POSSIBILITIES OF USING FACTS DEVICES IN POWER SYSTEM

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ABSTRACT

This article discusses about the issues of increasing loadability in power system (PS) by using FACTS (Flexible Alternating Current Transmission System) devices, while reducing active power losses that occur in the transmission of power in the network. For this purpose we used two types of FACTS devices. It is a TCSC (Thyristor Controlled Series Capacitor) and SVC (Static Var Compensator). All simulations were performed in Matlab program.

Keywords: *power system, FACTS, SVC, TCSC*

1. INTRODUCTION

Today we are witnesses of continuous increase in electricity demand. This fact, along with market liberalization causes problems in the management of PS and problems associated with the reliability of electricity supply.

As a result, operators of PS are forced to use new management capabilities. One of these options is the deployment of FACTS devices. Using FACTS devices can achieve control of power flow, improving voltage stability andpower oscillation damping in networks, increase the transfer capability of existing linesand decrease active power losses in the networks. Article is devoted to the last two goals, the impact of FACTS devices to enhance the transfer capability of the transmission network compared to the situation without the use of FATCS devices.

2. TCSC, SVC

TCSC – belongs to the series controller. The main circuit of the TCSC consists of a series capacitor *C* in parallel with a thyristor controlled reactor *L*. A TCSC is a series controlled capacitive reactance that can provide continuous control of power on the AC line over wide range. Use of TCSC offers the following advantages [1]:

- rapid, continuous control of the transmission line series compensation level,
- dynamic control of power flow in selected transmission line,
- damping of the power swings from local and inter area oscillations,
- voltage support,
- prevent the loop flow of power.

TCSC model consists of variable impedance connected in series to the line. As a result, there is a change of the total line reactance:

$$X_t = X_{line} + X_{TCSC} \tag{1}$$

Where X_t is total line reactance, X_{line} is line reactance and $X_{TCSC}$is added reactance by TCSC. In simulation we

considered line compensation from 0,4 to 1,6 times the original value line reactance as a result of using TCSC.

SVC – 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 (typically bus voltage). SVC is a general term for a thyristor controlled or thyristor switched reactor and/or thyristor switched capacitor or combination. SVC includes separate equipment for leading or lagging vars, thyristor controlled or thyristor switched reactor for absorbing reactive power and thyristor switched capacitor for supplying the reactive power [2]. Using of SVC we can achieve:

- stabilization and improved adjustability of voltage,
- reduction of active power losses,
- damping of oscillations and enhance damping of small faults,
- increase the capacity of existing transmission lines,
- increase transmission stability limits.

SVC model consists of variable reactive power source connected into the node. SVC can works in capacitive mode (SVC provide reactive power) and in inductive mode (SVC absorb reactive power). It was considered that the maximum possible consumed and supplied reactive power was 50 MVAr.
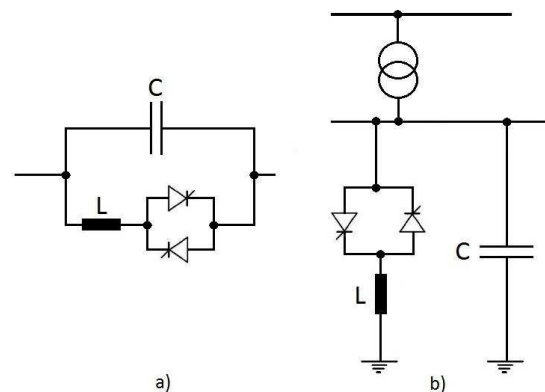

Fig. 1 a) TCSC, b) SVC

Both of these devices have the effect of modifying the active power flow in the network. The active power transported over a transmission line is given by the following equation:

$$P_{12} = \frac{V_1 V_2}{X_t} \sin(\delta_1 - \delta_2) \qquad (2)$$

Where P_{12} is transmitted active power over a transmission line, V_1 and V_2 are magnitudes of voltages, δ_1, δ_2 are voltage angles and X_t is total line reactance. TCSC has the effect of modifying the reactance line, SVC changing the voltage at the node to which it is connected. In this way are therefore able both devices to influence the active power flow in the network.

3. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by the social behaviour of flocks of birds or school of fish. PSO shares many similarities with evolutionary computation techniques such as genetic algorithms. The system is initialized with a population of random feasible solutions and searches for optima by updating generations. However unlike genetic algorithm, PSO has no evolution operators such as crossover and mutations.

In PSO the potential solution called particle fly through the problem space by following the current optimum particles. The particles change their positions by flying around in a multidimensional search space until a relatively unchanged position has been encountered, or until computational limitations are exceeded. Each particle keeps track of its coordinates in the problem space, which is associated with the best solution, fitness, it has achieved so far. The fitness value is also stored. The value is called *pbest*. Another best value that is tracked by the particle swarm optimizer is the best value obtained thus far by any particle in the neighbours of the particle. This location is called *lbest*. When a particle takes the whole population as its topological neighbours, the best value is a global best and is called *gbest*. The concept of the PSO consists of, at each timestep, changing the velocity of each particle toward its *pbest* and *lbest* locations[3].

The whole calculation process can be summarized into the following steps:
1. Initialization – generate random *n* particles. Each particle is considered to be a solution for the problem.
2. Counter updating.
3. Compute the objective function.
4. Velocity updating – using the global best and individual best.
5. Position updating – based on the updated velocity.
6. Individual best updating – Each particle is evaluated and updated according to the update position.
7. Search for the minimum value in the individual best where its solution has ever been reached in every iteration and considered it as the minimum.
8. Stop criteria – If one of the stopping criteria is satisfied, then stop, otherwise go to step 2.
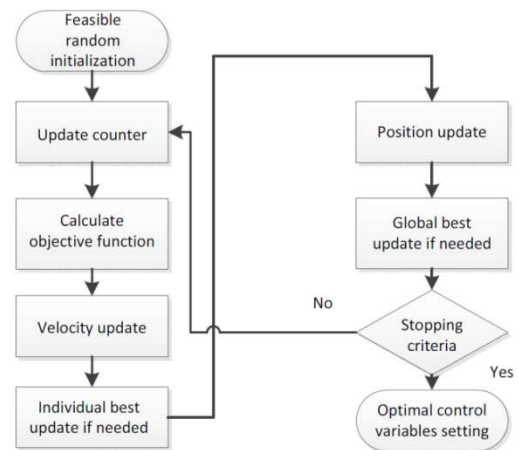

Fig. 2 Particle Swarm Optimization

4. PROBLEM FORMULATION

The main goal is to find maximum possible loadability of the power system while reducing total active power losses. We consider 14 nodes power system from fig. 3. The first five nodes are on 400 kV level, the others are on 110 kV level. All generations/loads are given in tab. 1. Generation/load at each node increases with each step of 2,5 % compared to the values given in tab. 1. The main constraints in the optimization process are[5]:
1. Voltage limitation – maximum voltages tolerances are 5 % and 10 % at 400 kV and 100 kV voltages levels respectively.
2. Max./min. reactive power generated by generators – The generator at node 3 has a control range ± 50 MVAr, generator at node 5 has a control range ± 100 MVAr.
3. Max./min. position on transformer tap changer – we consider taps control on the primary side of a step of 2,5 %.
4. Max. permissible current flow through the line – It is considered the maximum allowable current 2000 A for lines at 400 kV voltage level, 420 A for lines at 110 kV voltage level.
5. Maximum number of simultaneously working FACTS devices must not be more than three.
6. Max./min. possible supplied/consumed reactive power by SVC cannot be more than ± 50 MVAr.
7. Compensation range of TCSC allows line compensation from 0,4 to 1,6 times the original value line reactance.

Above mentioned restrictions are included in the objective function in the form of penalties.

In order to determine the size of the impact of FACTS devices considering the two scenarios:

Increase load system without FACTS devices – in this case, considering a gradual increase generation/load in network until there is a state in which it is not possible to keep all operation restrictions. Because we do not consider the use of FACTS devices, controlled variables are only:

- Reactive power generated by generators
- Transformer tap ratios

Increase load system with FACTS devices – it is considered to be available four FACTS devices (2 x SVC, 2 x TCSC) but at the same time can be used only three. The optimization process determines the number, type, location and optimal parameters of FACTS devices. This task is divided into two parts:

Case A – In this case it is possible to change the type, location and the optimal parameters of FACTS devices at each change of generation/load.

Case B – represent that in practise it is not possible change type and location of FACTS devices with change of generation/load. In this case optimization process determines only optimal parameters for FACTS devices. Locations and types of FACTS devices were determined in case A for scenario with maximum possible loadability.
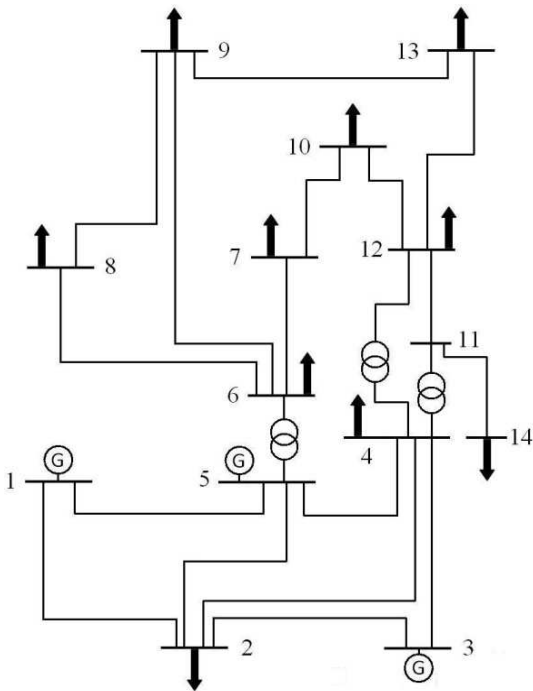

Fig. 3 14 nodes power system

Table 1 Generations and loads in nodes

| Node | Generation/Load | |
	P [MW]	Q [MVar]
1	639	-124
2	-400	-175
3	100	50
4	-400	-175
5	400	200
6	-40	-15
7	-40	-15
8	-40	-15
9	-40	-15
10	-40	-15
11	0	0
12	-40	-15
13	-40	-15
14	-40	-15

Increasing of generation/load in nodes has been stopped in state, which has not been possible to meet above mentioned operating constraints.

5. SIMULATION RESULTS

All simulation results are shown in the following graphs. Fig. 4 shows the change network loadability depending on changes in total active power losses. As seen in the case without FACTS devices operation restrictions are violated by increasing generation/load about 40 %. In case with FACTS devices can be generation/load increased about 62,5 % compared with the initial load. In this case the best result will be achieved if used two SVC devices (in nodes No. 8 and No. 10) with TCSC (connected between nodes No. 6 and No. 9). In case with maximum possible generation/load both SVC devices supplied to the network maximum possible reactive power (2 x 50 MVAr). TCSC worked in capacitive mode and reduce line reactance by 39 %. Above this level we are not able to meet all operating restrictions, even if we use FACTS devices.

With increasing generation/load is overloaded line between nodes No. 6 and No. 8 (also in case without FACTS devices). It is interesting to see what impact FACTS devices to change total active power losses. If you take into account the case when the maximum generation/load of network was achieved without FACTS devices in case with FACTS devices the total active power losses are the same when generation/load is higher by 7,5 %. It is clearly see that with FACTS devices will not increase only the loading capacity of the network, but also the total active power losses were lower.
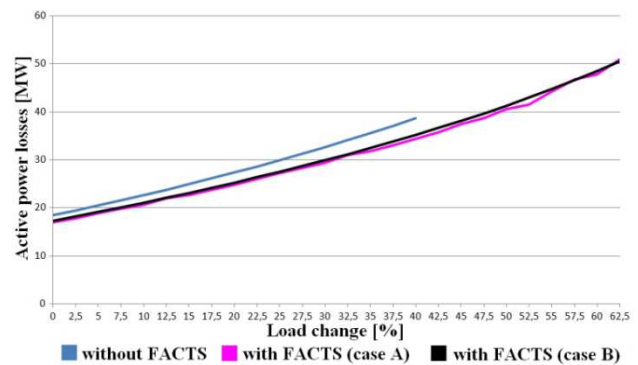

Fig. 4 Changes of active power losses

The difference in the change of total active power losses between cases A and B is caused due to the fact that in case B was not possible to change the location or type of used FACTS devices. Because of this in case B total active power losses were higher. On average, the difference is not greater than 2 % compared to the case A.

Fig. 5 and fig. 6 represents the changes in active power flows and losses in individual lines for cases when is increased generation/load by 40 % for case without (blue) and with (black) FACTS devices. Red colour represents the state of the system at maximum generation/load. As we can see active power flow in the line between node No. 6 and No. 8 does not vary in any of these cases. By using FACTS devices, active power flow has been pushed out from this line. Therefore line was not overloaded. This

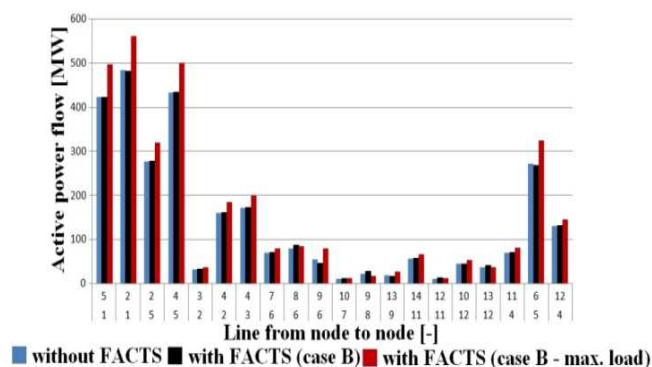occur only when the generation/load increases by more than 62,5 %.

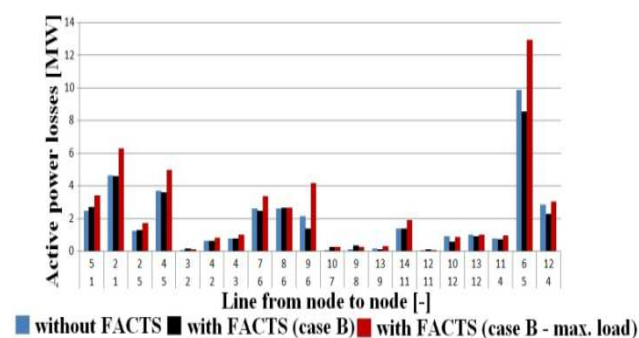**Fig. 5** Active power flow in all lines

Fig. 6 Active power losses in all lines

Fig. 7 represents the change of voltage. As we can see, voltages across the network nodes meet operational restrictions.
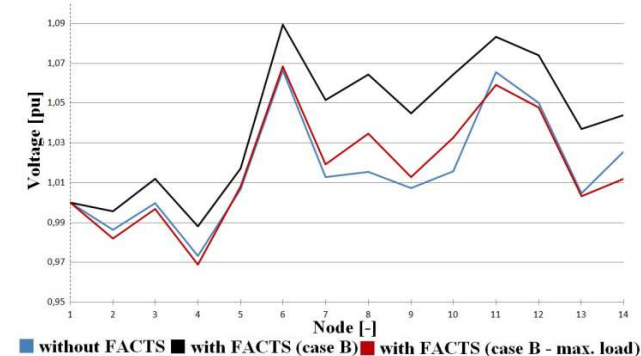

Fig. 7 Voltage profile

6. CONCLUSIONS

This article deals with the most efficient use of FACTS devices in the PS. The aim was to show that the deployment of certain FACTS devices can achieve several objectives simultaneously. In this case, it has been shown that it is possible to simultaneously increase the loadability while reducing total active power losses in PS. Because financial costs of these devices are high, we should use them to achieve multiple purposes simultaneously.

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BIOGRAPHIES

Roman Jakubčák was born in 1987 in Košice, Slovakia. His engineering study completed in the years 2006 to 2011 at the Technical University in Košice such as electrical power engineer. Today he is continuing his studies as a PhD student at the Department of Electrical Power Engineering, at the Technical University in Košice. He is interested in minimization active power losses in power system with using Flexible Alternating Current Transmission Systems.

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MiroslavKmec was born in 1988 in Bardejov, Slovakia. He received the B.E. and M.E. degrees in electrical power engineering from Technical University, Košice, in 2010 and 2012 respectively. Today he is continuing his studies as a PhD student at the Department of Electrical Power Engineering, at the Technical University in Košice. His areas of interest are digital protective relays,power system protectionandadaptive relay setting for flexible AC transmission systems (FACTS).