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Optimal Placement of Capacitor to Enhance the Efficiency of the Distribution Network

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Abstract**:** ***In this paper optimal placement of capacitor is carried out by using exhaustive load flow analysis for minimization of the power loss at different loading conditions. The shunt capacitor mainly used for reactive power compensation to maintain the good p.f in the network to improve the overall performance of the distribution networks. The obtained results are satisfactory interms of improvement in the efficiency of the distribution network operation.***

Index Terms**:** ***Capacitor placement, distribution network, exhaustive load flow analysis, power loss, and voltage profile.***

Notations used,

DG	Distributed Generation	AVR	Automatic Voltage Regulator
DTC	Distributed Transformer	FACTS	Flexible AC Transmission Systems
HVDC	High voltage DC	EMTP	Electromagnetic Transient Programming

I. INTRODUCTION

Due to modernization, every year 8-10% increase in the load, increases the burden on the generation, transmission and distribution systems. This leads to more losses in the network with low voltage profile. In distribution network 90% of the load is in inductive in nature and draws the more reactive power from the network causes huge increase in the current flowing in network makes the more power losses in the network interms of I^2R losses causes, heating effect in the power systems components reducing their life. Due to this effect, system will moves towards instability.

Many researchers are working to address these issues by,

- Network reconfiguration
- HVDC
- Introduction of FACTS devices
- DG Placement
- Line reconductoring
- Upgradation of transmission lines voltage levels
- AVR placement
- Smart substations
- Capacitor placement
- Smart metering
- Modern power system components
- Micro grids etc.,

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In this paper optimal placement of capacitor is chosen to improve the voltage profile in the network. The capacitors will supplies the required reactive power and maintain the good voltage profile in the network. The main objectives of the capacitor placement are,

- Improve the power factor in the network
- Minimize the power loss
- Release the pressure on the network
- Increase the voltage stability in the network

The main objective of the capacitor placement is power loss reduction and is given by,

$$\text{Min}\{P\text{loss}\} = \text{Min} \sum_{i=1}^{k} P_{(k,k+1)loss} \quad (1)$$

Where,

P_{loss} =Total loss in the circuit

$P_{(k,k+1)loss}$=Power loss in the branch connected between k and k+1

k= No. of non generators bus.

With Voltage profile,

$$V_{min} \leq V_k \leq V_{max}$$

Where,

V_{min}= Minimum voltage

V_k= Voltage at k^{th} node

V_{max}= Maximum voltage

The rest of this paper Methodology, results and discussions are explained in Section II and Section III Concludes the paper.

II. METHODOLOGY

The standard 14 bus is chosen as test system for optimal placement of the capacitors. The test has been carried out, with load factor 1.25 and 1.5 to illustrate the effectiveness of the placement of capacitor to minimize the power loss. The 14 bus network consists eleven loads dispersed in the network contributing total load of 375+91.875i. This power is supplied by three generators connected at bus 1, 2 and 3. It also consists of one shunt capacitor connected at bus 9 with 0.19p.u and three transformers are connected in the network. The analysis is carried out in MiPower 9.1 version. The MiPower software is user friendly power analysis package. It can be used for load flow analysis, harmonic analysis, short circuit analysis, EMTP and transient analysis. The load flow analysis carried out using Newton Raphson method. The load flow obtained results i.e., line flows and line losses are as shown in the Table.1

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Table.1 Line flows and line losses

From node	To node	Forward power flow		Power loss	
		MW	MVar	MW	MVar
1	2	120.894	67.595	3.3797	4.7123
2	3	12.749	-10.116	0.1083	-3.3241
2	4	57.032	13.611	2.0402	1.5431
2	5	50.235	16.283	1.6213	1.7376
3	4	46.916	21.215	1.7902	1.2635
4	5	-29.043	8.131	0.138	-0.7032
7	8	0.000	0.0000	0.000	0.000
6	11	8.914	3.359	0.1059	0.2218
6	12	14.515	3.773	0.3397	0.707
9	14	19.148	5.354	0.6217	1.3224
10	11	3.707	-0.852	0.0151	0.0353
12	13	1.675	1.066	0.0114	0.0104
1	5	71.244	39.919	3.3044	9.2315
6	13	30.703	10.17	0.8503	1.6745
13	14	6.516	2.301	0.0422	0.083
9	7	-48.093	-3.498	1.903	3.7476
9	10	16.33	6.724	0.1227	0.3261
1	3	164.21	37.768	4.9373	9.4109
6	9	-4.262	4.936	0.0166	0.0442

Algorithm for optimal placement of capacitor:

Step-1: Enter the generator, line, load, shunt devices and transformer data.

Step-2: Run the load flow analysis using NR method and compute the line flows, line loss, bus voltages and total loss.

Step-3: The capacitor should be placed at non generator bus for the required reactive power compensation.

Step-4: Select N= number of non generator bus.

Step-5: For capacitor placement every non generator bus will be considered as candidate bus in subsequent tests.

Step-6: For single capacitor placement run the load flow analyses for 'N' times and tabulate the voltage and total power loss in every test.

Step-7: Choose the candidate bus such a way that it gives the minimum power loss for capacitor placement.

Step-8: For two capacitor placement the combination of possible non generator buses is tested by running N*(N-1) times of load flow analysis.

Step-9: The suitable locations for multiple capacitors are chosen depending on minimum power loss with acceptable voltage limits at all the buses.

Case-1 Single capacitor placement with load factor 1.25

The optimal placement of first capacitor is as shown in the Table.2.The load flow analysis is carried out with capacitor placement at candidate bus. Out of N results few sample results are illustrated in the Table.2. Without connecting the shunt capacitor the power loss in the network is 12.913MW, after placement of capacitor the power loss reduction can be observed and capacitor at bus 13 will gives the minimum losses hence it can be used as optimal placement of single capacitor.

Table.2 Single capacitor placement results

Bus Number	Base Case	Capacitor Placement locations				
		Bus 4	Bus 6	Bus 8	Bus-13	Bus 14
1	1.060	1.060	1.060	1.060	1.060	1.060
2	1.0124	1.0177	1.0188	1.019	1.019	1.0186
3	1.0258	1.030	1.0305	1.031	1.030	1.0304
4	0.978	0.9935	0.9946	0.996	0.994	0.9945
5	0.9777	0.9899	0.9942	0.994	0.994	0.9937
6	0.9732	0.9896	1.021	1.008	1.019	1.0174
7	0.9956	1.0118	1.0271	1.043	1.027	1.0281
8	0.9956	1.0118	1.0271	1.079	1.027	1.0281
9	0.9705	0.9873	1.0124	1.009	1.013	1.014
10	0.9617	0.9786	1.0051	1.000	1.005	1.0058
11	0.9608	0.9775	1.0066	0.997	1.006	1.0052
12	0.9516	0.9684	0.9998	0.987	1.007	1.0025
13	0.9467	0.9636	0.9946	0.983	1.009	1.0027
14	0.9405	0.9577	0.9872	0.978	0.997	1.0101
Power Loss in MW	12.913	12.284	12.055	12.17	**12.03**	12.064

The Fig.1 shows the voltage comparison base case with capacitors at various locations. It is observed that the remarkable improvement of the voltage profile taken placed after connecting capacitor at bus 13. Fig.2 shows the power loss comparison after placement of capacitor at various candidate buses. In all cases minimum 500KW loss reduction can be observed only by placement one of shunt capacitor in the distribution network.

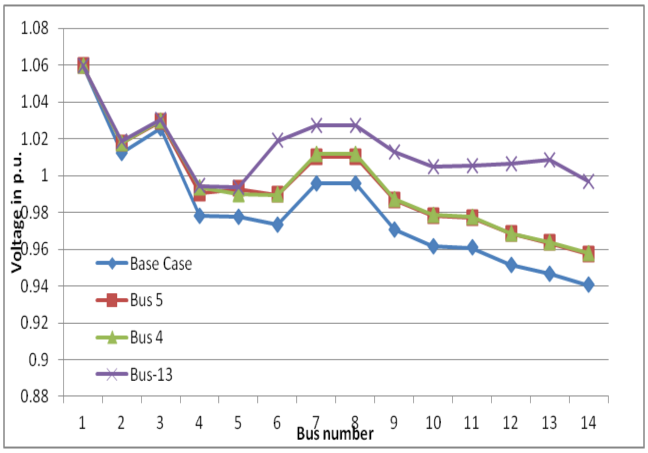

Fig.1 Voltage comparison with capacitor at various locations in the network

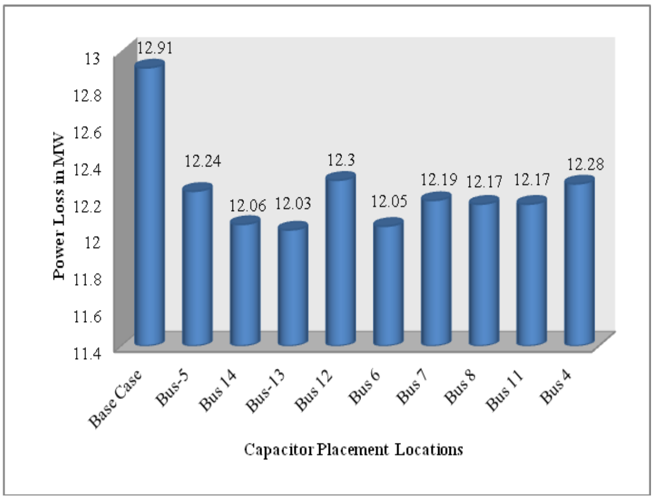

Fig.2 Power loss comparison with one capacitor placement in the network

Case.2 Two capacitor placement with load factor 1.25

The two capacitor placement is carried out by exhaustive load flow analysis with objective minimize the power loss with enhancement in the voltage profile. The possible combination of N*N-1 times load flow analysis has been carried out and obtained the results are tabulated as shown in the Table.3.After placement of two capacitor power loss reduction can be achieved more than the 1MW. After placing the capacitor at bus 6 and bus 13 the power loss reduced to 11.562MW with acceptable voltage limits. Fig.3 shows the voltage comparison with two capacitor placement in the network. Without capacitor the minimum voltage in the network was 0.9405p.u and with two capacitors the improvement of the voltage profiles occurred and minimum voltage in the network is 1.0122p.u. Fig.4 shows the power loss comparison with base case and with two capacitor placement at various locations.

Table.3 Two capacitor placement result

Bus No	Capacitor Placement locations				
	6,14	**5,14**	**6,13**	**4,11**	**5,8**
1	1.06	1.06	1.06	1.06	1.06
2	1.0255	1.024	1.0255	1.0243	1.0243
3	1.0354	1.034	1.0354	1.0348	1.0343
4	1.0122	1.0071	1.0122	1.0104	1.0084
5	1.0113	1.0092	1.0115	1.0066	1.0092
6	1.0687	1.0345	1.0704	1.038	1.0245
7	1.062	1.0431	1.0612	1.0438	1.0578
8	1.062	1.0431	1.0612	1.0438	1.0944
9	1.059	1.0307	1.0578	1.0298	1.0252
10	1.0523	1.0227	1.0516	1.0226	1.0163
11	1.0543	1.0223	1.0548	1.024	1.0141
12	1.0544	1.02	1.0588	1.0173	1.0044
13	1.0544	1.0203	1.0609	1.0121	1.0002
14	1.0612	1.028	1.0474	1.0049	0.9952
Power Loss in MW	11.586	11.627	**11.562**	11.658	11.7091

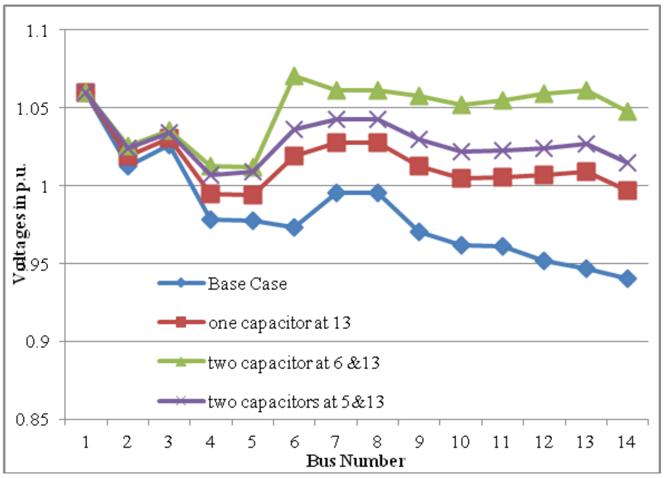

Fig.3 Voltage comparison with base case and capacitor at various locations in the network

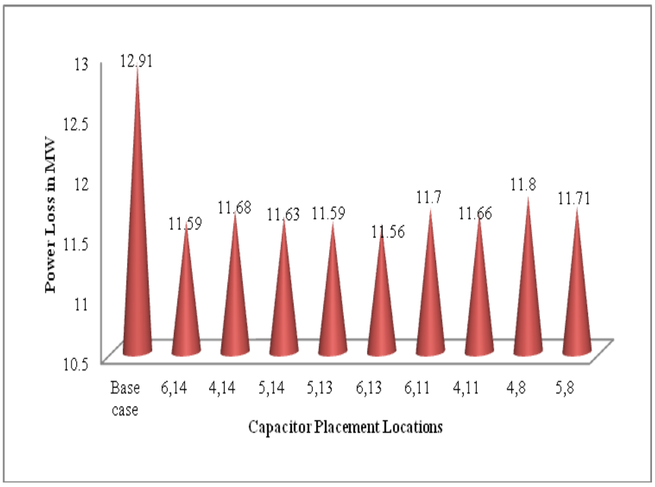

Fig.4 Power loss comparison with two capacitor placement in the network

Case.3 Three capacitor placement with load factor 1.25

The exhaustive load flow analysis is carried with three capacitor placement. The obtained results tabulated as shown in the Table.4. After selecting optimal location of three capacitors is bus 5, 8 and 13 leads to suppression of power loss achieved and it came down from 12.9126 MW to 11.2898MW.

Table.4 Three capacitor placement results

Bus Number	Base case	Capacitor Placement locations			
		4,7,12	**5,8,14**	**4,8,13**	**5,8,13**
1	1.06	1.06	1.06	1.06	1.06
2	1.0124	1.0308	1.031	1.0312	1.031
3	1.0258	1.0391	1.0393	1.04	1.0392
4	0.978	1.0254	1.0261	1.0294	1.026
5	0.9777	1.026	1.0264	1.0234	1.0265
6	0.9732	1.0729	1.0715	1.0716	1.0731
7	0.9956	1.0904	1.093	1.0949	1.0921
8	0.9956	1.0904	1.1309	1.1328	1.1299
9	0.9705	1.0687	1.0715	1.0723	1.0701
10	0.9617	1.0611	1.0632	1.0639	1.0623

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11	0.9608	1.061	1.0613	1.0617	1.0616
12	0.9516	1.0825	1.0584	1.0585	1.0626
13	0.9467	1.0579	1.0594	1.0596	1.0657
14	0.9405	1.0489	1.0689	1.0693	1.0547
Power loss in MW	12.912	11.5886	11.3451	11.4399	**11.2898**

Fig.5 shows the voltage profile comparison base case with optimal placement of one, two and three capacitors in the distribution network. From the Fig.5 it is observed that after feeding the appropriate amount of reactive power in particular locations leads to enhancement of the voltage profile with minimizing the power loss. After placement of three capacitors at their optimal location impressive loss reduction is observed with violation of the voltage limits i.e., 1.13p.u due to over compensation of the network. Hence optimal placement of two capacitors is suitable for minimization of the power loss without violation of the voltage limits.Fig.6 shows power loss comparison base case with three capacitor placement at various points in the network.

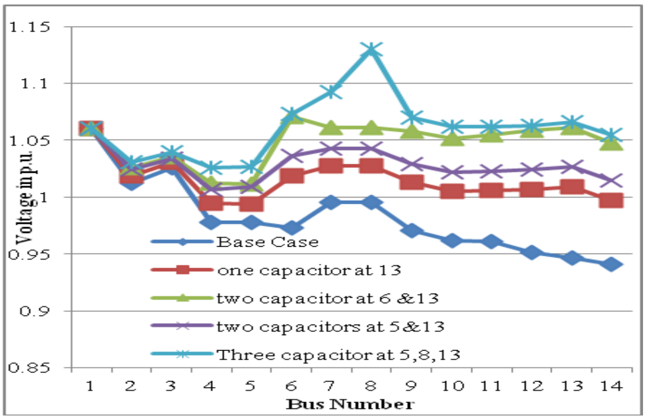

Fig.5 Voltage comparison with base case and capacitor at various locations in the network

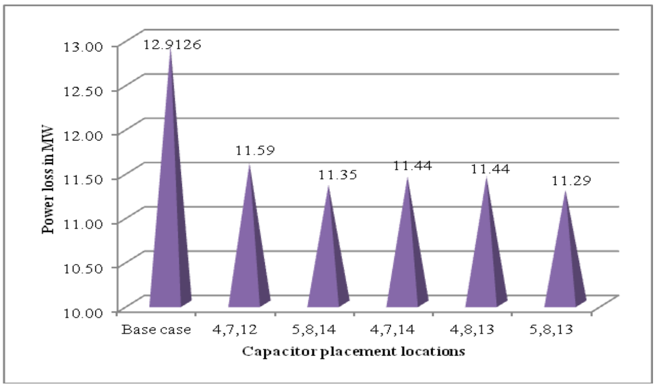

Fig.6 Total power loss comparison with three capacitor placement in the network

Case.4 Optimal location of the one, two and three Capacitors with load factor 1.5

In this case, optimal placement of capacitor is tested on over loading condition with 1.5 load factor. In over loading conditions, load will draws the more power and causes more power loss in the network interms of I^2R losses. This leads to unstable and unreliable operation of the power systems. Due to increase in the loading condition the power loss is increased from 12.9126 to 21.3154MW i.e., 8.4MW more power loss in the network with voltage drop from 0.9405p.u. to 0.8573p.u.Under this type of loading conditions the capacitor will play vital role in stabilizing the voltage profile with minimizing the power loss in the network. The capacitor will supplies the required reactive power and reduces the burden on the network.

Table.5 Voltage and power loss comparison

Bus number	Load factor=1.5			
	Base case	One Capacitor placed at Bus-13	Two capacitors placed at Bus 6 &13	Three capacitors placed at Bus 5, 8 and 13
1	1.06	1.06	1.06	1.06
2	1	1.0004	1.0078	1.0137
3	1.0108	1.0136	1.019	1.0231
4	0.9429	0.956	0.9754	0.9899
5	0.9433	0.9562	0.9754	0.9911
6	0.902	0.9445	0.999	1.0046
7	0.942	0.9703	1.0067	1.0385
8	0.9419	0.9703	1.0067	1.0745
9	0.899	0.9382	0.9866	1.0013
10	0.887	0.9273	0.9774	0.9907
11	0.8855	0.9272	0.9799	0.9895
12	0.8724	0.9238	0.9797	0.9866
13	0.8657	0.9237	0.9798	0.9877
14	0.8573	0.9103	0.9649	0.9752
Power loss in MW	**21.351**	**20.0049**	**18.574**	**17.9304**

Table.5 shows voltage comparison after placing the capacitors at various nodes. After connecting capacitor at bus 13 the power loss is reduced from 21.351MW to 20MW with improvement of the voltage profile from 0.8573 p.u to 0.9103 p.u. Similarly, two capacitors and three capacitors placement at their optimal locations the power loss reduction came down to 18.57MW and 17.93MW respectively. The improvement in the voltage profile after connecting various numbers of capacitors at their optimal locations is as shown in the Fig.7.

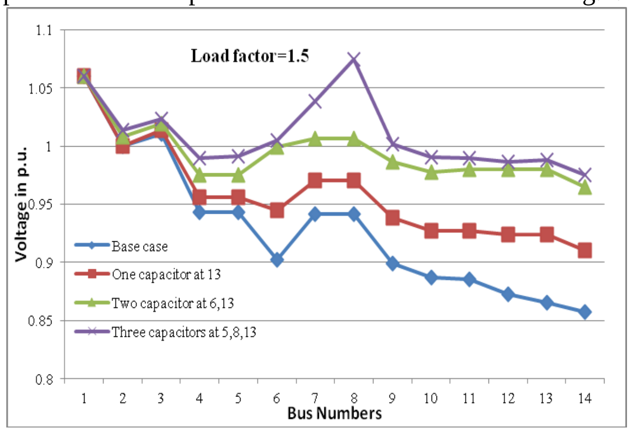

Fig.7 Voltage comparison with base case and capacitor at various locations in the network at load factor 1.5

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Table.6 shows the comparison of obtained results at 1.25 and 1.5 load factor. By considering the both load factors the optimal placement of two capacitors at bus 6 and bus 14 gives satisfactory power loss reduction with enhancement of the voltage limits without violating any voltage limits.

III.CONCLUSION

In this paper, optimal placement of capacitors is carried out using exhaustive load flow analysis for enhancement of the voltage profile with power loss reduction. The obtained results shows, selection of optimal number of capacitors and their optimal location plays important role in acceptable percentage power loss reduction without violating the voltage limits. This will helps in efficient, stable and reliable operation of the distribution network.

Table.6 Comparison of power loss and voltage at load factor 1.25 and 1.5

Load factors	Load factor=1.25			Load factor=1.5		
Different test cases	Case-i	Case-ii	Case-iii	Case-i	Case-ii	Case-iii
Number of Capacitors placement	One capacitor	Two Capacitor	Three Capacitor	One capacitor	Two Capacitor	Three Capacitor
Capacitor placement nodes	Bus 13	**Bus 6 &13**	Bus 5,8 & 13	Bus13	**Bus 6 &13**	Bus 5,8 & 13
Total power loss in the network (MW) before capacitor connection	12.9126	**12.9126**	12.9126	21.3513	**21.3513**	21.3513
Total power loss in the network (MW) after capacitor connection	12.0264	**11.5625**	11.2898	20.0049	**18.574**	17.9304
Net power Saving in MW	0.8862	**1.3501**	1.6228	1.3464	**2.7773**	3.4209
Percentage power loss reduction	**6.8630**	**10.45**	**12.5676**	**6.3059**	**13.0076**	**16.022**
Minimum voltage in network before capacitor connection	0.9405	**0.9405**	0.9405	0.8573	**0.8573**	0.8573
Minimum voltage in network after capacitor connection	0.9938	**1.0122**	1.026	0.9103	**0.9649**	0.9752

REFERENCES

1. D.B. Prakash , C. Lakshminarayana, "Multiple DG placements in radial distribution system for multi objectives using Whale Optimization Algorithm", Alexandria Engineering Journal (2018) 57, 2797–2806.
2. I. Ziari, G. Ledwich, A. Ghosh, D. Cornforth , M. Wishart, "Optimal allocation and sizing of capacitors to minimize the transmission line loss and to improve the voltage profile", Elsevier Computers and Mathematics with Applications 60 (2010) 1003-1013.
3. Rudresh.B.Magadum, Dr.D.B.Kulkarni, "Power Loss Reduction by Optimal Location of DG using Fuzzy Logic", IEEE conference ICSTM-2015, pp.338-343.
4. Ahmed Elsheikh, Yahya Helmy, Yasmine Abouelseoud, Ahmed Elsherif, "Optimal capacitor placement and sizing in radial electric power systems", Alexandria Engineering Journal (2014) 53, 809–816.
5. N. Gnanasekaran , S. Chandramohan , P. Sathish Kumar , A. Mohamed Imran, "Optimal placement of capacitors in radial distribution system using shark smell optimization algorithm", Ain Shams Engineering Journal (2016) 7, 907–916.
6. Rudresh B Magadum, D.B.Kulkarni, "Minimization of Power Loss with Enhancement of the Voltage Profile using Optimal Placement of Distribution Transformer and Distributed Generator", IEEE international conference ICCSP-2019, pp-392-395.
7. Rudresh B Magadum, D.B.Kulkarni, "Optimal Placement and Sizing of Multiple Distributed Generators using Fuzzy Logic", IEEE international conference ICEES-2019.
8. Rudresh B Magadum, D.B.Kulkarni, "Improvement of Voltage Profile by using Line Reconfiguration and Distribution Transformer Placement", IEEE international conference ICEET-2016, pp-330-340.
9. A.Y. Abdelaziz, E.S. Ali, S.M. Abd Elazim, "Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index", Engineering Science and Technology, an International Journal 19 (2016) 610–618.
10. K.Sukraj, T.Yuvaraj, R. Hariharan, "Optimal allocation of shunt capacitor in the radial distribution network using bio inspired bat algorithm", International Journal of Pure and Applied Mathematics Volume 119 No. 12 2018, 15901-15917.
11. Rudresh B Magadum, D.B.Kulkarni, "Optimal Location and Sizing of Multiple DG for Efficient Operation of Power System" IEEE international conference ICEES-2018, pp-88-92.
12. Rudresh B Magadum, Sateesh N Dodamani and Dr.D.B.Kulkarni, "Optimal Placement of Unified Power Flow Controller (UPFC) using Fuzzy Logic", IEEE international conference, ICEES 2019.
13. Rahul G. Suryavanshiu, Sonal R. Suryavan,shi, Diwakar R. Joshi, Rudresh B. Magadum, "Maximum power point tracking of SPV at varying atmospheric condition using Genetic Algorithm", International Conference on Energy Systems and Applications (ICESA 2015).

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