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Optimal Placement of SVC, TCSC, and UPFC Using Particle Swarm Algorithm and its Impact on the Transient Stability of Power Systems

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Abstract

As you know, one of the main causes of voltage instability reactive power limitation system. Improving hand with the capacitor reactive power system or devices Flexible AC Transmission System, avoid voltage instability and ultimately a solution for the voltage collapse. These devices are devices in addition to increased loading systems cause power system largely under control and rapidly that they are capable of stability margin and the system to enhance. In this paper, in the first with the optimal placement of SVC, TCSC and UPFC in IEEE-14 bus system by particle swarm algorithm aims to minimize losses and further decreases the overall cost of energy production, the optimization of the same time, location, Nominal amounts and Performance range this devices, we finally by placing them in achieved situations, we evaluated their effect on transient stability. For this purpose, generator rotor angle and terminal voltage magnitude of the power grid of the main parameters on the stability of power systems are, Both with and without the presence of these devices are examined to what extent we can see that the above parameters with the UPFC will improve.

Keywords: *Particle swarm algorithm (PSO), Flexible AC Transmission System (FACTS), stability, static reactive power compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Unified Power Flow Controller (UPFC).*

1. Introduction

One of the main concerns of mankind today is energy. Energy is one of the main pillars of the economy and the electricity has a special place as the highest form of energy. Declining oil and gas reserves on the one hand and the increasing global energy consumption on the other hand, scholars and researchers led to increasing efficiency And improve plant performance, reduce of losses and environmental protection Attention to optimizing energy production and transmission networks have power. In this regard, in recent years with the development of power electronics industry, Flexible AC Transmission System (FACTS) due to the many features and extensive use of fast networks and the transfer of power was used to create change in their transmission systems. A prominent characteristic of FACTS devices can large performance range, quick response and high reliability noted. The use of FACTS devices to the system is equipped with one or more of the following capabilities [6-8]:

Improve voltage stability margin, increasing of power system voltage profile, Regular control of load flow, Minimize production costs and productivity, Enhance capability loading lines by same heat capacity, Reduce the reactive power required in the transfer system.

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To take full use of the capabilities of FACTS devices is necessary to select the best locations for these elements, for this purpose some of the papers by load flow optimization aims to increase level loading or decrease losses has been used [3]. This paper uses particle swarm algorithm (PSO) with simultaneous consideration of losses (Increasing levels of loading) and costs simultaneously optimized nominal values, location and device performance range (r) approaches and Finally, the proper installation of these devices in the test system 14 bus IEEE, their impact on the transient stability will be evaluated.

2. Modeling of facts devices

According to the information given in reference [10], FACTS controllers based on the arrangement in transmission network are divided into three categories and for each of the types used in this study, a suitable model will be presented.

2.1. Model of SVC

SVC installed as parallel to inductive and capacitive compensation can be used. In this paper, SVC as an ideal reactive power injection at bus ith which operating range between -100 to 100 MVAR is.

$$\Delta Q_i = \Delta Q_{SVC} \tag{1}$$

$$Q_{SVC} = r \times 100 \quad (\mathrm{MVAR}) \tag{2}$$

Q_{SVC}, value the SVC reactive power compensation been and depending on in which part of the network is placed, will vary. as performance range of SVC that is between -1 to 1. Figure 1 shows Overview of SVC that in paper used.

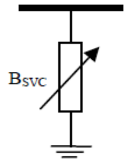

Figure 1: Overview of SVC

2.2. Model of TCSC

TCSC placed in series with the transmission line. TCSC of a capacitor bank in parallel with a thyristor controlled inductive bank is composed that by controlling of branch inductive, line reactance the corrected. TCSC reactance of the relationship (3) is obtained.

$$X_{TCSC} = \frac{X_C X_L}{\frac{X_C}{\pi}\left[2(\pi - \alpha) + \sin 2\alpha\right] - X_L} \tag{3}$$

Where α, X_L and, X_C the firing angle of the thyristor, capacitive reactance, and inductive reactance are respectively. TCSC placed in series on the line, and according to equation (4) is associated with the line reactance.

$$X_{ij} = X_{Line} + X_{TCSC} \tag{4}$$

for better modeling of TCSC in the optimization problems as equation (5) they defined.

$$X_{TCSC} = r \cdot X_{Line} \tag{5}$$

Where r, Compensation factor or performance range of TCSC depending on in which part of the line is placed, will vary and is between -0.7 to 0.2. Overview of TCSC is visible in Figure 2.

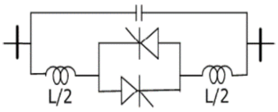

Figure 2: Overview of the TCSC

2.3. Model of UPFC

Basically, UPFC has two voltage source converters (VSC) and a DC capacitor is common between them that by two transformers in series-parallel is connected to the network. The overall structure of UPFC can be seen in Figure 3.

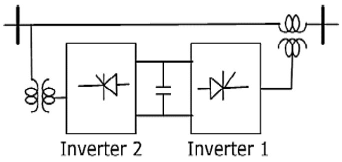

Figure 3: Overall structure of UPFC

To study the UPFC, its would modeling in two different ways, one coupled model with and the other decouple model. The first model is more complex because of the need to reform the jacobian matrix while the second model can easily be imported in algorithms load flow without modification or simplification jacobian matrix is required. In most of the articles about load flow of decoupling model is used. This model can be seen in Figure 4.

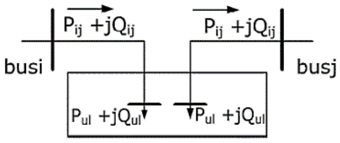

Figure 4: Decouple model of UPFC

3. Particle swarm algorithm (PSO)

Collective motion of the particles, a technique probable Optimization which has Population-based works. This method was introduced in 1995 by doctor Eberhart and Kennedy and the main idea of collective behavior is inspired by birds when searching for food. Group of birds in spatial are randomly searching food. There is only a piece of food in space. None of the birds do know the location food. One of the best strategies can pursue bird with the minimum distance to food. In fact, this strategy is base of PSO algorithm [9].

Each solution is called a particle. Each particle has a suitability and value is calculated by a Suitability function. Whatever particle in the search space to the target (food in birds motion model) is closer, has more Suitability. Also, each particle has a speed particle that is responsible for particle motion guiding. each particle with pursuit optimum particles in this case, it continues to move in space. The beginning of PSO is to this form that comes to a group of particles as random and with updating generations will try to find the optimal solution. At each step, each particle is updated using the best value. The first case, is the best position that particle has so far failed to reach it. The position is known and kept Pbest name. Another best value that is used by the algorithm, the best position that so far attained by the population of particles. This position with Gbest is displayed. After finding the best values of velocity and position of each particle using equations (6) and (7) will be updated.

$$\mathrm{V}[\ ] = \mathrm{V}[\ ] + \mathrm{C}_1 * \mathrm{rand}(\ ) * (\mathrm{Pbest}[\ ] - \mathrm{position}[\ ]) + \mathrm{C}_2 * \mathrm{rand}(\ ) * (\mathrm{Gbest}[\ ] - \mathrm{position}[\ ]) \tag{6}$$

$$\mathrm{position}[\ ] = \mathrm{position}[\ ] + \mathrm{V}[\ ] \tag{7}$$

In equations (6) and (7), V[ ] particle velocity and position [ ] are the current location of the particle that both arrays a length is the number of dimensions. Rand( ) is a random number in the interval (0,1). C_1 and C_2 are the learning parameters are usually considered equal to 2. In equation (1) in order to maintain the balance between local and global search will be presented with a new parameter called intermediate weight W is shown. For this purpose, in equation (6) is multiplied this coefficient on the initial velocity to be transferred only part of the initial velocity to future velocity. This parameter as equation (8) is calculated.

$$W = V_{max} - \frac{V_{max} - V_{min}}{Iter_{max}} \times Iter \tag{8}$$

V_{max} is the initial weight, V_{min} is the final weight, Iter is the current iteration number, and $Iter_{max}$ is the maximum iteration number (generations).

3.1. Objective function

The objective function is a function for assessing the compatibility of the particles and According to the optimizing objective is defined by the user and is the Part important algorithm of PSO and basis optimization program. The objective function in this paper include the reduction of system losses and reduce the costs of energy production and exploitation of transmission lines.

3.2. The function of network losses

The matter was unavoidable losses in transmission systems that case limits power transmission lines and the additional costs imposed to the network, Therefore designs purpose of transmission lines, further decreases it is always. In This paper, the total losses of the network from load flow method of Newton-Raphson obtained as one of the factors used in Objective function [4].

3.3. Cost function

The total cost of the system is composed of two components, it is seen in the equation (9).

$$C_{Total} = C_{PG} + C_{FACTS} \tag{9}$$

The first part, related to energy production costs is in power plants and from equation (10) is obtained.

$$C_{PG} = a_0 + a_1 P_G + a_2 P_G^2 \tag{10}$$

In which, P_G is the real output power of the power plant and a is constant coefficients that vary for different power plants and are given in the grid specifications.

The second part of the total cost function is the FACTS devices investment cost function, which varies for different elements, and is presented below for SVC, TCSC, and UPFC according to the Siemens standard.

$$\text{For SVC: } C_{SVC} = 0.0003\,S^2 - 0.305\,S + 127.38 \tag{11}$$

$$\text{For TCSC: } C_{TCSC} = 0.0015\,S^2 - 0.713\,S + 153.75 \tag{12}$$

$$\text{And for UPFC: } C_{UPFC} = 0.0003\,S^2 - 0.269\,S + 188.22 \tag{13}$$

That unit is for all three ($/KVAR) and range performance of FACTS devices based on KVAR with energy costs in the power plant, then should cost function of devices divided on the value of return investment during the period of five years (8760*5).

Particle swarm algorithm now assessing the compatibility of each population, the total system cost function and losses transmission lines, the objective function as equation (14) are introduced in [2].

$$F = \alpha_1 C_{Total} + \alpha_2 Loss \tag{14}$$

Where the α_1 and α_2 are constant coefficients that value them obtained with the help of trial and error and respectively equal to 0.141 and 0.02. At proposed algorithm, the objective is to with placement and determine the optimal parameters of the devices FACTS, to minimize the cost function and total system losses.

4. Simulation

At this paper, simulations are done at two parts. At first part using PSO algorithm with the aim of minimizing losses and costs simultaneously, we pay to optimize the nominal values, the location and range performance of FACTS devices. At second part by installing these devices in appropriate locations, their impact on the transient stability of power systems will be assessed.

4.1. Optimal placement of SVC, TCSC, and UPFC using PSO algorithm

To validate mentioned discussion, the program of PSO algorithm along with each of devices on the IEEE-14 bus system is simulated in MATLAB software. Single-line diagram of this network shown in Figure 5 and its data can found in [5]. First this algorithm, from among all possible states, the initial population selected randomly and makes the necessary changes in the network. Then using the method of Newton-Raphson load flow do and total system losses, costs of power plant generation and implementation of FACTS devices is determined (which is the same fitness). With repeating this process and compare fitness, is introduced best population by the algorithm (seen in Table 1). Figure 6 shows the process of change in fitness for 200 iterations, which according to the objective function, Reduce it means to losses reducing and decrease of Total costs in the network.

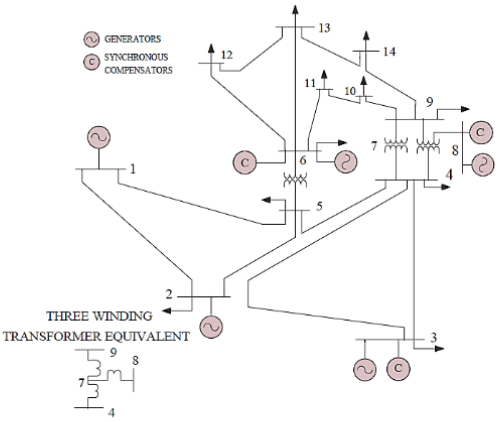

Figure 5: Single-line diagram of IEEE 14 bus test system

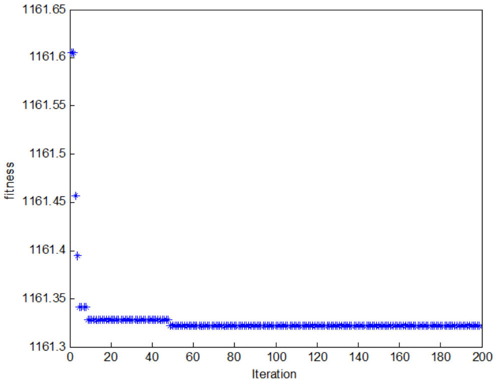

Figure 6: Process of change in Fitness for 200 iterations

In Table 1, the installation location and the nominal values and range of performance each of devices individually are shown. Also, is observed that each of these devices can reduce losses and total costs of energy generation. As is clear, UPFC has better performance compared to the other two elements and as the proposed element is presented for installation.

Table 1: Comparison of devices with and without the installation in power system with the help of particle swarm algorithm

	Without FACTS	**With the installation of FACTS devices**			**Proposed element**
Type of element	**-**	***SVC***	***TCSC***	***UPFC***	**UPFC**
Emplacement	-	BUS 14	Line 15 (between buses 7-9)	Line 10 (between buses 4-5)	**Line 10 (between buses 4-5)**
Performance range (r)	-	-0.0751	-0.1990	-0.6241	**-0.6241**
Reactive power of each element	-	-7.5142	4.6171	-28.1043	**-28.1043**
The total cost ($/KVAR)	8171.7	8169.6	8171.5	8168.5	**8168.5**
System losses (MW)	13.393	13.341	13.390	13.313	**13.313**
Fitness	-	1161.2	1161.5	1161	**1161**

4.2. Transient stability assessment with the presence of SVC, TCSC, and UPFC

Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle relationship. Consider a simple model of a single generator connected to an infinite bus through a transmission system as shown in figure 7.

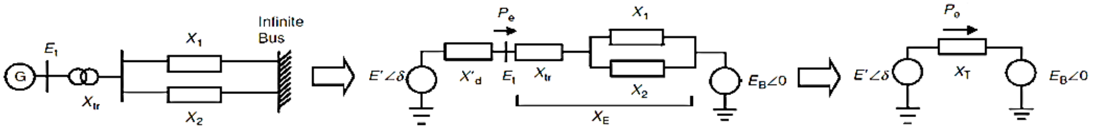

Figure 7: Simple model of a generator connected to an infinite bus

The power transferred from the generator to infinite bus is given by

$$P_e = \frac{E' E_B}{X_T} \sin\delta \tag{15}$$

Where P_e, power transferred from the generator to the infinite bus, E' internal voltage magnitude of the generator, E_B infinite bus voltage magnitude, X_T equivalent reactance between the generator and the infinite bus, and δ is the generator rotor angle.

Stability depends on both the initial operating state of the system and the severity of the disturbance. Usually, the system is altered so that the post-disturbance steady-state operation differs from that prior to the disturbance. Figure 8 illustrates the behavior of a synchronous machine for stable and unstable situations. It shows the rotor Angle responses for a stable case and for two unstable cases.

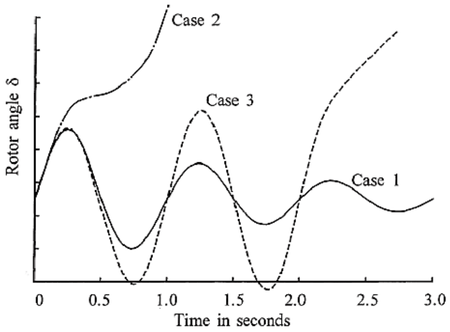

Figure 8: Rotor angle response to a transient disturbance

In the stable case (Case 1), the rotor angle increases to a maximum, then decrease and oscillates with decreasing amplitude until it reaches a steady state. In case 2, the rotor angle continues to increase steadily until synchronism is lost. This form of instability is referred to as first-swing instability and is caused by insufficient synchronizing torque. In case 3, the system is stable in the first swing but becomes unstable as a result of growing oscillations as the end stable is approached. This form of instability generally occurs when the post-fault steady-state condition itself is “small-signal” unstable, and not necessarily as a result of the transient disturbance. In a large power system, transient instability may not always occur as first-swing instability; it could be the result of the superposition of several modes of oscillation causing large excursions of rotor angle beyond the first swing.

For simulation used in this section of the PSAT software that a powerful software for the analysis and simulation of power systems with full performance and accurate [1]. The system studied, the same system shown in Figure 5. At this stage, each of FACTS devices placed in their proper locations that determined by PSO algorithm, then a three-phase short circuit applied at bus 2 and after the 0.04s fault spontaneous cleared is. In this case, investigate the transient oscillations generated in the rotor angle and voltage of the grid generators.

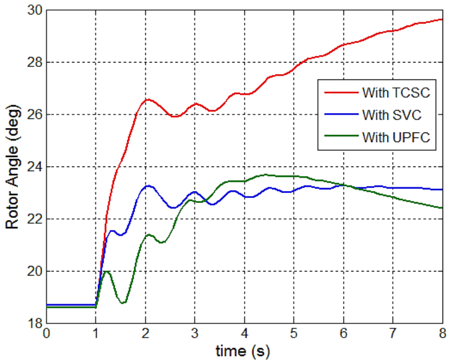

Figure 9: Rotor angle of the generator at bus 1 with different FACTS devices

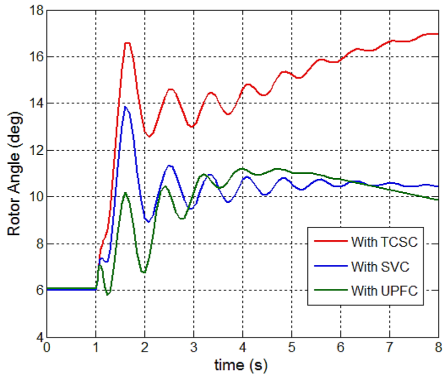

Figure 10: Rotor angle of the generator at bus 2 with different FACTS devices

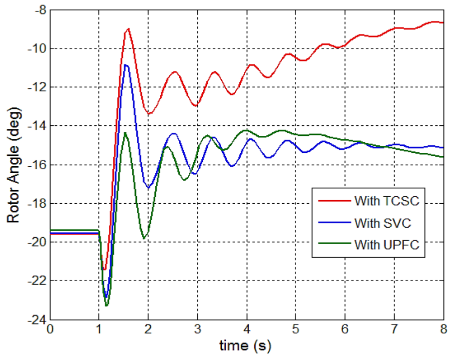

Figure 11: Rotor angle of the generator at bus 8 with different FACTS devices

Due to space limitations, is investigated only the generators rotor angle at buses 1 and 8 and also generator terminal voltage at bus 8. Figure 9, 10 and 11 respectively, the generators rotor angle at buses 1, 2 and 8 shows and is obviously after Acts 0.04s fault in bus 2, TCSC by installing generators lose their synchronism and becomes unstable. In this case, the system is stable in the first swing but becomes unstable as a result of growing oscillations as the end stable is approached. But by installing SVC and UPFC, The system after swings several at the new equilibrium point located and their synchronism not lose. In the stable case, the rotor angle increases to a maximum, then decrease and oscillates with decreasing amplitude until it reaches a steady state. As can be seen in the presence of UPFC, after fault clearing generators work with a smaller angle torque compared to SVC which enhances system security margin and thus Will be higher the probability of being transient stability.

Figures 12, 13 and 14 respectively, bus 8 voltage in the presence of SVC, TCSC and UPFC shows and indicates that after Acts 0.04 s fault in bus 2, voltage fluctuations at the desired bus whit presence of UPFC relative to other FACTS devices very quickly damped and to steady state is reached. Also, if upper and lower limit of allowed voltage in network buses respectively equal to 1.1 and 0.9 per unit, only in the presence of UPFC voltage has been in allowed range their own and indicated that its performance is better than SVC and TCSC.

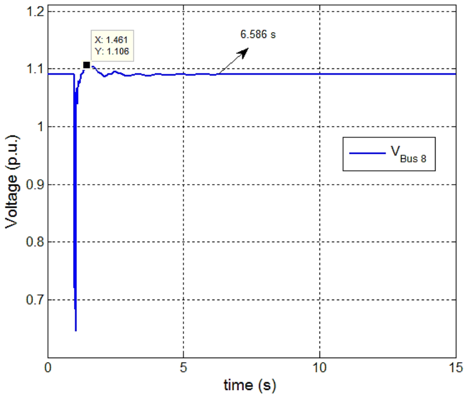

Figure 12: Voltage at bus 8 with the presence of SVC

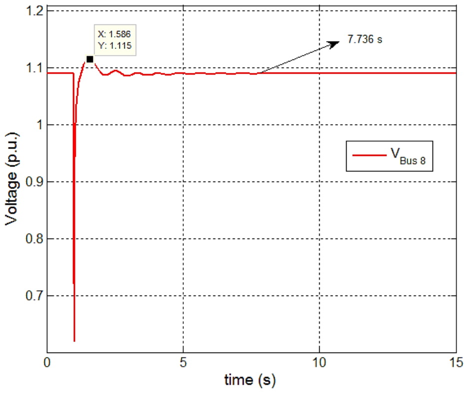

Figure 13: Voltage at bus 8 with the presence of TCSC

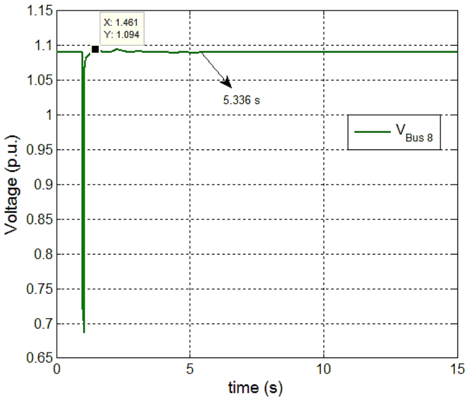

Figure 14: Voltage at bus 8 with the presence of UPFC

Conclusion

In this paper, from particle swarm algorithm to optimal placement of three types from FACTS devices (SVC, TCSC, and UPFC) with the aim of simultaneously minimizing losses and costs is used. Location, nominal capacity and performance range of these devices are considered as parameters to optimize in the algorithm. According to the simulation results we understand that with PSO algorithm can be the best location with the highest efficiency achieved by type suitable choosing of compensators, which contributes to decreased real power losses of the system and also reduce Total costs of producing energy. As is seen from results, from between these devices, UPFC best able to fulfill the optimization constraints. In this process, special attention is to coefficients of losses and economic cost. In this paper, only two factors of losses and costs were considered as the objective function, expected that in future studies by considering several other factors such as the network security, the objective function becomes wider and to test its Efficiency rate used of larger networks. Results of time domain show that transient stability of the system significantly improved with presence UPFC and has better performance than TCSC and SVC. Also, whit installing UPFC voltage fluctuation after clearing fault faster damped and reaches to their nominal value.

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