International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-7, Issue-6, March 2019

Optimal Placement of Facts Devices in Power System for Power Quality Improvement

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Abstract: Power Quality is an important issue in power systems where compensating devices play a very important role to improve voltage profile reduce power losses and mitigate power quality problems. Implementation of the Flexible AC Transmission Systems (FACTS) devices to optimally in power flow of IEEE 30 & 57 bus systems to shrink power losses and improved voltage profile for power quality improvement. In this paper four types of FACTS controllers STATCOM, SVC, TCSC and UPFC are implemented by conventional method for power quality improvement. Here an assessment is also made between conventional method and evolutionary computation method to authenticate performance, results shows usefulness of the projected method.

Index Terms: Power Quality, FACTS, IEEE 30 & 57 bus, Power losses.

I. INTRODUCTION

A proper planning and operation is necessary to supply electrical energy to customers with highest quality of power supplied at lowest cost. The power transmission capacity can be increased by installing new generating units with novel transmission lines in a right of way. The conception of FACTS technology is presented to enhance the power transfer capacity of transmission lines by power quality enhancement without producing power by new plants. In transmission lines reactive power generated due to industrial loads and generating equipments which leads to power quality problems such as sag, swell and harmonics so it will be duty of FACTS controller to mitigate power quality problems and enhance the power transmission capacity [1-6]. Power flow analyses using the FACTS are now essential technique for the safe and economic operation of modern power systems in this current scenario as these devices are very sensitive to power quality problems. Before installing compensating devices in transmission systems its appropriate location with parameters settings are to be decided [7-15] for any researchers.

Over the last few years optimal power flow problem using FACTS devices solved by evolutionary computational method as well as conventional method such as differential evolution[4], gravitational search algorithm [5,13], sparse optimization [7], particle swarm optimization (PSO) [13,28,32], firefly algorithm [21], Fuzzy genetic algorithm (GA) [22], Bacterial forging Algorithm [24], self adaptive forging algorithm [25,27]. This paper focuses on conventional method because it has many advantages, accurate result and less computational efforts over evolutionary method. Most favorable location of Flexible AC Transmission Systems (F.A.C.TS) devices with its proper parameter settings improves power flow by power losses minimization and maximizes voltage profile that will be tested with IEEE 30 and 57 bus is the main aim of this paper [15-30]. In this paper simulation studies are performed by proper location of F.A.C.TS devices optimally checked by conventional method and obtained result will be compared with evolutionary method. This paper is organized as Introduction followed by formulation of compensating devices in which four types of FACTS will be discussed with power flow solutions with flow charts. In next section simulations results are presented by figures and in Table and results & discussion in next chapter. Finally in last conclusions of present work are discussed in 'Conclusion' section.

II. Formulation of compensation devices

Power flow equations are nonlinear and solved by iterative methods. The Newton-raphson power flow solution is preferred to other as it has more efficient to solve the practical problem. T.C.S.C. influence reactance of line and angle of the voltage which control active power flow in the transmission line. The S.V.C. and S.TATCOM are shunt connected devices utilized for absorb or inject reactive power and regulate voltage. The UPFC be capable of separately control real and reactive power by being integrated into a universal power controller combining the functions of T.C.S.C. and S.V.C. [30-33].

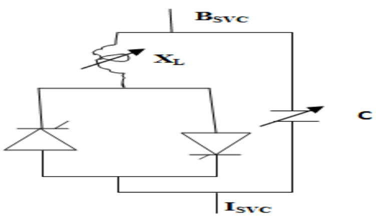

Fig. 1 (a). Equivalent circuit model of S.V.C.

Revised Manuscript Received on 30 March 2019.
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The equivalent circuit model of S.V.C. is shown in Fig. *1 (a)* which consists of variable reactor (X_L) and variable capacitor with thyristor. The switching control action of thyristor modified the susceptance and it draws either I_C or I_L current [8]. The power flow diagram with SVC using NR method is shown in Fig. 1(b) below. T.C.S.C. (Thyristor Controlled Series Compensators) acts as a variable capacitive reactance controller shunted with thyristor control reactor which compensates active power flow and voltage regulation. It will be modeled by reactance $X = X_{TCSC} + X_{LINE}$ and at every iteration reactance will be modified from its previous values. The TCSC model connected between bus x and y is shown in Fig.2 (a) below. A static synchronous compensator, shunt operated voltage source converter (VSC) is known as STATCOM comes in to operation with SVC and it will provide better regulation and dynamic power support. It consists of insulate gate bipolar transistor (IGBT) and gate turn off thyristor (GTO) and it adjusted in a flexible mode for voltage magnitude and phase angle from a minimum to maximum value. It continuously regulates voltage on buses and reactive power support to the system [22]. The model of STATCOM is shown in Fig.3 where Fig 3.*(a)* shows equivalent circuit in which V and δ are adjustable voltage magnitude and phase angle according to power flow [23]. The power flow solution with STATCOM using N-R method is shown in Fig. *3(b).* UPFC (Unified power flow controller) combined series compensator and fixed synchronous shunt compensators with a phase changing device jointly, between two transformers to control series voltage phase changing and power swap. Transformer impedances control voltage magnitude and phase angle for limits $V_{1sE}^{max} \leq V_{sE} \leq V_{1sE}^{min}$, $0 \leq \theta_{1sE} \leq 2\Pi$ and $V_{1sH}^{max} \leq V_{1sH} \leq V_{1sH}^{min}$, $0 \leq \theta_{1sH} \leq 2\Pi$. UPFC equivalent circuit connected between bus x and y shown in Fig. 4.

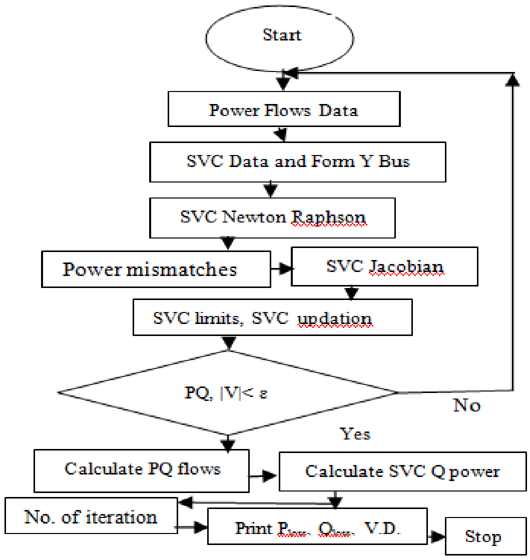


Fig. 1 (b). Flow chart for SVC power flow solutions

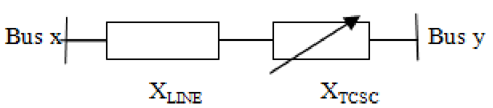


Fig. 2 (a). TCSC model

The TCSC power flow solution using NR method is shown in Fig. *2(b)* below

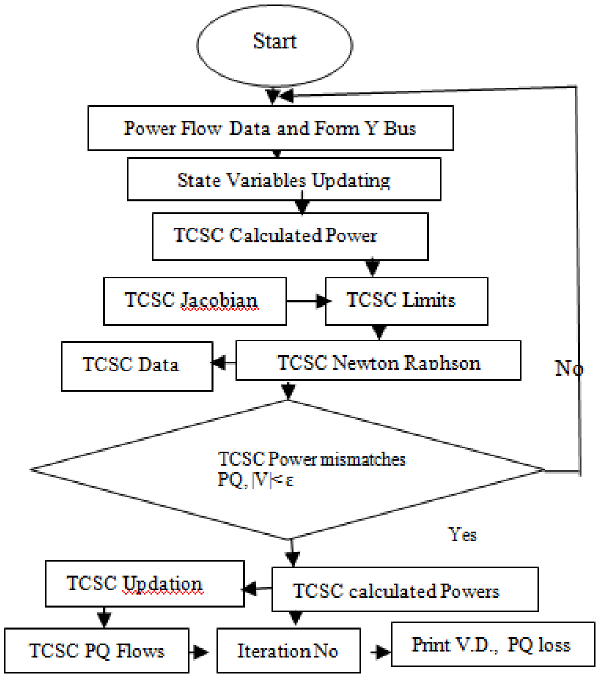


Fig. 2 (b). Flow chart for T.C.S.C. power flow solution

The flow chart of power flow solution with F.A.C.T.S. devices as illustrated in Fig.1 *(b)*, Fig.2 *(b)*, and Fig. 3*(b)* has involved following steps

Step 1: Power flow data of IEEE 30 and IEEE 57 bus system are read and form the Y Bus.

Step 2: Collect the S.V.C. Data, S.TATCOM and T.C.S.C. data where location of FACTS devices with their settings are fixed.

Step 3: Apply Newton Raphson Technique with FACTS device.

Step 4: Form Jaccobian matrix

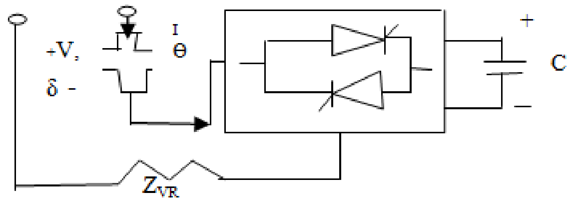
Step5: Define the limits of FACTS such as SVC, STATCOM and TCSC.

Steps 6: PQ flows and voltage magnitudes are within limits and satisfy constraints and power mismatches. If it satisfies go to next step7 otherwise repeat to step 1

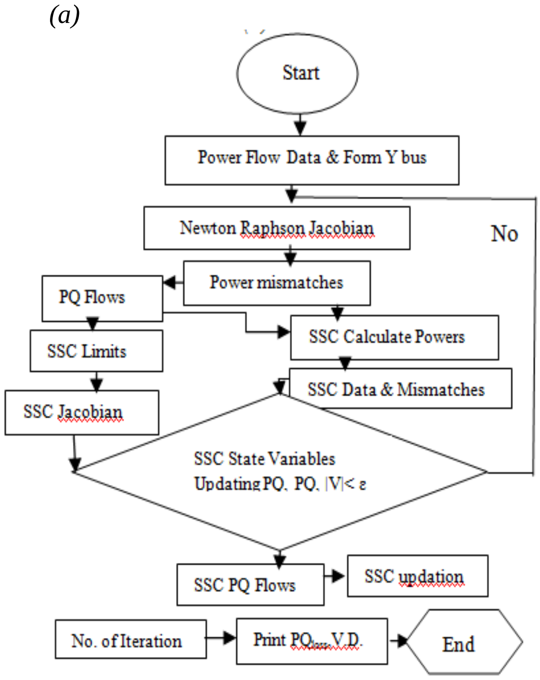
Step 7: Calculate PQ flows and its power with FACTS devices.

Step 8: Set number of Iterations and given result of P_{Loss}, Q_{Loss} and voltage deviation and found the best solutions for appropriate locations of F.A.C.T.S.

Step 9: End the program.



(a)



(b)

Fig.3 Model of STATCOM

(a) Equivalent circuit of STATCOM, (b). Power flow solutions with STATCOM using N-R method

For a given power system with m buses, let 1 to m be the PQ buses. The power flow equations under stable can be represented by:

$P1x = P1Gx - P1Dx = \sum_{y=1}^{n} VxVy\ Yxy\ (\text{Cos}\delta xy - \theta xy)$, x=1,… m-1,

$Q1x = Q1Gx - Q1Dx = \sum_{y=1}^{n} VxVy\ Yxy\ (\text{Sin}\delta xy - \theta xy)$, x=1,…m-1,

For simulation studies bus voltage magnitude are set at 1.0 and angle δ at 0 per unit for utilities to perform. In this conventional method shunt compensating devices located at every load bus and series compensating device locates at each transmission line to obtain the desired objective of power losses minimization and voltage deviation minimization. The effectiveness of proposed method for OPF solution with compensating devices is tested on IEEE 30 and 57 bus system [24-33].

The results obtained by proposed method are compared with different evolutionary optimization algorithm based on evolutionary optimization method [4][5][7][13][21,22,24,25,27, 28,32].

The power flow solution satisfies equality and inequality constraints with limitation on parameters and voltage magnitude constraints at all buses [20-23].

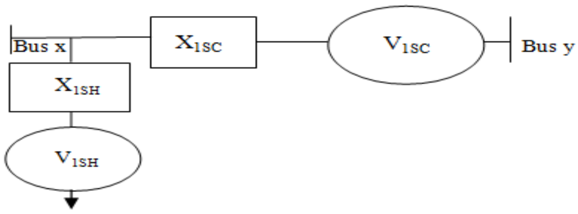


Fig. 4. Equivalent circuits for UPFC

III. SIMULATION RESULTS

In this work Matlab programs are developed on 100 MVA base data for power quality improvement of power flow with IEEE 30 and 57 bus test system and executed by means of newton- raphson technique for total 100 iterations. Results of proposed method are obtained for various types of FACTS devices by their placement in power flow at all buses of the network. The IEEE 30 bus system has six generators connected on buses 1, 2, 5,8,11 along with 13. The scheduled active and reactive powers contributed by generators are 40 MW and 151.1 MVAR respectively. Buses are interconnected with 41 transmission line branches and 24 load buses with a total load of 137.6 MW and 64.5 MVAR. The IEEE 57 bus test scheme has six generators connected on buses 2, 3, 6, 8, 9 and 12. The scheduled active and reactive powers contributed by generators are 800 MW and 191.8 MVAR respectively. The buses are interconnected with 80 transmission line branches and 50 load buses with a total load of 422.5 MW and 136.48 MVAR.

Case 1: Without any FACTS device

In this case power flow without FACTS devices for IEEE 30 & 57 bus test system simulated and result of power losses and voltage deviation are shown in Table I.

Table I. Simulation results power flow of IEEE 30 &57 bus system without FACTS devices

System	P_{loss}	Q_{loss}	Voltage Deviation
IEEE 30 Bus	0.0830	0.1515	0.2807
IEEE 57 Bus	0.5445	1.0585	0.7337

Case 2. With FACTS Devices

In this case power flows with various FACTS devices for IEEE 30 & 57 bus test system are simulated by their placement. The results of SVC & STATCOM placement in power flow at load buses and TCSC & UPFC placement in line shown in Table II. In this case the purpose is to real &reactive power losses minimization and voltage profile improvement in power flow studied to satisfy the objective that would be found out as shown in Table II that Ploss, Qloss and voltage deviation is smallest as compare to Table I.

Table II. Simulation results of power flow tested with IEEE 30 and IEEE 57 bus test method after FACTS placement

System	Devices	Bus	P_{loss} (pu)	Q_{loss} (pu)	V.D.
IEEE 30 bus	SVC	25	0.058	0.063	0.175
	STATCOM	25	0.0506	0.044	0.154
	TCSC	25-26	0.051	0.052	0.165
	UPFC	25-26	0.049	0.045	0.152
IEEE 57 bus	SVC	38	0.536	0.967	0.356
	STATCOM	38	0.533	0.96	0.35
	TCSC	14-46	0.5379	1	0.69
	UPFC	49-50	0.5	0.86	0.345

IV. RESULTS AND DISCUSSION

The voltage profile comparison for IEEE 30 bus IEEE 57 bus test system between without FACTS devices and after its placement are shown in Fig.5 and Fig.9 respectively. It is observed from these Fig.5 & 9 that after FACTS devices placed in case of SVC and STATCOM and in line in case of TCSC and UPFC the voltage profile is improved as compare to without FACTS devices After FACTS placement in system voltage deviation is least as shown in Fig.6 in all cases so voltage profile is improved. Table II shows simulation results of power flow with IEEE 30 bus and IEEE 57 bus test method after FACTS devices placement and it easily compare performance of various FACTS devices from Table II. The comparison performance between propose conventional method and various evolutionary method is shown in Fig.8 for IEEE 30 bus system which shows that proposed method achieved better performance than evolutionary method.

Comparison performance for power flow tested with IEEE 30 bus test system are shown in Fig.7 where Real power loss savings and voltage profile improvement with respect to stand value after assignment of FACTS devices placement is shown in Table 3 and in Fig.7 (a) & (b) respectively. Comparison performance for power flow tested with IEEE 57 bus test system is shown in Fig.10 where Fig.10 (a) & (b) shows Real power loss savings and voltage profile improvement. It can be observed from Fig. 7, 10 and Table III that all FACTS devices are proficient of power loss savings and Voltage profile enrichment and after placement of FACTS devices the active power loss and reactive power loss are reduced as compared to without FACTS devices thus Power Quality is improved.

The proposed conventional method for obtain power losses and enhancement of voltage profile after FACTS assignment are compared with evolutionary based computational method such genetic algorithm (GA) based gravitational search algorithm, PSO, Honey Bee Algorithm (HBA), Bacteria Foraging Algorithm (BFA) in reference [4][5][7][13][21,22,24,25,27, 28,32]and their results are shown in Table IV. It can be observed that the proposed method for obtaining real power loss by conventional method is much better than optimization method as this method provides better results as shown in Fig. 11 and in Table IV.

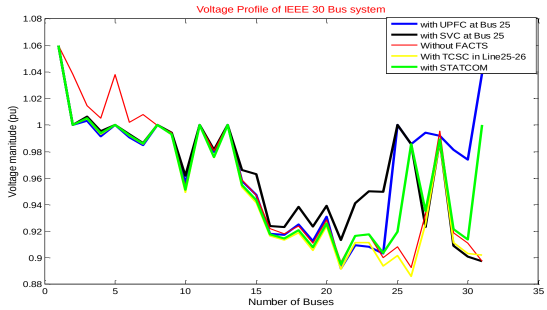


Fig. 5. Voltage profile comparison for power flow in IEEE 30 bus test system

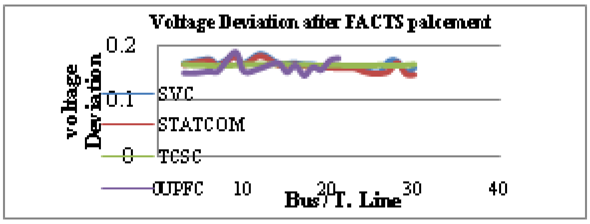
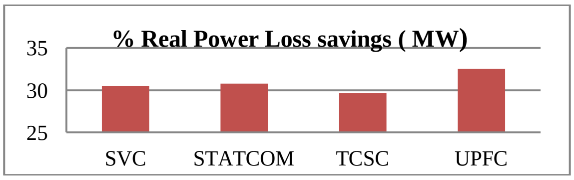
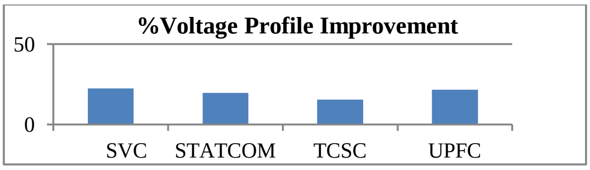


Fig.6. Voltage Deviation (p.u.) of IEEE 30 Bus system after FACTS devices placement



(a)



(b)

Fig.7. Comparison of performance
(a) % Real Power Loss Savings for IEEE 30 bus
(b) %voltage profile improvement for IEEE 30 bus

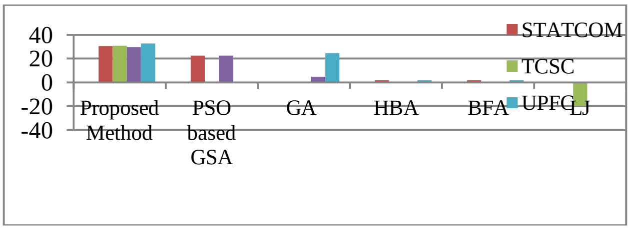


Fig. 8. Comparison performances between FACTS devices Placement by proposed method and optimization method for IEEE 30 Bus system.

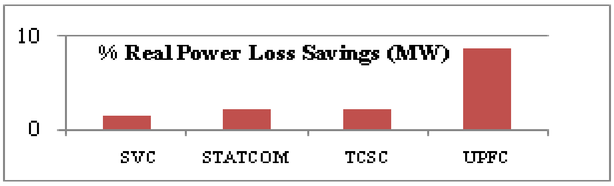
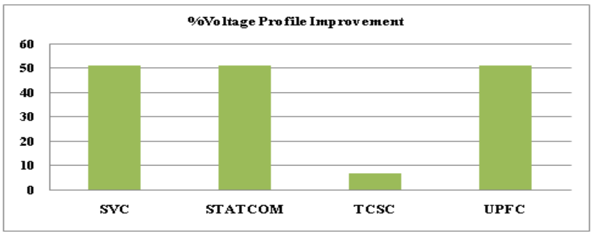


Fig. 9. Voltage profile comparison intended for IEEE 57 bus with and without FACTS

(a)



(b)

Fig.10. Comparison Performance in Power flow of IEEE 57 bus test system
(a).Comparison of % Real Power Loss Savings
(b). Comparison of % Voltage profile Improvement

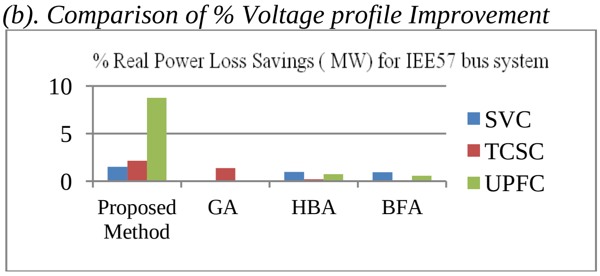


Fig.11. Comparison performance between FACTS devices placement by proposed method and optimization method for IEE57 Bus system

Table III: Performance comparison before and after FACTS placement

System	Objective	Before FACTS	After FACTS placement			
			SVC	STATCOM	TCSC	UPFC
IEEE 30 Bus	P_{Loss}	7.31	5.12	5.01	5.17	4.93
	Q_{Loss}	10.585	9.671	9.669	10.3	8.686
	Voltage Deviation (p.u.)	0.1851	0.1509	0.1546	0.165	0.15269
IEEE 57 Bus	P_{Loss}	54.45	53.6	53.31	53.79	50.06
	Q_{Loss}	105.8	96.7	96.69	103.0	86.8
	Voltage Deviation (p.u.)	0.7331	0.35	0.355	0.69	0.52

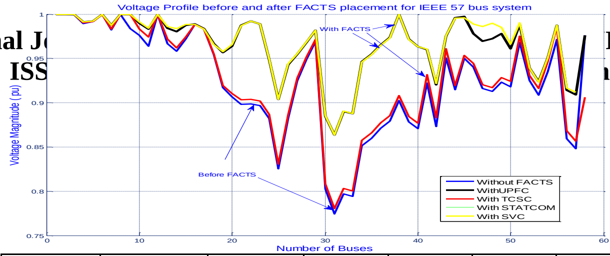


Table IV: Performance comparison between proposed method and Optimization method after FACTS placement for % Real power loss savings (MW)

System	After FACTS Placement	Proposed Method	PSO based GSA[13,28,32]	GA [22]	SFA [25,27]	BFA [24]
IEEE 30 Bus	SVC	30.5	22.56	--	1.79	1.78
	STATCOM	30.78	--	--	---	---
	TCSC	29.64	22.56, 2.73 [33]	4.86	0.34	0.29
	UPFC	32.55	--	24.6	1.79	1.78
IEEE 57 Bus	SVC	1.5	--		0.98	0.93
	TCSC	2.13	1.653	1.26	0.19	0.11
	UPFC	8.76	--	--	0.75	0.56

V. CONCLUSIONS

The usefulness of the FACTS devices for power quality improvement by reducing the real and reactive power losses in lines are investigated. In this paper standard test system IEEE 30 and IEEE 57 bus data is used for simulation study work. The simulation result shows that proposed conventional methods works better for the test system. On optimally putting FACTS devices by conventional method to IEEE bus system can diminish power losses and pick up the power flow by improvement of voltage profile. The proposed conventional methods reduce optimal power flow problem efficiently by minimize active power loss, reactive power flow and improve voltage profile of overall system and hence power quality is improved. Four types of FACTS devices of SVC, STATCOM, TCSC and UPFC are considered here for optimal placement by Newton Raphson power flow technique.

Simulation result are performed without any FACTS devices as in case I and results obtained of Table 1 now compared results of case 2 for simulation with FACTS devices SVC, STATCOM, TCSC and UPFC placement shown in Table 2, and it observed that after placement of FACTS devices power losses are reduced and voltage deviation is decreased at all buses which improves power quality. The proposed conventional technique for FACTS placement are now compared with various evolutionary based optimization such PSO, genetic algorithm (GA) based gravitational search algorithm, Honey Bee Algorithm (HBA), Bacteria Foraging Algorithm(BFA) method and results are shown in Table 4. It can be observed that the proposed conventional method approach for obtaining real power loss is much better than optimization method as this method provides better results

REFERENCES

1. Acha E., Ambriz H. and Fuerte- Esquivel C.R., , " Advanced SVC model for newton –raphson load flow and newton optimal power flow studies", IEEE transaction on Power system, February 2000, Vol.15, No.1, pp. 129-136.
2. Bina M.Tavakoli, Rahimzadeh S., "Looking for optimal number and placement of facts devices to manage transmission congestion", Energy conversion and management, (2011), Vol.52, pp 437-438.
3. Aghaei J., Kaji M., Gitizadeh M., "Placement and operation strategy of FACTS devices using optimal continuous power flow", Scientia Iranica D, (2012), Vol.19, pp 1683-1690.
4. Basu M.," Multi objective optimal power flow with FACTS devices", Energy conversion and management, (2011), Vol. 52 pp 903-909.
5. Bhattachryya B., Kumar S., "Reactive power planning using Gravitational search Algorithm", Ain Shams Engineering journal, (2015), Vol. 6, pp 865-871.
6. Bhattacharyya B. and Kumar S., "Approach for the solution of transmission congestion with multi-type FACTS devices", IET Generation Transmission & Distribution, (2016), Vol. 10, Iss. 11, pp. 2802–2809.
7. Duan Chao, Jiang Lin, Shuanbao Niu,"FACTS devices allocation via sparse optimization", IEEE Transactions on power systems, (2016) march, Vol. 31, No. 2.
8. Gitizadeh M., Kalantar M., "A novel approach for optimum location of FACTS devices using multi objective function", energy conversion and management, Elsevier, (2009), Vol.50, pp 682- 690.
9. Ghahremani Esmaeil, "Optimal placement of multiple types of FACTS devices to maximize power system loadebility using a genetic algorithm", IEEE Transaction on Power systems, (2013), Vol.28, pp 764-778.
10. Ghahremani Esmaeil, Kamwa I., " Analyzing the effects of different types of FACTS devices on steady state performance of Hydro-Quebec network", IET Generation, Transmission & Distribution, ISSN 1751-8687, (2013), iet gtd0316,pp 1-17.
11. Hingorani N.G., Gyugi L, 'High Power Electronics and Flexible AC Transmission Systems', IEEE Power Engineering Review, Understanding FACTS: concept and technology of flexible AC transmission systems, IEEE press 2000.
12. Inkollu S. R., Reddy Kota V., "Optimal setting of Facts devices for voltage stability improvement using PSO, GSA algorithm", Engineering Science & technology, Elsevier, (2016), pp1166-1176, Vol.19.
13. J. Bhaskaran, V.Palanisamy, "Optimal Location of FACTS devices in a power system solved by a hybrid approach", nonlinear analysis, (2006), Vol. 65 pp. 2094-2102.
14. Kumar Vijay B., Srikant N.V., "Optimal location and sizing of UPFC to improve dynamic stability: A hybrid technique", Electric power and Energy Systems, (2015), 64, pp 429-438.
15. Husain Ashfaque, "Electrical Power Systems", CBS publisher, (2010), pp.362-378,5th edition, ISBN:81-239-1448-2.
16. Huang Y.C., Huang C.M.,"Hybrid optimization method for optimal power flow using flexible ac transmission system devices", IET journal, May 2014, pp 2036-2045.
17. Lara Anaya O., Acha, E., Modeling and Analysis of Custom Power Systems by PSCAD/ EMTDC', IEEE Trans. Power Delivery, 2002, 7(1) 266–272.
18. Laghari J.A., Mokhlis H., A.H.A. Bakar, "Application of computational intelligence techniques for load shedding in power systems", Energy Conversion and Management, (2013), Vol.75 pp 130-140.
19. Mhaskar U.P., Mote A.B. and Kulkarni A.M., "A new formulation for load flow solution of power systems with series FACTS devices", IEEE Transactions on Power systems, 2013 November, Vol. 18, No.4, pp.1307-1315.
20. Mishra A., V. N. Kumar G. and Venkateswara Rao Bathina, real power performance index and line stability index-based management of contingency using firefly algorithm, IET Generation, Transmission & Distribution, (2016) April, Vol. 10, Iss. 10, pp. 2327–2335.
21. Niazi K.R., Phadke A.R., Fozdar Manoj, "A new multi objective fuzzy GA formulation for optimal placement and sizing of shunt facts controller", Electrical Power and Energy systems, (2012) Vol.40, pp 46.
22. P. Kundur, "Power system stability and control", McGraw- Hill, Inc. (1993).
23. Rajasekar N, Sathiyasekar K., Senthilnathan N., Sarjila R., Edward J Belwin., "An enhanced bacterial foraging algorithm approach for optimal power flow problem including FACTS devices considering system loadability", ISA Transactions, ELSEVIER, (2013), Vol.52 622–628.
24. Ranganathan S., Kalavathi M. S., C. A. Rajan C., "Self-adaptive firefly algorithm based multi-objectives for multi-type FACTS placement, IET Generation, Transmission & Distribution, (2016), Vol. 10, Issue. 11, pp. 2576–2584.
25. S.N. Singh and A.K. David, "Congestion Management by optimizing FACTS device location", International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, London, (2000), 4-7 April, pp 23-28.
26. Selvarasu R., C.Christober A.R., Surya M. K., "Optimal placement of TCSC for voltage constraint loss minimization using self adaptive firely algorithm", Journal of electrical engineering, Romania, (2014), Vol.14, No.2, pp.128-135.
27. Saravanan M., Mary S. R.Slochanal, P.Venkatesh, "Application of PSO technique for optimal location of FACTS devices considering cost of installation and system loadability", Electric Power System Research, (2007), Vol.77, pp-276-283.
28. Sreejith S., Simon S. P, Selvan M.P., "Analysis of FACTS devices on security constrained unit commitment problem", Electrical Power and Energy System, 2015, Vol.66, pp.280-293.
29. Tjing Lie and Wanhong Deng, " Optimal Flexible AC Transmission systems (FACTS) devices allocation", Electrical Power and Energy systems, (1997) Vol.19, No.2, pp 125-134.
30. Y. Xiao, Y.H.Song, Y.Z.Sun, "Power Flow control approach to power systems with embedded FACTS devices", IEEE transaction on Power system, November (2002), Vol.17, No.4, pp.943-950.
31. Rudra Pratap Singh, V. Mukharjee, S.P. Ghosal, "Particle swarm optimization with an aging leader and challengers algorithm for optimal power flow problem with FACTS devices", Electrical Power and Energy systems, (2015), Vol.64, pp 1185-1196.
32. C.S.Chang and S.W. Yang, "Optimal multiobjective planning of dynamic series compensation devices for Power quality improvement", IEE Proc-Gener.Trans.Distribution, (2001), Vol.148, No.4, pp 361-370.
33. Yan Zhang and Jovica V. Milanovic, "Global Voltage Sag mitigation with FACTS based devices", IEEE Transaction on Power Delivery, (2010) October, Vol.25, No.4, pp.2842-2850.