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OPTIMAL PLACEMENT OF FACTS DEVICES TO CHALLENGE GRID INTEGRATION OF WIND POWER USING BBO TECHNIQUE

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ABSTRACT

Renewable energy sources which are considered to be a promising alternative energy source, brings new challenges when connected to the power grid. Due to the environmental conditions the generated power from renewable energy source such as wind mill, keeps on fluctuating. The Fluctuating nature of the wind increases the uncertainty, thus challenges the power system security during wind power injection into an electric grid. The uncontrollable power flow in the power system may cause bottlenecks in the power system such as angle and voltage instability. The angle and voltage instability may result in generator outages, line tripping and blackouts, hence affects the power system security. This paper reveals the potential challenges of renewable energy on the smart grid and the enhancement of system security with the application of Flexible AC transmission system (FACTS) devices. The optimal placement of device is done using BBO algorithm. The FACTS devices considered in this work are TCSC and SVC. The proposed work is tested on standard IEEE 14 bus system.

INTRODUCTION

Among the renewable energy sources, wind farms contribution to the energy production is continuously growing. This attraction is because of its technological maturity, good infrastructure, relative cost competitiveness and environmental protection. In most power generating system, the main source of energy (the fuel) can be manipulated, but that is not the case with wind energy. Since the wind often fluctuates from minute to minute and hour to hour. Therefore Wind Energy Conversion Systems (WECS) exhibit variability in their output power as a result of change in their prime movers (wind speed). This uncontrollable power output results in intermittent generation and challenges the system security, when renewable energy resources are integrated into the power grid (Zhang, 2008). Their output power may not be available to meet the demand when needed. Due to this increase in load demand, the magnitude of the power flows in some of the transmission lines are well above their normal limits and in some other lines, it is below their normal. Its overall effect will detoriote the voltage profiles and decrease the security of the power system. This uncertainty on the grid, challenges the power system planners and the utility operators in terms of the power system grid integrity i.e. power system security, power system stability and power quality (Ayodele *et al*., 2012). The utilization of innovative technology like FACTS devices, has the ability to overcome this challenge. FACTS has the characteristics to mitigate technical problems in the smart grid, they increase the transmission capacity and system stability very efficiently and assist in militating cascading disturbances.

The application of FACTS devices results in much more secured and reliable power grid (Belkacemi *et al*., 2011). FACTS (Flexible Alternating Current Transmission Systems) is a concept introduced by Hingorani *et al*. (1999). The objective of FACTS devices is to bring a system under control and to transmit power as ordered by the control centres. It also allows increasing the usable transmission capacity to its thermal limits. FACTS technology opens up new opportunities for controlling power flow and enhancing the usable capacity of present, as well as new and upgraded lines. FACTS devices can effectively control the load flow distribution, improve the usage of existing system by increasing transmission capability, compensate for reactive power, and improve stabilities of the power network. The possibility of controlling power flow in an electric power system without generation rescheduling or topological changes can improve the performance considerably (Singh and David, 2001). However to achieve such benefits it is highly important to determine the suitable

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location and capacity of FACTS devices in the power system (Benabid *et al*., 2009). The proposed work deals with the placement of FACTS devices namely SVC and TCSC. SVC (Static Var Compensator) was the first device to be released in the market, when the concept of generating controllable reactive power through switching power converters was introduced. It is a shunt connected device and is installed parallel with a bus. It has the ability to generate or absorb reactive power at the point where it is connected. More than 800 SVC's are being installed worldwide both for utility and industrial (especially in electric arc furnace and rolling mills) (Sundareswaran *et al*., 2011). TCSC (Thyristor Controlled Series Capacitor) is a type of series compensator, which can provide many benefits for a power system including control of power flow in the line, damping power oscillations and mitigating sub synchronous resonance (Hugo Ambriz-Perez *et al*., 2006).

TCSC is a variable impedance type series compensator. It consists of a series compensating capacitor shunted by a thyristor controlled reactor. By controlling the firing angle of thyristor, TCSC can change the line reactance smoothly and rapidly. TCSC has one of the two possible characteristics either capacitive or inductive by increasing or decreasing the reactance of the line X_l (Naresh Acharya and Mithulanathan, 2007). Moreover to avoid the over compensation of the line, the maximum values of capacitance and inductance are fixed at $-0.8X_l$ and $0.2X_l$ (Ghamgeen I. Rashed *et al*., 2011). World's first 3 phase, 2*165 MVAR, TCSC was installed in 1992 in Kayenta substation, Arizona. It raised the transmission capacity of transmission line by 30% and effectively damped electromechanical power oscillations (Meikandasivam *et al*., 2008). Optimal placement of TCSC is essential to tap the maximum benefits in terms of system performance and cost effectiveness. A loss sensitivity index with respect to the control parameters of FACTS devices has been suggested and with the computed loss sensitivity index, the FACTS devices are placed on the most sensitive bus or line (Preecha Preedavichit and Srivastava, 1998). Fuzzy based approach for the optimal placement of FACTS device for enhancing the system security under normal and network contingencies has been discussed (Visaka *et al*., 2003).

The optimal location of a given number of FACTS devices is a problem of combinatorial analysis. To solve such kind of problems, heuristic methods can be used (Sung-Hwan Song *et al*., 2004). They permit to obtain acceptable solutions within a limited computation time. The application of Genetic Algorithm for the optimal location of multi type FACTS devices in order to maximize the system loadability is analysed in (Stephane Gerbex *et al*., 2001). A Differential Evolution based algorithm to decide the optimal location and device rating has been suggested in (Husam I. Shaheen *et al*., 2010) with an objective of enhancing the system security under single line contingencies. The Particle Swarm Optimization (PSO) is applied for the optimal location of FACTS devices to achieve minimum cost of installation and to improve system loadability, by considering thermal limit for the lines and bus voltage limit for the load buses as constraints (Saravanan *et al*., 2007). Sensitivity analysis approach for finding the optimal location and PSO for the optimal parameter setting of TCSC has been suggested in (Satyanarayana *et al*., 2011) so as to maximize the loadability. Biogeography based optimization, a population based algorithm, which uses the immigration and emigration behavior of the species based on various natural factors is explained in (Simon, 2008). Application of BBO to solve the economic dispatch problem is described in (Bhattacharya and Chattopadhyay, 2010) where it has been proved that BBO gives a solution which is comparable with evolutionary programming and differential evolution techniques. In this paper, BBO technique is applied to find the optimal placement and capacity of FACTS devices (TCSC & SVC). The objective function to be minimized comprises of cost of the device, line loadings and voltage deviations at the load buses.

Wind Energy Conversion System

Wind Turbine Generators (WTG) extract energy from wind and convert it into electricity via an aerodynamic rotor, which is connected by a transmission system to an electric generator. Fig.1. shows a horizontal axis WTG having three blades and Fig. 2 shows vertical-axis WTG.

Fig. 1. A standard WTG with three blades and horizontal axis

Fig. 2. Vertical-axis turbine

Problem Formulation

Objective of the optimization

Ideally, wind farms should be connected to stiff grids in order not to influence stability or power quality in a detrimental way. But, wind power is usually connected far out in the grid, at sub-transmission or distribution levels, where the grid was not originally designed to transfer power from the system extremities back into the grid. Particularly when the grid is weak, unacceptable voltage gradients may occur. FACTS devices plays a vital role to keep the bus voltages within limits. As the cost of the FACTS devices is high, in order to achieve the maximum benefit, the devices are to be installed at the optimal locations. The objective function has three terms, the first term represents the installation cost of the devices, the second and third terms representing the load bus voltage deviations and line loadings respectively. The minimization of the proposed objective function has to lead to a cost effective security oriented device placement.

The objective function is formulated as

$$MinF = W_1\left[(C_{SVC} * S) + (C_{TCSC} * S)\right] + W_2[LVD] + W_3[LL] \quad (1)$$

F is the objective function;

C_{TCSC} is the cost of TCSC device in US \$/KVar;

C_{SVC} is the cost of SVC device in US \$/KVar;

S is the operating range of the FACTS device;

LVD is the Load voltage deviation;

LL is the Line loading;

W_1, W_2 & W_3 are the weight factors.

(i) Cost (C_{TCSC}) & (C_{SVC})

The first term of the objective function C_{TCSC} presents the installation cost of TCSC device and C_{SVC} is the installation cost of SVC in the network, which are given by the following equations.

$$C_{TCSC} = 0.0015s^2 - 0.7130s + 153.75 \quad (2)$$

$$C_{SVC} = 0.0003s^2 - 0.3051s + 127.38 \quad (3)$$

(ii) Load voltage deviation (LVD)

Excessive high or low voltages can lead to an unacceptable service quality and can create voltage instability problems. FACTS devices connected at appropriate locations play a leading role in improving voltage profile thereby avoiding voltage collapse in the power system. The second term considered represents the load voltage deviations in order to prevent the under or over voltages at network buses.

$$LVD = \sum_{m=1}^{nb} \left(\frac{V_{mref} - V_m}{V_{mref}} \right)^n \quad (4)$$

V_m is the voltage magnitude at bus m

V_{mref} is the nominal voltage at bus m & is considered as 1.0 pu.

m refers to the load buses, where V_m is less than V_{mref} .

(iii) Line loading (LL)

TCSC is located in order to remove the overloads and to distribute the load flows uniformly. To achieve this, line loading is considered as the third term in the objective function.

$$LL = \sum_{l=1}^{nl} \left(\frac{S_l}{S_{l\max}} \right)^n \quad (5)$$

S_l is the apparent power in the line l .

$S_{l\max}$ is the apparent power rating of line l .

The optimization variables

The optimization variables considered in this work are

(a) The number of FACTS devices (TCSC & SVC) to be installed is taken as the first variable.
(b) The location of these devices is considered as the second variable to be optimized. TCSC is placed in a line and SVC is placed in a load bus. TCSC's are not installed in the lines where the transformers exist.
(c) Type of the device (TCSC or SVC) to be installed is considered as the third variable.
(d) The rating of the device is considered as the fourth variable.

Only one FACTS device per line or bus is permitted

Modelling of FACTS devices

TCSC Modelling

TCSC is a series compensator. It consists of a series compensating capacitor shunted by a thyristor controlled reactor as shown in Fig. (3).

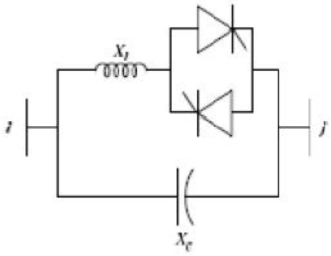


Fig. (3)

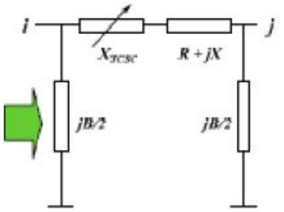


Fig. (4)

With TCSC the power flow control can be done by increasing or decreasing the overall lines effective series transmission impedance, by adding a inductive or capacitive reactance correspondingly. The TCSC is modeled as a variable reactance as shown in Fig. (4).

The working range of TCSC is considered as follows.

$$-0.8X_l \leq X_{TCSC} \leq 0.2X_l \tag{6}$$

X_{TCSC} is the reactance added to the line by placing TCSC.

X_l is the reactance of the line where TCSC is located.

SVC Modelling

SVC is a shunt connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system. The SVC is a general term for a TCR (thyristor controlled reactor), a TSC thyristor switched capacitor) or combination shown in figure (5). It works in two modes, capacitive or inductive mode. In inductive mode, it absorbs reactive power and in capacitive mode, it injects reactive power. It is modeled as an ideal reactive power injection at bus i, where it is connected as depicted in figure (6). SVC is placed in only at load buses.

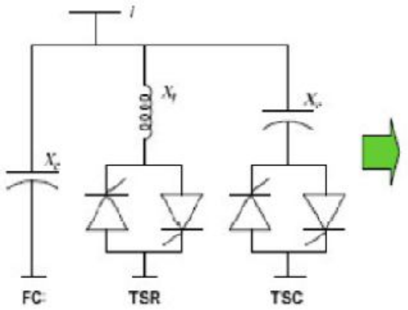


Fig. (5)

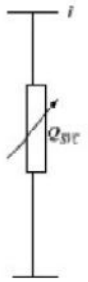


Fig. (6)

The reactive power is limited as follows

$$Q_{SVC}^{\min} \leq Q_{SVC} \leq Q_{SVC}^{\max} \tag{7}$$

Where

$$Q_{SVC}^{\min} = -100MVar$$
$$Q_{SVC}^{\max} = 100MVar$$

Overview of BBO Technique

Biogeography Optimization, an efficient optimization technique was introduced by Dan Simon (2008). BBO algorithm tries to solve the optimization problem through the simulation of immigration and emigration behaviour of the species in and out of a habitat. Species move in and out of the habitats depending upon various factors such as availability of food, temperature prevailing in that habitat, already existing species count in that area, diversity of vegetation, and species in that area etc and the process strikes a balance when the rate of immigration is equal to the rate of migration. But these behaviours are probabilistic in nature. BBO algorithm exploits the search of the individuals to find them a suitable habitat to probe into the promising regions of the search space. A habitat is formed by a set of integers that form a feasible solution for the problem and an ecosystem consist of a number of such habitats. A set of habitats are generated randomly, satisfying the constraints and their HSI is evaluated. In order to retain elitism, extremely good solutions are retained while modification operation is performed over the rest of the members, HSI recalculated for the modified ones thereafter mutation operation is carried out over the extremely good and bad solutions leaving aside the solutions in the middle range. Stopping criteria is similar to any other popular population based algorithm where the algorithm terminates after a pre-defined number of trials or after the elapsing of the stipulated time or where there is no significant change in the solution after several successive trials.

Algorithm

The algorithm of the proposed work is explained below.

Step1: The system data and the load factor are initialized.

Step2: BBO parameters such as the size of the suitability index variable n, maximum number of iterations, limits of each variable in the habitat are initialized.

Step3: An initial set of solutions is randomly generated considering the variables to be optimized.

Step4: The immigration rate λ and emigration rate μ are determined for each of the habitats.

Step4: Elite habitats are identified and they are exempted from modification procedure.

Stpe5: A habitat Hi is selected for modification proportional to its immigration rate λi and the source for this modification will be from the habitat Hj proportional to its emigration rate μ_j. This represents the migration phenomena of the species wherein the new habitats are formed through migration.

Step6: The probability of mutation P_i calculated from λ and μ is used to decide the habitat Hi for mutation and its j^{th} SIV is replaced by a randomly generated SIV.

Step7: Already existing set of elite solutions along with those resulting from the migration and mutation operations result in a new ecosystem over which the steps 4 to 6 are applied until any one of the stopping criteria is reached.

Step8: The same procedure is repeated for different load factors.

HIS – Habitat Suitability Index.

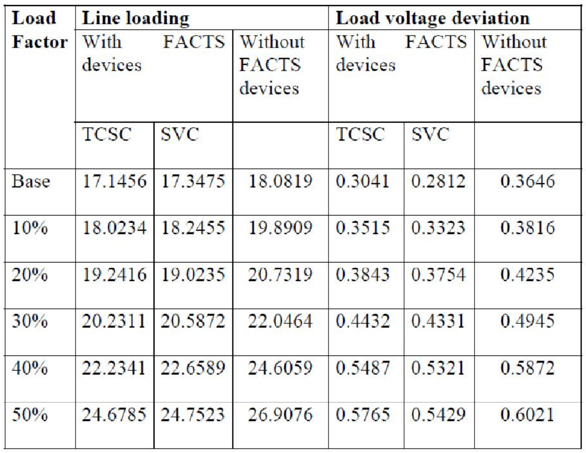
SIV – Suitability index variable.

λ - Immigration rate
μ - Emigration rate
P - The probability of mutation

RESULTS AND DISCUSSION

The proposed method has been tested on standard IEEE 14 bus test system and the results are presented. To study the effect of the installation of TCSC and SVC on load bus voltages and line loadings under overload conditions with the integration of wind power, the loads on the system were increased in a step by step manner; the real and reactive power loads connected at various load buses were increased keeping the load power factor constant. From the simulated results, the comparison study is carried out between with and without FACTS device. From the table 1, it is observed that optimal placement of FACTS devices considerably minimizes the line loading and load voltage deviation, hence the security of the system is enhanced.

Table 1. Line loading and Load voltage deviation for different load factors



Load Factor	Line loading			Load voltage deviation		
	With FACTS devices		Without FACTS devices	With FACTS devices		Without FACTS devices
	TCSC	SVC		TCSC	SVC	
Base	17.1456	17.3475	18.0819	0.3041	0.2812	0.3646
10%	18.0234	18.2455	19.8909	0.3515	0.3323	0.3816
20%	19.2416	19.0235	20.7319	0.3843	0.3754	0.4235
30%	20.2311	20.5872	22.0464	0.4432	0.4331	0.4945
40%	22.2341	22.6589	24.6059	0.5487	0.5321	0.5872
50%	24.6785	24.7523	26.9076	0.5765	0.5429	0.6021

Conclusions

In future, electricity from wind generators is considered to be one of the solution for the energy needs and environmental concerns. However, the variability and the diffuse nature of the wind power is a challenge to the operation of a power system. The proposed method optimizes the location of FACTS devices, with the objective of minimizing the line loading and load voltage deviation, so as to enhance the system security under various loading conditions with fluctuating wind power integration. The simulated results shows that, TCSC placed in the transmission network distributes the power flow and minimizes the overall line loading better when compared to SVC. Similarly SVC placed in the transmission network improves the voltage profile and hence minimizes the overall Load voltage deviations better when compared to TCSC.

REFERENCES

Ayodele, T.R., A.A. Jimoh, J.L Munda, J.T Agee, “Challenges of Grid Integration of Wind Power on Power System Grid Integrity: A Review”, International Journal of Renewable Energy Research, Vol.2, No.4, 2012.

Belkacemi, R., A. Feliachi, M. A. Choudhry, “Multi-Agent Systems Hardware Development and Deployment for Smart Grid Control and Applications”, IEEE Power Engineering Society General Meeting. Sam Diego, CA. July 24-29 2011: pages 1-8.

Benabid, R., M. Boudour, M.A. Abido, “Optimal location and setting of SVC and TCSC devices using non-dominated sorting Particle Swarm Optimization”, Electric Power Systems Research vol 79, 2009, pages 1668-1677.

Bhattacharya A, Chattopadhyay PK, “Solving complex economic dispatch problems using biogeography-based optimization”, Expert System Applications, 2010, vol37, pages 3605–3615.

Ghamgeen I. Rashed, Yuanzhang Sun, Kai-Pei Liu, “Optimal placement of Thyristor Controlled Series Compensation in Power System based on Differential Evolution Algorithm” IEEE, seventh International Conference on Natural Computation, 2011, pages 2204-2210.

Hingorani, N.G. and L. Gyugyi, “Understanding FACTS”, IEEE Press, 1999.

Hugo Ambriz-Perez, Enrique Acha, Claudio R. Fuerte-Esquivel, “TCSC-firing angle model for optimal power flow solutions using Newton’s method”, Electric Power Systems Research vol 28, 2006, pages 77-85.

Husam I. Shaheen, Ghamgeen I. Rashed, S.J. Cheng, “Optimal location and parameter setting of UPFC for enhancing power system security based on differential evolution algorithm”, Electric Power Systems Research vol 33, 2010, pages 94-105.

Meikandasivam, S., Rajesh Kumar Nema, Shailendra Kumar Jain, “Behavioral Study of TCSC device- A matlab / simulink Implementation “World Academy of Science, Engineering and Technology, 2008. Pages 694-699.

Naresh Acharya, N. Mithulanathan, “locating series FACTS devices for congestion management in deregulated electricity markets”, Electric Power Systems Research vol 77, 2007, pages 352-360.

Preecha Preedavichit, S.C. Srivastava,”Optimal reactive power dispatch considering FACTS devices” Electric Power Systems Research vol 46, 1998, pages 251-257.

Saravanan, M., S. Mary Raja Slochanal, P. Venkatesh, J. Prince Stephen Abraham, ”Application of particle swarm optimization technique for optimal location of FACTS devices considering cost of installation and system loadability”, Electric Power Systems Research vol 77, 2007, pages 276-283.

Satyanarayana, K., B.K.V. Prasad, G. Devanand, N. Siva Prasad, “optimal location of TCSC with minimum installation cost using PSO”, International Journal of computer science and technology, vol 2, dec 2011, pages 156-160.

Simon D, “Biography-based optimization”, IEEE Trans Evol Computvol 12, 2008. Pages 702–713.

Singh, S.N., A.K. David, “Optimal location of FACTS devices for congestion management”, Electric Power Systems Research vol 58, 2001, pages 71-79.

Stephane Gerbex, Rachid Cherkaoui, Alain J. Germond, “Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms” IEEE Transactions on power systems, vol. 16. Aug. 2001, pages 537-544.

Sundareswaran, K., P. Srinivasarao Nayak, Durga Venkatesh Ch, Hariharan B, “Optimal placement of FACTS devices using probabilistic Particle Swarm Optimization", IEEE PES Innovative Smart Grid Technologies, 2011, pages1-6.

Sung-Hwan Song, Jung-Uk Lim, Seung-II Moon, "Installation and operation of FACTS devices for enhancing steady – state security" Electric Power Systems Research vol 70, 2004, pages 7-15.

Visaka, K., D. Thukaram, Lawrence Jenkins, "Application of UPFC for system security improvement under normal and network contingencies" electric power systems research-2003, pages 46-55.

Zhang, X.P. "A Framework for Operation and Control of Smart Grids with Distributed Generation" Power and Energy and Society General Meeting-Conversion and Delivery of Electrical Energy in the21st Century. IEEE. 20-24 July 2008; pages1-5.

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