2020 IEEE 7th Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON) | 978-1-6654-0373-3/20/$31.00 ©2020 IEEE | DOI: 10.1109/UPCON50219.2020.9376508

Optimal planning framework of three phase unbalanced distribution system using multiple DG and DSTACOM under different loading condition

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Abstract— **In recent times nations across the world are facing an unprecedented crisis due to coronavirus (Covid-19) outbreak, which has adversely affected health care system, economy and the societies across the globe. Resilient power utility system is the need of the hour to revive the economy. Distribution systems across many parts of the globe have the problem of high system loss, high voltage unbalance and poor maintenance of system voltage profile. In this paper the major aim in allocating Distributed Generation (DG) and DSTATCOM is to reduce line loss, decrease voltage unbalance and to maintain the voltage profile in the practical unbalanced distribution system. Improvement of these system performance parameters will in turn enhance the system resilience. Improved Particle Swarm Optimization based on success rate (IPSO-SR) is chosen as the optimization algorithm to solve the planning problem. Security constraints of voltage profile, power factor and power flow were considered in the problem. To validate the proposed methodology IEEE 37 bus feeder which is a real 4.8 KV feeder of California is chosen. The system performance is analyzed for residential load demand as per its growing demand in current pandemic situation. Open Distribution system simulator software (Open DSS) is used for three phase unbalanced power flow analysis of the network. Result of the work validates the effectiveness of this approach.**

Keywords— Electrical distribution system, Distributed Generation, DSTATCOM, voltage unbalance, power loss reduction, IPSO-SR

I. INTRODUCTION

In present scenario nations across the world are facing an unprecedented situation due to Covid-19 outbreak. Considering this, the long -term focus of power sector across the world has shifted majorly towards enhancing the system sustainability and resilience. Recently there has been a paradigm shift from corporate single office to distributed residential areas. As a result, the commercial and industrial power demand has reduced and there has been a rise in residential load demand. This " new normal" trend will continue in the coming years as the companies are gearing up for expediting work from home facility to their employees in response to the current pandemic condition. Distribution system should be planned in accordance to current situation considering fall in commercial and industrial load demand [1]

Decentralized Distributed Generation can play a major role in this situation to provide uninterrupted power to the residential region. DG can also aid in enhancing the network performance which will in turn improve the system resilience [2]. The distribution system is major part of the power system, which can drive different kinds of loads at various operating voltages. Due to high R/X ratio, distribution network have high system losses as compared to transmission system.

Issue of voltage unbalance is another important aspect of the distribution networks. Effects of unbalance voltage may include shunt and series faults in network, breakdown of components, motors to operate in single phase, fuse burnout. These factors may cause serious damage to the equipment's [3].

Poor maintenance of voltage profile is another important problem faced by the networks. During peak load period the low voltage problem arises due to consumption of reactive power by the inductive loads. Similarly, during low load condition high voltage problem occurs [2].

Incorporation of Distributed Generation (DG) and DSTATCOM can improve all the technical parameters. DG and DSTATCOM can locally inject real and reactive power in the network and thus contribute significantly in improving the system parameters. Amalgamation of DG and DSTATCOM in the network defers the requirement of system upgrades. Capacitor does not function properly in light load and it is very slow in comparison with DSTATCOM that means DSTATCOM is more superior to Capacitor because it is extremely fast and it can easily provide and absorb reactive power in all loading condition Major advantage of DSTATCOM is that it can reduce voltage unbalance [3-4].

However, DG and DSTATCOM should be incorporated in the network after proper planning [5-6]. To maximize the benefits it is very essential choose appropriate number, location and rating of the device to be allocated. Improper allocation will lead to harmful affect such as reverse power flow, high line loss and voltage unbalance.

In [6] authors have explained the technical advantage of allocation of solar and wind DG in the distribution network. Authors in [7] have described different methods to allocate DSTATCOM in the network with an aim to improve technical parameters such as reduction of the line loss, improvement of the voltage profile etc. It is observed that simultaneous placement of DG and DSTATCOM in the network [4] enhances the system benefits. It is noted that in most of the previous research works [6-7] did not consider the issue of voltage unbalance. Most of the test network chosen is balanced network whereas practically distribution networks are unbalanced in nature. Further the networks were not tested under voltage dependent residential load condition to validate the methodology [4-7].

In this paper, proper planning strategy is undertaken to simultaneous allocate DG and DSTATCOM in practical unbalanced distribution network. Improved Particle Swarm optimization based on success rate (IPSO-SR) [8] is used for allocation of DG and DSTATCOM. Minimization of voltage unbalance and system loss is considered as the fitness function. Security constraints of power network such as voltage, power flow, power factor are considered in order to get the optimal solution

IEEE 37 bus unbalanced test feeder [9] is used to validate the proposed methodology. Due to current situation of drop in commercial and industrial demand the proposed methodology is tested for both base load and low load condition. Open Distribution system simulator software (Open DSS) [3] developed by Electric Power research institute (EPRI) which is primarily used for electric power utility distribution network is used for three phase unbalanced power flow analysis in this paper. The solution results are compared with other algorithms such as Simple Particle Swarm Optimization (SPSO), Adaptive Particle Swarm Optimization (APSO) [8] to prove its efficacy in planning three phase unbalanced distribution network with DG and DSTATCOM.

II. DSTATCOM

Distributed static compensator termed as DSTATCOM, is primarily, a shunt connected custom device that introduce current at the point of common coupling (PCC). By the support of generating or absorbing reactive power static synchronous compensator maintain the overall voltage of the system. The principle part of DSTATCOM is controller, voltage source converter/inverter (VSC/VSI), energy storage device and RC filter. Fig.1 shows the diagram of DSTATCOM in distribution network. Six IGBT (insulated gate bipolar transistor) switches are utilized to makes VSC which is three phase. The form of load may be nonlinear load, an unbalance load or balanced load. VSC's AC side inductors are used so that DSTATCOM is connected to the system in shunt [10].

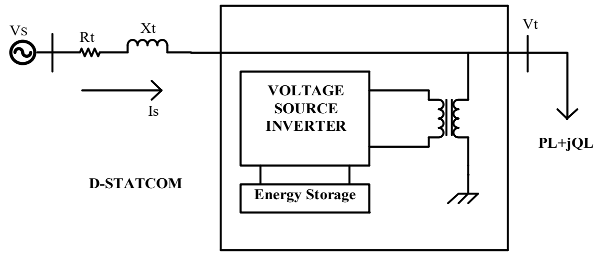

Fig.1 DSTATCOM allocated in distribution network.

III. TECHNICAL PARAMETERS

In this paper voltage unbalance, voltage profile and system loss is considered as the technical parameters. The detailed description of these parameters is gives as follows

A. Voltage Unbalance

Voltage unbalance has following effects on system and Equipment [5]

- Increase Neutral Return Current
- High power loss
- Reduce Motor life by heating, Vibration of Motor, Reduce Efficiency of motor, Motor failure.

Mathematically voltage unbalance can be expressed as

$$VU = V_2/V_1 \tag{1}$$

VU stands for voltage unbalance. V_2 stands for negative sequence voltage and V_1 stands for positive sequence voltage. Lower the voltage unbalance ratio better it is for the system. The safe voltage unbalance ratio in the distribution system is 2% [3].

B. Voltage Profile improvement

In distribution system voltage at the tail end of the network is generally low. For same power low system voltage leads to high current and increase system loss. Sustained poor voltage may lead to voltage instability. Proper planning of distribution network with DG and DSTATCOM incorporation leads to acceptable level of voltage in each and every bus [3] of the network Therefore voltage profile is considered as a technical parameter in this paper.

C. Loss reduction

Distribution networks have high R/X ratio, therefore it is susceptible to high system loss. Further various inductive loads are amalgamated in the system such as induction motors, electric furnace which draws reactive power. This leads to poor power factor and consequently high system loss. However local injection of active and reactive power by using DG and DSTATCOM can considerably improve the performance with regards to system loss. In this paper Loss reduction index (*LRI)* is used to quantify the loss reduction using DG and DSTATCOM. Mathematically *LRI* is expressed as follows:

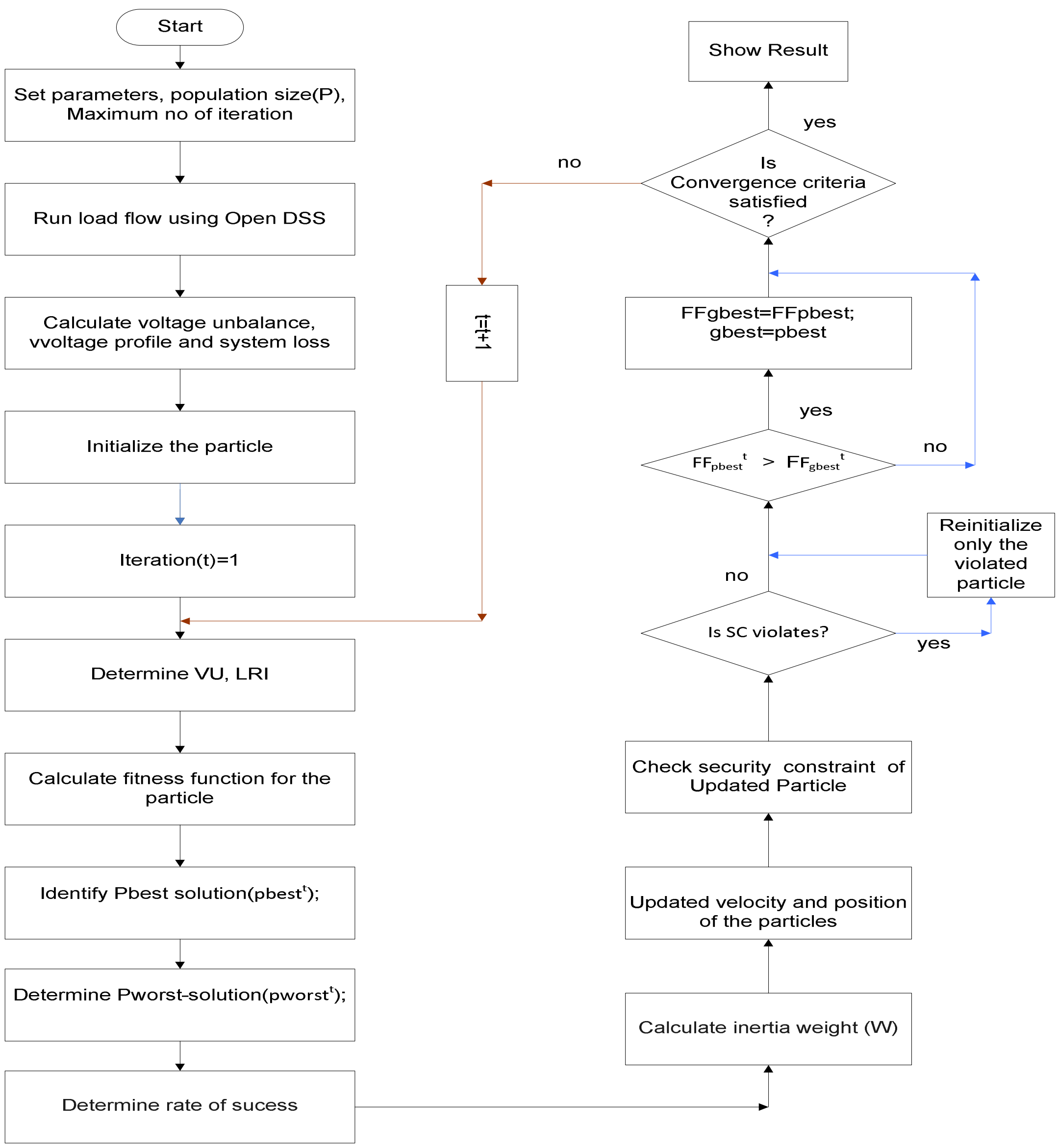

Fig. 2 Flow chart

$$LRI = L_{DG/DSTATCOM}/\ L_{\ without\ device} \qquad (2)$$

$L_{DG/DSTATCOM}$ and $L_{\ without\ device}$ in this paper indicates line loss with incorporation of DG, DSTACOM and without device respectively.

IV PROBLEM FORMULATON

In this paper DG and DSTATCOM is allocated in an unbalanced distribution network considering minimization of loss and voltage unbalance ratio. The fitness function is minimized considering various security constraints *(SC)* such as voltage profile, power flow and power factor.

The mathematical expression of fitness function is given as follows.

$$FF= w_1\ VU+\ w_2\ LRI \qquad (3)$$

Both the fitness function is given equal importance in this paper. Therefore, the value of w_1 and w_2 is considered as 0.5.

V. METHODOLOGY

In this paper IPSO-SR algorithm is used for optimal allocation of DG and DSTATCOM. The detail explanation regarding the algorithm is given in [8]. DG and DSTATCOM number, size and location are considered as the variable in this paper. DG is modelled as a real power source operating at unity power factor in this paper. Fig.2 shows the flowchart of the implementation of the IPSO-SR algorithm. The parameters used for the implementation of IPSO-SR strategy is as follows: Number of trials: 20 population size: 200; Maximum iteration: 100;inertia weight is set at 0.1 to 0.9 as lower and upper limit respectively and social coefficient is set at 2. The convergence criteria in this paper are the maximum number of iterations. All the load buses are set as prospective location and size of DG and DSTATCOM is varied from 10 % to 40% of total real and reactive power load respectively. Instead of constant power models practical voltage dependent residential load model is considered in this paper. A three-phase unbalanced load flow algorithm is solved using Open DSS. To maximize the system benefits DG and DSTATCOM are placed at the same bus.

To validate the proposed methodology IEEE 37 bus feeder [9] which is a real 4.8 KV feeder of California is chosen. The system is highly unbalanced in nature. There is one voltage regulator connected between bus 799 and 701. A transformer is connected between bus 709 and 775. This unbalance distribution system also consists multiphase that is single phase, two phase and three phase buses. In this system 701 and 728 are three phase buses. The one-line diagram of 37 bus test feeder is shown in Fig.3.

VI. RESULTS AND ANALYSIS

In this section technical result of 37 bus unbalanced distribution test feeder is given with the incorporation of DG and DSTATCOM under both base load and low load condition.

A. Planning under Baseload operation.

The base load operation of the distribution system is a setup without DG and capacitor. A three- phase unbalanced power flow analysis is done utilizing software Open DSS. At baseload condition the minimum per unit line to neutral voltages are found as 0.9679, 0.9671, and 0.9672 at bus no: 738, 740 and 741 respectively. Highest voltage unbalance ratio is found at bus number 711, 740 and 741as 3.423, 3.441 and 3.336 respectively. The total line losses and transformer losses are found as 62.3KW & 90 KW respectively and the total active power losses and total reactive power losses are 152.4 KW & 386 KVAR respectively. At base load condition the total active power load in the system is 2436 KW. Table I shows the results of optimal allocation DG and DSTATCOM in IEEE 37 test feeder. In this paper in order to enhance the significant benefits DG and DSTATCOM are allocated at the same bus. Fig 4 shows per unit line to neutral voltage at base load and per unit line to neutral voltage at Base load with DG & DSTATCOM. After strategic allocation of device the minimum per unit voltages are found as 0.9742, 0.9736, 0.9737 at bus no: 738,740 and 741 respectively. The per unit voltages are improved at each bus of the unbalanced distribution system as shown in Fig.3. Table II explains about the ratio of positive sequence voltage to the negative sequence voltage in the case of base load and with DG and DSTATCOM integrated. From Table II it is clearly visible that the system is highly unbalanced.

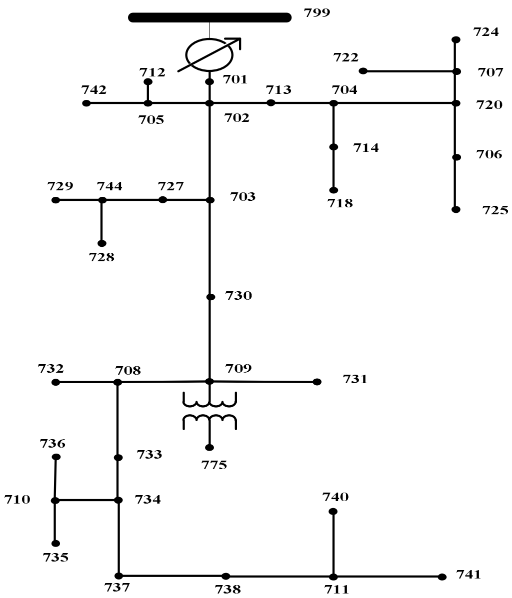

Fig.3 37 bus unbalanced test feeder

TABLE I. SIZE AND LOCATION OF DG AND DSTATCOM AT BASE LOAD

Bus Number	**Phases**	**DG rating (KW)**	**DSTATCOM rating (Kvar)**
735	A	21.25	10
728	A B C	31.5 31.5 31.5	15.75 15.75 15.75
740	A	21.25	10
720	A	21.25	10
730	A	21.25	10
713	A	21.25	10
734	A	10.5	5.25

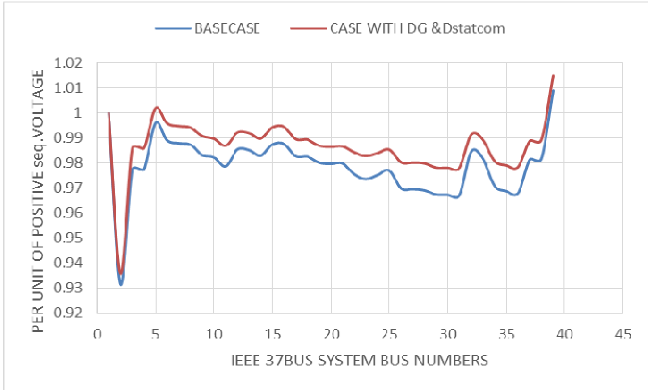

Fig.4 Voltage Profile graph at base case

TABLE II. VOLTAGE UNBALANCE RESULT AT BASE CASE

Bus number	Voltage unbalance without injection(%)	Voltage unbalance with injection(%)
799	1.795	0.5259
709	2.945	0.5829
775	2.945	0.5829
701	2.39	0.3215
702	2.556	0.344
705	2.549	0.3139
713	2.551	0.3602
703	2.749	0.4499
727	2.775	0.462
730	2.905	0.5465
704	2.509	0.4009
714	2.51	0.4078
720	2.45	0.4433
742	2.512	0.333
712	2.573	0.2837
706	2.432	0.4562
725	2.416	0.47
707	2.237	0.6292
724	2.192	0.6727
722	2.217	0.6488
708	3.03	0.6505
733	3.106	0.7277
732	3.045	0.6348
731	2.908	0.571
710	3.247	0.8052
735	3.266	0.8007
736	3.168	0.7911
711	3.423	0.9815
741	3.436	0.9749
740	3.441	0.9776
718	2.531	0.443
744	2.782	0.4809

734	3.23	0.8244
737	3.333	0.9571
738	3.384	0.9916
728	2.784	0.481
729	2.789	0.4965

To mitigate the adverse issue arising out of voltage unbalance as explained in Section III, DG and DSTATCOM is allocated. It is clearly observed from Table II that there is reduction in system voltage unbalance with planned incorporation of DG and DSTATCOM in the system. As observed from Table II in the entire system voltage unbalance ratio is within the prescribed limit of 2 %. Table III represents total line losses, total transformer losses and also total losses in the distribution system in case of base load and base load with DG and DSTATCOM. The result in Table III shows system loss with the deployment of DG and DSTATCOM reduces. This suggests that the planned injection of active and reactive power in the distribution at base case have a positive impact on system performance with regards to system loss.

TABLE III. RESULTS OF SYSTEM LOSS AT BASE LOAD WITH DG AND DSTATCOM

IEEE 37Bus Base Load	**Base Load with injected DG& DSTATCOM**
Total Line Losses= 62.3 kW	Total Line Losses= 55.8 kW
Total Transformer Losses= 90.0 kW	Total Transformer Losses= 83.9 kW
Total Losses= 152.4 kW	Total Losses= 139.7 kW

B. Low load Operation:

At low load operation (75 *base load) the low per unit line to neutral voltage are found as 0.9943, 0.993 and 0.9925 at bus number 735, 738 and 740 respectively. Highest p.u voltage is found as 1.014, 1.009 and 1.008 at bus number 701, 702 and 705 respectively. Table IV shows the results of DG and DSTATCOM allocation at low load case. Fig. 4 shows the voltage profile curve at low load conditions. The results clearly indicate that voltage at all the buses are maintained with the incorporation of DG and DSTATCOM. Due to local injection of real and reactive power in the network it is observed that there is no issue of under voltage and overvoltage in the network even with low load case. Table V shows the results of system loss with the incorporation of DG and DSTATCOM. The result shows that in low load condition there is significant loss reduction in the network. Table VI shows the voltage unbalance at low load Condition. It shows that in all the buses voltage unbalance ratio have reduced with planned incorporation of DG and DSTATCOM in the network.

TABLE IV. SIZE AND LOCATION OF DGS & DSTATCOM AT LOW LOAD

Bus Number	**Phases**	**DG rating (KW)**	**DSTATCOM rating (Kvar)**
728	A B C	21.5 21.5 21.5	15.75 15.75 15.75
740	A	21.25	10
730	A	21.25	10
734	A	10.5	5.25

TABLE V. RESULTS OF SYSTEM LOSS AT LOW LOAD WITH DG AND DSTATCOM

IEEE 37Bus Low Load(75%load)	**Low Load(75%load) with injected DG& DSTATCOM**
Total Line Losses= 34.3 kW	Total Line Losses= 29.8 kW
Total Transformer Losses= 48.6 kW	Total Transformer Losses= 43.9 kW
Total Losses= 82.9 kW	Total Losses= 73.7 kW

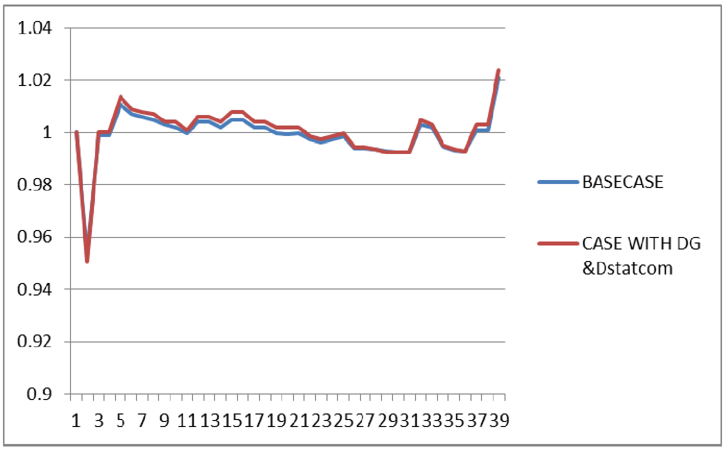

Fig. 5 Graph between bus number Vs per unit voltage in case of low load & low load with DG and DSTATCOM.

Table VI. RESULTS OF VOLTAGE UNBALANCE RATIO AT LOW LOAD CASE WITH DG AND DSTATCOM

Bus number	**Voltage unbalance without injection**	**Voltage unbalance with injection**
799	1.309	0.147
709	1.446	0.303
775	1.446	0.303
701	1.164	0.132
702	1.269	0.214
705	1.284	0.235
713	1.279	0.229
703	1.347	0.251
727	1.356	0.255
730	1.429	0.297
704	1.264	1.221
714	1.259	0.216
720	1.277	1.253
742	1.264	1.22
712	1.307	1.259
706	1.272	1.25
725	1.265	1.245
707	1.205	1.214
724	1.189	1.206
722	1.199	1.212
708	1.484	1.319
733	1.516	0.329
732	1.499	1.335
731	1.427	1.289
710	1.61	1.382
735	1.629	1.396
736	1.561	1.339

711	1.682	1.413
741	1.693	1.421
740	1.7	1.426
718	1.242	1.189
744	1.352	1.248
734	1.582	1.363
737	1.619	1.37
738	1.648	1.388
728	1.353	1.249
729	1.349	1.244
799r	0.9188	0.918

TABLE VII. COMPARISON OF SIMULATION RESULT

Different Parameters	APSO	‘SPSO	IPSO -SR
Convergence rate	40	45	35
Convergence time (second)	50	55	40
Standard deviation	0.235	0.250	0.011

Table VII shows the comparison of simulation results with different algorithm. The convergence rate in Table VII refers to number of iteration required for convergence of the algorithm. It is observed that the best results in terms of convergence rate, time and standard deviation which is a statistical parameter is obtained in case of IPSO-SR algorithm. This proves its efficacy in solving planning problems of unbalanced network.

VII. CONCLUSION

An optimal planning strategy is presented in this paper to allocate DG and DSTATCOM in unbalanced radial distribution system with an aim to reduce line loss, voltage unbalance and to maintain the system voltage profile. IPSO-SR algorithm is chosen to optimally allocate DG and DSTATCOM in three phase network. The results clearly indicate that additional injection of real and reactive power using DG and DSTATCOM in planned manner improves the systems performance parameters. Considering the present pandemic situation the system is planned considering voltage dependent residential load demand. To validate the proposed strategy it is tested for both base case load and case with low load condition. In both the cases the present planning strategy brought significant benefits in terms of reduction of voltage unbalance, system loss and improvement of voltage profile. This work is tested on the IEEE 37 bus systems and Open DSS software is chosen for unbalanced load flow study. The comparative results show the efficiency of IPSO- SR algorithm in terms of convergence and standard deviation. In future scope, new objective function will be formulated considering the reliability aspects of the system. Financial aspects will also be considered in future. Further to prove the efficacy of the algorithm IPSO-SR it will be compared with other benchmark functions. Other optimization algorithms such as Jaya algorithm [11] and teacher-learner-based-optimization [12], will be applied in future to solve the planning problem of unbalanced distribution network and the performance will be compared.

REFERENCE

[1] K. Baker, J. Guo, G. Hug, and X. Li, “Distributed MPC for efficient coordination of storage and renewable energy sources across control areas,” *IEEE Transactions on Smart Grid*, vol. 7, no. 2, pp. 992-1001, Mar. 2016.

[2] P. Sharma and A. Tandon, "Techniques for optimal placement of DG in radial distribution system: A review," *2015 Communication, Control and Intelligent Systems (CCIS)*, Mathura, 2015, pp. 453-458.

[3] S. Roy Ghatak, S. Sannigrahi and P.Acharjee,” Multiobjective Framework for Optimal Integration of Solar Energy Source in Three-Phase Unbalanced Distribution Network," in *IEEE Transactions on Industry Applications*, vol. 56, no. 3, pp. 3068-3078, May-June 2020,

[4] S. Devi and M. Geethanjali. "Optimal location and sizing determination of Distributed Generation and DSTATCOM using Particle Swarm Optimization algorithm." *International Journal of Electrical Power & Energy Systems"* vol.62 2014 pp.562-570

[5] N. Hayat, S. Roy Ghatak, S. Rani Pani and S. Mishra, "Performance Improvement of Three Phase Unbalance Distribution System Using DG and DSTATCOM," *2020 IEEE Calcutta Conference (CALCON)*, Kolkata, India, 2020, pp. 200-205

[6] P. Kayal, and C. K. Chanda. "Optimal mix of solar and wind distributed generations considering performance improvement of electrical distribution network." *Renewable energy* , vol.75, 2015, pp.73-186.

[7] P. M. Saradva, K. T. Kadivar, M. H. Pandya and A. J. Rana, "Reactive and real power compensation in distribution line using DSTATCOM with energy storage," *2016 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)* Chennai, 2016, pp. 726-732.

[8] S.R. Ghatak, S. Sannigrahi, and P. Acharjee, “Comparative performance analysis of DG and DSTATCOM in a deregulated energy market using improved PSO based on success rate,” *IEEE System Journal,* 2017

[9] I. Kim, R. Regassa and R. G. Harley, "The modeling of distribution feeders enhanced by distributed generation in DIgSILENT," *2015 IEEE 42nd Photovoltaic Specialist Conference (PVSC)*, New Orleans, LA, 2015, pp. 1-5,.

[10] S. R. Ghatak and P. Acharjee, "Optimal Allocation of DG Using Exponentential PSO with Reduced Search Space," *2016 Second International Conference on Computational Intelligence & Communication Technology (CICT)*, Ghaziabad, 2016, pp. 489-494.

[11] S. P. Singh, T. Prakash, M. G. Babu, “Analytic hierarchy process based automatic generation control of multi-area interconnected power system using Jaya algorithm”, Engineering applications of artificial intelligence, Vol. 60, No. 3, pp. 35-44, 2017.

[12] N. S. Rathore, “Design of optimal PID controller for the reverse osmosis using teacher-learner-based-optimization”, Membrane Water Treatment, Vol. 9, No. 2, pp. 129-136, 2018.