32.

TABLE I. OPTIMAL PLACE AND SIZE OF THE DERs WITH BASE LOAD

<table>
<thead>
<tr>
<th>S.No</th>
<th>Distribution type</th>
<th>Optimal DER BUS Number</th>
<th>DER Value (*100kW)/reactive power loss (*100kVAR)</th>
<th>Active power loss (100%kW)</th>
<th>Reactive power loss (100%kVAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No DER Added (Base Case)</td>
<td>0.20221/0.13484</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>DER as Negative load</td>
<td>14/0.63</td>
<td>0.1428/0.09457</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Solar</td>
<td>31/0.630/3.227</td>
<td>0.11886/0.0794</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Fuel cell</td>
<td>30/0.63/2.5146</td>
<td>0.14206/0.1003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Wind mill</td>
<td>13/0.471</td>
<td>0.17652/0.1174</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Neg.load model &amp;Solar</td>
<td>13/0.6275</td>
<td>0.07555/0.0499</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Neg.load model, Solar&amp;Fuel cell.</td>
<td>32/0.627/0.321</td>
<td>0.14/0.608/0.311</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Combination of All 4 DERs</td>
<td>28/0.575</td>
<td>0.02947/0.0206</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TABLE II. PERFORMANCE INDICES FOR BASE LOAD

<table>
<thead>
<tr>
<th>Der as Negative load</th>
<th>Solar</th>
<th>Fuel cell</th>
<th>Wind mill</th>
<th>Neg.load model &amp;Solar</th>
<th>Neg.load model, Solar &amp; Fuel cell.</th>
<th>All 4 DERs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILP</td>
<td>0.7064</td>
<td>0.5878</td>
<td>0.702</td>
<td>0.872</td>
<td>0.3736</td>
<td>0.1457</td>
</tr>
</tbody>
</table>
The placement of the single impact indices for 90% IVD IC ILQ ILP of IVD IC ILQ ILP of 0.5688 0.8953 0.5612 0.0578 0.1448 0.5009 0.02987 0.0209

<p>| TABLE III. OPTIMAL PLACE AND SIZE OF THE DERs WITH 90% OF BASE LOAD |</p>
<table>
<thead>
<tr>
<th>Distribution generations type</th>
<th>S.No</th>
<th>Optimal DER BUS Number</th>
<th>DER Value (*100kW)/reactive power (*100kVAR)</th>
<th>Active power loss (100*kW)</th>
<th>Reactive power loss (100* kVAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 No DER Added (Base Case)</td>
<td>1</td>
<td>0.6169</td>
<td>0.013551</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>2 DER as Negative load</td>
<td>13</td>
<td>0.6293</td>
<td>0.02296</td>
<td>0.0166</td>
<td></td>
</tr>
<tr>
<td>3 Solar</td>
<td>31</td>
<td>0.597/0.306</td>
<td>0.02485</td>
<td>0.0174</td>
<td></td>
</tr>
<tr>
<td>4 Fuel cell</td>
<td>29</td>
<td>0.6169</td>
<td>0.013551</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>5 Wind mill</td>
<td>11</td>
<td>0.69/0.21</td>
<td>0.02485</td>
<td>0.0174</td>
<td></td>
</tr>
<tr>
<td>6 Neg. load model &amp;Solar</td>
<td>0.5688</td>
<td>0.63/0.3227</td>
<td>0.05531</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>7 Neg. load model, Solar &amp; fuel cell</td>
<td>30</td>
<td>0.63/0.3227</td>
<td>0.05531</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>8 Combination of All 4 DERs</td>
<td>31</td>
<td>0.334</td>
<td>0.02485</td>
<td>0.0174</td>
<td></td>
</tr>
</tbody>
</table>

<p>| TABLE IV. PERFORMANCE INDICES FOR 90% OF BASE LOAD |</p>
<table>
<thead>
<tr>
<th>DER as Negative load</th>
<th>Solar</th>
<th>Fuel cell</th>
<th>Wind mill</th>
<th>Neg. load model &amp;Solar</th>
<th>Neg. load model, Solar &amp; Fuel cell</th>
<th>All 4 DERs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILP</td>
<td>0.6910</td>
<td>0.5578</td>
<td>0.6421</td>
<td>0.8699</td>
<td>0.3429</td>
<td>0.1423</td>
</tr>
<tr>
<td>ILQ</td>
<td>0.6868</td>
<td>0.5612</td>
<td>0.6811</td>
<td>0.8684</td>
<td>0.3410</td>
<td>0.1552</td>
</tr>
<tr>
<td>IC</td>
<td>0.8945</td>
<td>0.8955</td>
<td>0.9469</td>
<td>0.8945</td>
<td>0.8944</td>
<td>0.8944</td>
</tr>
<tr>
<td>IVD</td>
<td>0.0646</td>
<td>0.0642</td>
<td>0.0481</td>
<td>0.0695</td>
<td>0.0377</td>
<td>0.0169</td>
</tr>
<tr>
<td>OF</td>
<td>0.6410</td>
<td>0.5688</td>
<td>0.637</td>
<td>0.7550</td>
<td>0.4345</td>
<td>0.3140</td>
</tr>
</tbody>
</table>

<p>| TABLE V. OPTIMAL PLACE AND SIZE OF THE DERs WITH 110% OF BASE LOAD |</p>
<table>
<thead>
<tr>
<th>Distribution generations type</th>
<th>S.No</th>
<th>Optimal DER BUS Number</th>
<th>DER Value (*100kW)/reactive power (*100kVAR)</th>
<th>Active power loss (100*kW)</th>
<th>Reactive power loss (100* kVAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 No DER Added (Base Case)</td>
<td>1</td>
<td>0.6169</td>
<td>0.013551</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>2 DER as Negative load</td>
<td>13</td>
<td>0.6293</td>
<td>0.02296</td>
<td>0.0166</td>
<td></td>
</tr>
<tr>
<td>3 Solar</td>
<td>31</td>
<td>0.597/0.306</td>
<td>0.02485</td>
<td>0.0174</td>
<td></td>
</tr>
<tr>
<td>4 Fuel cell</td>
<td>29</td>
<td>0.6169</td>
<td>0.013551</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>5 Wind mill</td>
<td>11</td>
<td>0.69/0.21</td>
<td>0.02485</td>
<td>0.0174</td>
<td></td>
</tr>
<tr>
<td>6 Neg. load model &amp;Solar</td>
<td>0.5688</td>
<td>0.63/0.3227</td>
<td>0.05531</td>
<td>0.0366</td>
<td></td>
</tr>
<tr>
<td>7 Neg. load model, Solar &amp; fuel cell</td>
<td>30</td>
<td>0.63/0.3227</td>
<td>0.05531</td>
<td>0.0366</td>
<td></td>
</tr>
</tbody>
</table>

Table V shows the optimal Placement and sizing of DERs with 110% of base load. With the maximum number of DERs integration the active power losses is decreased from 0.248599 to 0.02987 and Reactive power loss from 0.16582 to 0.0209. In this case also the placement of the single DERs are almost same of the base case but in case of multiple DERs the bus numbers are changing in sensible busses like 7,11,13,14,28,29,30,31 and 32 Table III and Table IV shows the impact indices for 90% and 110% of Base load case. With the addition of multiple DERs the losses are decreasing but the number of the DERs increased from 3 to 4 the loss reduction ratio is comparatively less in all the load cases, therefore the DER number is limiting to 4.

Figure 3. Voltage profile with combination of DERs for Base load

Figure 4. Voltage profile with combination of DERs for 90% of Base load

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Figures 3, 4 and 5 are the voltage profiles of base load, 90% of base load and 110% of the base load conditions. In the base load the lowest voltage occurred at 19th bus, is 0.91. With the decrees of the base loading the voltage profile increased and the 19th bus voltage is improved to 0.925. the same bus voltage when 110% of load condition is again dropped to 0.905. Because of the low variation of the placement of the DERs in 90% and 110% of load conditions, the DERs can fix in to the same busses founded in base case.

VII. CONCLUSIONS

In this paper an algorithm for optimal placement and size of the DERs is proposed considering system loss minimization and voltage profile improvement as objective functions. The solar and wind systems are modeled as constant power factor model and variable reactive power model and the other two; Fuel cell and Micro turbine are modeled as negative load model and constant voltage model respectively. Combinations of DERs also studied and for every combination, all indices, active and reactive losses and voltage profiles are studied. The proposed algorithm is tested for base load, 90% of the base load and 110% of the base load and results are presented. This work is tested on 37-bus distribution systems and results are found to be satisfactory.

REFERENCES


