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Optimal Placement and Optimal Combination of DTC, STATCOM and Line Reconfiguration to Minimize the Power Loss in Distribution Networks

Rudresh. B. Magadum, D.B. Kulkarni

Abstract*: Due to deregulation, exponential growth in the electricity demand, integration of renewable energy sources, lack of analytical computing facility and expansion of network increases the complexity with poor operation of the network. Existing analytical computing facility is failed to give efficient and accurate results for secure operation of the distribution network. Many researchers are working to give potential solution to improve the performance of network operation considering the real time variables. In this paper minimization of power loss is chosen as objective function. Considering the network parameters the optimal placements with different combination of DTC, STATCOM and line reconfiguration are tested on IEEE-15 bus system using MiPower simulation package. The obtained result shows more than 50% power loss reduction, which leads to efficient and stress free operation of the distribution networks.

***Index Terms*: Distributed transformer; statcom; power loss, line reconfiguration; optimal placement and voltage profile.**

Nomenclature:

RDS	Radial Distribution Network
kW	Kilo Watt
N	Number of buses
DTC	Distributed Transformer
p.u.	Per unit systems
I_k	Current flowing in the line k
NR	Newton Raphson
P_L	Power loss
DG	Distributed generation
R_k	Resistance of the k^{th} line
Q	Reactive power
RES	Renewable Energy Sources
LFA	Load flow analysis

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* Correspondence Author
Rudresh.B.Magadum*, Research scholar, Department of Electrical and Electronics Engineering, KLS Gogte Institute of Technology, Belagavi-590008, Karnataka, India.
Dr. D.B.Kulkarni, Professor, Department of Electrical and Electronics Engineering, KLS Gogte Institute of Technology, Belagavi-590008, Karnataka, India

I. INTRODUCTION

The growth in population, economic development, expansion of the power system and deregulation contributed complex operation of the power systems [1]. The developing countries are facing huge power quality related problems with shortage in the generation. This leads to low voltage profile with total loss of 30-45% of the generation [2-3]. Many researchers used different techniques and devices to improve the total performance of the network operation. Mainly [4-5],

- Line reconfiguration[6]
- Optimal placement of FACTS devices [7]
- AVR placement
- Decentralized power generation [8][9]
- DTC placement [10] [11].

In this paper, optimal placement of DTC, STATCOM and line reconfiguration with different combination are tested on IEEE-15 bus system. The line reconfiguration is changing the best network topology by adding the new lines at key points of the network to reduce the power loss followed by satisfying the network constraints.

The optimal placement of DTC plays important role in voltage profile enhancement. Depending on the load condition OLTC facilitates the maintaining the stable in the network. The optimal placement of DTC will accelerates the stable voltage profile throughout the network followed by reducing the total power losses in the network. The use of STATCOM also plays important role in enhancement of the voltage profile followed by minimizing the active power loss by compensating required reactive power. The combination of DTC, line reconfiguration and STATCOM are tested to achieve the maximum efficiency of the distributed network using MiPower software package.

The section-2 introduces the methodology consisting of objectives and algorithm. Section-3 discusses the simulation results of different scenarios consisting of different combinations of DTC, STATCOM and line reconfiguration and section-4 discusses the conclusion.

II. METHODOLOGY

To improve the performance of the distribution network, two objective functions are chosen,

- Minimize the total power loss [10]

The total power loss of the any network is computed by,

$$P_{LT}=\sum_{k=1}^{N}(Vm^2+Vn^2-2Vm*Vn*\cos(\delta m-\delta n)) \quad (1)$$

➢ Voltage limits

The under voltage and over voltage causes the voltage instability hence all bus voltages should be maintained within the prescribed range and is given by,

$$V_{kMin} \leq V_k \leq V_{kmax}$$
$$\delta_{kmin} \leq \delta_k \leq \delta_{kmax}$$

Algorithm

Step-1: Enter the load, line, generation, transformer, shunt devices and their data in MiPower software.
Step-2: Run the LFA using NR method choosing appropriate tolerance and number of iterations.
Step-3: Compute the line flows, line losses, bus voltages and total real and reactive power losses in the network.
Step-4: Check the violation of the voltage and power limits.
Step-5: Connect the STATCOM with appropriate size at particular bus and again run the LFA to compute new values of voltages, power flows and power losses.
Step-6: Step-5 is repeated for all the buses in the network.
Step-7: Tabulate the subsequent LFA results.
Step-8: Steps 5, 6, 7 are repeated for line reconfiguration and DTC placement.
Step-9: The different combination is tested and new values of the voltages and power losses are computed.
Step-10: The best combinations with their optimal location are chosen to boost the efficiency of the network maintaining better operating conditions.

III. RESULTS AND DISCUSSIONS

The Fig.1 shows the single line diagram of IEEE-15 bus network drawn in MiPower software. It consists of fourteen loads distributed throughout the network with total load of 1.22+1.255i. One generator connected at bus-1 with 1 p.u as a specified voltage. Table.1 shows base case LFA results. The base case is the system without integrating of new devices and without changing any network topologies considering the steady state parameters. From the Table.1 it can be observed 1.288+1.304i power is flowing through the transmission line connected between buses 1 and 2. Similarly all fourteen lines power flows and power losses are shown.

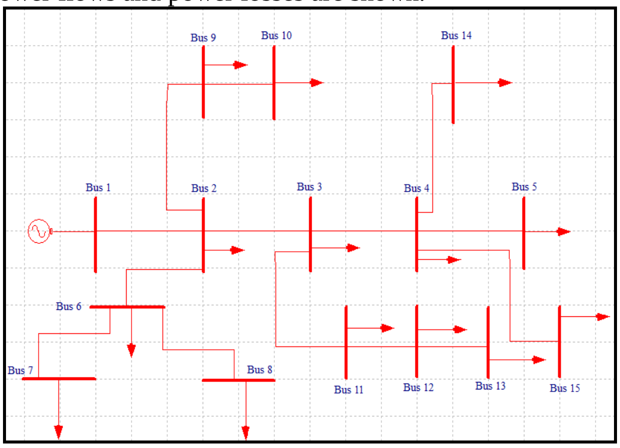

Fig.1. Single line diagram of IEEE 15 bus system.

Table.1. Power flow and line losses in IEEE-15 bus distribution network.

Sl.no	From Node	To Node	Forward power flow		Power loss	
			KW	KVAR	KW	KVAR
1	1	2	1.288	1.304	0.0376	0.0325
2	2	3	0.735	0.748	0.0112	0.011
3	3	4	0.397	0.405	0.0024	0.0024
4	4	5	0.044	0.045	0.0001	0.0000
5	2	9	0.115	0.117	0.0005	0.0003
6	9	10	0.044	0.045	0.0001	0.0000
7	2	6	0.356	0.361	0.0057	0.0039
8	6	7	0.140	0.143	0.0004	0.0003
9	6	8	0.070	0.071	0.0001	0.0001
10	3	11	0.257	0.261	0.0022	0.0015
11	11	12	0.115	0.117	0.0006	0.0004
12	12	13	0.044	0.045	0.0001	0.0000
13	4	14	0.070	0.072	0.0002	0.0001
14	4	15	0.140	0.143	0.0004	0.0003

Table.2 shows the comparison of voltage values obtained from LFA at each bus after connecting DTC in each line. After connecting DTC between line 2-3 it can be observed that, enhancement of the voltage value from 0.915 p.u to 0.9718 p.u at bus-5. The DTC placement is tested by connecting DTC out of all results few random samples few shown in Table.2. Fig.2 shows the improvement of voltage profile after integrating of DTC between line 1-2 taking bus-16 as extra bus for the DTC connection.

Table.2. Total power loss and voltage magnitude in presence of DTC at different locations.

Bus No	Base case	DTC at 2-3	DTC at 3-11	DTC at 1-2	DTC at 3-4
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9730	0.9729	0.9730	0.9902	0.9730
3	0.9584	0.9784	0.9584	0.9758	0.9584
4	0.9527	0.9728	0.9526	0.9702	0.9746
5	0.9517	0.9718	0.9517	0.9692	0.9736
6	0.9600	0.9599	0.9600	0.9774	0.9599
7	0.9577	0.9577	0.9577	0.9752	0.9577
8	0.9587	0.9586	0.9587	0.9761	0.9587
9	0.9697	0.9696	0.9697	0.9869	0.9697
10	0.9686	0.9685	0.9686	0.9859	0.9686
11	0.9517	0.9718	0.9745	0.9693	0.9517
12	0.9476	0.9678	0.9705	0.9652	0.9475
13	0.9463	0.9665	0.9692	0.9639	0.9462
14	0.9504	0.9705	0.9503	0.9679	0.9723
15	0.9502	0.9704	0.9502	0.9678	0.9722
Ploss KW	61.5	61.6	61.6	61.3	61.6

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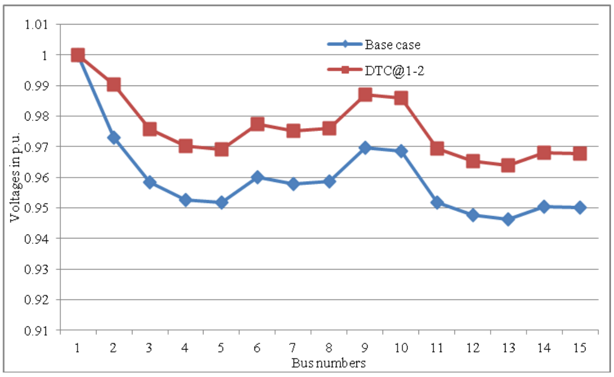

Fig.2. Voltage profile comparison base case with DTC connected between nodes 1-2.

Table.3 shows the power loss and voltage profile with line reconfiguration. Line reconfiguration is making small changes in the network topology by connecting new transmission lines in the network. Integrating new transmission lines the stress on the network can be reduced with minimizing the power losses. Connecting new line between bus 1-2 the power loss is reduced from 61.5kW to 41.6kW and minimum voltage in the network at bus-13 is increased from 0.9463 p.u to 0.9604 p.u. Fig.3 shows the voltage comparison with and without line reconfiguration. Integrating new transmission lines between buses 1-2 the significant level enhancement of the voltage profile is achieved.

Table.3. Total power loss and voltage magnitudes with tie lines.

Bus No	Base case	Line reconfiguration			
		2 to 3	1 to 2	2 to 11	2 to 12
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9730	0.9731	0.9867	0.9732	0.9731
3	0.9584	0.9659	0.9723	0.9651	0.9636
4	0.9527	0.9602	0.9666	0.9594	0.9579
5	0.9517	0.9592	0.9657	0.9584	0.9569
6	0.9600	0.9601	0.9739	0.9601	0.9601
7	0.9577	0.9579	0.9717	0.9579	0.9579
8	0.9587	0.9588	0.9726	0.9589	0.9588
9	0.9697	0.9698	0.9834	0.9698	0.9698
10	0.9686	0.9687	0.9824	0.9688	0.9688
11	0.9517	0.9592	0.9657	0.9668	0.9635
12	0.9476	0.9552	0.9617	0.9627	0.9682
13	0.9463	0.9539	0.9604	0.9614	0.9669
14	0.9504	0.9579	0.9644	0.9571	0.9556
15	0.9502	0.9577	0.9642	0.9569	0.9555
Ploss KW	61.5	55.4	41.6	53.3	53.9

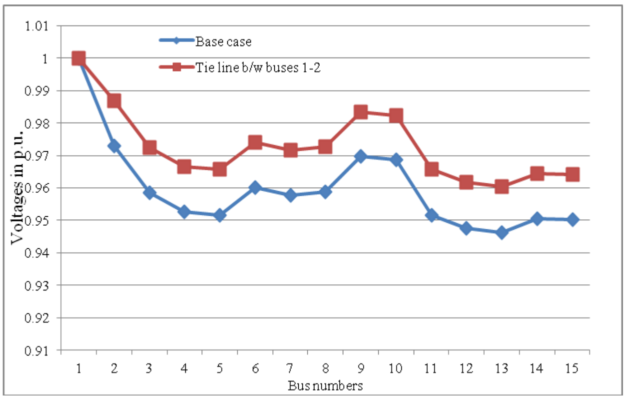

Fig.3. Voltage profile comparison base case with tie line connected between nodes 1-2.

Table.4 shows the comparison of the voltage profile after integrating the statcom at various buses. The appropriate size is chosen depending on the network parameters. After connecting statcom at bus-4 the improvement in the minimum voltage at bus-13 from 0.9463 p.u. to 0.9503 p.u is achieved with acceptable improvement in the efficiency of the network. Fig.4 shows the voltage comparison of the base case with statcom at bus-4. After connecting statcom significant enhancement of voltage improvement is achieved.

Table.4. Total power loss and voltage magnitudes by integration of STATCOM at different nodes.

Bus No	Base case	STATCOM Placement			
		Bus-3	Bus-4	Bus-6	Bus-11
1	1.0000	1.0000	1.0000	1.0000	1.000
2	0.9730	0.9750	0.9760	0.9750	0.9750
3	0.9584	0.9624	0.9644	0.9605	0.9624
4	0.9527	0.9567	0.9607	0.9547	0.9567
5	0.9517	0.9557	0.9598	0.9537	0.9557
6	0.9600	0.9620	0.9631	0.9649	0.9620
7	0.9577	0.9598	0.9608	0.9627	0.9598
8	0.9587	0.9608	0.9618	0.9636	0.9608
9	0.9697	0.9717	0.9727	0.9717	0.9717
10	0.9686	0.9707	0.9717	0.9706	0.9707
11	0.9517	0.9557	0.9577	0.9538	0.9578
12	0.9476	0.9516	0.9537	0.9497	0.9537
13	0.9463	0.9503	0.9524	0.9484	0.9524
14	0.9504	0.9544	0.9585	0.9524	0.9544
15	0.9502	0.9542	0.9583	0.9523	0.9542
Ploss KW	61.5	53.2	48.4	53.5	52.1

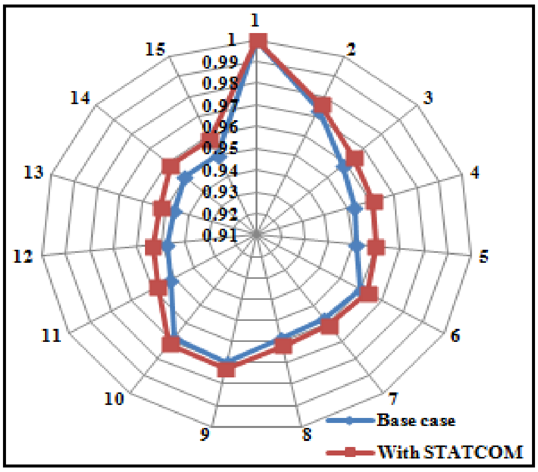

Fig.4. Voltage profile comparison base case with STATCOM connected at node 4.

Table.5 shows the improvement of the voltage profile base case with combination of DTC and line reconfiguration. After placing DTC between buses 1-2 and tie lines at different points are tested with all possible combinations the acceptable improvement of the voltage profile and power loss is achieved. Fig.6 shows the single line diagram of IEEE-15 bus system with DTC between buses 1-2 and tie line between buses 2-11. The power loss reduces from 61.5kW to 53.3kW. Fig.7 shows the voltage comparison connecting DTC between buses 1-2 with different combination of line reconfigurations. From the graph it can be observed impressive improvement in the voltage profile throughout the network.

Table.5. Voltage profile in presence of DTC and tie lines.

Bus No	Base case	DTC is connected b/w 1-2		
		Tie line b/w 2-12	Tie line b/w 2-3	Tie line b/w 2-11
1	1.0000	1.0000	1.0000	1.0000
2	0.973	0.9904	0.9903	0.9904
3	0.9584	0.9810	0.9832	0.9825
4	0.9527	0.9754	0.9776	0.9768
5	0.9517	0.9744	0.9767	0.9759
6	0.9600	0.9776	0.9775	0.9776
7	0.9577	0.9754	0.9754	0.9754
8	0.9587	0.9763	0.9763	0.9763
9	0.9697	0.9871	0.9871	0.9871
10	0.9686	0.9861	0.986	0.9861
11	0.9517	0.9809	0.9767	0.9841
12	0.9476	0.9855	0.9727	0.9801
13	0.9463	0.9843	0.9714	0.9789
14	0.9504	0.9732	0.9754	0.9746
15	0.9502	0.9730	0.9752	0.9744
Ploss KW	61.5	53.9	55.3	53.3

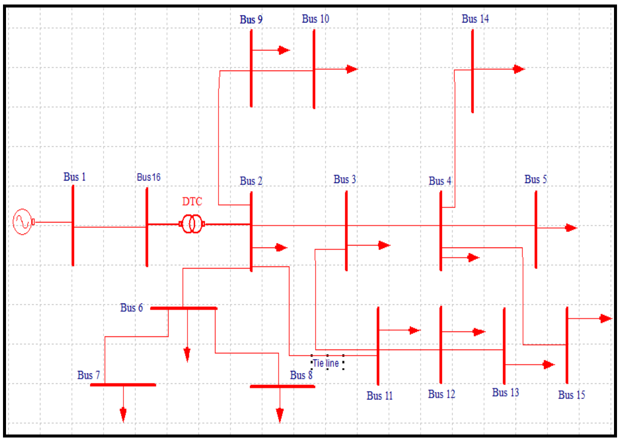

Fig.5. SLD of IEEE 15 bus system with DTC connected between nodes 1-2 and tie line 2-11.

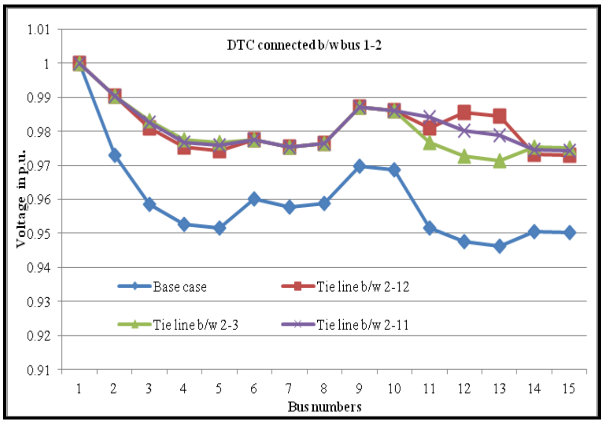

Fig.6. Voltage profile with DTC and Tie line.

Table.6 shows the voltage comparison results of base case and DTC-statcom combination. The test is carried out placing the statcom at bus-4 and DTC at different locations and also observed that more than 205 of power loss reductions. Fig.7 shows the single line diagram of IEEE-15 bus system with DTC-statcom. Fig.8 shows the voltage comparison at each bus after connecting statcom and DTC at various locations. From the graph it can be observed that significant enhancement in the voltage profile.

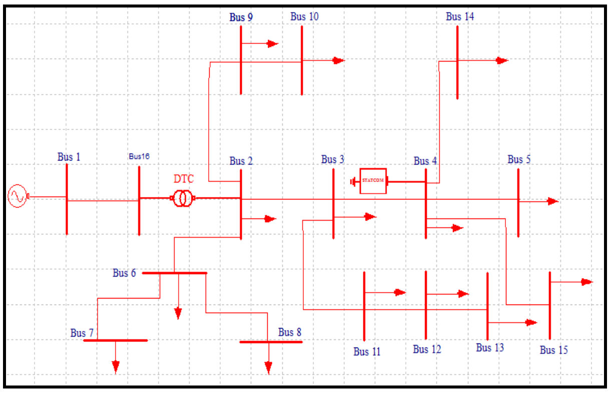

Fig.7. SLD of IEEE 15 bus system with DTC connected between nodes 1-2 and STATCOM at 4.

Table.6. Voltage profile comparison by integration DTC and STATCOM at various locations.

Bus No	Base case	STATCOM at Bus-4		
		DTC at 3-11	DTC at 2-3	DTC at 3-4
1	1.0000	1.0000	1.0000	1.0000
2	0.9730	0.9760	0.9761	0.9761
3	0.9584	0.9644	0.9865	0.9645
4	0.9527	0.9607	0.9830	0.9849
5	0.9517	0.9597	0.9820	0.9839
6	0.9600	0.9630	0.9631	0.9631
7	0.9577	0.9608	0.9609	0.9609
8	0.9587	0.9618	0.9618	0.9618
9	0.9697	0.9727	0.9728	0.9728
10	0.9686	0.9717	0.9717	0.9717
11	0.9517	0.9807	0.9800	0.9579
12	0.9476	0.9767	0.9760	0.9538
13	0.9463	0.9754	0.9748	0.9525
14	0.9504	0.9584	0.9808	0.9827
15	0.9502	0.9583	0.9806	0.9825
Ploss KW	61.5	48.5	48.1	48.2

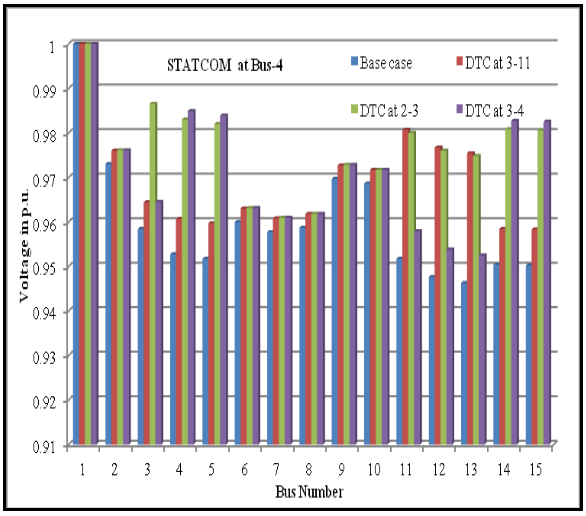

Fig.8. Voltage profile of IEEE 15 bus system in presence of STATCOM and DTC

Table.7 shows the voltage and power comparison of base case with combination of statcom-line reconfiguration choosing optimal location of both will makes 50% power loss minimization. The single line diagram of IEEE-15 bus with statcom-line reconfiguration is shown in Fig.9. The enhancement of the voltage profile throughout the network after integrating statcom and line reconfiguration can be observed in Fig.10.

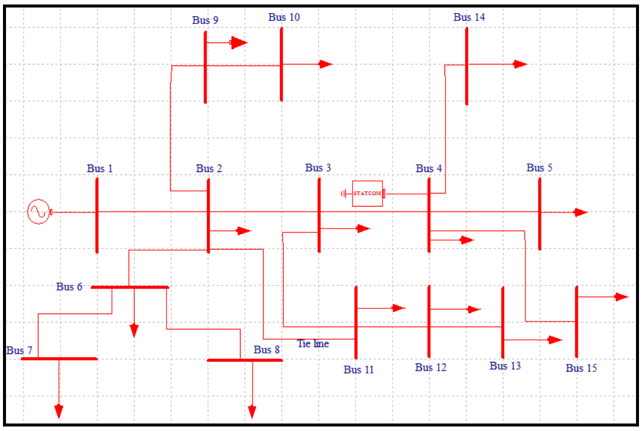

Fig.9. Single line diagram of IEEE 15 bus system with STATCOM and tie line.

Table.7. Voltage profile of IEEE 15 bus system with STATCOM and tie lines.

Bus No	Base case	STATCOM at 4			
		Tie line b/w 1-2	Tie line b/w 2-12	Tie line b/w 2-11	Tie line b/w 1-2 & 2-11
1	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9730	0.9882	0.9762	0.9762	0.9883
3	0.9584	0.9767	0.9689	0.9701	0.9823
4	0.9527	0.9731	0.9653	0.9665	0.9787
5	0.9517	0.9722	0.9643	0.9655	0.9777
6	0.9600	0.9754	0.9632	0.9632	0.9754
7	0.9577	0.9732	0.9610	0.9610	0.9733
8	0.9587	0.9741	0.9619	0.9619	0.9742
9	0.9697	0.9849	0.9729	0.9729	0.985
10	0.9686	0.9839	0.9718	0.9718	0.9839
11	0.9517	0.9702	0.9681	0.9708	0.9829
12	0.9476	0.9661	0.9719	0.9667	0.9789
13	0.9463	0.9648	0.9706	0.9654	0.9777
14	0.9504	0.9709	0.9630	0.9642	0.9765
15	0.9502	0.9707	0.9629	0.9640	0.9763
Ploss KW	61.5	32.8	42.4	42.2	26.9

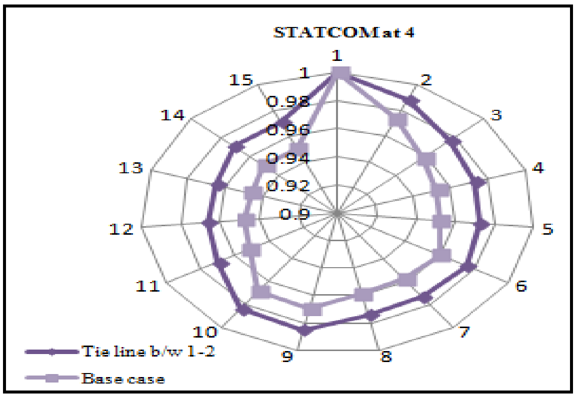

Fig.10. Voltage profile in presence of STATCOM and line reconfiguration.

Table.8 shows the comparison of different test scenarios in terms of minimum voltage in the network and percentage power loss reduction. It can be observed that out of all combinations the statcom and line reconfiguration gives 56.26% power loss reduction with enhancement of minimum voltage from 0.9463p.u to 0.9773 p.u. Fig.11 shows the comparison of voltage profile with all test scenarios. Fig.12 shows the power loss minimization in kW. In all test case scenarios significant power loss minimization is observed.

Table.8. Percentage power loss and minimum voltages in the network at different scenarios.

Scenario	Description	Min. Voltage in the n/w	Power loss	% Power loss reduction
I	Base case	0.9463	61.50	--
II	With DTC	0.9639	61.30	0.33
III	With line reconfig.	0.9604	41.60	32.36
IV	With STATCOM	0.9524	48.40	21.30
V	DTC & reconfig.	0.9789	53.30	13.33
VI	DTC & STATCOM	0.9748	48.10	21.79
VII	Reconfig & STATCOM	0.9777	26.90	56.26

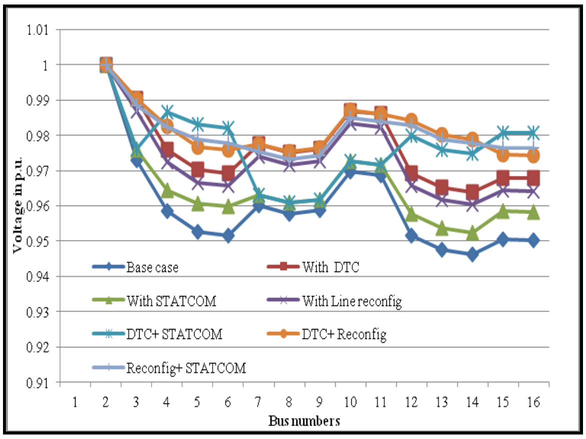

Fig.11. Voltage profile comparison at different scenarios.

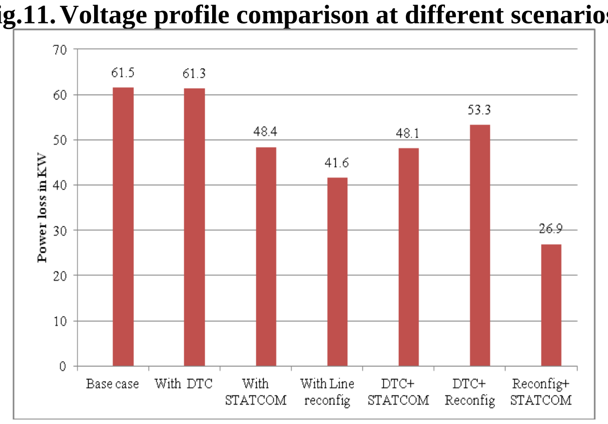

Fig.12 Power loss comparison at different test scenarios

IV.CONCLUSION

In this paper, different combinations of statcom, line reconfiguration and DTC placement are tested considering their optimal location on IEEE-15 bus network. The best combination is selected for efficient operation of the network with optimal number and optimal placement. The MiPower analysis tool is used for the simulation. The obtained result shows the enhancement of the efficiency with voltage stability of the network.

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