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Optimal Location of Thyristor Controlled Series Compensator (TCSC) for Enhancing Power System Loadability

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ABSTRACT

This paper presents analytical method to find optimal location of FACTS device in power system. The loadability limit of the system is found by observing constraints like bus voltage, line loading and voltage angle while doing incremental changes in generation and load. As Thyristor Controlled Series Compensator (TCSC) is having good capabilities for enhancement of loadability, TCSC is introduced, when any of constraints is violated. The performance of TCSC is verified for each branch except branch containing tap-changing transformer. The loadability is found for the system without TCSC and after introducing TCSC in every branch (one line at a time). Simulation using MATPOWER is done on IEEE-14 bus system. The performance of TCSC is analyzed for all probable 17 locations of IEEE-14 bus system by analytical method.

KEYWORDS: TCSC, Power system loadability, analytical method, IEEE-14 bus system

I-INTRODUCTION

In the current scenario of power system, the load demand is increasing day by day. Due to de-regulated power system the lines are operated near thermal limit [1]. So, it is mandatory to search for options to overcome this scenario. This option may be anyone of followings: (1) Construct a new transmission line (2) Apply some topological changes into the existing system.

It is never be feasible to go for first option. FACTS are having characteristic of doing some topological changes into the existing system. They enhance the system performance by re-dispatching the flow patterns and reducing the loop flows in such a way that the contractual requirement between grid and stockholders and increased load demands are satisfied [2].

The cost of FACTS devices is to be justified for a given system [3]. So, FACTS should be located optimally in a system. The methods for optimization the location of FACTS may be analytical method or heuristic method [1-11]. Before applying any kind of heuristic method, it is very advantageous to study analytical method for finding the optimal location of FACTS in given system.

The objective for optimization may be loss minimization, cost minimization, enhancing voltage stability, power system security and may be enhancing power system loadability. Among all these aspects enhancing loadability is very important concept. Because, if there is any reserve capacity available, why the other alternatives should be searched like constructing new transmission line or establishing new generating station.

This paper is organized as follows. The influence of FACTS device on power flow equation is discussed in section-II. In section-III steps to be followed for analytical method is discussed. In section-IV the result and discussion for IEEE-14 bus system is discussed and section-V concludes the paper.

II- FACTS devices in power flow

There are three types of FACTS devices: series device, shunt device and combined device. These FACTS are having different parameters to be controlled, which can be understood by power flow equations.

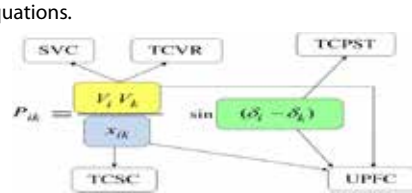


Fig.1. Impacts of FACTS devices on the variables involved in the active power flow equation [11].

The power flow equations can be written as:

$$P_{ik} = -P_{ki} = \frac{V_i V_k}{x_{ik}} \sin(\delta_i - \delta_k)$$

$$Q_{ik} = -Q_{ki} = \frac{1}{x_{ik}} [V_i^2 - V_i V_k \cos(\delta_i - \delta_k)]$$

where Vi and Vk are the voltage magnitudes of buses i and k, xik is the line reactance and δi-δk =δik is the difference angle between phasors Vi and Vk . In normal power system operation, δik is small and the voltage magnitudes are typically 1.0 p.u. We can therefore easily decouple the active and reactive power controls from each other. While the active power flow is influenced by δik and xik, the reactive power flow is related to the value of (Vi -Vk) and xik. Fig. 1 shows the active power flow equation between two buses i and k and it is the variables that can be controlled by each FACTS device.

To Study the effects of FACTS devices on power system, the modeling of FACTS devices is done. In available literature mathematical modeling of FACTS devices are done. Mathematical models for FACTS devices are implemented by MATLAB programming language. [1] In some papers other software like EUROSTAGTM software is used [3]. In other paper the modeling is done using MATPOWER, which is extension of MATLAB [1,11].

For a power system without FACTS devices, the power flow with normal power equations can be done using Newton-Raphson method. But, when FACTS devices are involved in power system for compensation and performance improvement, the modeling is done. i.e. when TCSC is used in power system, for analysis purpose it is modeled as variable reactance.

The TCSC may have one of the two possible characteristics: capacitive or inductive, respectively to decrease or increase the reactance of the line. It is modeled with three ideal switched elements in parallel: a capacitance, an inductance and a simple wire, which permits the TCSC to have the value zero. The capacitance and the inductance are variable and their values are function of the reactance of the line in which the device is located. In order to avoid resonance, only one of the three elements can be switched at a time. Moreover, to not over compensate the line, the maximum value of the capacitance is fixed at -0.8XL.For the inductance, the maximum is 0.2XL [1,12].

CSC can be very efficient in enhancing loadability of power system. By changing reactance of TCSC, ultimately impedance of branch is changed in which TCSC is connected. The power flowing in that branch changes and due to this power flowing in other branches is re-dispatched.

In this paper TCSC is selected to enhance the loadability of power system. The software used is for power flow analysis is MATPOWER. As there are 20 numbers of branches in IEEE-14 bus system, the probable locations of TCSC may be all the branches excluding the branches in which tap-changing transformer is connected. In MATPOWER branches are model as pi-line. So, the parameter affected by selected FACTS devices are to be changed to run power flow analysis [11,12]. If TCSC is connected in any branch it will be treated as if a new bus is created and impedance of old line is transferred between newly created bus and one of the old bus [13].

III -Analytical method

1. Assume initial loading condition as load factor λ=1.0
2. Power in generation is modified as
   $PGi = \lambda . PGoi$.
3. For the load buses the P and Q are modified as
   $PLi = \lambda . Ploi$
   and
   $QLi = \lambda . PLoi$.
4. The constraints to be considered are as follows :

$Sl \leq Slmax$: for all branches of the network
$|\Delta Vbi| \leq 0.05$: for all buses of the network
$Pgimin \leq Pgi \leq Pgimin$: for all generation buses

One more constraint can be add-up is voltage angle.
$|\theta bi| \leq 30^{\cdot}$: for all buses of the network

5. When any of above constraints is violated include TCSC for that load condition in all branches one by one.
6. If the condition is reached when there is no violation, increase the loading and generation as shown in step 2 and 3.
7. Repeat step 5 and 6 for all branches, where TCSC may be located.

IV-Result and discussion

When incremental change in load and generation is done without FACTS devices the maximum active power generation is 522 MW. The best result can be obtained in branch 14. The power system loadability is reached up active power generation 602 MW. It is very clear that 522 MW is 90% increase in base load, and 602 MW is 120% increase in base load. So, overall loadability is enhanced up to 30% using single TCSC in branch 14. All results are shown in TABLE-01.

Effect of TCSC on System Loadability for all possible locations

Branch	fbus	tbus	X LINE	X minvalue	X maxvalue	Set Value	Increase in System Loadability
1	1	2	0.05917	-0.04734	0.011834	ALL	NIL
2	1	5	0.22304	-0.17843	0.044608	ALL	NIL
3	2	3	0.19797	-0.15838	0.039594	ALL	NIL
4	2	4	0.17632	-0.14106	0.035264	ALL	NIL
5	2	5	0.17388	-0.1391	0.034776	ALL	NIL
6	3	4	0.17103	-0.13682	0.034206	-0.13682	10%
7	4	5	0.04211	-0.03369	0.008422	ALL	NIL
8	4	7	Tap-changing transformer				
9	4	9					
10	5	6					
11	6	11	0.1989	-0.15912	0.03978	ALL	NIL
12	6	12	0.25581	-0.20465	0.051162	ALL	NIL
13	6	13	0.13027	-0.10422	0.026054	ALL	NIL
14	7	8	0.17615	-0.14092	0.03523	-0.14092	30%
15	7	9	0.11001	-0.08801	0.022002	-0.08801	20%
16	9	10	0.0845	-0.0676	0.0169	ALL	NIL
17	9	14	0.27038	-0.2163	0.054076	-0.2163	10%
18	10	11	0.19207	-0.15366	0.038414	ALL	NIL
19	12	13	0.19988	-0.1599	0.039976	ALL	NIL
20	13	14	0.34802	-0.27842	0.069604	-0.27842	10%

V-Conclusion

By using single TCSC the loadability of IEEE-14 bus system is increased up to 30%. The loadability can be enhanced even more by increasing numbers of TCSC. When the larger system is taken, calculation by analytical method becomes tedious. So, there is a need to go for AI methods for optimization to reach solution near global optimum.

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