Multi-objective Pareto based Optimal Placement and Sizing of Solar PV and Wind Generation System

M.S.Giridhar, P.Sobha Rani

Abstract**:** ***Appropriate placement and sizing of distributed generation is required for reducing power loss and improvement in voltage profile of power system. Solar photovoltaic (PV) and wind energy are two prominent sources of distributed generation. In this paper, the authors propose a novel method to analyze the optimal placement and sizing of the solar PV and wind generation system in a radial distribution system..A multi objective function is selected for optimal siting and sizing. A 33-bus distribution system has been considered for testing the developed algorithm. Optimal location is obtained by placing DG source at each bus and satisfying objective function. Jaya algorithm is implemented for optimal sizing of PV and wind system. Also the system has been analyzed by placing the solar PV and Wind generation system independently and then simultaneously.***

Keywords: Multi objective Jaya algorithm (MOJA), Radial Distribution System (RDS), solar PV (photo voltaic), wind energy. About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

The increase in demand for electricity can be met by renewable power generation. Renewable energy sources have advantages of less green house emissions, reduced cost and small in size. Distributed generation (DG) also called local generation is connected at appropriate points of distribution network. These sources generate power near to the loads, thus reducing the need for expansion of the new transmission line. The net line losses in the system are also reduced. The technologies mainly used in DG are fuel cell, micro turbines, solar PV and wind. As these renewable resources form a micro-grid to supply the power to the local loads, they reduce the burden on the thermal and hydro generating plants. To get the maximum benefits their type, number, location and size should be selected properly. Otherwise, improper placement leads to power loss and deviation from voltage limits. Among DG technologies, solar and wind sources are more popular due to their abundant availability, flexibility in operation.

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* Correspondence Author
M.S.Giridhar*, Department of Electrical and Electronics Engineering,Lakireddy Bali Reddy college of Engineering, Mylavaram, India. Email: munigoti7@gmail.com
P.Sobha Rani, Department of Electrical and Electronics Engineering, Lakireddy Bali Reddy college of Engineering, Mylavaram, India. Email: sobhareveru@gmail.com

Much research work utilizing analytical and heuristic methods has been carried out for optimal sizing and placement of DG. Hybrid algorithm of particle swarm optimization (PSO) and Honey bees mating optimization (HBMO) is implemented to obtain optimal location and sizing of multi DGs [1].PSO based optimal power flow is implemented to select best candidate buses for optimal location of DG with objective of reduced power loss [2]. Imperialist competitive algorithm is applied to determine the optimal siting and sizing of single DG in distribution systems[3].A new method for placement of solar PV and wind energy system is implemented for voltage stability improvement [4]. PSO technique is used to get the optimal location of different types of DG at optimal power factor and the results compared with analytical method [5]. Monte Carlo Simulation is implemented for DG placement [6]. The authors considered wind turbine generator as DG. A heuristic method is presented for placement of solar PV system. Optimal siting and sizing of distributed generation along with reconfiguration of distribution networks for maximum loss reduction was discussed by new heuristic method [7]. Four optimization techniques cuckoo search, gravitational search, PSO, genetic algorithm are used for appropriate placement and sizing of renewable energy system with objective of reduction in power loss. Genetic algorithm technique appears to be slow and gravitational search algorithm fast [8]. In most research papers the objective functions are one or two of the following: power loss reduction, voltage profile (stability) improvement, minimizing cost function, optimal power factor and improving reliability indices. In this paper, Jaya algorithm with multi objective function including real, reactive power loss reduction, reducing voltage deviation, and maximizing power factor for optimal placement and sizing of solar PV and wind generator is implemented. The impact of both these sources on distribution network is also studied. Power flow implementation combined with the optimization method is used to obtain the result.

II. PROBLEM FORMULATION

A. Proposed DG models and objective functions

The distributed generator models considered here are
(i) Solar PV generation (Only active power injections)
(ii) Wind turbine generation (Both active and reactive power injections)
Any optimization problem involves maximization or minimization of objective function by satisfying equality and inequality constraints.

In this paper the multi objective functions considered are:

$$OF_1 = min \sum_{k=1}^{32} B_k^2 R_k$$

$$OF_2 = min \sum_{k=1}^{32} B_k^2 X_k$$

$$OF_3 = \min\left(V_{sp} - \left(\frac{\sum_{j=1}^{nbus} V_j}{nbus}\right)\right)^2$$

$$OF_4 = \min\left(pf_{sp} - pf_{sys}\right)^2$$

Where, B_k is the branch currents in the feeders.

R_k and X_k are the branch resistance and reactance respectively.

V_{sp} is the rated/specified voltage at each bus i.e 1.0 p.u.

OF_1, OF_2, OF_3 and OF_4 are the objective functions of minimization of total system active power losses, minimization of total system reactive power losses, OF_3 converted to maximization of voltage deviation Index and OF_4 is converted to maximization of system power factor Index.

B. Jaya Algorithm

It is specific parameter-less algorithm proposed by R. Venkata Rao [14] in 2016. Let $f(x)$ is the objective function to be minimized (or maximized). At any iteration i, assume that there are 'm' number of design variables, 'n' number of candidate solutions (i.e. population size, p =1,2,…,n). Let the best candidate *best* obtains the best value of $f(x)$ (i.e. $f(x)_{best}$) in the entire candidate solutions and the worst candidate *worst* obtains the worst value of $f(x)$ (i.e. $f(x)_{worst}$) in the entire candidate solutions. If $X_{q,p,i}$ is the value of the q^{th} variable for the p^{th} candidate during the i^{th} iteration, then this value is modified as per the following Eq. (1).

$$X'_{p,q,i} = X_{p,q,i} + r_{1,q,i}(X_{q,best,i} - |X_{q,p,i}|) - r_{2,q,i}(X_{q,worst,i} - |X_{q,p,i}|) \quad ....(1)$$

Where, $X_{q,best,i}$ is the value of the variable q for the *best* candidate and $X_{q,worst,i}$ is the value of the variable q for the *worst* candidate. $X'_{p,q,i}$ is the updated value of $X_{p,q,i}$ and $r_{1,q,i}$ and $r_{2,q,i}$ are the two random numbers for the q^{th} variable during the i^{th} iteration in the range [0, 1]. The term "$r_{1,q,i}(X_{q,best,i} - |X_{q,p,i}|)$" indicates the tendency of the solution to move closer to the best solution and the term "$-r_{2,q,i}(X_{q,worst,i} - |X_{q,p,i}|)$" indicates the tendency of the solution to avoid the worst solution. $X'_{p,q,i}$ is accepted if it gives better function value.

III. NUMERICAL RESULTS AND DISCUSSIONS

Analytical study has been carried out to identify the minimum and maximum values of objective functions independently for the DG models considered by injecting active and reactive powers in to the RDS.Simultaneous multi-objective optimization of DG Size has been carried out using the MOJA on 33-Bus RDS.

A. Pareto analysis of optimal DG placement and sizing

Proposed algorithm is as follows :

Step-1: Initialize the distribution network line and load data.

Step-2: For the available solar and wind power distributed generation, obtain the optimal location based on the feasibility region of the objective space obtained in the range of DG power active and reactive power injections.

Step-3: For a single objective case with the objective function of minimization of total active power losses (TAPL), minimization of total reactive power losses (TRPL), minimization of voltage deviation index (VDI) and maximization of system power factor, subjected to the total generation should match with the total load, for optimal location of DGs.

Step-4: For the considered two objective functions at a time, a pareto optimal solution have been obtained using the multi-objective JAYA Algorithm, with two objectives at a time, and the obtained results are tabulated and useful for thesystem planner/operator for online optimal location and sizing of DGs. The offline results obtained can be used to train neural networks to predict the location and size in the scenario of smart grid operation.

Step-5: The optimal DG Size satisfying both the objective functions has been obtained as output for the test system. Also, the improved voltage profile and the objective function values have been obtained.

B.Procedure to identify the optimal location and size:

(a) Single DG Case

1. Place each DG at each bus starting from the bus other than the slack Bus.
2. To find the optimal location and sizing of the considered distributed generators at a particular bus based on the study of the search space of optimal DG, active and reactive power injections in a range of 200 kW to 1350 kW each has been carried out.
3. The obtained optimal size and location of each DG satisfying each objective function independently are presented in Table-1.

(b) Double DG Case

Double DG Location Implementation Procedure

1. Initially set the DG power injections in the range of 200 kW to 1350 kW, with an incremental power injection in each step of 25 kW,perform power flow solution to compute over all total active power losses (TAPL) in the system for each power injection, find the minimum TAPL of the system obtained for a specific power injections of DG.
2. Repeat Step-1 by fixing the location of solar-DG at Bus-2 and location of wind-DG at Bus-2, Bus-3,......Bus-33.
3. With Step-1 and Step-2, 32 values of minimum TAPL of the system obtained for specific power injections of DG.
4. Again the Step-1 is repeated by fixing the solar-DG at Bus-3 and locating of Wind-DG at Bus-2, Bus-3,......Bus-33 to get 32 values of minimum TAPL of the system.

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5. Similarly the Step-4 is repeated with changing the location of Solar-DG to Bus-4,Bus-5,......Bus-33 and all 32 sets of minimum TAPL of the system are computed.
6. By performing above steps 32 number of minimum TAPL of the system are obtained (a Look-up Table),Thus the feasible region of minimum TAPL for the DG power injections of step-1 has been obtained.
7. From the values obtained in step-6 it is possible to locate/Identify the best possible locations of DG satisfying the minimum TAPL of the system.
6. The Step-1 to Step-7 are repeated for different objective function independently to find the location of DGs, which are presented in Table-I.

Table-I: The DG Sizes satisfying the proposed objective functions independently

Objective functions	Min(TAPL) **kw**	Min(TRPL) **kw**	Max(VDI)	Max power factor
	DG Size **kw**	DG Size **kw**	DG Size **kw**	DG Size **Kw**
Single DG Type-II (Both P & Q Injections) **(Solar-DG at Bus-30)**	**71.341**	**51.695**	**0.97897**	**0.9248**
	1300	**1254**	**1351**	**1357**
Single DG Type-I (Only P Injections) **(Solar-DG at Bus-30)**	**128.619**	**89.558**	**0.9542**	**0.9894**
	1350	**1350**	**1350**	**1350**
Solar and Wind Type-I (Only P Injections) **(Solar-DG at Bus-30 and Wind-DG at Bus-13)**	**96.62**	**65.81**	**1.0**	**1.0**
	1043 **884**	**1013** **862**	**1192** **988**	**1218** **835**
Solar and Wind Type-II (Both P & Q equal Injections) **(Solar-DG at Bus-30 and Wind-DG at Bus-11)**	**37.18**	**26.56**	**1.0**	**1.0**
	948 **816**	**926** **801**	**882** **770**	**1065** **900**

Table I gives the optimal values of total active and reactive power losses, power factor and the mean voltage of the 33-bus radial distribution system, with DG placed at each bus correspondingly. This feasibility study reveals the optimal location and sizing of the DG to be placed to satisfy the above mentioned parameters of the system, subjected to total generation matching with the load.
Each value in the table is obtained by observing the objective spaces of total active and reactive power losses, system power factor and the mean voltage of the system in the range of DG power injections of DG-1 (Solar Generator) 500 kW to 1350 kW in the steps of 25 kW and DG-2 (Wind Generator) 500 kW to 1100 kW in steps of 25 kW, the minimum values of total system active power losses, reactive power losses, the maximum power factor and mean voltages are specified.
The values in the table indicate the maximum size of DG beyond which the extra power is pumped to the grid, as there is increase in TAPL and TRPL as well as the voltage and currents flowing in lines go beyond limit.Figure 1 and figure2 represents total real power loss (TAPL) and total reactive power loss (TRPL) with single DG power injection at each bus.

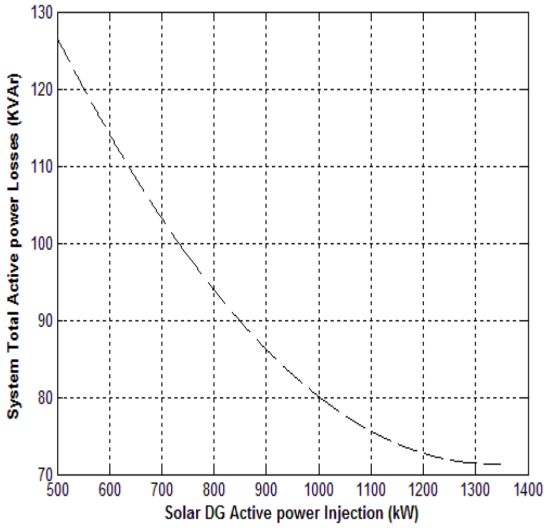

Fig-1: The TAPL with Single DG power injection at each bus

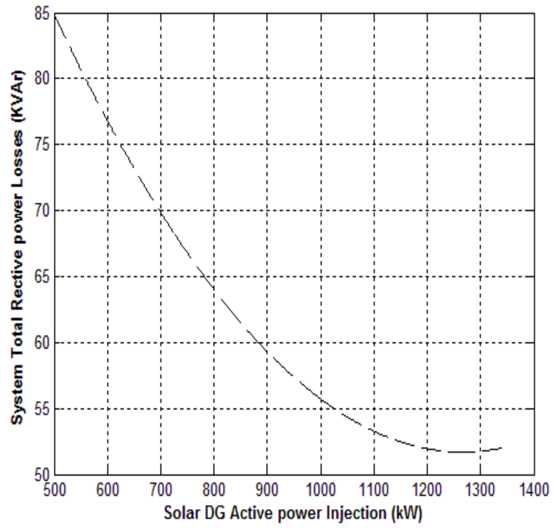

Fig-2: The TRPL with Single DG power injection at each bus

The following pareto optimal solutions have been obtained for the two objective functions taken at a time with the range of DG1 Injections of 200 to 1350 kW, and DG2 Injections in the range of 200 to 1100 kW, for the case (a). The range of DG1 injections being from 500 to 850 kW and DG2 being 500 to 800 kW for the case (b). The range of DG1 injections of active and reactive powers in the range of 800 to 1350 kW and DG2 being 800 to 1100 kW as for the case (c).

Case a) Minimization of Total Active power Losses Vs Minimization of Total Reactive Power Losses.

Caseb) Minimization of Total Active power Losses Vs Maximization of Voltage Deviation Index .

Case c) Maximization of Voltage Deviation Index Vs Maximization of power factor.

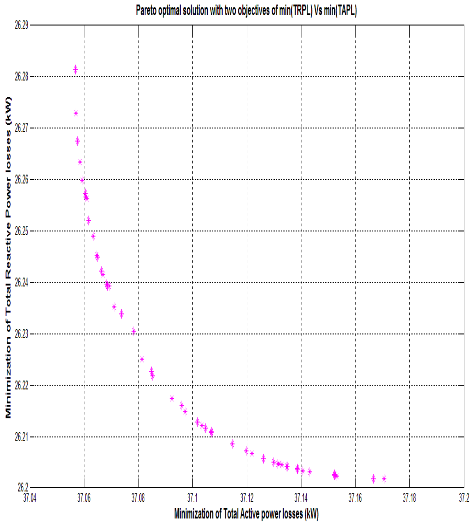

Fig-3: Pareto solution for the case (a)

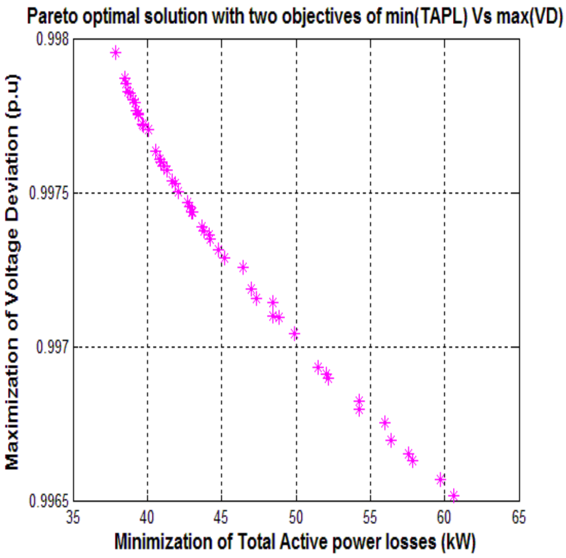

Fig-4: Pareto solution for the case (b)

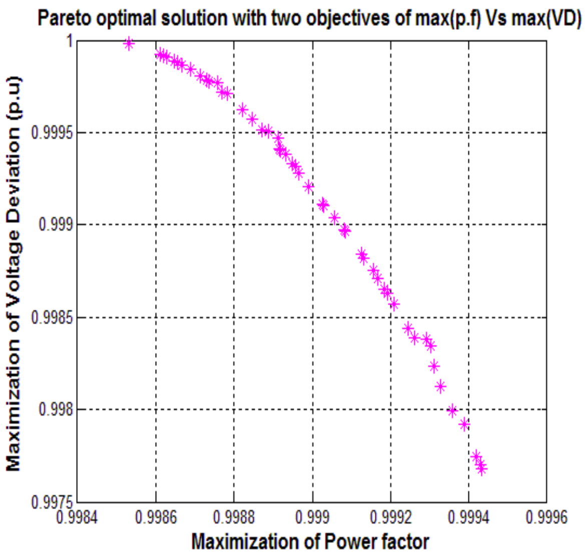

Fig-5: Pareto solution for the case (c)

For the injected DG powers, the voltage profiles of the system for the dominant and non-dominant regions of objective functions are presented in figure 6, 7 and 8 for the three cases of Pareto sets.

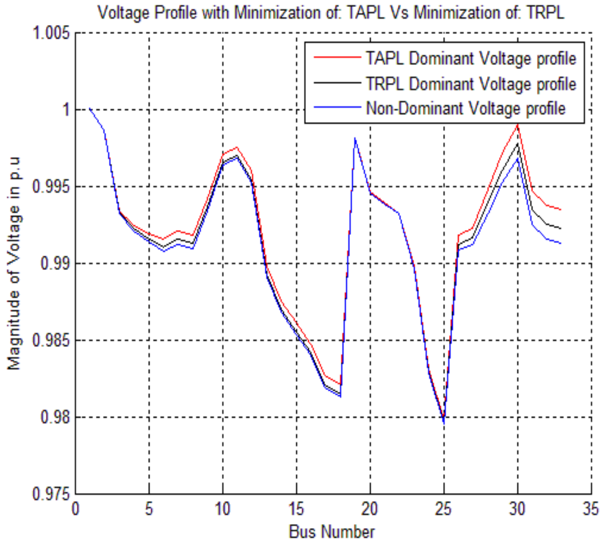

Fig.6: Voltage Profile for the case (a).

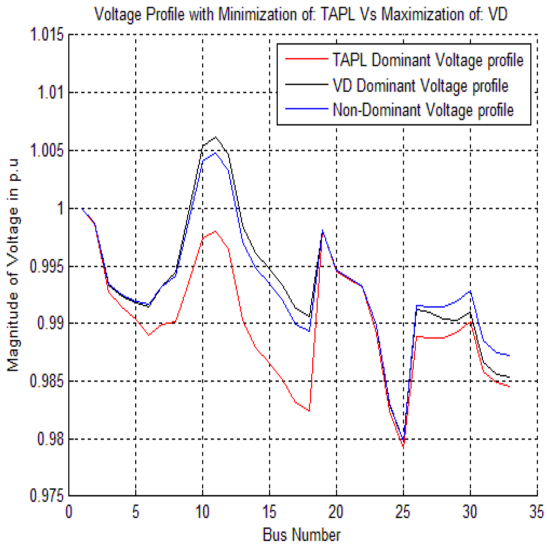

Fig.7: Voltage Profile for the case (b).

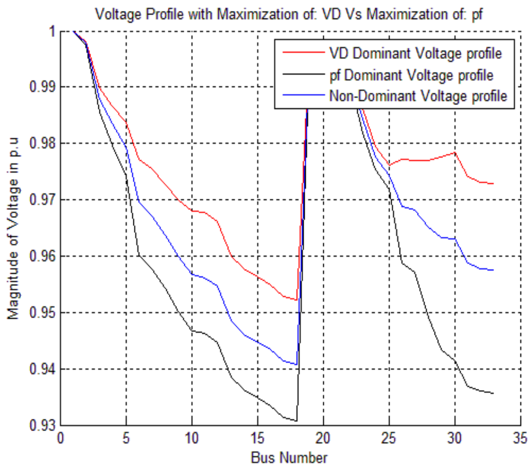

Fig.8: Voltage Profile for the case (c)

Similarly, for the injected DG powers, the active and reactive power flows in the branches of the system for the dominant and non-dominant regions of objective functions are presented in figures 9 to figure14 for the three cases of Pareto sets. It has been observed that the active and reactive power flows in the branches close to the substation are more with two objectives of case(c) than case (a) & (b). Also it is observed that the variation in the branch power flows for the dominant and non-dominant case are less in the case (a) than in the case (b) and (c).

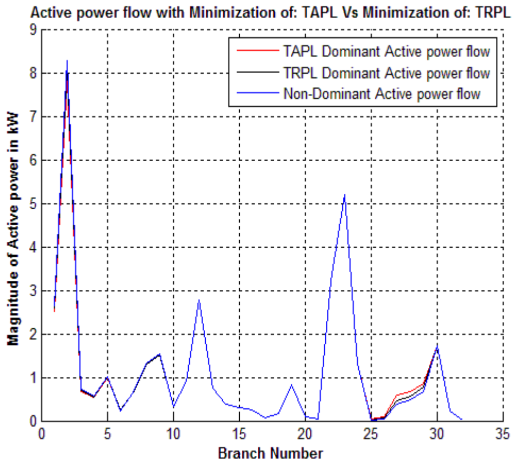

Fig.9: The branch active power flows in each branch for the case (a)

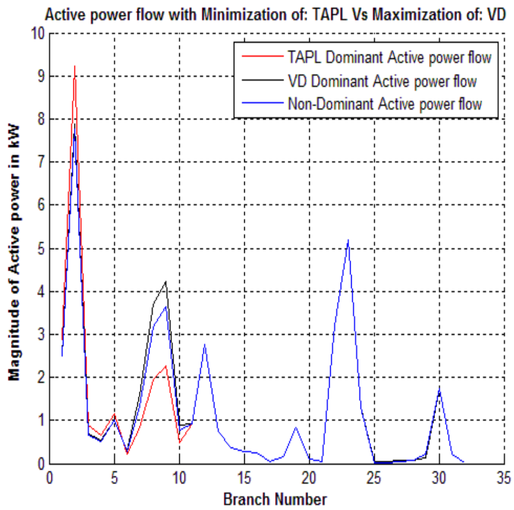

Fig.10: The active power flows in each branch of the case (b).

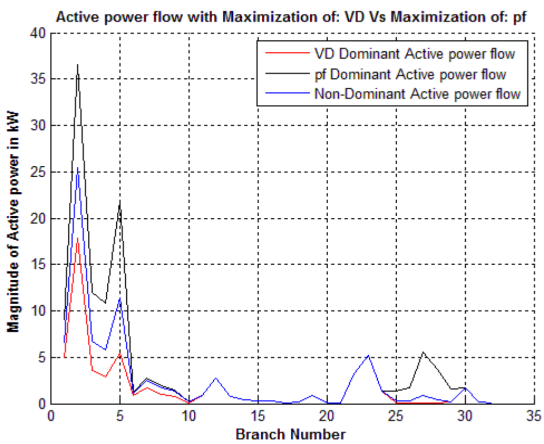

Fig.11: The active power flows in each branch of the case (c)

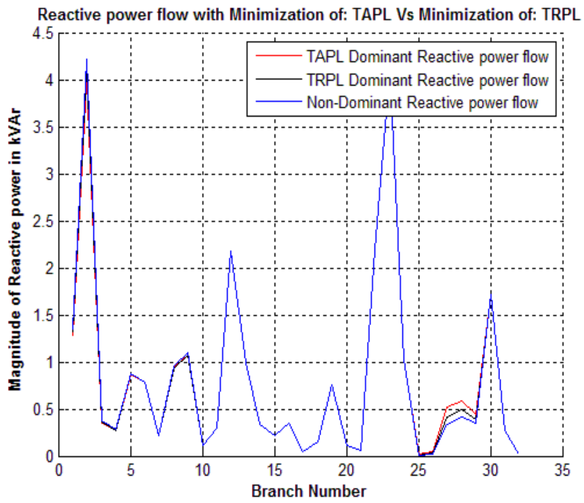

Fig.12: The reactive power flows in each branch for the case (a)

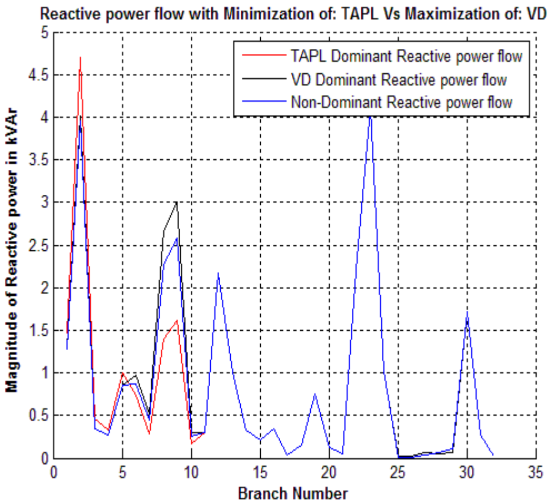

Fig.13: The reactive power flows in each branch of the case (b)

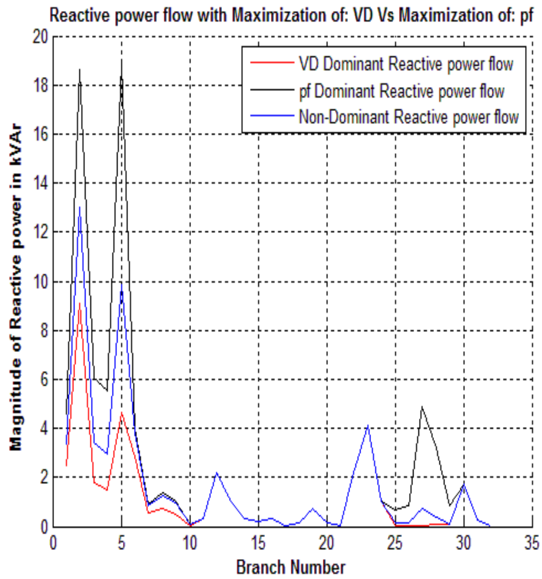

Fig.14: The reactive power flows in each branch of the case (c).

The following observations can be made from the above plots :

1. The pareto optimal solution set is convex for the case when both the objective function are minimization, and also for the case with one objective of maximization and other as minimization.
2. The pareto optimal solution set is concave for the case when both the objective function are maximization.
3. The maximum DG power injections happened in the case when the maximization of voltage deviation index is taken as the objective functions, with the second objective function being the minimization of total reactive power losses of the system, or the minimization of total active power losses of the system.
4. The standard deviation of the pareto set values are more, when both the objective functions are maximization, also if one of the objective function is power factor.
5. Skewness characterizes the degree of asymmetry of a distribution around its mean. Positive skewness indicates a distribution with an asymmetric tail extending toward more positive values. Negative skewness indicates a distribution with an asymmetric tail extending toward more negative values.
6. The skewness is more negative when the maximization of voltage deviation index is taken as objective function.
7. Also it is observed that with the increase in the load the negative skewness of DG sizes in the pareto set is alsoincreasing.

IV. CONCLUSION

In this paper the authors have proposed an analytical method to search the optimal location and sizing of the DGs satisfying independent objective functions for the considered test RDS. Simultaneous multiobjective optimal sizing of the DGs have been achieved with the pareto optimal solution set using multiobjective Jaya Algorithm. The solution sets with the DGs sizes have been presented satisfying two objectives taken at a time as this is more realistic that we need to satisfy the voltage at each bus to be within limits as well as the total active/reactive power lossesof the system should be minimum and the overall power factor should be maximum in the scenario of ever changing dynamic/electronic loads used by the customers. Also the dominant and non-dominant voltage profiles and branch currents for the test RDS have been presented for the three cases taking two objectives at a time.

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AUTHORS PROFILE

Dr. M.S.Giridhar completed M.Tech from NIT.Calicut. He received P.hD degree from J.N.T.U.Kakinada. He is presently working as Professor in Lakireddy Bali Reddy college of Engineering, Mylavaram. He has more than 20 publications to his credit in various national and international journals. His areas of interest include power systems, distributed generation, power flows, optimization techniques.

Dr. P.Sobha Rani completed M.Tech from JNTU Hyderabad.She received P.hD degree from S.V.university, Tirupathi. She is presently working as Professor in Lakireddy Bali Reddy college of Engineering, Mylavaram. She has more than 16 publications to her credit in various national and international journals. Her areas of interest include power quality, distributed generation, automation and converters.