Optimal Placement of Static Var Compensator to Maximize System Loadability and Reduce Installation Cost using ABC Algorithm

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Abstract—

Due to huge increase in load, modern power system networks are being operated under highly stressed conditions. As a result, power system networks find it extremely difficult to meet reactive power requirement and maintain the bus voltage of power system within acceptable limits. In this work, artificial bee colony algorithm (ABC) is proposed for enhancing and controlling power flow using Flexible AC transmission system (FACTS) controllers. The objectives considered are enhancement of system loadability, reduction of Installation cost of devices and reduction of transmission loss. Three types of FACTS devices such as Static VAR compensator (SVC), Thyristor controlled series compensator (TCSC) and unified power flow controller (UPFC) are used. The optimal location and parameter setting of FACTS devices is achieved using ABC algorithm. In this paper SVC device is implemented on IEEE 57 and IEEE 118 bus systems using MATLAB platform. The power flows are analyzed. The results obtained are compared with existing literature. The results indicates that the proposed algorithm gives better improvement in system loadability, reduction of transmission loss and installation cost. Hence the proposed algorithm will be useful in restricting of power networks.

Keywords: static var compensator, optimal location, artificial bee colony algorithm

I. INTRODUCTION

Voltage instability has been a major concern in power systems, especially in planning and operation [1-3]. Voltage stability is concerned with the ability of a power system to maintain acceptable voltage at all buses in the system under normal conditions and also after being subjected to a disturbance [4-8]. Some of the causes of voltage instability are (i) increase in load demand; (ii) changes in system condition (iii) load centres far from generation locations; (iv) overloaded transmission lines; (v) inability to meet reactive power demand. Voltage instability is the absence of voltage stability, and results in progressive voltage decrease (or increase). In recent years, voltage instability has been responsible for several major network collapses.

Flexible AC Transmission Systems (FACTS) was introduced in the late 1980 by the Electric Power Research Institute (EPRI), USA. FACTS is defined as a power electronic based system with other static equipment, providing control of one or more AC transmission system parameters to enhance controllability and increase in power transfer capability [9]. FACTS has made power systems operation more flexible and secure. It has the ability to control the phase angle, the voltage magnitude at chosen buses and line impedance of transmission system in a quick and effective manner. It also controls active as well as the reactive power flow over a line [10, 11].

FACTS devices are revolutionary power transmission networks, leads increasing efficiency and stability of power systems [12].Control the reactive power flow for more efficient use of transmission lines using FACTS devices. [13]. FACTS devices can also significantly reduce voltage sags in the system and in modifying the effects of the remaining sags to minimize the high associated costs of equipment disoperation [14]. Voltage sag is defined as a short duration reduction of the root mean square value of AC voltage lasting between half a cycle and several cycles [15]. Voltage instability is considered as a primary concern in power systems mainly in planning and operation. Several power interruptions are related due to voltage instability [16-18]. Some of the factors for voltage instability are power system configuration, generation pattern and load pattern [19-21].

Proper location is a key to maximizing the benefits of the FACTS devices [22]. The location of FACTS devices is dependent on static or dynamic performances of the system. The sensitivity factor methods are used to find the best place to improve the static performance of the system [23].Meta heuristic Grey Wolf Optimizer (GWO) algorithm to solve OPF problems equipped with shunt connected FACTS device SVC[24].The TCSC location-allocation problem is formulated as a mixed integer nonlinear program, and proposes a novel decomposition procedure for determining the optimal location of TCSCs and their respective size for a network[25].An adaptive differential evolution algorithm to allocate TCSC incorporated with the reactive power management problem[26].For the restructuring power system (RPS), the self-adaptive differential evolutionary (SADE) algorithm is proposed for enhancing and controlling the power flow using UPFC under practical security constraints (SCs)[27].

This paper presents optimal location and sizing of FACTS devices SVC using ABC algorithm. In this work, SVC is modeled as a reactive source added at both ends of the line. The optimal location is done to maximize system loadability, reduce transmission loss, and installation cost of FACTS devices. The cost function of SVC are taken from Siemens database [28]. The developed code is tested on IEEE-57 bus and IEEE-118 bus test systems in MATLAB platform.

II. Modeling of Static Var Compensator

SVC is a shunt-connected static var generator or absorber whose output can be automatically adjusted according to whether capacitive or inductive current is required in order to maintain or control specific parameters of the electrical power system (typically bus voltage). It is modelled as an ideal reactive power injection or absorption at the load end. Variable shunt susceptance model of SVC has been used in this research; this is shown in Figure 1.

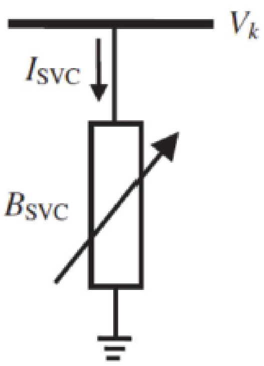

Figure 1. Variable shunt susceptance model

Current drawn by SVC is

$$I_{svc} = j\beta_{SVC} * V_K \qquad (1)$$

Reactive power drawn by SVC is

$$q_{svc} = -V_K^{\,2}\beta_{SVC} \qquad (2)$$

The equation (4) tells the reactive power is the square of voltage magnitude (V_k) and susceptance β_{SVC}. When the system voltage is low then it generates reactive power and when the system voltage is in high then the system can absorb the reactive power.

Load flow equations:

$$p_{Gi} - p_{Di} - p_i - \sum_{j=1}^{n} v_i v_j \left[G_{ij}\cos(\delta_{ij}) + \beta_{ij}\sin(\delta_{ij})\right] = 0 \qquad (3)$$

$$q_{Gi} - q_{Di} - q_i - q_{svc} - \sum_{j=1}^{n} v_i v_j \left[G_{ij}\sin(\delta_{ij}) - \beta_{ij}\cos(\delta_{ij})\right] = 0 \qquad (4)$$

III. Problem Formulaton

Multi-objective optimization problem is formulated considering five objective functions of minimization of voltage stability index, generator cost, power loss, load voltage deviation and cost of SVC. The optimization problem is subjected to equality and inequality constraints. Power balance constraints are considered as equality constraints. Inequality constraints are considered for the real power output of generating units, generator reactive power, voltages of all PV buses, transformer tap positions, bus voltage magnitudes of all PQ buses, power flow in the transmission line and reactive power rating of SVC. Fitness value is found by satisfying all the constraints. The optimal placement and parameter setting of FACTS device is done using artificial bee colony algorithm.

The Multi objective optimization problem is formulated as:

Maximize $\lambda = P_d^{\,i}/P_d^{\,0}$

Subject to $F(\lambda, V, \delta, P, Q, Q_{svc},) = 0$ (5)

with constraints given by (14)-(23)

Where $F = \lambda + TL + VD + LFD + IC_{cost}$

And $F(V,\delta,P,Q)$ is the power flow equations described by (3),(4).

A. Maximization of System loadaility (λ):

The Maximum System Loadability, MSL is calculated by

$$P_d^{\,1} = \lambda P_d^{\,0} \qquad (6)$$

Where λ, is loading parameter, P_d^0 and P_d^1 are system load before and after FACTS device placement.

(i) Voltage Deviation (VD):

The desirable limits of voltage in power system are within ±5%. The Voltage Deviation is calculated using equation (15).

$$VD = \sum_{i=1}^{n} \left(\left|V_i^{ref}\right| - \left|V_i\right|\right)^2 \qquad (7)$$

V_i –Voltage at i'th bus

V_i^{ref}–Reference Voltage at 'i th bus

(ii) Line flow deviation (LFD):

The line flow limits of the transmission network must be maintained within specified limits. The line flow deviation is calculated using equation (8).

$$LFD = \sum_{ij-lines} \left(\left|LF_{ij}^{ref}\right| - \left|LF_{ij}\right|\right)^2 \qquad (8)$$

LF_{ij} –Line flow of line 'ij'

LF_{ij}^{ref}– Line flow limit of line 'ij'

B. Reduction of Transmission loss (TL):

The proposed algorithm considers the minimization of transmission losses by optimal placement of FACTS devices. The transmission loss is calculated using equation (9).

$$TL = \sum_{i=1}^{gen} p_{Gi} - \sum_{i=1}^{n} p_{Di} \qquad (9)$$

Where n is number of buses.

C. Reduction Of Installation Cost (IC_{cost}):

The installation cost is SVC cost. The cost functions of IPFC, TCPST are taken from Siemens database [22].

$$IC_{COST} = IC_{SVC} \qquad (10)$$

(i)SVC installation cost (IC_{SVC}):

The cost function of SVC is given as:

$$c_{svc} = 0.0003r^2 - 0.3051r + 127.38 \quad (11)$$

$$IC_{svc} = c_{svc} \times r \times 1000\,US\$ \quad (12)$$

In the equations (12) the value of r is the operating range of FACTS device given as :

$$r = |Q_2 - Q_1| \quad (13)$$

Where Q_2 and Q_1 are the reactive power flow in the line after and before installing the FACTS devices in MVAR respectively. The cost depends on the operating range of the facts device.

D. Constraints:

The optimal placement of FACTS devices is a constrained optimization problem which includes equality and inequality constraints.

(i). Equality constraints:

The equality constraints are given as:

$$P_{gi} + P_i - P_{di} = \sum_{j=1}^{n} V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) \quad (14)$$

$$Q_{gi} + Q_i - Q_{di} = \sum_{j=1}^{n} V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) \quad (15)$$

Where P_{gi}, Q_{gi} are real and reactive power generations, Pi, Qi are real and reactive power injections, P_{di}, Q_{di} are real and reactive power demands at the i^{th} bus. $Y_{ij}\angle\theta_{ij}$ is ij^{th} element of admittance matrix.

(ii). Inequality constraints:

The inequality constraints are given as:

$$P_G^{\min} \le P_G \le P_G^{\max} \quad (16)$$

$$Q_G^{\min} \le Q_G \le Q_G^{\max} \quad (17)$$

$$V^{\min} \le V \le V^{\max} \quad (18)$$

$$\delta^{\min} \le \delta \le \delta^{\max} \quad (19)$$

$$\lambda \le \lambda^{\max} \quad (20)$$

Where P_G, Q_G are real and reactive power generations at generator busses, V and δ are bus voltage magnitude and phase angle and λ is the system loadability.

(iii)SVC Constraints:

$$q_{SVC}^{\min} \le q_{SVC} \le q_{SVC}^{\max} \quad (21)$$

$$\beta_{svc}^{\min} \le \beta_{svc} \le \beta_{svc}^{\max} \quad (22)$$

$$-100\,MVAR \le q_{svc} \le 100\,MVAR \quad (23)$$

IV. PROPOSED METHODOLOGY

The electric power is transmitted from one end to anther end over the transmission line in accordance to the consumer requirements incurring minimum amount of losses. The consumer power is varied on the basis of load variation or disturbances in the transmission line. The flexible alternating current transmission systems devices are introduced to change the voltage, phase angle and impedance in power systems. During the operation of these devices the active and reactive power is maintained in the balanced manner. The FACTS device can control the power flow and increase the transmission capacity. The various electrical parameters in the transmission circuits are controlled by the solid state converters of the FACTS devices and the installation cost of these devices are reduced when the location of these device are optimal while satisfying the constraints. In this case single type FACTS devices like SVC, TCSC, and UPFC and multi type devices are used.

The Meta heuristic technique of artificial bee colony algorithm [34] is defined by Karaboga in 2005. This algorithm is derived from the foraging behaviour of honey bee and it searches the food source around multidimensional search space. The bees are classified into three based on its experience and without experience as employee, onlooker and scout bees. In which each employed bees find out the food source and share the information among the other bees through specialized dance. The waggle dance is proportional to the quality of food source. The other bees are waiting in the dancing area to choose the best food source. The scout bees search the food source without any guidance.

The employed bees move towards the food source from its original location (a_{ij}1) to new location (z_{ij}) and it may be written by (37),

$$z_{ij} = a_{ij} + \pi_{ij}(a_{ij} - a_{kj}) \quad (24)$$

π_{ij} is the number of food sources and uniform random umber between -1 to 1. If the new location of the food source is better than that of the current position then the new location is dated. The new position can be updated by,

$$z_{ij} = a_{ij} + w\pi_{ij}(a_{ij} - a_{kj}) \quad (25)$$

The weight coefficient of employed bee information is mentioned as w. The probability of food source can be calculated by,

$$P = \frac{fit}{\sum_{j=1}^{sn} fit_j} \quad (26)$$

The employed bees fitness values is find out by,

$$fit_j = \begin{cases} \dfrac{1}{1+f(x)} & f(x) \ge 0 \\ 1+|f(x)| & f(x) < 0 \end{cases} \quad (27)$$

Where $f(x)$ represents the amount of objective function to be used in optimization.

$$fit_j = IC + pf * \|j-1\| \quad (28)$$

Where IC denotes the installation cost of FACTS devices, pf is the penalty factor. The flowchart of proposed algorithm is given in Fig.2

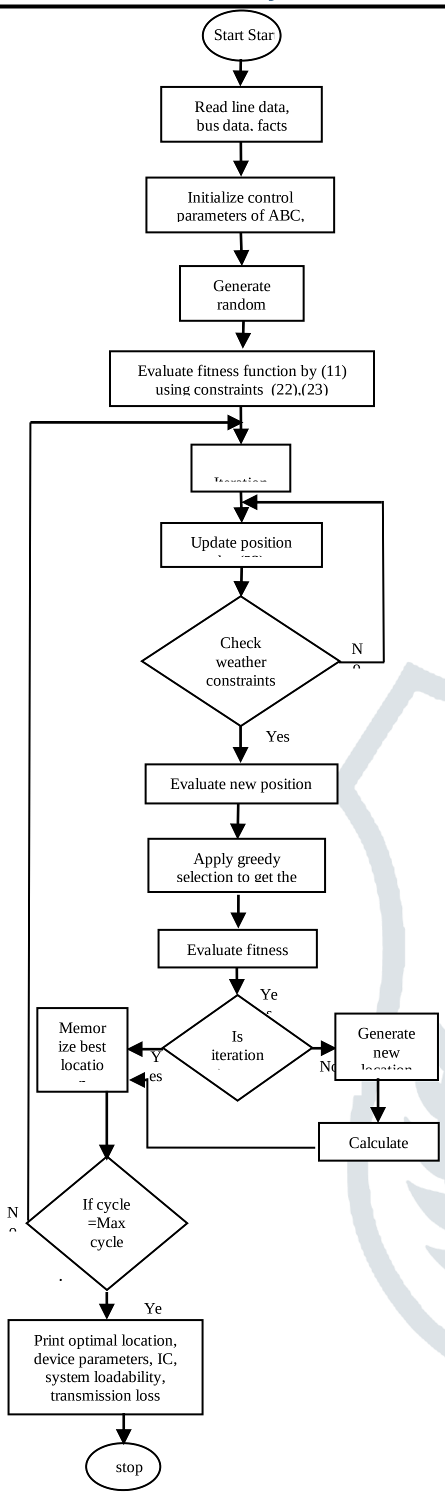

Fig.2. Flow chart of proposed methodology

V. Results and Discussion

The optimal placement of FACTS devices are done under the platform MATLAB. The optimal location and sizing of FACTS devices is carried out using ABC algorithm with a colony size of 20 and MCN 100. To prove the Effectiveness of locating FACTS devices with SVC is considered.

A. *IEEE 57 Bus System*

The data for IEEE 57 bus system is taken from matpower 3.0. and this system contains 1 slack bus, 6 PV buses, 50PQ buses and 80 transmission lines.

Table. 1. line flow in IEEE 57 Bus System

Type	From line	To line	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
SVC	1	2	102.390	37.476	105.084	32.219	42.8Mvar	1,061.27	1.95
	3	4	77.260	60.052	78.488	10.068	25.7 Mvar		
	8	9	60.538	56.696	77.427	54.392	25.7 Mvar		
	12	13	5.469	-11.99	7.496	11.024	25.7 Mvar		
	20	3	61.620	-36.79	65.730	-6.852	25.7 Mvar		

The simulations are performed in MATLAB and the results are obtained using ABC algorithm. Table.1. shows line flows in IEEE 57 bus system. In single type, SVC is located in lines 1-2, 3-4, 8-9, 12-13, 20-3. The system loadability with single type SVC is 1.82. From IEEE 57 bus system we concluded that highest system loadability is achieved with low installation cost with SVC. Highest installation cost at moderate system loadability is obtained with UPFC. System loadability and installation cost variations are shown in Fig.3. and Fig.4.

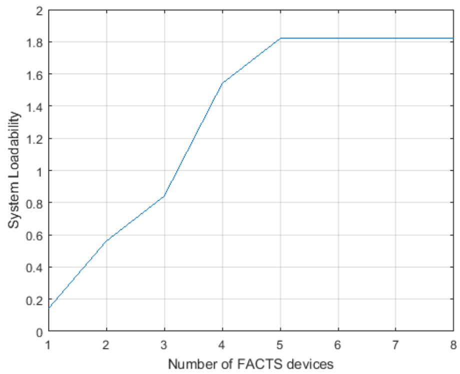

Fig. 3. System loadability in IEEE 57 bus system with SVC

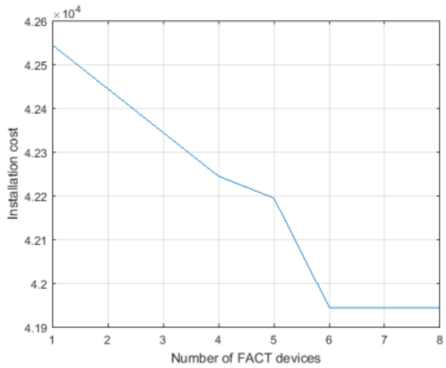

FIG.4. Installation cost in IEEE 57 bus system with SVC

B. *IEEE 118 bus system*

The line data and bus data of 118 bus system are taken from [38]. The system contains 1 slack bus 53PV buses, 64PQ buses and 186 lines.

Table. 2. Line flows in IEEE 118bus system

Type	From line	To line	P_b	Q_b	P_a	Q_a	Device setting	IC(US$)	MSL (%)
SVC	1	2	65.102	-36.03	64.223	36.189	21.9Mvar	4050.14	1.95
	6	7	46.754	-12.32	25.609	14.793	21.9Mvar		
	15	17	27.501	14.951	26.150	19.395	21.9Mvar		
	18	19	21.129	17.222	12.236	-2.738	13Mvar		
	19	20	15.975	10.229	17.220	6.230	3.28Mvar		
	31	32	38.035	17.915	37.825	11.985	3.28Mvar		

	40	42	20.442	-8.077	20.515	-8.009	3.28Mvar		

Power flows in IEEE 118 bus system are shown in Table.3. In single type, SVC is located in lines 1-2, 6-7, 15-17, 18-19, 19-20, 31-32, 40-42. The system loadability in single type of SVC is 1.95%,Installation cost is minimum with SVC at moderate system loadability. The variations of system loadability and installation cost in IEEE 118 bus system are shown in Fig.5. and Fig.6

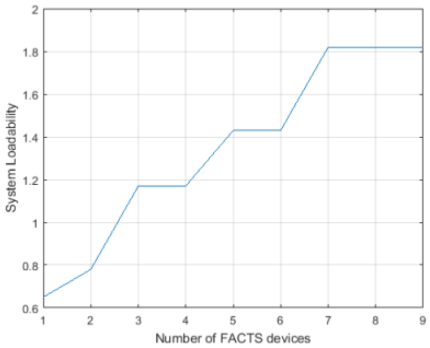

Fig.5. System loadability in IEEE 118 bus system with SVC

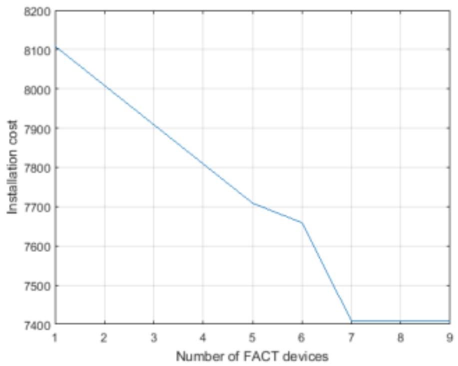

Fig.6. Flow chart of proposed methodology with SVC

VI. CONCLUSION

T he main objective of this research work is to obtain the optimal location and susceptance rating of SVC to enhance voltage stability using ABC algorithm. Simulations are performed on IEEE 57 and IEEE 118 bus systems. Single type FACTS device SVC are placed. Voltage deviation and line flow deviation are within limits. Voltage profile is improved. Power flow is improved with reduction of reactive power. Hence voltage instability problems are solved. The total loss in the system is reduced compared to existing literature. Thus proposed system enhances the power flow better than existing methods and reactive power is maintained in balanced condition. In IEEE 57 and 118 systems SVC gives lowest cost of installation with maximum system loadability. Hence proposed algorithm gives reduction in Transmission loss and installation cost of FACTS device, system loadabiliyty is improved.

References

[1] N.G. Hingorani, L. Gyugyi, Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems, IEEE Press, 2000, ISBN0-7803-3455-8

[2] R.D. Christie, B.F. Wollenberg, and I. Wangensteen, "Transmission management in the deregulated environment," In the proceedings of I EEE, vol. 88, no. 2, pp. 170-195, 2000.

[3] L.J. Cai, I. Erlich, and G. Stamtsis"Optimal choice and allocation of FACTS devices in deregulated electricity market using genetic algorithms," In the proceedings of Power Systems, no. 1, pp.201-207, 2004.

[4] Hiroshi Okamoto, Akihiko Yokoyama, and Yasuji Sekine "Stabilizing control of variable impedance power systems: applications to variable series capacitor systems," Electrical engineering in Japan, vol. 113, no. 4, pp. 89-100, 1993.

[5] B. Wang, and GiriVenkataramanan, "Evaluation of shunt and series power conditioning strategies for feeding sensitive loads," In the proceedings of applied Power Electronics, vol. 3, pp. 1445-1451, 2004.

[6] Ajay R. Nair, Ann Maria Paul, K.V. Ashkar, AzimFaizal, T. Varsha Varghese, and Able Alex, "Alleviation of Voltage Sag Using D-STATCOM," Digital Signal Processing, vol. 8, no. 8, pp. 217-221, 2016.

[7] Narain G. Hingorani, and Laszlo Gyugyi, "Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems", IEEE Press, 2000.

[8] R. Mohan Mathur and, Rajiv K. Varma. "Thyristor-based FACTS controllers for electrical transmission systems," wiley inter science, a john wiley & sons inc. publication 2002.

[9] Kankar Bhattacharya, Math Bollen, and Jaap E. Daalder, "Operation of restructured power systems," Operation of Market Oriented Power Systems, vol. 1, no. 1, pp. 1-7, 2003.

[10] SajadRahimzadeh and Mohammad TavakoliBina, "Looking for optimal number and placement of FACTS devices to manage the transmission congestion," Energy Conversion and Management, vol. 52, no. 1, pp. 437-446, 2011.

[11] Ashwani Kumar, S. C. Srivastava and S. N. Singh, "Congestion management in competitive power market: A bibliographical survey," Electric Power Systems Research, vol. 76, no. 1, pp. 153-164, 2005.

[12] OmidZiaee, and F. Fred Choobineh, "Optimal location-allocation of tcsc devices on a transmission network," IEEE Transactions on Power Systems, vol. 32, no. 1, pp. 94-102, 2017.

[13] M. Venkateswara Rao, S. Sivanagaraju, and Chintalapudi V. Suresh, "Available transfer capability evaluation and enhancement using various FACTS controllers: Special focus on system security", Ain Shams Engineering Journal, vol. 7, no. 1, pp. 191-207, 2016.

[14] Mihai Sanduleac, CatalinChimirel, MirceaEremia, Lucian Toma, and Joao Martins. "Metrology based calculation of voltage control services provided by advanced power generation modules," In the proceedings of Compatibility, Power Electronics and Power Engineering (CPE-POWERENG), no. 1, pp.76-81, 2016.

[15] Antonio Gómez Expósito, Antonio Gomez-Exposito, Antonio J. Conejo, and Claudio Canizares, "Electric energy systems: analysis and operation," CRC Press, 2016.

[16] Johannes Schiffer, Thomas Seel, JörgRaisch and TevfikSezi, "Voltage stability and reactive power sharing in inverter-based micro grids with consensus-based distributed voltage control," IEEE Transactions on Control Systems Technology, vol. 24, no. 1, pp.96-109, 2016.

[17] Tao Jiang, Linquan Bai, HongjieJia, Haoyu Yuan, and Fangxing Li, "Identification of voltage stability critical injection region in bulk power systems based on the relative gain of voltage coupling", IET Generation, Transmission & Distribution, vol. 10, no. 7, pp. 1495-1503, 2016.

[18] ArthitSode-Yome, and Kwang Y. Lee, "Applications of MATLAB symbolic and optimization toolboxes in static voltage stability in power systems," IFAC Proceedings, Vol. 42, no. 9, pp.374-379, 2009.

[19] Javad Modarresi, Eskandar Gholipour and Amin Khodabakhshian, "A comprehensive review of the voltage stability indices," Renewable and Sustainable Energy Reviews, vol. 63, no. 1, pp.1-12, 2016.

[20] ArthitSode-Yome, NadarajahMithulananthan and Kwang Y. Lee, "A maximum loading margin method for static voltage stability in power systems," IEEE Transactions on Power Systems, vol. 21, no. 2, pp.799-808, 2006.

[21] ArthitSode-Yome and Nadarajah Mithulananthan, "Comparison of shunt capacitor, SVC and STATCOM in static voltage stability margin enhancement," International Journal of Electrical Engineering Education, vol. 41, no. 2, pp.158-171, 2004.

[22] E. Hirst, "Transmission Capacity: Present Status and Future Prospects," Edison Electric Institute and Office of Electric Transmission and Distribution, U.S. Department of Energy, 2004.

[23] S.N. Singh, and A.K. David, "Optimal location of FACTS devices for congestion management", Electric Power Systems Research, vol. 58, no. 1, pp. 71–79, 2001.

[24] Ladumor DP, Trivedi IN, Bhesdadiya RH, Jangir P. Optimal Power Flow problems solution with SVC using meta-heuristic algorithm. In Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB), 2017 Third International Conference on 2017 Feb 27 (pp. 283-288). IEEE.

[25] Ziaee O, Choobineh FF. "Optimal location-allocation of tcsc devices on a transmission network. IEEE Transactions on Power Systems". 2017 Jan; 32(1):94-102

[26] Sakr WS, El-Sehiemy RA, Azmy AM. “Optimal allocation of TCSCs by adaptive DE algorithm”. IET Generation, Transmission & Distribution”. 2016 Nov 17; 10(15):3844-54.

[27] Acharjee P. Optimal power flow with UPFC using security constrained self-adaptive differential evolutionary algorithm for restructured power system. International Journal of Electrical Power & Energy Systems. 2016 Mar 31;76:69-81.

[28] K. Habur, and D. Oleary, “FACTS - flexiable AC transmission systems, for cost effective and reliable transmission of electrical energy”, http://www.siemenstd.com/TransSys/pdf/CostEffectiveReliabTrans.pdf.

[29] Prasad KRSS, Damodar Reddy M. “Optimal Placement of SVC and UPFC in Transmission Networks using SFLA”. Discovery2015, 45(210), 175-181

[30] M. Nayeripour and M. Mahdi Mansouri “Analyze of Real Switching Angle Limits in TCSC on Capacitor and Inductor Values and their Selection Factors” International Journal of Advanced Science and Technology, Vol. 57, August, 2013.

[31] Rao VS, Rao RS. “Optimal Parameter Setting of FACTS Devices” (IJETEE – ISSN: 2320-9569) Vol. 11, Issue. 6, Oct-2015.

[32] Xiao. X.P.Zhang, Ch.Rehtanz, and B.Pal, “Flexible AC Transmission Systems: Modeling and Control,” 2nd Edition, Springer, Feb 2012.

[33] M.Sadi, S.Ali, “A Comprehensive Analysis Of Transient StabilityEnhancement Methods Of Electric Power System,” *IEEE trans*, 2015

[34] M. Kefayat, A. LashkarAra, and S.A. NabaviNiakib, “A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources,” Energy Conversion and Management, vol. 92, no. 1, pp.149-161, 2015.

[35] A.RezaeeJordehi, “Brainstorm optimisation algorithm (BSOA): An efficient algorithm for finding optimal location and setting of FACTS devices in electric power systems,” International Journal of Electrical Power & Energy Systems, vol. 69, no. 1, pp.48-57, 2015.

[36] BiplabBhattacharyya, SanjayKumar“Loadability enhancement with FACTS devices using gravitational search algorithm,” International Journal of Electrical Power & Energy Systems. Vol. 78, no. 1, pp. 470-479, 2016.

[37] Saravanan M, Slochanal SM, Venkatesh P, Abraham JP. Application of particle swarm optimization technique for optimal location of FACTS devices considering cost of installation and system loadability. Electric Power Systems Research. 2007 Mar 31; 77(3):276-83.

[38] http://shodhganga.inflibnet.ac.in/bitstream/10603/10241/15/15_appendices%201%20to%205.pdf[online]