Voltage Stability Improvement using Thyristor Controlled Series Capacitor (TCSC) based on L_{mn} and VCPI Stability Indices

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Abstract - Reactive power control is the basic requirement for maintaining the voltage levels thereby the stability of the interconnected power system. Voltage variations can be stabilized and controlled by providing required reactive power. These low voltages may also reduce the power Transfer through the transmission lines and may lead to Instability Hence FACTS Controllers are widely used in Interconnected Power Systems to control the voltage levels within the tolerable limits. FACTS Controllers are used to enhance controllability and increase power transfer capability. Among the FACTS devices, the TCSC controller has given the best results in terms of performance and flexibility. An IEEE 9 bus system is programmed in MATLAB and assessed the voltage stability using L and VCPI Stability Indices. Finally the voltage stability has been improved using TCSC

Index Terms— **Keywords:** TCSC, Voltage Stability, L_{mn} -index, VCP Index, Voltage Stability Improvement. Minimum 7 keywords are mandatory, Keywords should closely reflect the topic and should optimally characterize the paper. Use about four key words or phrases in alphabetical order, separated by commas.

1 INTRODUCTION

Reactive power (vars) is required to maintain the voltage to deliver active power through transmission lines. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines. Many devices contribute to systems reactive power and voltage profile. Example: Capacitors supply reactive power, inductors absorb reactive power.

Voltage stability is required for the perfect functioning of the system; compensating devices are required for the compensation purposes.

1.1 Reactive power

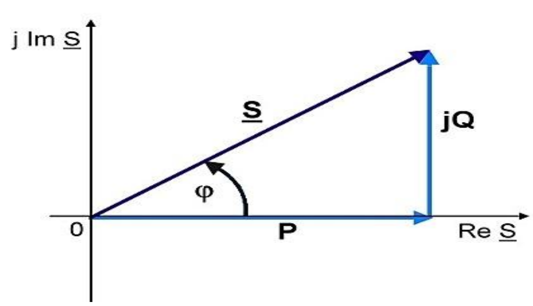

Fig 1. Power Triangle

The figure.1 represents the general phasor diagram showing active power (P) reactive power (Q) where as S represents the apparent power. Reactive power does not transfer energy, so it is represented as the imaginary axis of the vector diagram. Real power moves energy, so it is the real axis.

1.2 Significance of Reactive power

Many devices contribute to reactive power compensation and voltage profile. A transmission line, due to its physical characteristics, supplies reactive power under light loading and consumes it under heavy loading conditions. Power system voltages are controlled through the supply and consumption of reactive power. In general terms, decreasing reactive power margin causes voltage fall, while increasing reactive power margin causes voltage rise. A voltage collapse occurs when the system is trying to serve much more load than the voltage can support.

To maintain efficient transmission and distribution, it is necessary to improve the reactive power balance in a system by controlling the production, absorption, and flow of reactive power at all levels in the system.

1.2 Dependency of Voltage on Reactive Power varitions

1.

The Reactive power in a power system has a great deal of impact on the voltage that is prevailing in the system. By compensating the reactive power the voltage profile in the whole power system can be greatly improved which finally leads to the overall improvement of the efficiency and also the power factor of the power system.

For a simple radial Transmission line the relation between receiving end bus voltage is given by, $V_2 = V_1 * Q X / V_1$.In order to keep the receiving end voltage V_2 fixed for a particular sending end voltage V_1, the drop $(Q X / V_1)$ must remain constant.

- Voltage variations are mostly dependent on reactive power variations
- So, to keep the receiving end voltage constant for constant sending end voltage any deviation of Q must be adjusted locally or by remote control.
- Hence reactive power control is required to maintain the voltage within the acceptable limits.

2 Voltge Instability

Voltage instability is basically caused by an unavailability of reactive power support in an area of the network, where the voltage drops uncontrollable. Lack of reactive power may essentially have two origins: firstly, a gradual increase of power demands without the reactive part being met in some buses or secondly, a sudden change in the network topology redirecting the power flows in such a way that the required reactive power cannot be delivered to some buses. Introducing FACTS devices is the most effective way for utilities to improve the voltage profile and voltage stability margin of the system.

Many power system blackouts all over the world have been reported where the reason for the blackout has been voltage instability.

1) WSCC USA July 2 1996: A short-circuits on a 345 kV line started a chain of events leading to a break-up of the western North American power system. The final reason for the break-up was rapid overload/voltage collapse/angular instability.

2) Florida USA 1985: A brush fire caused the tripping of three 500 kV lines and resulted in voltage collapse in a few seconds.

3 Voltge stability Indices

The purpose of voltage stability indices is to determine the point of voltage instability, the weakest bus in the system and the critical line referred to a bus. These indices are referred either to a bus or a line.

3.1 Line stability Index *Lmn*

This stability criterion is used to find the stability index for each line connected between two bus bars in an interconnected network. This voltage stability criterion is based on a power transmission concept in a single line. Stability criterion is developed considering a single line of a network.

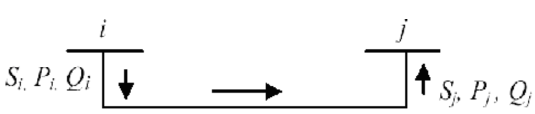

Fig 2. Single Line Diagram of Two Bus Test System

$$L_{mn} = 4XQ_j / [V_i \, \mathrm{Sin}(\theta-\delta)]^2 \quad (1)$$

θ = line impedance angle
δ= angle difference between the sending end and the receiving end voltage
X = line reactance
Qj = reactive power flow at the receiving end
Vi = sending end voltage.

The system is said to be stable, in the sense of transmission lines, as long as Lmn remains much less than 1; and approaches 1 towards the point of bifurcation. The most critical line connecting the weak buses in the system can be easily identified from the value of Lmn closest to 1

3.2 Line stability Index VCPI

The VCPI investigates the stability of each line of the system and they are based on the concept of maximum power transferred through a line.

$$\mathrm{VCPI} = P_r / P_{rmax} \quad (2)$$

where the values of P_R e Q_R are obtained from conventional power flows calculations, and $P_R(max)$ and $Q_R(max)$ are the maximum active and reactive power that can be transfered through a line.The VCPI indices varies from 0 (no load condition) to 1 (voltage collapse).

4 Flexible A.C. Transmission System

A Flexible Alternating Current Transmission System (FACTS) is a system comprised of static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. It is generally a power electronics based device

FACTS devices are defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability .FACTS could be connected:

- in series with the power system (series compensation)
- in shunt with the power system (shunt compensation)
- both in series and in shunt with the power system

4.1 Series Compensation

In series compensation, the FACTS are connected in series with the power system. It works as a controllable voltage source

Examples of FACTS for series compensation

Static Synchronous Series Compensator, Thyristor Controlled Series Capacitor, Thyristor Controlled Series Reactor (TCSR), Thyristor Switched Series Capacitor (TSSC), Thyristor Switched Series Reactor (TSSR.

Advantages of FACTS:

ISSN 2229-5518

- It increases the loading capability of the lines to their thermal capability. Overcoming their limitations and sharing of power among lines can accomplish this.
- Provides greater flexibility in sitting new generation.
- FACTS devices improve the speed of operation of the overall system
- It improves the stability of the system and thus makes the system secure

5 Thyristor Controlled Series Capacitor (TCSC)

The basic conceptual TCSC module comprises a series capacitor, C, in parallel with a thyristor-controlled reactor, L_s, as shown in Fig(a). However, a practical TCSC module also includes protective equipment normally installed with series capacitors.

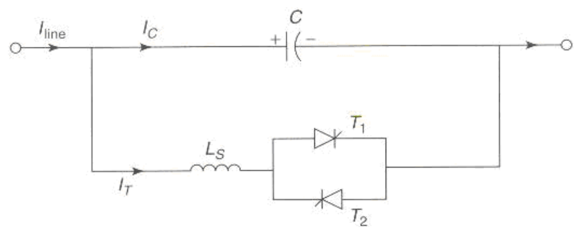

Fig 3. TCSC

Also installed across the capacitor is a circuit breaker, CB, for controlling its insertion in the line. In addition, the CB bypasses the capacitor if severe fault or equipment-malfunction events occur. A current-limiting inductor, L_d is incorporated in the circuit to restrict both the magnitude and the frequency of the capacitor current during the capacitor-bypass operation .A TCSC is a series-controlled capacitive reactance that can provide continuous control of power on the ac line over a wide range.

$$Z_{eq}= -j/[\omega C-(1/\omega L)] \qquad (3)$$

If $\omega C - (l/\omega L) > 0$,the reactance of the FC is less than that of the parallel-connected variable reactor and that this combination provides a variable-capacitive reactance are both implied
If $\omega C - (1/\omega L) = 0$, a resonance develops that results in an infinite-capacitive impedance-an obviously unacceptable condition. If, however, $\omega C - (1/\omega L) < 0$, the LC combination provides inductance above the value of the fixed inductor. This situation corresponds to the inductive mode of the TCSC operation.
The behaviour of the TCSC is similar to that of the parallel LC combination. The difference is that the LC-combination analysis is based on the presence of pure sinusoidal voltage and current in the circuit, whereas in the TCSC, because of the voltage and current in the FC and thyristor-controlled reactor (TCR) are not sinusoidal because of thyristor switching.

6 Improvement of System Stability Limit Using TCSC

It is advantageous to install a TCSC in transmission paths, which can adapt its series-compensation level to the instantaneous system requirements and provide a lower loss alternative to fixed-series compensation.
The series compensation provided by the TCSC can be adjusted rapidly ensure specified magnitudes of power flow along designated transmission line This condition is evident from the TCSC's efficiency, that is, ability to change its power flow as a function of its capacitive-reactance setting:

$$P_{12}= (V_1V_2/X_L-X_C) \sin\delta \qquad (4)$$

Where P_{12} = the power flow from bus 1 to bus 2 and V_1, V_2 are the voltage magnitudes of buses I and 2, respectively
X_L is the line-inductive reactance
Xc is the controlled TCSC reactance combined with fixed-series capacitive Reactance, δ= the difference in the voltage angles of buses 1 and 2.
This change in transmitted power is further accomplished with minimal influence on the voltage of interconnecting buses, as it introduces voltage in quadrature. The freedom to locate a TCSC almost anywhere in line is a significant advantage

6.1 Advantages of TCSC

Use of thyristor control in series capacitors potentially offers the following little-mentioned advantages:

- Rapid, continuous control of the transmission-line series-compensation level.
- Dynamic control of power flow in selected transmission lines within the network to enable optimal power-flow conditions and prevent the loop flow of power.
- Damping of the power swings from local and inter-area oscillations.

7 IEEE-Nine Bus Test System

9 bus system is there as above given figure.4 it contains 9 buses, load, Generators. As per the project undertaken before, TCSC has been placed in the system to improve the voltage stability. The process undertaken for it is the GS method using the matlab simulation.

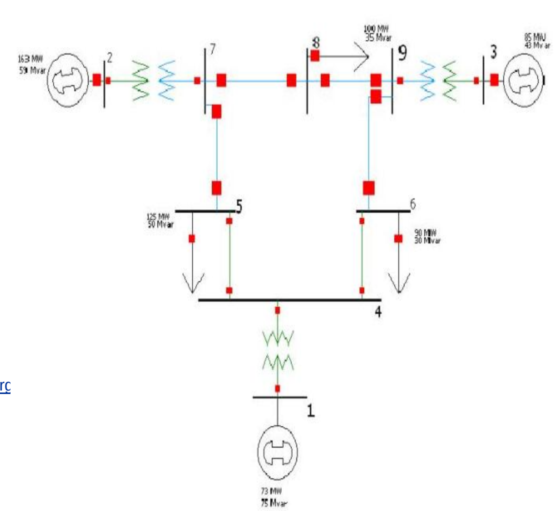

Fig 4. IEEE 9-Bus Test System

The results have been shown with the stability indices and the results are shown as below.

8 Case Study: Results

Table 1 shows the Bus voltages of IEEE 9-Bus Test system with and without TCSC. Similarly Table.2 and Table 3 Shows the values of Lmn and VCPI Indices respectively.

Table 1: Bus Voltages Without and With TCSC

S.No	Bus Voltage	Bus Voltage Without TCSC in P.U	Bus Voltage With TCSC in P.U
1	V1	1.04	1.04
2	V2	1.018	1.019
3	V3	1.012	1.013
4	V4	1.003	1.004
5	V5	0.969	0.971
6	V6	0.982	0.984
7	V7	1.004	1.006
8	V8	0.866	0.937
9	V9	1.006	1.008

Table 2: Line Stability Index Without and With TCSC

S.No	Line Stability Index (L_{mn})	L_{mn} Without TCSC	L_{mn} With TCSC
1	1-4	0.1374	0.1374
2	4-5	0.1098	0.1098
3	4-6	0.0455	0.0455
4	3-9	0.0306	0.0306
5	2-7	0.1062	0.1062
6	7-8	0.5576	0.5576
7	7-5	0.0972	0.0972
8	8-9	0.5530	0.1055
9	9-6	0.0545	0.0545

Table 3: VCP Index Without and With TCSC

S.No	Line Stability Index (L_{mn})	VCPI Without TCSC	VCPI With TCSC
1	1-4	0.148	0.13
2	4-5	0.11	0.1
3	4-6	0.05	0.04
4	3-9	0.04	0.03
5	2-7	0.12	0.11
6	7-8	0.58	0.56
7	7-5	0.14	0.09
8	8-9	0.6	0.11
9	9-6	0.09	0.05

8 Conclustions

This paper shows the effect of TCSC on the Voltage stability Improvement. The voltages, Lmn and VCPI Indices with and without TCSC have been recorded. The results show that the voltage profile is better with TCSC and Lmn and VCPI Indices have been improved tremondesly to improve the stability.

References

1. N.G. Hingorani and L. Gyugyi, Understanding FACTS, IEEE Press, New York, USA, 1999
2. R.M. Mathur and R.K. Varma, Thyristor-Based FACTS Controllers for Electrical Transmission Systems, IEEE Press and Wiley Inters-cience, New York, USA, Feb. 2002.
3. D M Tagare, Reactive Power Management, McGraw-Hill Publica-tion, India,1982.
4. IEEE Power Engg. Society/CIGRE, "FACTS Overview", Publication 95 TP 108, IEEE Press, New York, 1995.
5. P. Kundur, Power System Stability and Control, McGraw-Hill, Inc., New York, 1994.
6. IEEE Power Engineering Society, "FACTS Applications", Publication 96 TP 116-0, IEEE Press, New York, 1996
7. W.A.Lyon, Transient Analysis of Alternating–Current Machinery, Chapter 2, John Wiley, New York, 1954.
8. D.Irwin, Basic Engineering Circuit Analysis. 4th Ed., Mac-milan , New York 1993.
9. Jack R. Smith , Programming the PIC *microcontroller*. , McGraw-Hill Publication, India, 2005.
10. A.Mohamed, G.B.Jasmon, S.Yusoff "A Static Voltage Collapse Indi- cator using Line Stability Factors" Journal of Industrial Technology, Vol.7, N1, pp. 73-85, 1989
11. P.Kessel, H.Glavitsch "Estimating *the* Voltage Stability of a Power System" IEEE, Transactions on Power Delivery, Vol.PWRD-1, N3, July 1986

Acknowledgements

We are immensely thankful to Management and Principal of VNR VJIET for providing R&D lab and other facilities to carryout this work.

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