Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

8th International Conference
on Electrical Engineering
ICEENG 2012

Optimal allocation of SVC to enhance voltage stability of power systems

By

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Abstract:

With the continuous increase of power demand, FACTS provide a suitable solution by maximizing the usage of existing utilities rather than increasing power generation and building new lines.

Due to high cost of such devices their optimal allocation must be ascertained. Particle swarm optimization (PSO) is used in this paper to determine the best location and size of Static VAR Compensator (SVC) where the objective function is to achieve the accepted voltage profile taking into consideration the SVC cost.

Simulations are performed on IEEE-14 test system. Results prove the effectiveness of PSO in solving such allocation problem.

Keywords:

Allocation, Flexible AC Transmission Systems (FACTS), Optimization, Particle Swarm Optimization (PSO), Static VAR Compensator (SVC).

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1. Introduction:

Nowadays, the development of power systems is in continuous expansion. The growing demand for energy leads to the necessity to gathering different power systems. By this way, large interconnected systems have been built. These structures are very complexes, so the appearance of a disturbance can lead to major cascading outages which finally can result in a blackout, if no preventive action is committed.
Blackouts are very difficult to be predicted due to complex sequence of cascading events which precede them [1].

On the other hand, some transmission lines are already close to their thermal limit. Political and environmental constraints make the building of new lines difficult and lead electrical utilities to a better use of the existing network. Therefore it is attractive for electrical utilities to have a way of permitting a more efficient use of the transmission lines by controlling the power flows. Until a few years ago, the only means of carrying out this function were the electromechanical devices such as switched inductors or capacitors banks and phase-shifting transformers. However, specific problems related to these devices make them not very efficient in some situations. They are not only relatively slow, but they also cannot be switched frequently, because they tend to wear out quickly. Appearance of FACTS devices (Flexible AC Transmission Systems) linked to the improvements in semiconductor technology permitted to suppress these drawbacks. It opens up new opportunities for controlling power and enhancing the usable capacity of existing transmission lines [2].

Shunt FACTS controllers, such as static VAR compensator (SVC) and static synchronous compensator (STATCOM), are capable of effectively controlling the voltage profile by dynamically adjusting the reactive power output at the point of connection. However, these controllers are very expensive and, hence, their optimal locations in the network must be ascertained. Among these two FACTS controllers, SVC is more popular due to its lower cost as compared to the STATCOM [3].

In this paper PSO is used to optimally allocate SVC in power system in case of overloaded network and outage of a transmission line.

2. Overview on facts:

FACTS are defined as AC transmission systems incorporating power-electronic based and other static controllers to enhance controllability and increase power transfer capability [4]. FACTS controllers have the ability to control the basis parameters of transmission systems including series impedance, shunt impedance, current, voltage, and phase angle. A well-chosen FACTS controller can overcome the specific limitation of designated transmission line. FACTS devices can provide benefits in increasing system transmission capacity and power flow control flexibility and rapidity. FACTS devices provide strategic benefits for improved transmission management through:

better utilization of existing transmission assets; increased transmission system reliability and availability; increased stability; increased quality of supply for sensitive industries and enabling environmental benefits. FACTS devices make better utilization of available power system capacities and improve system performance considerably by controlling the power flows in the network without generation rescheduling or topological changes [5].

3. Particle Swarm Optimization(PSO):

PSO was originally designed and developed by Kennedy and Eberhart in 1995 [6]. This technique relies on the exchange of the information between the particles of the swarm. In effect, each particle adjusts its trajectory towards its own previous best position, and towards the best previous position attained by any member of its neighborhood. In the global variant of PSO, the whole swarm is considered as the neighborhood. Thus, global sharing of information takes place and particles profit from the discoveries experience of all other companions during the search for promising regions of the landscape [7].

3.1. Basic Algorithm of PSO

The process for implementing the global version of PSO is as follows [8]:

1) Initialize a population (array) of particles with random positions and velocities on *d* dimensions in problem space.
2) For each particle, evaluate the desired optimization fitness function in *d* variables.
3) Compare particle's fitness evaluation with particle's pbest. If the current value is better than pbest, then set pbest value equals to the current value, and the pbest location equals to the current location in *d*-dimensional space.
4) Compare fitness evaluation with the population's overall previous best. If the current value is better than gbest, then reset gbest to the current particle's array index and value.
5) Change the velocity and position of the particle according to equations (1) and (2), respectively:

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times (pbest_i - s_i^k) + c_2 rand_2 \times (gbest - s_i^k) \qquad (1)$$

$$s_i^{k+1} = s_i^k + v_i^{k+1} \qquad (2)$$

Where v_i^k is velocity of agent *i* at iteration *k*, *w* is weighting function, c_1 and c_2 are weighting coefficients, $rand_1$ and $rand_2$ are random numbers between 0 and 1, s_i^k is current position of agent *i* at iteration *k*, $pbest_i$ is pbest of agent *i*, and gbest is gbest of the group.

6) Loop to step (2) until a criterion is met, usually a sufficiently good fitness or a maximum number of iterations is achieved.

One of the most important issues that must be taken into consideration when applying PSO is parameters selection. Parameters selection guarantees the convergence of the solutions. It includes the following:

(a) Population size: Population sizes of 20-50 were probably most common. It was learned early on that smaller populations than were common for other evolutionary algorithms (such as genetic algorithms and evolutionary programming) were optimal for PSO in terms of minimizing the total number of evaluations (population size times the number of generations) needed to obtain a sufficient solution [8]. The population size utilized in this paper is 20.

(b) Inertia weight: A large inertia weight facilitates a global search while a small inertia weight facilitates a local search. By linearly decreasing the inertia weight from a relatively large value to a small value through the course of the PSO run, the PSO tends to have more global search ability at the beginning of the run while having more local search ability near the end of the run. The simulation results on the benchmark problem of Schaffer's F6 function illustrate that an inertia weight starting with a value close to 1 and linearly decreasing to 0.4 through the course of the run will give the PSO the best performance compared with all fixed inertia weight settings [9].

(c) Acceleration coefficients (c_1 & c_2): The two constants c_1 and c_2 which are usually called cognition and social coefficients are used to balance the effect of self memory and group memory on the motion of the particle. c_1 and c_2 are set to 2 in this paper.

(d) The maximum velocity: It actually serves as a constraint that controls the maximum global exploration ability PSO can have.

4. Problem Formulation:

The primary purpose of SVC is usually control of voltages at weak points in a network. The SVC is a shunt-connected static VAR generator or absorber whose output is adjusted to maintain or control specific parameters of the electrical power system, typically bus voltage [4]. Accordingly, SVC is modelled as shunt susceptance within a certain range. The effect of this modelling shall be reflected on load flow while building the YBus matrix. The range of the modelled SVC rating is -0.6 pu to 0.6 pu.

In this paper, PSO is utilized to allocate SVC to achieve minimum voltage deviation with minimum cost of installation of SVC considering two main cases: overloading the network by 100% of the load and outage of a transmission line. Accordingly, the design vector of each particle is designed to include the rating and location of the bus where

SVC shall be installed. Design Constraints are the three following constraints:

1- Acceptable range of voltage profile: ($0.95pu \leq V_i \leq 1.05pu$ For i=1,…n where n is the number of system load buses),
2- SVC rating range (-0.6 pu $\leq$ Qsvc ≤ 0.6 pu),
3- Typical load flow equations.

The Objective Function is to minimize voltage deviation with minimum cost of installation of SVC.

A. Minimization of voltage deviation (*VD*):

Min. $VD = \sum_{i=1}^{n} (V_i - 1)^2$, i=1,…n where: n is the number of system load buses, V_i is the voltage magnitude at load bus i and 1 is the reference voltage.

B. Minimization of installation cost of SVC (Csvc):

According to [10-11] the cost function of SVC can be calculated as follows:

$\mathrm{Csvc} = 0.0003\mathrm{S}^2 + 0.3051\mathrm{S} + 127.38$ (US$/kVAR) ,

Where: Csvc is in united states dollars/kVAR and S is the operating range of the FACTS devices in MVAR.

C. Overall Objective Function:

Therefore, the overall objective function is formed as a linear combination of the multiple objective functions as follows: Min Z = $\alpha 1 VD + \alpha 2\,\mathrm{Csvc}$

Where: α1 and α2 are constants which indicate the relative weight of each objective function relative to the other. In this paper, α1 and α2 are taken such that the two functions will have the same degree of importance; however decision makers can give more priority to an objective function than the other.

5. Simulation Results:

To test the effectiveness of the proposed PSO technique to achieve minimum voltage deviation with minimum cost of installation of SVC, simulation studies have been carried out in IEEE 14 Bus test system shown in Figure 1 [12], which represents a portion of the American Electric Power System (in the Midwestern US).

The following cases have been considered:

- Overloading the network.
- Outage of a transmission line.

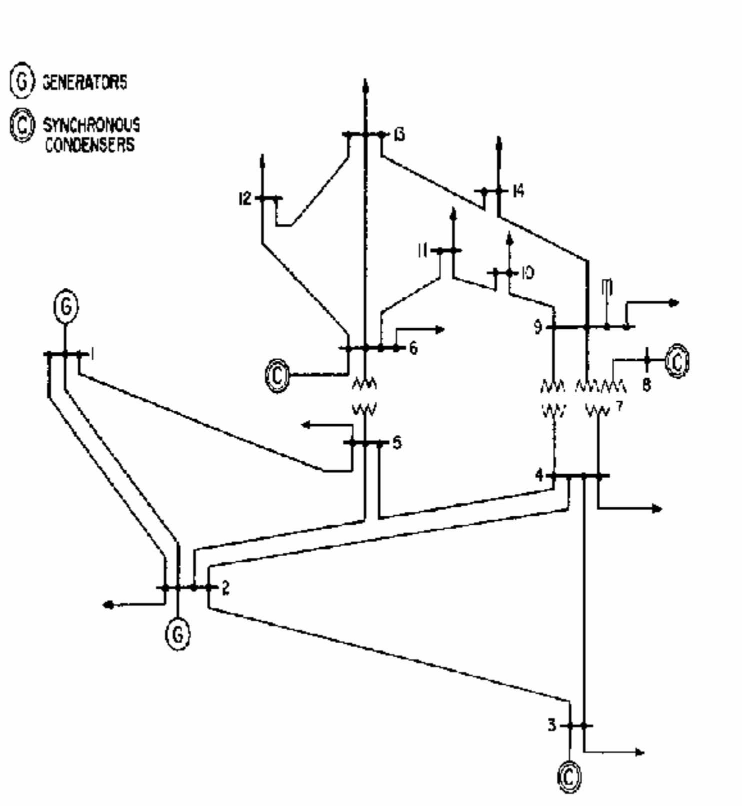

Figure (1): *IEEE-14 bus system*

5.1. Overloading the Network:

If the network is overloaded by 100%, the voltage profile without installing SVC is as shown in Table 1, as obviously shown, the voltage of buses 9, 10 and 14 are below the minimum accepted value.

Table (1): *Voltage profile in case of overloading the network (without installing SVC)*

Bus no.	**Voltage (p.u.)**
4	0.976
5	0.984
7	0.964
(9)	**0.929**
(10)	**0.925**
11	0.954
12	0.964
13	0.950
(14)	**0.896**

Applying the proposed PSO technique (a Matlab program) to achieve minimum voltage deviation with minimum cost of installation of SVC, the best location of SVC in this case is achieved at bus 14 with 0.422 pu rating where all busses are within acceptable limits as obviously shown in Table 2.

Table (2): *Voltage profile in case of overloading the network (with SVC)*

Bus no.	Voltage (p.u.)
4	0.981
5	0.987
7	0.979
9	0.959
10	0.950
11	0.967
12	0.975
13	0.971
14	0.988

5.2. Outage of a Transmission Line:

If the transmission line connecting bus 6 with bus 13 is out of service, the voltage profile will be as shown in Table 3, the voltage of buses 13 and 14 are below the minimum accepted value.

Table (3): *Voltage profile in case of outage of a transmission line (without installing SVC)*

Bus no.	Voltage (p.u.)
4	1.0115
5	1.0168
7	0.9965
9	0.9761
10	0.9721
11	0.9819
12	0.9599
(13)	**0.9221**
(14)	**0.9325**

Applying the proposed PSO technique, the best location of SVC in this case is achieved at bus 13 with rating of 0.113 pu where all busses are within acceptable limits as obviously shown in Table 4.

Table (4): *Voltage profile in case of outage of a transmission line (with SVC)*

Bus no.	Voltage (p.u.)
4	1.012
5	1.017
7	0.999
9	0.982
10	0.977
11	0.984
12	0.977
13	0.954
14	0.950

It was observed from the discussed results that PSO succeeded in both cases to find the optimal location and size of SVC in the IEEE 14-bus system to improve voltage stability with minimum installation cost.

6. Conclusion:

This paper has addressed the application of PSO for optimal sizing and allocation of SVC in IEEE 14-bus test system to enhance voltage stability. The objectives are to minimize voltage deviations of load buses in the system and to minimize cost of installation of SVC. Optimal allocation is successfully achieved using PSO considering overloading the network and outage of a transmission line. PSO has simple algorithm, it is able to escape local minima, it has less parameters to adjust unlike many other competing evolutionary techniques and it does not require a good initial solutions.

References:

[1]- Radu, Y. Besanger, *Blackout prevention by optimal insertion of FACTS devices in power systems*, IEEE International Conference on Future Power Systems, p: 1-6, Nov. 2005.

[2]- S. Gerbex, R. Cherkaoui, A. Germond, *Optimal location of multi-type FACTS devices in a power system by means of genetic algorithms*, IEEE Transactions on Power Systems, Vol. 16, No. 3, pp. 537–544, Aug. 2001.

[3]- J. G. Singh,S. N. Singh,S. C. Srivastava, *An approach for optimal placement of Static VAR compensators based on reactive power spot price*, IEEE Transactions

on Power Systems, Vol. 22, No. 4, pp. 2021 – 2029, Nov. 2007.

[4]- A. Edris, R. Adapa, M.H. Baker, L. Bohmann, K. Clark, K. Habashi, L. Gyugyi, J. Lemay, A.S. Mehraban, A.K. Myers, J. Reeve, F. Sener, D.R. Torgerson, *Proposed Terms and Definitions for Flexible AC Transmission System (FACTS)*, IEEE Transactions on Power Delivery, Vol. 12, No.4, pp. 1848-1853, Oct. 1997.

[5]- M. Karami, N. Mariun, M.Z.A.A Kadir, *On basic definition of optimal allocation of FACTS devices in power system*, IEEE Student Conference on research and development (SCOReD), pp: 418 – 421, Nov. 2009

[6]- X. Hu ,Y. Shi, R.Eberhart , *Recent Advances in Particle Swarm*, Proceedings of the Congress on Evolutionary Computation, (CEC-2004), Vol.1, pp: 90 – 97, 2004.

[7]- E.Ozcan, C.K Mohan, *Particle Swarm Optimization: Surfing the Waves*, Proceedings of the Congress on Evolutionary Computation, (CEC-1999), Vol.3, pp: 1939-1944, 1999.

[8]- R. Eberhart; Y. Shi, *Particle Swarm Optimization: Developments, Applications and Resources*, Proceedings of the 2001 Congress on Evolutionary Computation, Vol. 1, pp: 81-86, 2001.

[9]- R. Eberhart, Y. Shi, *Empirical Study of Particle Swarm Optimization*, Proceedings of the 1999 Congress on Evolutionary Computation, Vol.3, 1999.

[10]- L.J. Cai, I. Erlich, G.Stamtsis, *Optimal Choice and Allocation of FACTS Devices in Deregulated Electricity Market using Genetic Algorithms*, IEEE/PES, Power Systems Conference and Exposition, Vol.1, pp: 201–207, 2004.

[11]- M.M. Farsangi, H. Nezamabadi, *Differential evolutionary algorithm for allocation of SVC in a power system*, International Journal on Technical and Physical Problems of Engineering, Vol.1, pp: 15-22, 2009.

[12]- http://www.ee.washington.edu/research/pstca/

Nomenclatures:

α1 & α2………	Constants indicate the relative weight of objective functions
c_1 & c_2………	Weighting coefficients
Csvc …………	Cost of SVC in united states dollar/kVAR
$rand_1$ & $rand_2$	Random numbers between 0 and 1
S ……………	Operating range of the FACTS device in MVAR
s_i^k ……………	Current position of agent *i* at iteration *k*
v_i^k ……………	Velocity of agent *i* at iteration *k*
V_i ……………	Voltage magnitude at load bus
VD……………	Voltage deviation
w ……………	Weighting function