Grenze International Journal of Engineering and Technology, Jan Issue

Cost Benefit Analysis for Distribution Transformer Placement in Electrical Networks

Rudresh B. Magadum[1], Sateesh N. Dodamani[2], Sudhakar C J[3] and Sanjeev G. Kulkarni[4]
[1-4]Department of E&E, KLS-GIT, Belagavi, Karnataka, India
Email: rrudreshmagadum@gmail.com

***Abstract*—The generation, transmission and distribution are the three main parts of the electrical networks. Now a day's electric utilities experiencing remarkable change with digitalization of their customers and systems. The de-carbonization initiatives are boosting effective use and descent growth of RES integration with grid. Last two decades electrical DN experiencing over loading, low frequency, high power loss, inadequate power generation, lack of electrical infrastructure etc directly effects on the industry production as well as national growth. Many effective methods/ techniques are being adapted to cut down load shedding, voltage issues and power loss reduction. The placement of DG's, Capacitor, FACTs, DTC, AVR etc are more effective in mitigating the issues mentioned. Out of all these methods, the DTC placement is found to be more effective and its cost benefits analysis carried out to know the feasibility of the proposed methodology. The proposed method is tested on twenty nodes RDN.**

***Index Terms*— Distribution transformer; Benefit to investment ratio; Voltage profile; Total power loss; Load flow analysis; Distribution networks.**

O&M	Operation and maintenance	NR	Newton Raphson Method
RDN	Radial Distribution network	FACTS	Flexible AC Transmission Systems
DTC	Distributed Transformer	T&D	Transmission and distribution
LFA	Load flow analysis	DG	Distributed Generation
RES	Renewable Energy sources	I	Current in the network
Q	Reactive Power	MW	Megawatts
BC	Base case	R	Resistance of the lines
V_{base}	Base Voltage	P	Active Power
N	Number of lines	P_{TL}	Total power

I. Introduction

The present electrical power systems are facing many challenges such as exponential growth in load, lack of interest/investments in electrical infrastructure up-gradation and adoption of new technologies, integration of highly fluctuating RES etc which are causing poor, inefficient and unreliable operation of the power systems [1, 2]. To meet the existing power demand, requirement of reduction of load shedding, nullifying the power failure can be achieved by integration of thousands of dispersed power generating units at load points, changing network topology, enhancing T&D capacity, integration of FACTs devices, DTC placement/ relocation etc [3-4].

Grenze ID: 01.GIJET.8.1.69
© Grenze Scientific Society, 2022

From the literature, DG is one of the promising techniques to reduce the power loss up to great extent [5]. The bottleneck of the DG is its availability, optimal sizing, high O&M charges, high investments etc [6]. The low voltage profiles in the distribution network causing high I^2R losses can be addressed by optimal placement or relocation of the distribution transformer [7].

In this paper optimal placement of DTC is carried out with an objective of on the power loss minimization and cost benefit analysis. The proposed method is tested on the twenty bus radial network [8-9]. The obtained result shows the feasibility of the DTC placement and power loss reduction in the network by enhancing the voltage profiles.Figure.1 shows the typical electrical network [10-12].

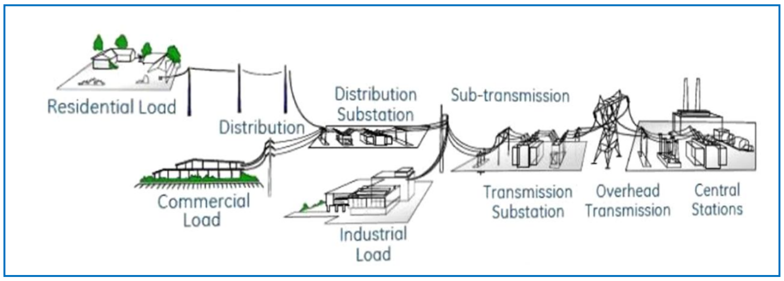

Figure 1. Electrical network

II. Results and Discussions

The main aim of this work is to minimize the P_{TL} with acceptable rise in the voltage profile.

$$F = \mathrm{Min}\{P_{TL}\} \qquad (1)$$

$$V_{min} \leq V \leq V_{max} \qquad (2)$$

The optimal placement of DTC plays key role in deciding the feasibility depending on the cost benefit analysis. Figure.2 shows the flow chart for DTC placement. The DTC placement is carried out on all the lines in the network in subsequent tests taking one extra (dummy) bus. The obtained LFA results the effectiveness and feasibility of the proposed method.

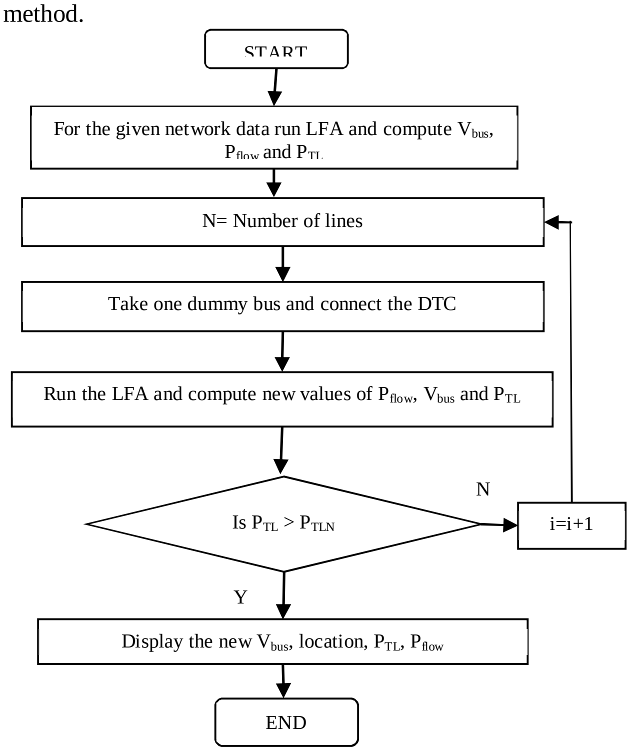

Figure.2 Flow chart for DTC placement

Figure.3 shows the single line diagram of twenty nodes RDN. The twenty bus network consists of nineteen loads and nineteen transmission lines at 33 kV voltage levels. Only one centralized generator is connected at bus-1 (slack bus).

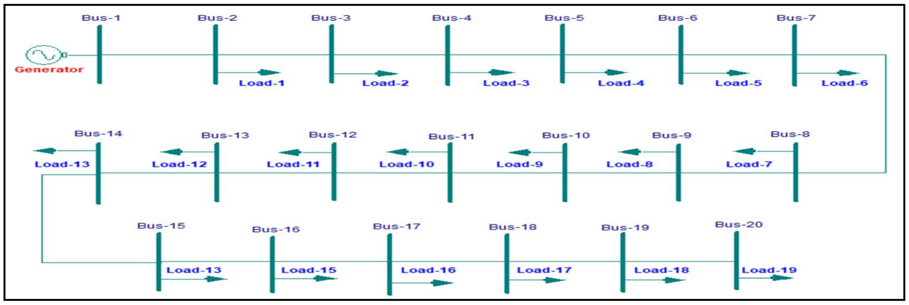

Figure.3. SLD of twenty nodes system

Table.I shows the power flow and transmission line losses in each branch. The power flowing between node-1 and node-2 is 49.455 MW of active power and 19.986 MVAr of reactive power. The I^2R loss in the branch is 1.4494 MW of active and 0.6534 MVAr of reactive power. This table also indicates the line loading conditions. In RDN the losses in each branch increasing when loads are very far from the central generating station due to over loading of the electrical infrastructure.

TABLE I. POWER FLOW AND PTL IN THE TWENTY BUS NETWORK

From-node	To-node	Flow of power		Losses	
		MW	MVAr	MW	MVAr
1	2	49.455	19.986	1.4494	0.6534
2	3	46.005	18.675	1.3342	0.6014
3	4	41.671	17.088	1.1655	0.5252
4	5	38.005	15.741	1.0300	0.4640
5	6	33.776	14.225	0.8643	0.3891
6	7	30.711	12.473	0.7451	0.3352
7	8	27.166	10.781	0.6090	0.2737
8	9	22.957	9.324	0.4584	0.2056
9	10	18.299	6.852	0.2970	0.1326
10	11	16.202	6.128	0.2414	0.1074
11	12	14.760	5.439	0.2053	0.0911
12	13	12.955	4.573	0.1611	0.0712
13	14	7.994	2.924	0.0635	0.0270
14	15	7.530	2.727	0.0571	0.0242
15	16	6.673	2.440	0.0457	0.0190
16	17	5.068	1.665	0.0261	0.0102
17	18	3.842	1.260	0.0152	0.0052
18	19	2.406	0.788	0.0060	0.0011
19	20	0.600	0.196	0.0004	-0.0014

Figure.4 shows the BC voltage profiles. It is observed 1.02 p.u., is the maximum voltage at slack bus and minimum voltage of 0.7505 p.u., at bus-20. The figure clearly indicates the voltage values at each bus. The very low voltage at certain buses and loads pertaining to these buses demands more power for the same work and causes more I^2R losses in the network.

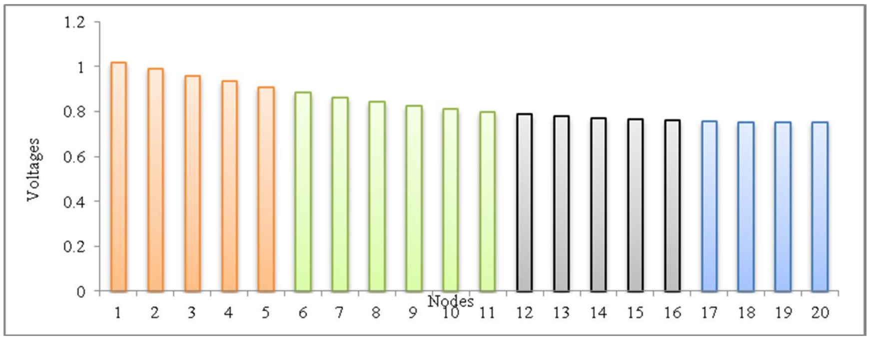

Figure.4. BC voltage profiles

Table. II shows the P_{TL} and voltages after integrating DTC at various branches. The results are compared with BC shows DTC placement enhances the voltage with reduced losses. In base case the least voltage is 0.7505 p.u. with P_{TL} of 8.7747 MW. Integrating DTC between nodes 4-5 improves the voltages to 0.7514 p.u with P_{TL} of MW. In the same background, connecting DTC between node-10 and node-11 the minimum voltage of 0.7474 p.u with total power loss of 8.6816 MW. Out of all results branch between node-4 and node-5 is the best location of DTC placement in terms of diminishing in the P_{TL} with significant enhancement of the voltage values.

TABLE II. VOLTAGES AND TOTAL POWER LOSS IN PRESENCE OF DTC AT VARIOUS POINTS IN THE NETWORK

Nodes	BC	Line between node 4-5	Line between node 7-8	Line between node 10-11	Line between node 14-15
1	1.0200	1.0200	1.0200	1.0200	1.0200
2	0.9896	0.9919	0.9908	0.9888	0.9876
3	0.9604	0.9650	0.9630	0.9610	0.9598
4	0.9332	0.9400	0.9380	0.9360	0.9348
5	0.9075	0.9110	0.9090	0.9070	0.9058
6	0.8840	0.8949	0.8929	0.8909	0.8897
7	0.8622	0.8781	0.8761	0.8741	0.8729
8	0.8426	0.8534	0.8514	0.8494	0.8482
9	0.8255	0.8322	0.8302	0.8282	0.8270
10	0.8117	0.8222	0.8202	0.8182	0.8170
11	0.7993	0.8045	0.8025	0.8005	0.7993
12	0.7879	0.7970	0.7950	0.7930	0.7918
13	0.7778	0.7821	0.7801	0.7781	0.7769
14	0.7714	0.7798	0.7778	0.7758	0.7746
15	0.7654	0.7707	0.7687	0.7667	0.7655
16	0.7600	0.7654	0.7634	0.7614	0.7602
17	0.7560	0.7598	0.7578	0.7558	0.7546
18	0.7529	0.7564	0.7544	0.7524	0.7512
19	0.7509	0.7534	0.7514	0.7494	0.7482
20	0.7505	0.7514	0.7494	0.7474	0.7462
P_{TL} in MW	8.7747	8.4382	8.6205	8.6816	8.7162

Figure.5 shows the single line diagram of twenty bus radial distribution network with DTC connected between nodes 14 and 15 taking bus-21 as dummy bus. The bus-21 is used in all the lines for DTC connection in subsequent tests.

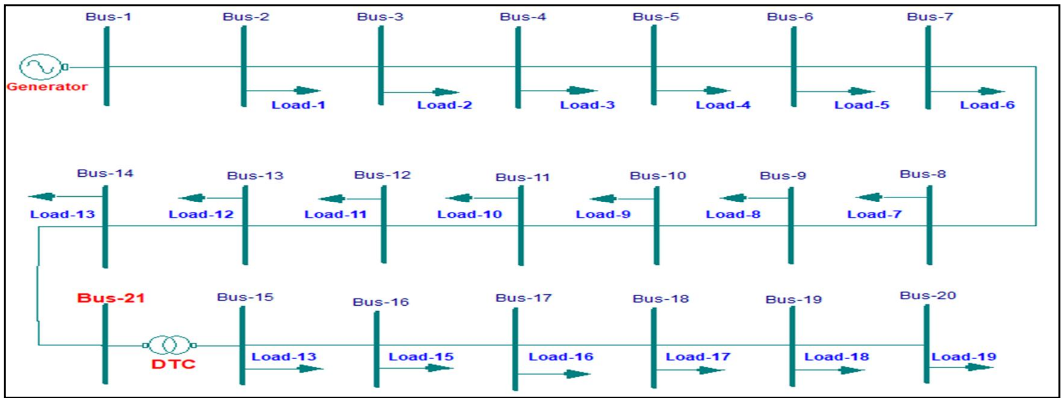

Figure.5. Twenty bus RDN with DTC

Figure.6 shows the voltage profile comparison in p.u. at all the nodes in the network during base case, DTC connected between nodes 7-8, 4-5 and 10-11. Out of all DTC integration between nodes 4-5 gives better results among all the results. Figure.7 shows the P_{TL} comparison after integrating DTC at various branches. Improvement in the voltage profiles diminishes the P_{TL} in the network.

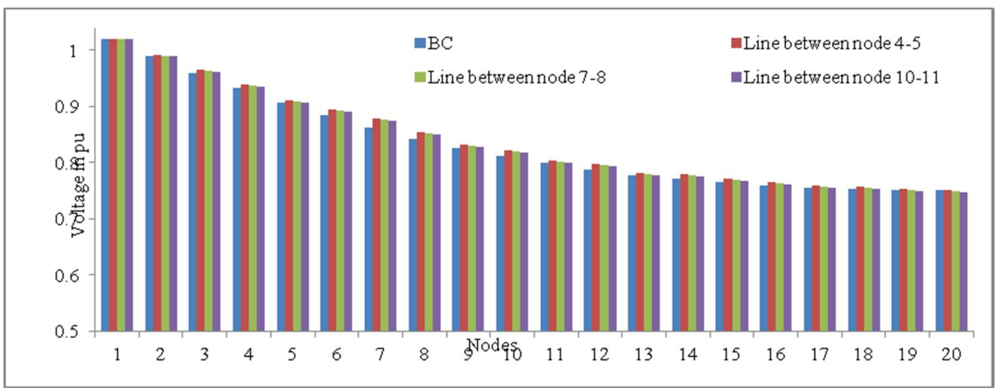

Figure.6. Voltage comparison in presence of DTC

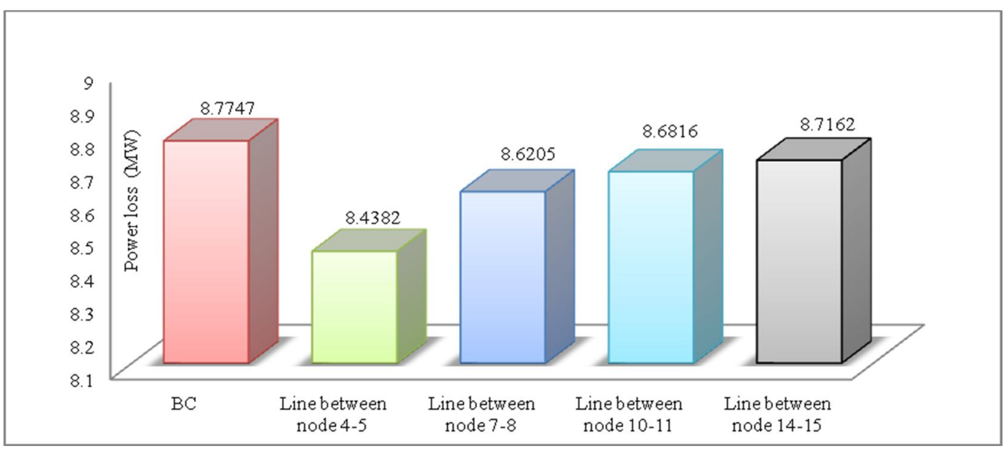

Figure.7. Twenty bus RDN with DTC

Case A. DTC between nodes 4-5

The cost benefit analysis is carried out to test the feasibility of DTC placement. The approximate costs are considered for feasibility assessment. The 5 MVA 33/33 kV transformer cost Rs 50, 00,000 is considered with 12% interest and 8% O&M costs. The project life is 5 years considered for the assessment. From the LPA it is observed 0.34 MW of power saving. In a year 12, 86,676 units of energy can be saved. Even though at 2Rs/unit electricity price rate yearly Rs 25, 73,342 can be saved. The benefit to investment ratio is 1.5668 clearly states DTC placement between nodes 4-5 is feasible. Table.III shows the cost benefit assessment.

TABLE III. COST BENEFIT ANALYSIS FOR FEASIBILITY ASSESSMENT

Investments	Rs. 50,00,000	Peak Load Power saving	0.34 MW
Interest	12%	Load factor	0.25
Operational and maintenance	8%	Loss of load factor	0.432
Project life	5 Years	Unit energy charges	2 Rs/kWhr
Annual expenses	Rs. 4,00,000	Annual saving in energy	12,86,676
Present worth of annual expenses	Rs. 14,41,912	Cost of energy Saving	Rs.25,73,342
Present worth of net cash out flow	Rs. 64,41,918	Present worth of net cash in flow	Rs. 92,76,314
Project Feasibility			
Net Present Worth	Rs. 28,34,468	Net Benefit	Rs. 7834426
Benefit to Investment ratio	1.5668	Feasibility	Feasible

Case A.DTC between nodes 7-8

Table IV shows the feasibility assessment of DTC connection between nodes 7-8 for 5 MVA transformer placement. Total 11, 67,085 units of energy can be saved annually. The benefit to invest ratio is computed depending on the power saving and it is 0.553 and DTC placement between nodes 7-8 is financially not feasible due to high investment, interest and OM charges.

TABLE IV. COST BENEFIT ANALYSIS AND FEASIBILITY ASSESSMENT

Present worth of annual expenses	Rs. 14,41,912	Cost of energy Saving	11,67,085
Present worth of net cash out flow	Rs. 64,41,918	Present worth of net cash in flow	42,07,085
Project Feasibility			
Net Present Worth	Rs. -22,34,836	Net Benefit	27,65,178
Benefit to Investment ratio	0.553	Feasibility	Not Feasible

Table.V shows the cost benefits and feasibility assessment at various locations in the network. For the same 5 MVA rating transformer nodes 4-5 is the best location and it is financially feasible for DTC installation. The other location in the network are not feasible for DTC placement due to low benefit to investment ratios.

TABLE V. COST BENEFIT ANALYSIS AND FEASIBILITY ASSESSMENT

	V_{min}	P_{TL}	P_{save} in kW	% PTL reduction	Benefit to Investment Ratio	Feasibility
BC	0.7505	8.7747	--	--	--	--
Line between node 4-5	0.7514	8.4382	336.5	3.835	1.5688	Feasible
Line between node 7-8	0.7494	8.6205	154.2	1.757	0.553	Not feasible
Line between node 10-11	0.7474	8.6816	93.1	1.061	0.2196	Not feasible
Line between node 14-15	0.7462	8.7162	58.5	0.667	0.1826	Not feasible

III. CONCLUSIONS

In this paper, optimal placement of distribution transformer is carried out depending on the cost benefit ratio. The optimal placement/relocation of transformer enhances the significant voltage level in the network. The minimum power loss in the network gives good cost benefit ratio to decide the implementation of the proposed project feasibility. In this paper, twenty nodes RDN is used to test the feasibility of DTC placement. The obtained results shows the potential points in the network to get good cost benefit ratio to carry out the DTC placement. Hence, this proposed technique can be used for any electrical network to test the financial feasibility.

APPENDIX

Voltage level= 33 kV
Line length between the nodes =1 kms

A TWENTY BUS LOAD DATA

Node	P in MW	Q in MVAr	Node	P in MW	Q in MVAr
2	2.0	0.657	12	1.60	0.775
3	3.0	0.986	13	4.80	1.578
4	2.5	0.822	14	0.40	0.170
5	3.2	1.052	15	0.80	0.263
6	2.2	1.363	16	1.56	0.756
7	2.8	1.356	17	1.20	0.394
8	3.6	1.183	18	1.42	0.467
9	4.2	2.267	19	1.80	0.592
10	1.8	0.592	20	0.60	0.197
11	1.2	0.581			

REFERENCES

[1] R. B. Magadum and D. B. Kulkarni, “Performance Enhancement of Distribution Network by Optimal Placement of Multiple Capacitors using FKBC,” in Advances in Intelligent Systems and Computing, Springer-2020,Vol.1119, pp 591-602.

[2] M. Haghifam, M. Esmaeeli, A. Kazemi and H. Shayanfar, "Optimal placement of the distribution substations to improve reliability under load growth," 2015 IEEE Power & Energy Society General Meeting, 2015, pp. 1-5.

[3] Vishwanath Hegde, Raghavendra C. G., Prashanth Nayak Pradeep S., Themchan Woleng, “Optimal placement of distribution transformers in radial distribution system”, International Journal of Smart Grid and Clean Energy, vol. 3, no. 2, April 2014.

[4] R. B. Megadum and D. B. Kulkarni, "Minimization of Power Loss with Enhancement of the Voltage Profile using Optimal Placement of Distribution Transformer and Distributed Generator," 2019 International Conference on Communication and Signal Processing (ICCSP), 2019, pp. 0392-0395.

[5] R. B. Magadum, C. J. Sudhakar, A. V. Deshpande and S. N. Dodamani, "Optimal Placement of Multiple STATCOM and It’s Impact on Voltage Stability," IEEE conference on ICACCS-2021, pp. 238-242.

[6] A. Nakadomari, R. Shigenobu and T. Senjyu, "Optimal Control and Placement of Step Voltage Regulator for Voltage Unbalance Improvement and Loss Minimization in Distribution System," *2020 IEEE Region 10 Conference*, 2020, pp. 1013-1018

[7] R. Shigenobu and M. Damien Palmer, "Multi-objective optimization of auto-tap-changer pole transformer considering optimum placement in distribution systems," 2015 IEEE Congress on Evolutionary Computation (CEC), 2015, pp. 925-930.

[8] R. B. Magadum and D. B. Kulkarni, “Optimal Placement of Distributed Transformer with STATCOM to Enhance the Efficiency of the Distribution Networks,” International Journal of Recent Technology and Engineering, Volume 8, Issue 2, Jul. 2019, pp. 3720–3725.

[9] R. B. Magadum and D. B. Kulkarni, “Optimal Placement of Capacitor to Enhance the Efficiency of the Distribution Network,” International Journal of Innovative Technology and Exploring Engineering, Volume 8, Issue -9, pp. 2877–2881, Jul. 2019.

[10] W. Linyu, W. Xue and S. Qiang, "Cost benefit analysis of combined storage and distribution generation systems in smart distribution grid," International Conference on Renewable Power Generation 2015, pp. 1-5.

[11] R. B. Magadum and D. B. Kulkarni, “Optimal Placement and Sizing of Multiple Distributed Generators using Fuzzy Logic,” in IEEE conference ICEES-2019, pp. 1–6.

[12] A. Papaemmanouil, L. Bertling, L. A. Tuan and G. Andersson, "Improved cost-benefit analysis for reliable long-term transmission planning," *2011 IEEE Trondheim PowerTech*, 2011, pp. 1-6.