Optimal Location of TCSC for Congestion Management in Transmission Line using Sensitivity Method

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Abstract -This paper presents a methodology to relieve congestion in transmission line using thyristor controlled series capacitor. Congestion takes place when the transmission network is unable to transfer all of the contracted power because of violation of system operating limits. In this paper congestion management is obtained using thyristor controlled series FACTS device. The most striking feature of FACTS technology is its ability to directly control line flows by structurally modifying parameters of the fast switching. Reactive power sensitivity factor is used to determine optimal location of TCSC. The efficiency of the proposed method is tested on IEEE 4 bus test system and it can be readily extended to any practical systems.

Keywords - Congestion management, Optimal Location, Deregulated Power System, sensitivity analysis.

1. INTRODUCTION

Introduction to de-regulated electricity market brought about two main features to the power system i.e. distributed generation and competition in the electricity market. Distributed generation means generation was de-licensed and captive generation was encouraged. Industrial and commercial user operates their own plant to produce power at cheaper rate and also sell excess power to small consumer. With technological innovation it was possible to generate power efficiently using small generating units. Thus cost effective production with small power plant near load center was obtained. This also gave possibility for private played to generate and sell power to utility. Technological change provided acceleration to concept of "Independent Power Producer". Transmission however run as government owned utility. Expansion and operation of transmission is governed at Central as well as State level. Increase in number of non-utility generator and greater competition between public services have increased stress on transmission corridor. ISO has to establish co-ordination between demand and supply so that system is maintained in risk-free state. To alleviate congestion ISO can uses mainly two types of techniques they are-

Cost free means: It include following technique:

- Out-ageing of congested lines
- Operation of transformer taps changer/phase shifters
- Operation of FACTS devices particularly series

Non Cost free means: It includes following technique:

- Re-dispatching the generation amounts.

Employing this method, some generators back off while some increase their output. The consequence of re-dispatching is that generators cease to run at equal incremental charge.

Curtailment on loads and the practice of load interruption options. Congestion management techniques employed today may have negative impacts on energy markets, such as disruptions and monetary penalties, under some conditions. To reduce these issues various congestion management techniques were suggested, including re-dispatch and curtailment of scheduled energy transmission. Curtailment on loads and the practice of load interruption options. The outcome of re-dispatching is usually that generators do not operate at identical incremental charges In the restructured electric energy industry, FACTS technology is one such technique that strives to achieve the desired degree of reliability while supporting competition in the bulk power market. It leads to better utilization of the existing grid infrastructure. Various issues relating to the usage of FACTS devices are their choice of appropriate FACT device, its optimal location and modeling.

2. SYSTEM MODEL

2.1 Flexible Ac Transmission System (Facts)

FACTS are the abbreviation for Flexible AC Transmission Systems and refer to a set of resources employed to eliminate certain boundaries in the static and dynamic transmission capacity of electrical networks. The reliability and practical readiness of the system relies on static and dynamic stability of system under any disruption. Consequently the operation and expansion of the system are scheduled to ensure all possible emergency situations thoroughly in advance and choices in regard to repairs to the network exports and imports of power for the system depend on the result of the analysis. The feasible capacity which can be imported or exported is based partly on the thermal capacity of the transmission lines and to some extent on system stability limits that can be established through routine calculations, while using limit being arranged at the smaller of the two. Thermal stability refers to maximum current carrying capacity and system stability refers to voltage stability. FACTS provide efficient and reliable technique for regulating voltage, impedance, and phase angle when transmitting power over high-voltage lines. It provides better utilization of existing transmission networks and substantially increase the availability and reliability of networks, and enhance both dynamic and transient stability of network although ensuring an improved quality of supply. Fact devices are classified as series connected and shunt, based on the best way they may be attached to the power system. A variation is made between parallel compensation and series compensation.

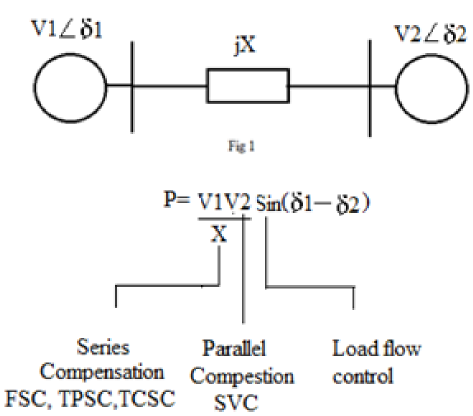

Fig 2.1 Active power transmission equation

Consider a network with sending end voltage be V1∠δ1 and and receiving end voltage be V2∠δ2 and X the reactance of transmission line. The power flow through the line is given by

$$P = \frac{V1 * V2}{X} \sin \delta$$

The active power transmission equation illustrates which FACTS components selectively influence which transmission parameters.

2.2 Parallel compensation

Parallel reactive power compensation enables to selectively influence important transmission line parameters. Parallel capacitor banks assist the voltage under heavy load conditions. This protection can enhance maximum transmittable power, prevent voltage instability and regulate the voltage profile. Parallel reactors protect against overvoltage under low load condition. The key constituents of a parallel reactive power compensation system are thyristor controlled reactors (TCRs) and thyristor switched capacitors (TSCs) that can be added to transmission lines with filter branches as per need.

2.2.2Disadvantage of parallel compensation

The application of shunt capacitors requires careful system design. The circuit breakers connecting shunt capacitors should withstand high-charging in-rush currents and also, upon disconnection, should withstand more than 2-pu voltages, because the capacitors are then left charged for a significant period until they are discharged through a large time-constant discharge circuit. Also, the addition of shunt capacitors creates higher-frequency–resonant circuits and can therefore lead to harmonic over voltages on some system buses.

2.3 Series compensation

Series capacitors are used to cancel out the effects of the series inductance of transmission lines. Series compensation contributes to improve the maximum power-transfer capability of the transmission line. The net outcome is a lower load angle for any given power transmission level and, subsequently, a higher stability margin. The reactive-power absorption of a line is based on the transmission current, when series capacitors are utilized the subsequent reactive-power compensation is adjusted proportionly. Also, since the series compensation efficiently lowers the overall line reactance, it is expected that the net line-voltage drop would certainly become less susceptible to the loading conditions. The transmission of active power is especially restricted by the impedance of the line, comprising the ohmic resistance and capacitive and inductive reactance.

2.3.1 Benefits of series compensation

- Line voltage drops reduces.
- Influence load flow in parallel corridor.
- Increases line transfer capability.

- Reduces transmission angle (δ).
- Increases steady state and dynamic stability.

3. PREVIOUS WORK

Paper [1] by A.R. Abhayankar etal describes the restructuring of electric power supply system. The centralized system planning and operation management that exited in vertically integrated system is remodeled to adapt to the new market environment In de regulated environment retaining power system security is among the most challenging tasks for the power system engineers. Congestion management is a serious concern for Independent System Operator (ISO) in present deregulated electricity markets as it can arbitrarily increase the prices and hinders the free electricity trade. G.V. Kumar e.tal in his paper[2] summarises two methodologies for managing congestion , first is using series FACTS devices and second by Changing Participation Factor of Generator. B.Likitha e.tal in [5] utilizes TLR sensitivities for the purpose of congestion management by load curtailment. Mixed Integer Iinear Programming is utilized in finding location of TCSC in power system in [9] by Kanwardeep Singh. Significant improvement in Total Transfer Capability (TTC) after using TCSC and SVC had been obtained as mentioned in [10] by Chandan Giri in "Congestion management in Electrical Power Grid".

This paper makes use of thyristor controlled seriese capacitor to control the power flow over designated transmission routes for management of transmission congestion. The positioning of the series FACTS devices, especially to regulate congestionwithin the deregulated electricity markets are determined by sensitivity factor methods. The positioning of FACTS devices are usually determined by static or dynamic efficiency of the system.

4. PROPOSED METHODOLOGY

4.1 Characteristics & Static Modeling Of TCSC

In this paper thyristor controlled series capacitor is utilized to increase the power transfer capacity of transmission line. TCSC designs include controlled reactors shunted to section of capacitor bank. This combination permits smooth control over frequency dependent capacitive reactance over a broad range. The thyristor valve includes a string of series connected high power thyristors and inductor in series. No interfacing equipment like high voltage transformers is required.

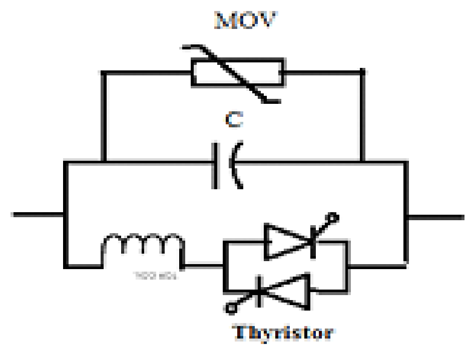

Fig 4.1 Thyristor controlled series capacitor

The bi-directional thyristor control device is fired with an angle α ranging between 90° and 180° with respect to the capacitor voltage. In each half cycle when the thyristor is fired, it conducts current through current limiting reactor for the rest of the cycle till the natural current zero. During the off time of thyristor, current flows through capacitor. During on time of thyristor current is conducted by thyristor and capacitor is short circuited. The same process is repeated in other half cycle. The reactance characteristics curve of a TCSC device drawn between reactance of TCSC and the firing angle alpha(α). The reactance characterstic is divided into three different region i.e. inductive region, resonance region and capacitive region. The effective reactance of TCSC starts raising from XL till parallel resonance condition take place ie XL(a)=XC. when XTCSC is infinity. This region is resonance region extending between value of a extending between Llim and Clim. On further increasing α capacitive region occur till α= ρ. Hence, impedance characteristics of TCSC exhibits, both inductive region and capacitive region are possible by varying firing angle (α).

$$90 < \alpha < L_{lim} \text{ Inductive region}$$

$$L_{lim} < \alpha < C_{lim} \text{ Resonance region}$$

$$C_{lim} < \alpha < 180 \text{ Capacitive region}$$

To get both effective inductive and capacitive reactance across the device, value of inductive reactance is kept small as compared to capacitive reactance. If capacitive reactance XC is smaller than the inductive reactance XL , then only capacitive region is possible in impedance characteristics. Also XL should not be equal to Xc value otherwise a resonance condition takes place that result in infinite impedance and transmission line would be an open circuit. The effective reactance of TCSC with respect to firing angle alpha (α).

$$X(TCSC) = \frac{XL(\alpha)XC}{(XL(\alpha) - XC)}$$

Where

$$XL(\alpha) = XL * (\frac{\pi}{\pi - 2\alpha - 2sin2\alpha})$$

And capacitive reactance

$$XC = -(\frac{1}{2\pi f C})$$

$X_L(\alpha)$ varies from actual inductive reactance X_L to infinity.

$$XL \le XL(\alpha) \le \infty$$

The Fig shows a simple transmission line network represented by its π equivalent circuit connected between buses i and j.

Let the complex voltages at buses i and j are Vi∠δi and Vj ∠δj respectively. The power flow, real and reactive between buses i to j can be written as

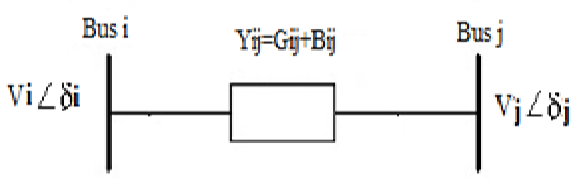

Fig 4.2 Model of transmission line without TCSC

$$Pi = |V| \sum_{k=1}^{n} |Vk|\,|Yik|(\delta i - \delta k) i = 2,3, \dots\dots n$$

$$Qi = -|Vi| \sum_{k=1, k\neq i}^{n} (|Vk||Yik| \cos(\delta i - \delta k)) + |Vi|^2|Yii|, i = 1,2, \dots\dots n$$

The figure shows the model of transmission line with TCSC connected in between the buses -i and -j. During steady state condition of system the TCSC can be viewed as a static reactance –jXc.

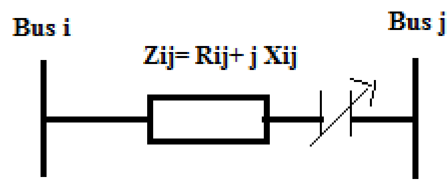

Fig 4.3 Model of transmission line with TCSC

The diagonal and off-diagonal elements of YBus represented in complex form, by the inclusion of - jXc , are represented as follows.

$$Yii = \sum_{q=1}^{N} 1/[j(Xij - vijxc(ij))]$$

$$Yij = -1/[rij + j(xij - vij * Xc(ij))]$$

Where vij is integer decision variable (0/1) vij is 1 for i-j with TCSC and zero elsewhere.

4.2 Optimal location of TCSC

Reduction of system reactive power loss.

In this paper the approach based on sensitivity of reactive power loss with regard to control variable of TCSC is implementing for best possible location of the device. For TCSC coupled between bus i and j the net series reactance of the line is viewed as as control parameter. Loss sensitivity in terms of control parameter of TCSC is scheduled as-

$$aij = \frac{dQ}{dxij} = \frac{\left[[Vi^2 + Vj^2 - 2ViVj\cos\delta ij][rij^2 - xij^2]\right]}{[rij^2 + xij^2]^2}$$

While the sensitivity indices resolved for TCSC, following criteria may be utilized to determine its optimal location:

With regard to reactive power loss elimination method, TCSC ought to be positioned in a line getting the most positive loss sensitivity index.

5. SIMULATION/EXPERIMENTAL RESULTS

The efficiency of the method is tested on IEEE4-bus system. The reactance of TCSC is considered to be 70% of series reactance of the line in which it would be placed.

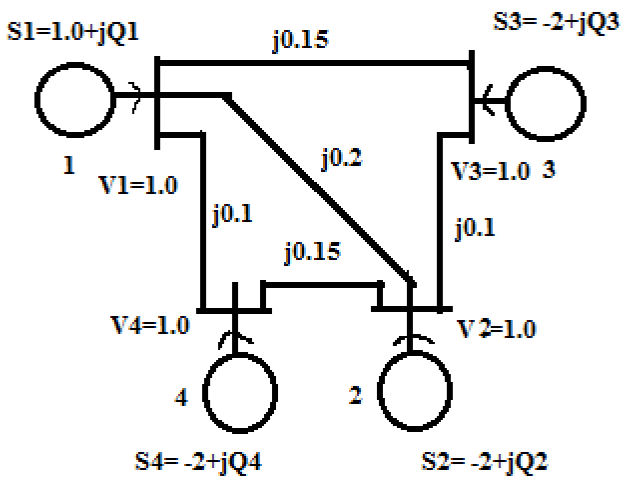

Fig 5.1 IEEE 4 bus test system

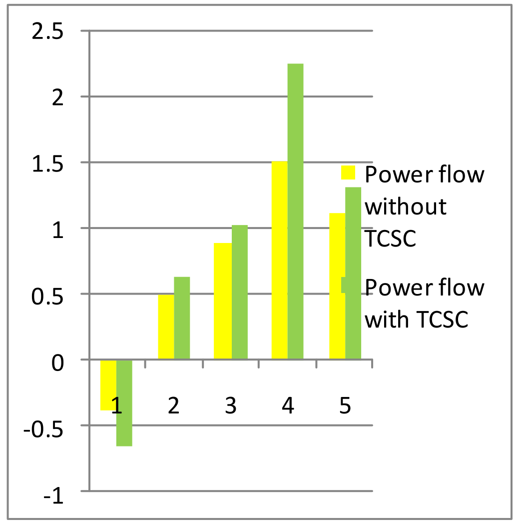

Fig 5.2 Power flow with and without TCSC

Table-1 Power Flow In 4 Bus System Without Tcsc

Line	From-To	Real Power Flow
1	1-2	0.385
2	1-3	0.492
3	1-4	0.891
4	2-3	1.50
5	2-4	1.1092

Table 2 Calculated sensitivity indices

Line	a_{ij}
1	**-0.148**
2	-0.242
3	-0.79
4	-2.26
5	-1.224

The real power flow through the line and sensitive of reactive power loss reduction have been calculated and so are shown in table 1 and table 2 respectively. The most sensitive line is highlighted in table-2. It can be seen from table -2 that line 1 is a lot more sensitive based on reduction of system reactive power loss method. Power flow of the system after positioning TCSC in line 1 is shown in table-3. The values are compared to those obtained without TCSC. The reactance of TCSC is considered as 70% of line reactance.

Table 3 Power flow after placing TCSC.

Line	Power flow without TCSC	Power flow with TCSC
1	-0.385	-0.66
2	0.492	0.632
3	0.891	1.027
4	1.50	2.242
5	1.1092	1.301

6. CONCLUSION

Congestion management is an very important issue in deregulated power systems. Simulations have proved that FACTS devices are powerful tool for congestion management. The application of FACTS devices enhances the line flow thus more power can be transmitted through same line. The results shown in this paper indicate that reactive power loss sensitivity index is effectively utilized for determining location of TCSC device. Simulations carried out on IEEE 4-bus and test system indicate that the proposed technique is effective at providing the optimal locations of TCSC device..

7. FUTURE SCOPES

This approach can be fully extended to other FACTS devices also as they possibly can transfer the approach from ‘preventive’ method demanding large standbys for emergency purpose into a ‘corrective’ method by making immediate corrections with much less flexible,manageable and controllable devices.

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