Optimal Placement of Thyristor Controlled Series Compensator in IEEE 57 and IEEE 118 Bus Systems to Reduce Transmission Loss using ABC Algorithm

Y. V. Balarama Krishna Rao [1], R. Srinivasa Rao [2], V. V. K. Reddy [3]

[1, 2] *Department of Electrical and Electronics Engineering*, J. N. T. University, Kakinada, Andhra Pradesh, India.
[3] *Department of Electrical and Electronics Engineering*, NBKR Institute of Science and Technology, Nellore, Andhra Pradesh, India.

Abstract **- Flexible Alternating Current Transmission Systems (FACTS) represents a vast development in the area of power system operation and control. As we know that under heavily loaded conditions our power system is at high risks of consequent voltage instability problem. This paper gives an overview about application of series connected Flexible alternating current transmission system (FACTS) for improvement of power system performance like transfer stability, secure voltage profile and reduce the system losses etc. In this work, Artificial Bee Colony algorithm (ABC) is proposed for enhancing and controlling power flow using Thyristor Controlled Series Compensator (TCSC) for improvement of power system performance. This paper gives details of optimal placement and sizing of TCSC devices based on different evolutionary techniques which is used for minimization of transmission loss, enhancement of stability of power system. In this paper TCSC device is implemented on IEEE 57 and IEEE 118 bus systems using MATLAB platform. The results indicates that the proposed algorithm gives better improvement in system load ability, reduction of transmission loss and installation cost. Hence the proposed algorithm will be useful in optimum utilization of power networks.**

Keywords - TCSC, optimal location, artificial bee colony algorithm.

I. INTRODUCTION

FACTS (Flexible Alternating Current Transmission System) devices are generally based on power electronics which is used for increasing transmission capacity in the power system. They also have the capacity to control several parameters in transmission network. These types of devices can increase the stability of power system network and support voltage with better controllability of their parameters like impedance, current, phase angle and voltage [1]. FACTS have the capability to increase the reliability of power system networks. It also enhance the power flow control of the system. There are various methods to connect the FACTS devices such as in series, shunt, series-series and series-shunt [2,3].

Voltage instability has been a major concern in power systems, especially in planning and operation [4-6]. 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 [7-11]. Some of the causes of voltage instability are (i) increase in load demand; (ii) changes in system condition (iii) load centers 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.

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 TCSC using ABC algorithm. In this work, TCSC is modeled as a variable reactance added in the line. The optimal location is done to maximize system loadability, reduce transmission loss, and installation cost of FACTS devices. The cost function of TCSC is 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 THYRISTOR CONTROLLED SERIES COMPENSATOR

Thyristor Controlled Series Compensator (TCSC) provides controlling and increasing power transfer level of a system by varying the apparent impedance of a specific transmission line. A TCSC can be utilized during contingencies to enhance the power system stability. It is possible to operate stably using TCSC at power levels well beyond those for which the system was originally intended without endangering system stability. It consists of series controlled capacitor which is shunted by a Thyristor controlled Reactor. The figure2 shows model of a transmission line with series impedance and a TCSC connected between two buses [29].

TCSC acts as the inductive or capacitive compensation by modifying the reactance of the transmission line and the reactance of the transmission line is adjusted by TCSC directly. The rating of TCSC depends on the reactance of the transmission line where the TCSC is located.

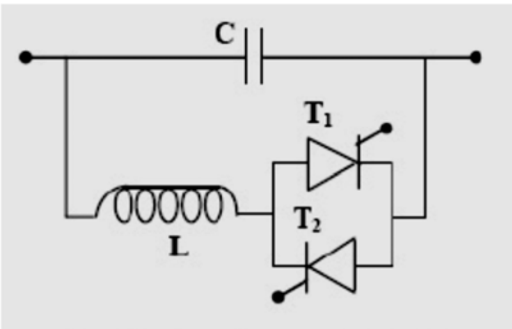


Figure 1.Basic structure of TCSC

A. Model of TCSC

The basic idea behind power flow control with the TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactive, respectively and it is shown in Fig.2. The TCSC (Hingorani and Gyugyi, 2000) is modelled as variable impedance where the equivalent reactance of line, connected between bus-i and bus-j, is defined as:

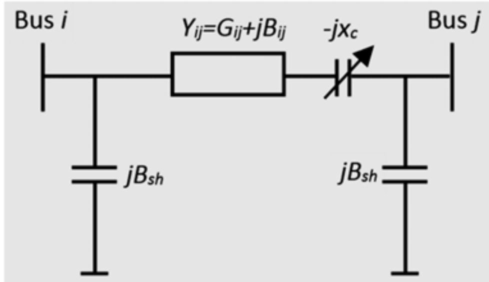


Fig. 2.Transmission line with TCSC

The total reactance of the line including TCSC is given by

$$x_{line}^{new} = x_{line}^{old} + x_{t\,\mathrm{csc}} \tag{1}$$

where x_{line}^{old} is line reactance itself and $x_{t\,\mathrm{csc}}$ is the effective reactance of TCSC.

Load flow equations:

$$p_{Gi} - p_{Di} - p_i - \sum_{j=1}^{n} v_i v_j \left[G^1{}_{ij}\cos(\delta_{ij}) + \beta^1{}_{ij}\sin(\delta_{ij})\right] = 0 \tag{2}$$

$$q_{Gi} - q_{Di} - q_i - \sum_{j=1}^{n} v_i v_j \left[G^1{}_{ij}\sin(\delta_{ij}) - \beta^1{}_{ij}\cos(\delta_{ij})\right] = 0 \tag{3}$$

$G^1{}_{ij}, \beta^1{}_{ij}$ are modified line conductance and susceptance due to TCSC reactance.

$$x_{t\,\mathrm{csc}} = -k_{se} x_{line} \tag{4}$$

Where k_{se} is percentage of series compensation in reactance of transmission line (xline) [30].

III. PROBLEM FORMULATON

Multi-objective optimization problem is formulated considering five objective functions of minimization of voltage deviation, transmission loss, load flow deviation and cost of TCSC and maximizing system loadability. 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 TCSC. 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:

Minimize $TL = \sum_{i=1}^{gen} p_{Gi} - \sum_{i=1}^{n} p_{Di}$

$$F(\lambda, V, \delta, P, Q, X_{tcsc}) = 0 \tag{5}$$

DOI 10.5013/IJSSST.a.20.01.38 ISSN: 1473-804x online, 1473-8031 print

with constraints given by (14)-(23),

Where F= TL+λ+ VD+ LFD+ IC_{tcsc}

And F (V,δ,P,Q) is the power flow equations described by (2),(3).

A. Maximization of System Load-ability (λ):

The Maximum System Load ability, MSL is calculated by:

$$P_d^1=\lambda P_d^0 \quad (6)$$

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

A1. Voltage Deviation (VD):

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

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

V_i –Voltage at i'th bus

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

A2. 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).

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

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).

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

Where n is number of buses.

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

The installation cost is TCSC cost. The cost functions of TCSC are taken from Siemens database [22].

$$IC_{COST}= IC_{TCSC} \quad (10)$$

C1. TCSC installation cost (IC_{TCSC}):

The cost function of TCSC is given as:

$$c_{t\,\mathrm{csc}} = 0.015r^2 - 0.7130r + 153.75 \quad (11)$$

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

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

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

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.

D1. 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.

D2. Inequality Constraints:

The inequality constraints are given as:

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

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

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

$$\delta^{\min} \le \delta \le \delta^{\max} \tag{19}$$

$$\lambda \le \lambda^{\max} \tag{20}$$

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 load ability.

D3. TCSC Constraints:

$$x_{t\,\mathrm{csc}}{}^{\min} \le x_{t\,\mathrm{csc}} \le x_{t\,\mathrm{csc}}{}^{\max} \tag{21}$$

$$-0.8 \le x_{t\,\mathrm{csc}} \le 0.2 p.u \tag{22}$$

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 TCSC device is used.

The Meta heuristic technique of artificial bee colony algorithm [34] is defined by Karaboga in 2005. This algorithm is derived from the foraging behavior 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),

$$z_{ij} = a_{ij} + \pi_{ij}\left(a_{ij} - a_{kj}\right) \tag{24}$$

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:

$$z_{ij} = a_{ij} + w\,\pi_{ij}\left(a_{ij} - a_{kj}\right) \tag{25}$$

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

$$P = \frac{fit}{\sum_{j=1}^{sn} fit_j} \tag{26}$$

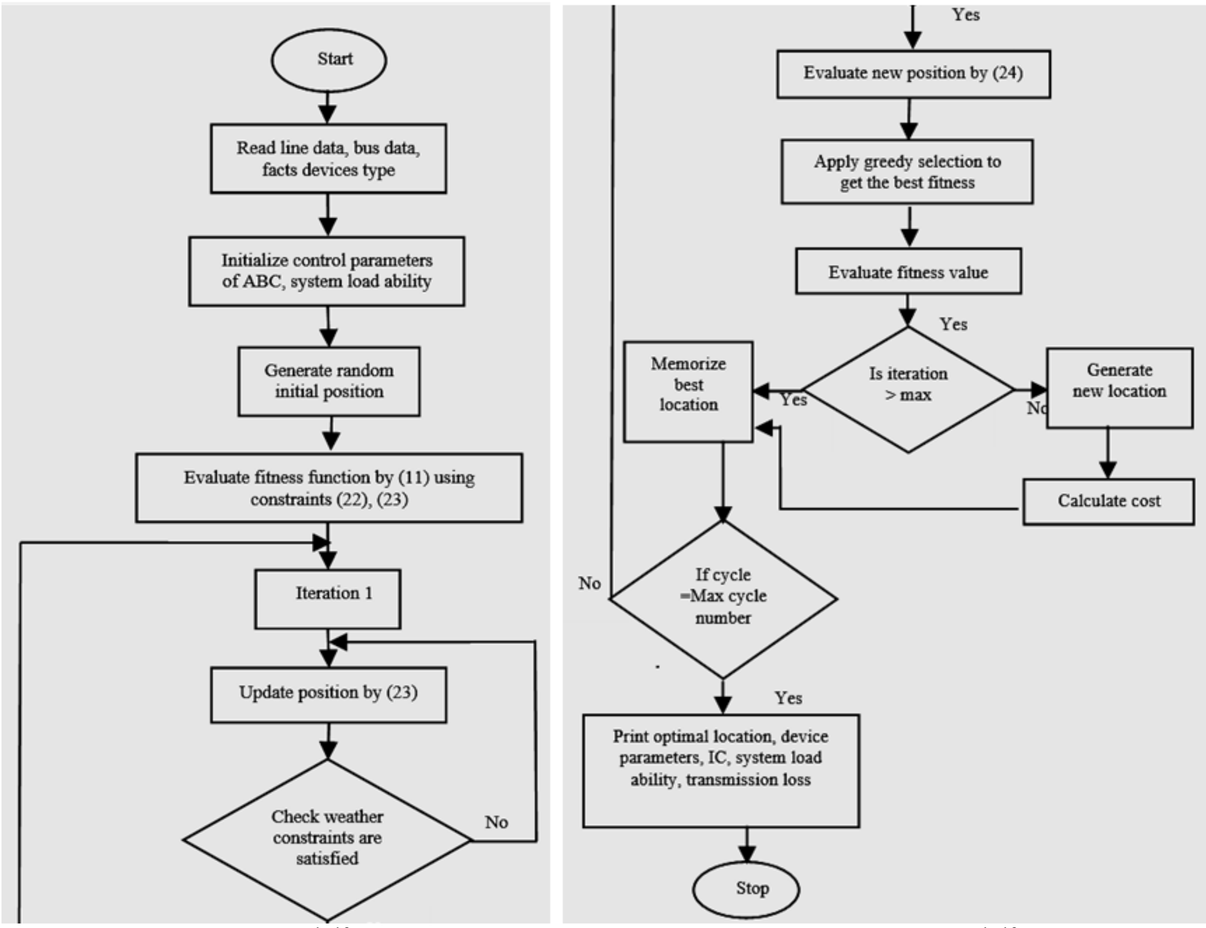
The employed bees fitness values is find out by,

$$fit_j = \begin{Bmatrix} \dfrac{1}{1+f(x)} & f(x) \ge 0 \\ 1+\left|f(x)\right| & f(x) < 0 \end{Bmatrix} \tag{27}$$

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

$$fit_j = IC + pf * \left\| j - 1 \right\| \tag{28}$$

Where IC denotes the installation cost of FACTS devices, pf is the penalty factor. The flowchart of proposed algorithm is given in Fig.3.



Top half Lower half

Fig.3. 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 TCSC 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. I. LINE FLOW IN IEEE 57 BUS SYSTEM

Type	From bus	To bus	Pb	Qb	Pa	Qa	Device setting	IC(US$)	MSL (%)
TCSC	1	2	104.416	42.261	128.03	43.22	0.00761pu	41,944.6	1.82
	8	9	60.538	56.696	58.572	32.309	0.00534pu		
	9	10	21.864	14.227	30.276	-15.74	0.00534pu		
	9	11	23.007	19.115	25.021	-21.35	0.00534pu		
	9	12	7.633	3.496	12.798	-5.133	0.00534pu		
	13	15	39.531	25.998	53.644	3.161	0.00534pu		

The simulations are performed in MATLAB and the results are obtained using ABC algorithm. Table I shows line flows in IEEE 57 bus system. In single type, TCSC is located in lines 1-2, 8-9, 9-10, 9-11, 9-12, and 13-15. The system load ability with single type TCSC is 1.82%. From IEEE 57 bus system we concluded that highest system load ability is achieved with low installation cost with TCSC. System load ability and installation cost variations are shown in Fig.4. and Fig.5.

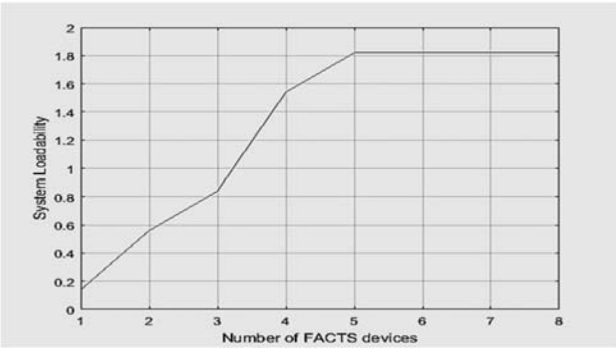


Fig. 4. System load ability in IEEE 57 bus system with TCSC

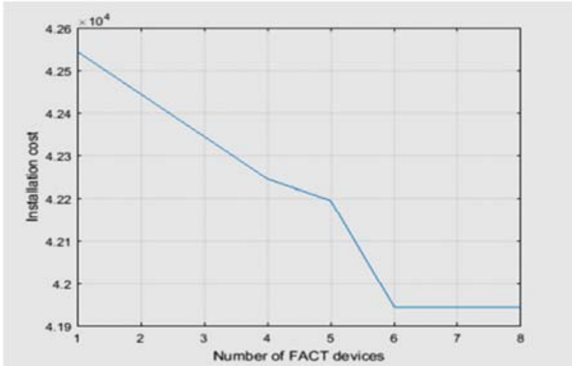


Fig.5. Installation cost in IEEE 57 bus system with TCSC

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. II. LINE FLOWS IN IEEE 118BUS SYSTEM

Type	From bus	To bus	Pb	Qb	Pa	Qa	Device setting	IC(US$)	MSL (%)
TCSC	59	60	47.300	26.328	44.313	22.730	0.0151pu	67023.5	1.96
	62	67	29.235	8.361	36.981	25.010	0.189pu		
	66	67	58.227	32.603	45.015	29.365	0.0151pu		
	69	75	55.978	35.514	22.764	19.569	0.00848pu		
	70	74	27.313	17.125	24.534	17.550	0.0151pu		
	75	77	47.095	24.958	71.768	23.660	0.00848pu		
	83	85	76.298	39.634	74.391	47.252	0.00848pu		

Power flows in IEEE 118 bus system are shown in Table.2. In single type, TCSC is located in lines 59-60, 62-67, 66-67, 69-75, 70-74, 75-77, 83-85. The system load ability in single type of TCSC is 1.96%. Installation cost of TCSC is 67023.5US$. Installation cost is minimum with TCSC at improved system load ability. The variations of system load ability and installation cost in IEEE 118 bus system are shown in Fig.6 and Fig.7

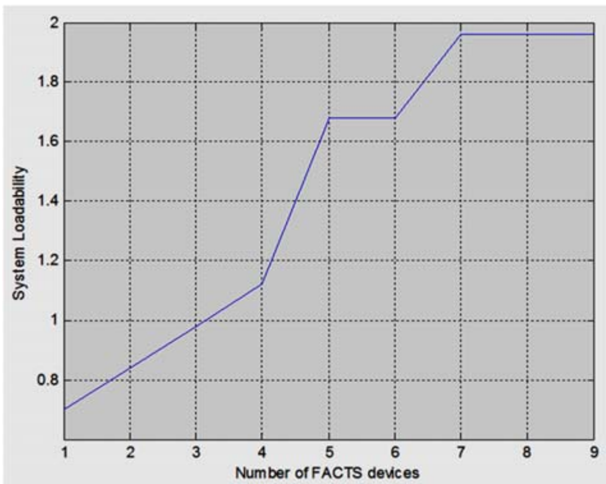


Fig.6. System load ability in IEEE 118 bus system with TCSC

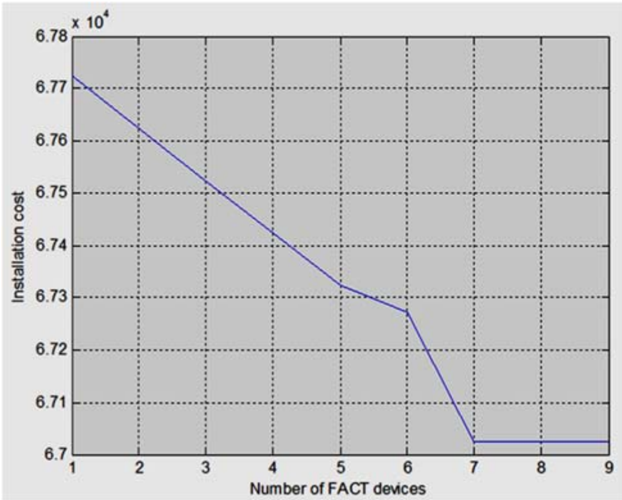


Fig.7. Installation cost in IEEE 118 bus system with TCSC

Transmission loss of the system before and after placement of TCSC using ABC algorithm is given as follows:

TABLE.III. TRANSMISSION LOSS COMPARISON

Transmission Loss		
Case	IEEE 57	IEEE 118
Basic	5.999	16.051
TCSC	5.007	15.205

From Table. III. we can conclude that the transmission loss in IEEE 57 and IEEE 118 bus systems is reduced after installing TCSC compared to before placement of TCSC.

VI. CONCLUSION

We presented a review and simulations of optimal placement of Thyristor Controlled Series Compensator, TCSC, to enhance the power system stability by using optimization technique Artificial Bee Colony, ABC, algorithm. The simulations were performed on IEEE 57 and IEEE 118 bus systems. Single type Flexible Alternating Current Transmission Systems, FACTS, device TCSC was placed. Voltage deviation and line flow deviation were within limits. We further investigated the capability of the optimal installation of TCSC for reducing the active power loss in the power system. It is possible to place TCSC in the transmission line and proper power planning can be achieved with system Transmission loss minimization. In IEEE 57 and 118 systems TCSC gives lowest cost of installation with maximum system load ability. Hence the proposed algorithm resulted in a reduction in transmission loss and installation cost of FACTS device, and improved system load ability.

REFERENCES

[1] 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.

[2] 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.

[3] 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.

[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] 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.

[10] 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.

[11] 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.

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

[13] 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.

[14] 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.

[15] 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.

[16] 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.

[17] 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.
[18] 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.
[19] 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.
[20] 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.
[21] 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.
[22] 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
[23] 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.
[24] 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.
[25] 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.
[26] Prasad KRSS, Damodar Reddy M. "Optimal Placement of SVC and UPFC in Transmission Networks using SFLA". Discovery2015, 45(210), 175-181
[27] 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.
[28] Rao VS, Rao RS. "Optimal Parameter Setting of FACTS Devices" (IJETEE – ISSN: 2320-9569) Vol. 11, Issue. 6, Oct-2015.
[29] Y.H.Song, and A.T.John, "Flexible Transmission System (FACTS)",IEE Power and Energy Series 30, 1999.
[30] Xiao. X.P.Zhang, Ch.Rehtanz, and B.Pal, "Flexible AC Transmission Systems: Modeling and Control," 2nd Edition, Springer, Feb 2012.
[31] M.Sadi, S.Ali, "A Comprehensive Analysis Of Transient StabilityEnhancement Methods Of Electric Power System," IEEE trans, 2015
[32] 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.
[33] 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.
[34] 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.
[35] 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.
[36] http://shodhganga.inflibnet.ac.in/bitstream/10603/10241/15/15_appendices%201%20to%205.pdf[online]

.