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VAR Management to Improve Maximum Loading In IEEE 30 Bus System Using FACTS Controllers

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Abstract
The maximum loading of the transmission lines depends upon various limits. These are related to the environmental conditions, length of the line and various stability related issues. The VAR plays important role in maximising the power transfer through a transmission line. The FACTS Controllers have a major part to play in the VAR Management, in order to increase the maximum loading capability. This gives an additional benefit of enhancing the voltage stability margin of the entire system as well. In this paper this aspect of VAR Management, is investigated for an IEEE 30 Bus Test System incorporating various FACTS Controllers like TCSC, STATCOM and SVC.
Keywords: - VAR, Loadability, Voltage Stability, FACTS, SVC, STATCOM

I. Introduction

The maximum power that can be transferred over a transmission line has a limit defined by thermal limit for very short lines and the angle or voltage stability limit for a medium or long line. The angle stability aspect is related to the difference in the phase angles of sending and receiving end voltages for a transmission line. The voltage stability is related to the magnitude part of the voltage phasor on the receiving end keeping the sending voltage at a fixed value. The reactance of the transmission line decides a drop or rise in the transmission line receiving end voltage. For medium length line the inductive reactance of the line becomes predominant, absorbing the reactive part of the power, whereas the capacitive reactance contributes to surplus reactive power as the length of the line increases. There for the management of the reactive power becomes a matter of utmost importance in order to increase the power carrying capacity of the line. The need of the reactive power desired by the transmission system can be met by the generator itself but it has got a limit imposed by the capability curves for a particular generator.

The option we are left with is either we have a separate synchronous machine reserved as a reactive power generator or the production of reactive power outside the main generator. This can be achieved by connecting the capacitors or inductors in series, parallel or both as per requirement. The idea should be that the reactive power can be produced and controlled in the desired manner. The system at an instant may require the leading VARs or may be in a condition of VAR surplus where the absorption of reactive power is necessary. The mechanical switching of capacitor and inductors in steps can be a feasible solution, but the smooth control cannot be guaranteed. The maintenance need is another drawback of such control of reactive power in addition to the stepped control depending upon the minimum size of the capacitor or inductor used. The power electronics provide a fast and reliable switching to facilitate smooth control of the reactive power. The maintenance requirements are reduced considerably as a result. There are various power electronics based FACTS controllers such as TCSC, SVC, and STATCOM etc. which are used in order to control the flow of active and reactive power through the transmission line.

Various researchers have worked on the subject of voltage stability. Galina et al. [1] have investigated the problem of voltage collapse and determination of voltage stability margin without relying on load flow solution. The convergence problem in the load flow has been a problem in the assessment of voltage stability margin. The feasibility region for load flow and the margin in terms of an index FM is proposed.

The problem of convergence was addressed by Ajjarapu et al. [2] who proposed a method based on predictor corrector scheme for the load flow analysis which is capable to draw the complete P-V curve.

The absorption or delivery of the reactive power can be effectively controlled by FACTS devices. These controllers not only improve the reactive power flow, but the entire power system operation as a whole can be effectively controlled by them. The active and reactive power flows and even phases of voltages and currents can also be favourably altered by using FACTS [3].

II. Continuation Power Flow Method

The problem of singularity of Jacobian Matrix can be avoided by the method of Continuation

Power Flow. It involves the reformulation of the load flow equations, to include a load parameter λ, so that the divergence and the error due to singular Jacobian are not encountered. It employs the predictor corrector method to find the solution of the non linear differential equations.
Let λ be the load parameter such that

$$0 \leq \quad \lambda \leq \quad \lambda_{critical}$$

Where λ= 0 corresponds to the base load and λ = $\lambda_{critical}$ corresponds to the critical load.
For an n bus system, if $V_i \angle\delta_i$ *and* $V_j \angle\delta_j$ are the voltages at bus i and bus j respectively. The variable $y_{ij} \angle\gamma_{ij}$ is the (i, j) th element of Y bus matrix, then for any bus i,

$$P_{Gi} - P_{Li} - P_{Ti} = 0, \quad P_{Ti} = \sum_{j=1}^{n} V_i V_j \, y_{ij} \cos(\delta_i - \delta_i - \gamma_i) \quad ...(1)$$

$$Q_{Gi} - Q_{Li} - Q_{Ti} = 0, \quad Q_{Ti} = \sum_{j=1}^{n} V_i V_j \, y_{ij} \sin(\delta_i - \delta_i - \gamma_i) \quad ...(2)$$

Where the P, Q terms with subscripts with G, L and T represents the real and reactive power Generation, Load and the Injection. The load change can be simulated as a two component where first component represents the original load at bus i and the other component brought about by a load parameter λ.

$$P_{Li} = P_{Lio}(1 + \lambda) \quad ...(3)$$

$$Q_{Li} = P_{Lio}(1 + \lambda) \quad ...(4)$$

The value of load parameter λ, in this case, gives an idea about the distance from the point of collapse or in other words the loadability margin of the system without any kind of voltage collapse. In fact the value of λ can fairly indicate the improvement in loadablity conditions of the system as a whole.

In this paper only system with FACTS controllers are investigated in terms of improvement in the maximum value of λ which is actually $\lambda_{critical}$. Only the shunt and series connected FACTS controllers are investigated here for the loadability improvement. The IEEE 30 bus test system shown in fig.1 is selected for study. The test system is taken without any FACTS controller is considered and the loadability of the system is studied in terms of the maximum loading parameter **λ**.

Various FACTS controllers are selected and placed at different load buses to investigate their effect on loadablity of the system which is compared in terms of the change in the value of maximum loading parameter **λ**. The SVC, STATCOM and TCSC are selected for this analysis. The TCSC controller is selected first and the loadability is checked with the locations decided with the help of weak node analysis based upon power flow data.

The PSAT model for standard IEEE 30 bus system is made with the line and bus data available. These data gives the base load condition for the load flow analysis. This model is also known as the Base model for the purpose of analysis. Continuous power flow method is used for the purpose of load flow calculations.

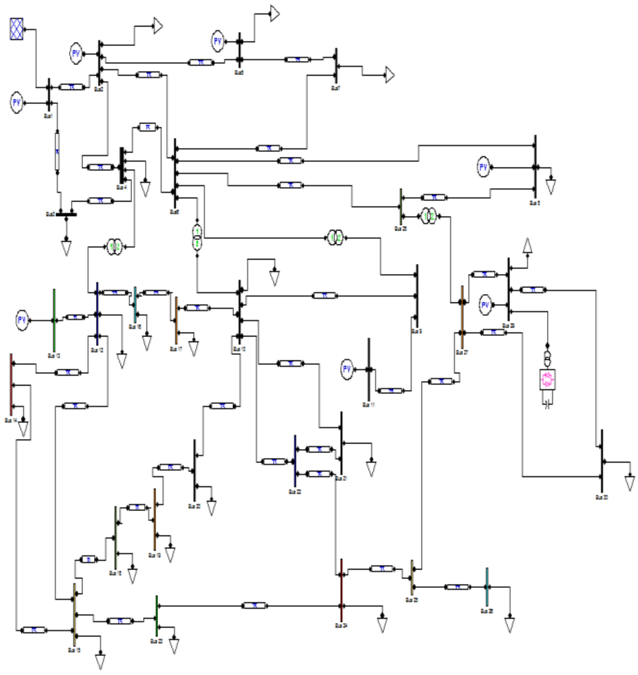

Fig.1. PSAT model for IEEE 30 bus Test System

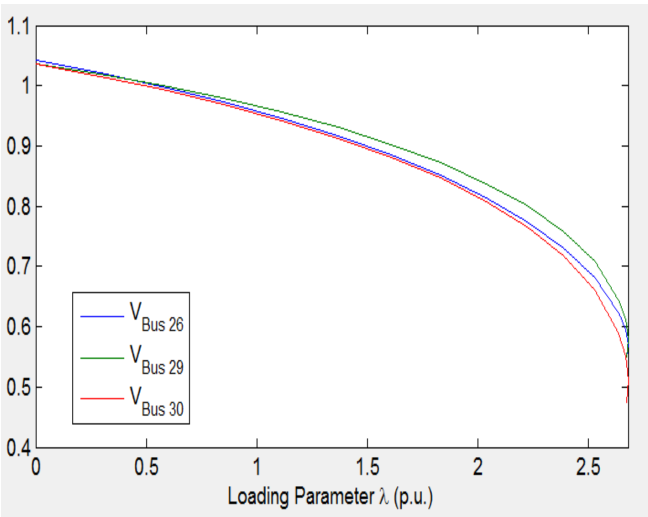

Fig.2. PV curves for test system without any FACTS controller

The study of other FACTS controllers like SVC and STATCOM is done for all the load buses. These are fixed at various load buses and the maximum loading condition is determined using the CPF method of load flow by comparing the value of maximum loading parameter **λ**. These values are tabulated in Table No. 1 and 2.
The various cases are discussed in detail as follows.

Case I: Base load conditions: -

The PSAT model for IEEE 30 bus system with base load conditions is shown in Fig.1. The CPF method is used for the purpose of analysis. The loading parameter **λ** is taken as a tool to compare the loadability of system. The PV curves are also shown in Fig. 2 for weakest and next two weaker buses for the purpose of comparison. The maximum value of loading parameter λ recorded without any kind of reactive power support through a FACTS controller as 2.681.

Case II: With TCSC between Bus 27 and Bus 30.

The second case is taken with TCSC controller fixed to the base model. The Weakest and weaker buses are identified by using PSAT model of the system and power flow data of CPF method. These are the buses which constitute the area where the reactive power flow is essentially to be controlled. The Buses 27, 29 and 30 are selected as candidate buses. TCSC is fixed between bus no. 29 and 30 as a first study and bus no. 27 and 30 as another case. Table no.1 depicts the values of loading parameters for the basic model and then for the cases with TCSC controllers. Best results are obtained when the TCSC is connected between bus no. 27 and bus no. 30.

Sr. No.	Model Type	Maximum Loading Parameter (λ)
1	Basic Model	2.681
2	With TCSC between Bus 29 and Bus 30	2.7621
3	With TCSC between Bus 27 and Bus 30	2.9076

Table.1 Lodability margin in terms of maximum loading parameter λ for Base model and for TCSC.

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Sr. No.	Load bus No.	Max. Loading Parameter (λ)	
		With SVC	With STATCOM
1	3	2.7128	2.7327
2	4	2.7323	2.7251
3	7	2.7012	2.7095
4	10	3.0282	2.9687
5	12	2.8065	2.8527
6	14	2.8016	2.8152
7	15	2.9124	2.9529
8	16	2.8385	2.8604
9	17	2.943	2.9814
10	18	2.8785	2.896
11	19	2.8982	2.917
12	20	2.9085	2.9299
13	21	3.0883	3.0088
14	23	2.9703	3.0025
15	24	3.253	3.084
16	26	3.0151	3.0192
17	29	3.0999	3.0994
18	30	3.0859	3.0925

Table.2 Lodability margin in terms of maximum loading parameter λ for Models with SVC and STATCOM.

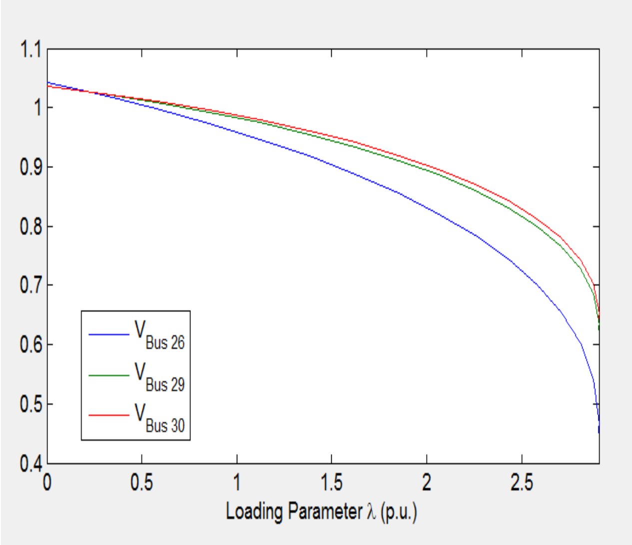

Fig.3. PV curves for test system with TCSC between Bus no. 27 and Bus no.30.

PV curves are also shown in Fig.3 for this case for the weakest and then weakest buses for comparison. The maximum value of loading parameter λ recorded here is 2.9076.

Case III: The SVC Connected at Bus No. 29: -

The various models for test systems were made with SVC placed at various load buses. The results show that the maximum improvement in the loading conditions of the system occurs when SVC is connected at bus no. 29. The PV curves for the same are plotted in fig. 4. It shows considerable improvement in the voltage levels not only for bus no. 29 but also for bus no. 30. The maximum value of loading parameter λ recorded as 3.0999 with SVC at bus no. 29.

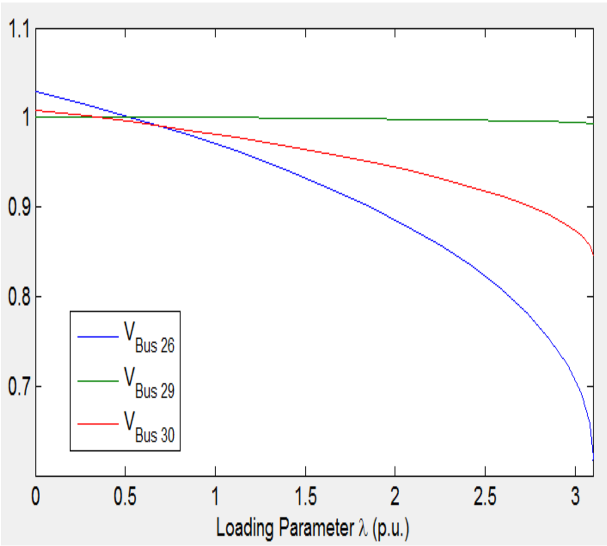

Fig.4. PV curves for test system with SVC fixed at Bus no. 29.

Case IV: With STATCOM Connected at bus 29:-

The STATCOM controller is also tested for the margin improvement. The controllers are placed at various load buses and the values of parameter ⌊ are recorded. The results show that the maximum value occurs for the model with STATCOM placed at bus no. 29. PV curves for the same are also shown in Fig.5. These curves show the considerable improvement in bus voltages for Bus no. 29 and 30. The maximum value of loading parameter λ recorded as 3.0994 with STATCOM at bus no. 29.

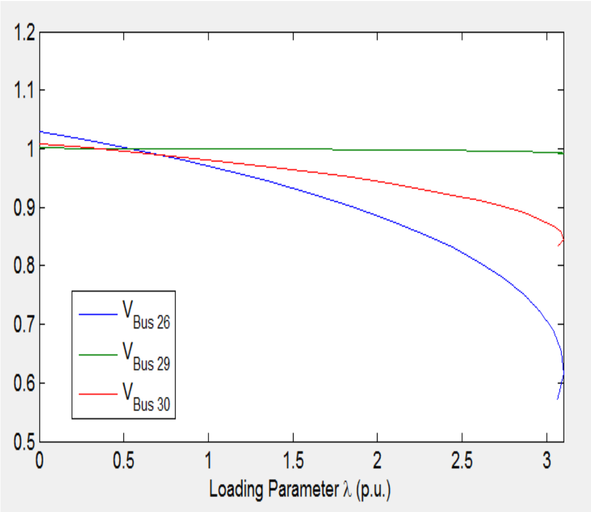

Fig.5. PV curves for test system with STATCOM fixed at Bus no. 29.

Case V: With STATCOM at Bus No.29 and SVC at Bus No. 30:-

As another case study, the STATCOM and SVC together are taken at different buses and the improvement in the voltages of buses is estimated. The candidate bus for STATCOM is Bus No. 29 and for SVC bus no. 30 is selected. The system is simulated and tested here without any consideration for the feasibility or economic aspects.

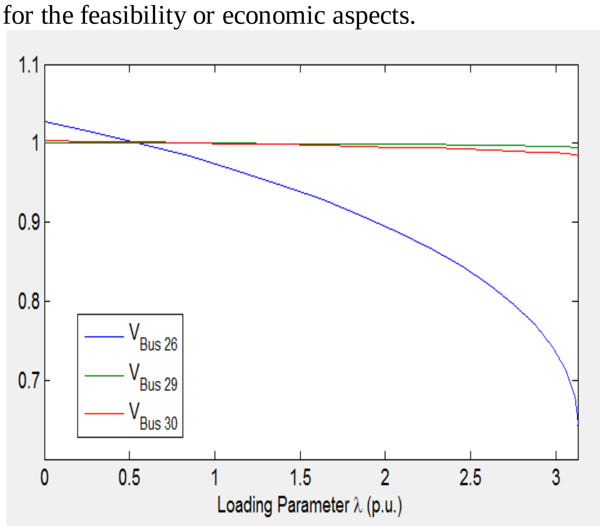

Fig.6. PV curves for test system with STATCOM fixed at bus no. 29 and SVC fixed at Bus no. 30.

The PV curves are also plotted for the same and Fig.6. These curves clearly show the considerable improvement not only in loadability of the system but also the bus voltages are improved as a result. The maximum value of loading parameter recorded here is 3.1293.

III. Conclusion

With the increasing demand of power and slow progress on the front of installation of various types of power plants has forced power system engineers to find out means and ways to increase the loadability of transmission lines. Various researches have been undertaken to improve the maximum loading capacity of the transmission lines. In this paper IEEE 30 bus system with various FACTS controllers is investigated for the loadability margin improvement. It has been observed that the considerable improvement is achieved with various controllers placed at suitable locations. It is seen that there is an improvement in the value of loading parameter with TCSC alone, but further improvement is achieved if we use SVC or TCSC. There is not much difference in the loadability parameter improvement due to SVC and STATCOM but the voltages of system with SVC are better. The maximum values of loadability parameter are achieved with both SVC and STATCOM fixed at bus no. 29 and 30 respectively. Although the study promises a considerable improvement in the loadablity of the system as a whole with FACTS, but this investigation does not consider any feasibility aspect or any kind of economic considerations involved in the installations of the FACTS controllers. Further to note that only series and shunt connected FACTS controllers like TCSC, SVC and STATCOM are considered for the study. Although the research can be extended to a series of various controllers, which have been recently invented following the advances in the FACTS technology, which combine the benefits of most of them.

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