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P-V Curve Method for Voltage Stability and Power Margin Studies

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Abstract:
This paper presents improvement of voltage stability and power margin using Thyristor Controlled Series compensator (TCSC). P-V curves are used to assess the voltage security and to compute the real power margin. The process of P-V analysis involves using a series of load flow solutions for incremental power transfers at constant power factor to obtain the voltage to MW transfer relationship.

Keywords: Voltage stability, Power margin, Thyristor Controlled Series Compensator (TCSC), P-V curves, Q-V curves

I. INTRODUCTION

Electric power supply systems are interconnected for various economical reasons like reducing the cost and also to improve the reliability of the system. But this increases the system complexity and may further lead to system collapse due to major outages. The increases in load demand and bulk power transfer between the utilities are the major reasons for the voltage collapse and disturbances in the system. Voltage instability is caused by reactive power imbalance. If there is inadequate reactive power support the system reaches to Maximum loading point leading to voltage collapse. At this point real and reactive power losses increase rapidly [1]. Different types of FACTS devices are used for reactive power compensation. Optimal location of FACTS device will solve voltage instability problem and also increase the loadable margin [2]. Voltage stability of a system can be assessed using P-V and Q-V curves [4,5]. The margins of real and reactive power are computed using these curves. Initially NR method is used to solve the load flow problem to obtain the base case values. Candidate buses are chosen to plot the P-V curves with incremental change of real power and Q-V curves are plotted with incremental change in reactive power. In this paper an effort is made to depict the effect of series compensation on P-V curves and loadable margin of a system.

II. VOLTAGE STABILITY, P-V AND Q-V CURVES:

A power system can be represented by a circuit model with a group of generators acting as source and loads acting as sink. The real power transfer between the source and sink is incremented to obtain P-V curves. The voltage at a particular bus is influenced by the real power transferred, reactance of the line and power factor of the load. As the load is increased voltage decreases and reaches a nose point, any further increase in load causes instability of the system. Consider a simple system consisting of source with voltage $E\angle 0$ and load at voltage $V\angle\delta$ fed by an infinite bus transmission system. Neglecting the transmission line resistance real and reactive powers are given by the equations 1 and 2

$$P = \frac{EV}{X} Sin\delta \tag{1}$$

$$Q = \frac{EV}{X} Cos\delta - \frac{V^2}{X} \tag{2}$$

P-V curves show the relationship between the load in MW in a particular area and the bus voltage for different power factors (where $\tan\phi = \frac{Q}{P}$) as the load angle is not considered for this study it can be eliminated.

Let $p = \frac{PX}{E^2}$, $q = \frac{QX}{E^2}$ and $v = \frac{V}{E}$

Normalizing the equations 1 and 2 based on the short circuit power

$$S = \frac{E^2}{X}$$

We obtain

$$p = vSin\delta \tag{3}$$

$$q = vCos\delta - v^2 \tag{4}$$

Load angle δ can be eliminated

By assuming resistive load i.e $\tan\phi = \frac{Q}{P} = 0$ as $Q = 0$

Using identity $v^2 = v^2Cos^2\delta + v^2Sin^2\delta$

$$vSin\delta = \sqrt{v^2 - v^2Cos^2\delta}$$

From transform equation (3) and (4)

$p = vSin\delta = \sqrt{v^2 - v^2Cos^2\delta}$ and $q = vCos\delta - v^2$

$$p = \sqrt{v^2 - (q + v^2)^2} \tag{5}$$

Because $Q = 0; q = \frac{QX}{E^2} = 0$

$$p = \sqrt{v^2 - v^4} \tag{6}$$

The above relationship is used to plot p-v curve as shown in Figure 1

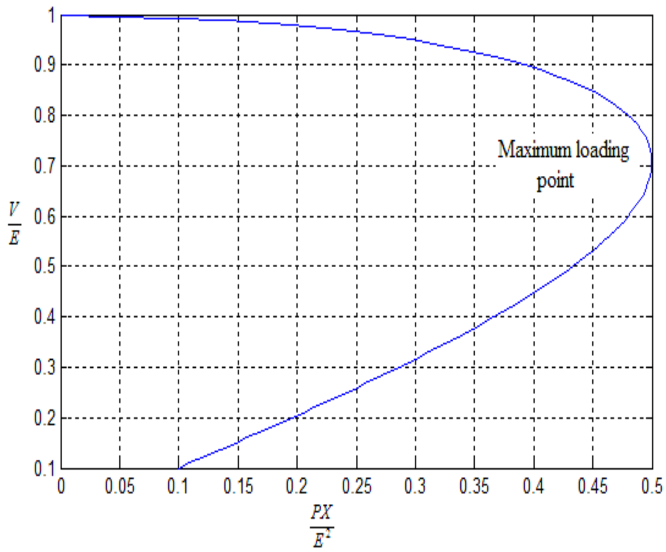

Figure.1. P-V Curve

III. EFFECT OF SERIES COMPENSATION ON VOLTAGE STABILITY AND LOADABLE MARGIN

Voltage stability can be improved and loadable margin can be enhanced with the help of Flexible AC Transmission System (FACTS) devices [3]. These solid state converters are capable of improving available transfer capability, voltage profile, enhancement of power system stability, reducing reactive power losses in a system. Various types of FACTS devices are Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Compensator (TCSC), Static Synchronous Series Compensator (SSSC) Thyristor Controlled Series Compensator (TCSC) is used for reactive power compensation and they are connected in series with the transmission line. The circuit model of TCSC is shown in Figure 2.

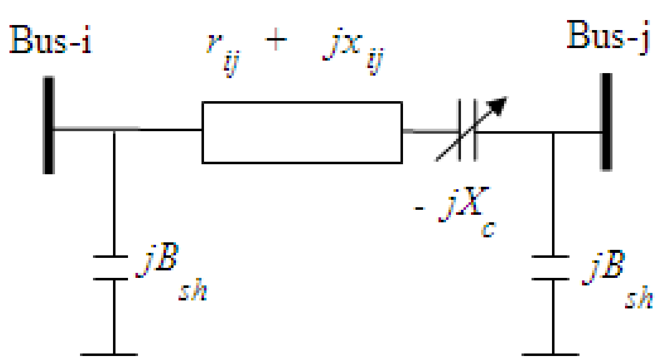

Figure.2. Static model of tcsc

IV. RESULTS AND DISCUSSION

The effect of series compensation on PV curves, loadable margin and reactive power losses is illustrated by considering a 7 bus system as shown in figure. The system includes one slack bus, 4 generator buses and 6 loads. Base case load flow analysis has been done by NR method to obtain the bus voltages, line flows, real and reactive power losses[6].

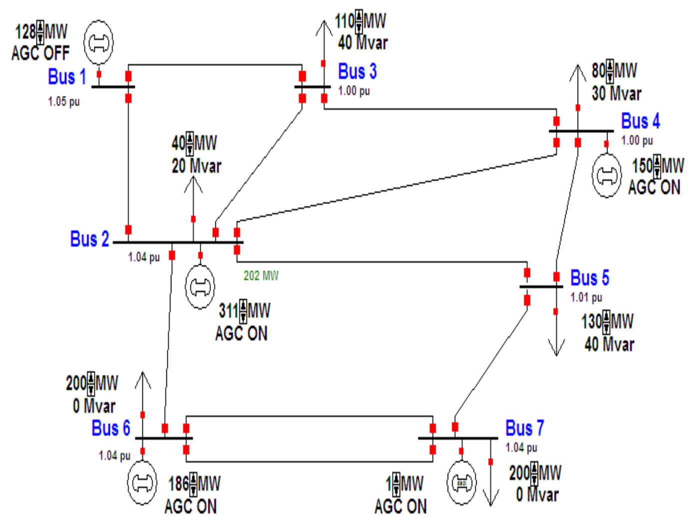

Figure.3. 7-bus system

V. POWER – VOLTAGE (P-V) CURVES

The process of obtaining P-V Curves involves a series of load flow solutions by increasing the real power (MW) transfer from source to sink and as a result variation of voltage at different buses is monitored. As the relation between P and V is non-linear, it involves the full power flow solution. In this proposed work all the generator buses except slack bus are considered as source and all the loads are considered as sink. The real power transfer is incremented as at constant power factor and the bus voltages are monitored. Curves are plotted for bus 3 and Bus 5 as shown in figure and these are considered to be the most critical buses. It can be observed that the voltage decreases rapidly at Knee point which is the indicative of instability. This nose point or knee point indicates the stability limit and power system should never be operated near stability limit as it may lead to large scale black out. Sufficient power margin should be allowed for satisfactory operation of system.

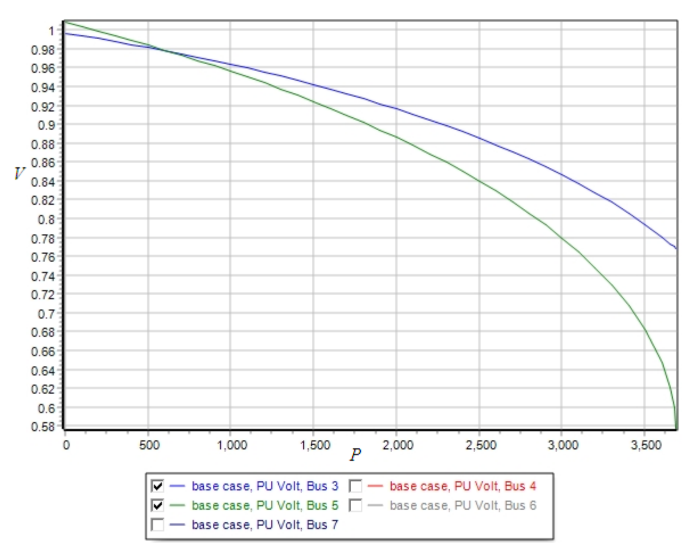

Figure.4. Voltage profile at bus 3 and bus 5

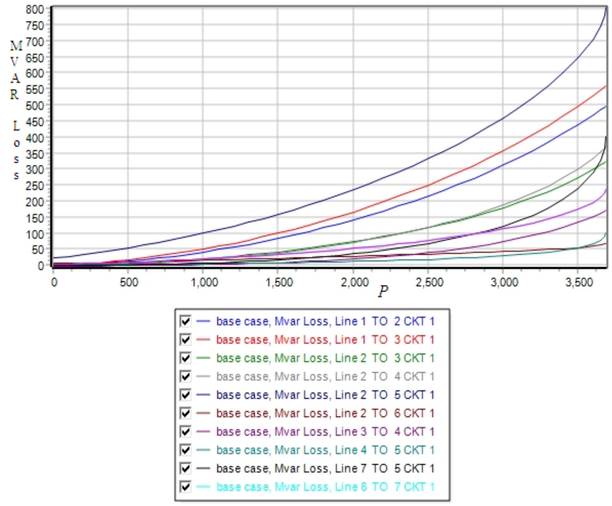

Figure.5. Mvar loss – power transfer curve

It is observed that by using series compensation the power margin has increased as shown in figure5

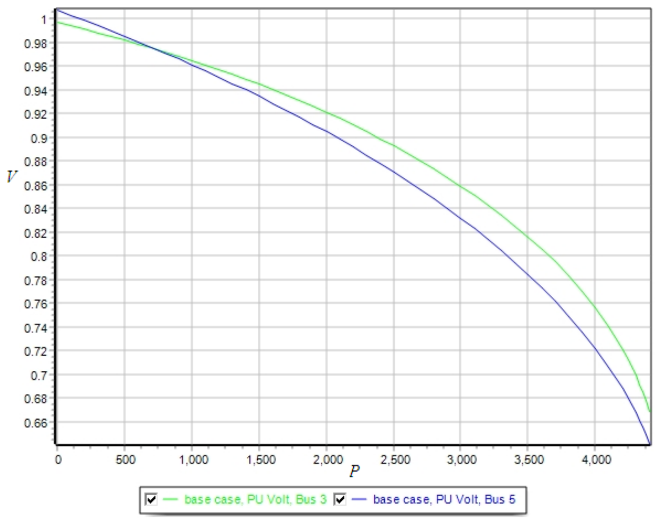

Figure.6. Voltage profile at bus 3 and bus 5 with TCSC

The real and reactive power increase rapidly at the knee point as shown in figure 5

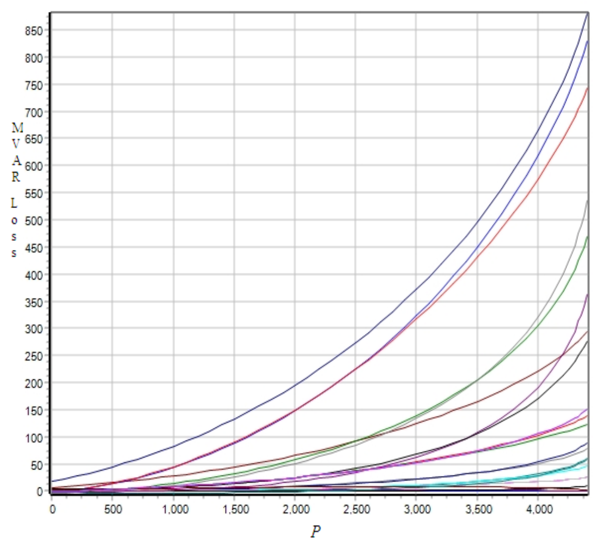

Figure .7. MVAR loss – power transfer curve with TCSC

The reduction in reactive power loss with TCSC for 0.5X is illustrated in Figure 7.

Table.1. Comparision of losses and power margin with and without TCSC

	Without TCSC	With TCSC
Load (MW)	760	760
Load(MVAR)	130	130
Generation (MW)	773.8	774.7
Generation (MVAR)	163	145.5
MW Losses	13.9	14.8
MVAR Losses	33	15.5
Power Margin (MW)	3750	4750

The increase in power margin with TCSC is shown in Table I. It is observed that there is substantial decrease in reactive power loss with marginal increase in real power loss.

VI. CONCLUSIONS:

The non-linear relationship between Real Power and Voltage is used to obtain the P-V curves of a 7-bus system. These curves are useful to find power margin from the base operating point. The effect of series compensation on power margin and reactive power losses are demonstrated using static model of TCSC. P-V and Q-V curves are effective tools for studying voltage stability and power margin. It is found that reactive power compensation is the most effective way to improve voltage profile and power margin.

VII. REFERENCES

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