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EFFECTIVE LOCATION OF THYRISTOR CONTROLLED PHASE ANGLE REGULATOR (TC-PAR) FOR CONGESTION MANAGEMENT

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Abstract - FACTS is one aspect of the power electronics revolution that is taking place in all areas of electric energy. FACTS devices can be an alternative to reduce the flows in heavily loaded lines, resulting in an increased loadability, low system loss, improved stability of the network, reduced cost of production and fulfilled contractual requirement by controlling the power flows in the network. This paper investigates a methodology for placement of thyristor controlled phase angle regulator (TCPAR) in order to relieve congestion in the transmission lines while increasing static security margin and voltage profile of a given power system. Sensitivity-Based Methodology is opted for finding the optimal location The effectiveness of the purposed methods is demonstrated on modified IEEE 30-bus system by using Power World Simulator Software version 12.0.

***Keywords** - Congestion, TC-PAR, Sensitivity-Based methodology, Optimal location, Power World Simulator Software.*

I. INTRODUCTION

Under the deregulated electricity industry, electricity concept changes into a commodity by separation in generation, transmission and distribution sections in electricity market. Transmission networks have an important role in the earned benefits of producers and consumers. In the deregulated electricity market, most of the time the power system operates near its rated capacity as each player in the market is trying to gain as much as possible through full utilization of the existing resources.

After deregulation, transmission networks are operated near their security constraints for economical issues as well as for security constraint. Congestion management is one of the most challenging aspects in the recently deregulated electricity markets. Congestion in one or more transmission lines may occur due to a lack of coordination between generation and transmission utilities or as a result of unexpected contingencies such as generation outages, sudden increases in load demand, or failure of equipment. Due to the transmission congestion, which may prevent the existence of new contracts and can threaten system security and reliability, the electricity prices in some regions of the electricity markets may increase and SO must manage congestion to avoid inefficiency in electricity markets. Therefore, congestion management is one of the key functions of any system operator (SO) in the restructured power industry.

Congestion can be corrected by applying controls (corrective actions) such as phase shifters, tap transformers, reactive power control, re-dispatch of generation and curtailment of loads. Fast relief of congestion may be possible by removing congested lines to prevent severe damages to the system. Environment restrictions usually restrict opportunities of reinforcement through the consideration of new routes. In such a situation**[1]**, Flexible AC Transmission Systems (FACTS) controllers plays an important role in increasing loadability of the existing system and controlling the congestion in the network.

The problem with FACTS devices is that the allocation implies the enumeration of all the possible positions among which one represents the most suitable according to a predefined objective. The definition of an opportune performance index is needed to discriminate among all the candidate locations **[1]-[4].** A considerable computational effort is required in the search for the optimal location. For this reason, the scientific community has devoted a great deal of interest in rapidly calculated performance indexes in conjunction with efficient algorithms to find the best solution within the whole search space.

D.Devaraj et al **[3]**, describe about the optimal power flow for steady state security enhancement using enhanced genetic algorithm with FACTS devices. A.Kumar et al[6] explains about the Impact of TCPAR on Cluster-Based Congestion Management Using Improved Performance Index. B.Singh et al[9] effectively describes the Coordination Control Techniques of FACTS Controllers in Multi-Machine Power System.

In this paper, real power flow sensitivity index is calculated for the optimal location of TCPAR by using Power World Simulator Software version 12.0.

II. MODELING OF FACTS DEVICES

[A] Thyristor Controlled Phase Angle Regulator(TC-PAR):

In a thyristor controlled phase angle regulator **[10]**, the phase shift is accomplished by adding or subtracting a variable voltage component in perpendicular to the phase voltage of the line. Fig .1 shows the static model of a thyristor controlled phase angle regulator. The additional voltage source changes the bus voltage from *Vi* to *Vj* corresponding to the shifting of the voltage by an angle α.

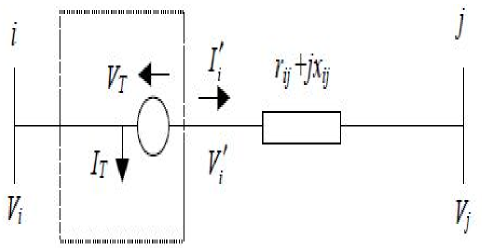


Fig 1. Static model of TC-PAR

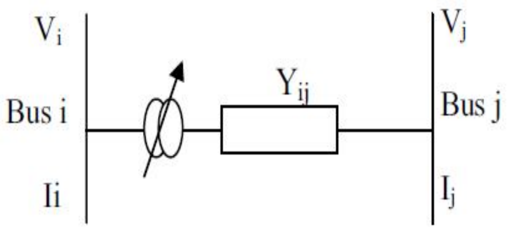


Fig 2. Circuit diagram of phase angle regulator

In general, phase shifting is obtained by adding a perpendicular voltage vector in series with a phase. This vector is derived from the other two phases via shunt connected transformers. The perpendicular series voltage is made variable with a variety of power electronics topologies. A circuit concept that can handle voltage reversal can provide phase shift in either direction. This Controller is also referred to as Thyristor-Controlled Phase Shifter Transformer (TCPST) as shown in fig.2.

The injected active power at bus-i (P_{is}) and bus-j (P_{js}) of a line having a phase shifter are

$$P_{is} = -V_iV_j\,K(G_{ij}sin\delta_{ij} - b_{ij}cos\delta_{ij}) \qquad (1)$$

$$P_{js} = -V_iV_j\,K(G_{ij}sin\delta_{ij} - b_{ij}cos\delta_{ij}) \qquad (2)$$

where K= tanφ

III. METHODS FOR EFFECTIVE LOCATIONS OF FACTS DEVICES

The location of FACTS devices can be based on static or dynamic performance of the system. The sensitivity factor methods are generally used to find the best location to enhance the static performance of the system. FACTS device should be placed on the most sensitive lines.

[A] Performance index Sensitivity Indices

The severity of the system loading under normal case can be described by a real power line flow performance index [12], as given below.

$$PI = \sum_{m=1}^{Nl} \frac{\omega_m}{2a}\left(\frac{P^m}{P_{lm}^{max}}\right)^{2n} \qquad (3)$$

where P^m, is the real power flow and P_{lm}^{max} is the rated capacity of line-m, n is the exponent and w_m, a real nonnegative weighting coefficient which may be used to reflect the importance of lines. PI will be small when all the lines are within their limits and reach a high value when there are overloads.

The real power flow PI sensitivity factors with respect to the parameters of TCPAR placed in line-k, one at a time, are defined as,

$$a_k^s = \left.\frac{\partial PI}{\partial \varphi_k}\right|_{\phi_k=0} \qquad (4)$$

Using equation (3), the sensitivity of PI with respect to TCPAR parameter φ_k connected between bus-i and bus-j can be written as

$$\frac{\partial PI}{\partial \varphi_k} = \sum_{m=1}^{Nl} \omega_m P_m^3 \left(\frac{1}{P_m^{max}}\right)^4 \frac{\partial P_m}{\partial \varphi_k} \qquad (5)$$

The real power flow in a line-m (P_{lm}) can be represented in terms of real power injections using power flow equations [7] where **s** is slack bus, as

$$P_{lm} = \begin{cases} \sum_{n=1, n\neq s}^{N} S_{mn} P_n & \text{for } m \neq k \\ \sum_{n=1, n\neq s}^{N} S_{mn} P_n + P_j & \text{for } m = k \end{cases} \qquad (6)$$

where S_{mn} is the mn^{th} element of matrix [S] which relates line flow with power injections at the buses without FACTS devices and N is the number of buses in the system. P_j is the additional flow, at bus j, in the line containing the FACTS device, due to the presence of the device.

Using (6), the following relationship can be derived,

$$\frac{\partial P_{lm}}{\partial \phi_k} = \begin{cases} \left(S_{mi}\frac{\partial P_i}{\partial \phi_k} + S_{mj}\frac{\partial P_j}{\partial \phi_k}\right) & \text{for } m \neq k \\ \left(S_{mi}\frac{\partial P_i}{\partial \phi_k} + S_{mj}\frac{\partial P_j}{\partial \phi_k}\right) + \frac{\partial P_j}{\partial \phi_k} & \text{for } m = k \end{cases}$$

The terms $\left.\frac{\partial P_i}{\partial \phi_k}\right|_{\phi_k=0}$ $\left.\frac{\partial P_j}{\partial \phi_k}\right|_{\phi_k=0}$ (7)

can be obtained using equations (1-2) are given below

$$\left.\frac{\partial P_i}{\partial \phi_k}\right|_{\phi_k=0} = \left.\frac{\partial P_{is}}{\partial \phi_k}\right|_{\phi_k=0} = V_i V_j (G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}) \quad (8)$$

$$\left.\frac{\partial P_j}{\partial \phi_k}\right|_{\phi_k=0} = \left.\frac{\partial P_{js}}{\partial \phi_k}\right|_{\phi_k=0} = -V_i V_j (G_{ij}\sin\delta_{ij} + B_{ij}\cos\delta_{ij}) \quad (9)$$

The sensitivity factors a_k can now be found by substituting equations (6-9) in equation (5).

[B] Criteria for Optimal Location

The FACTS device should be placed on the most sensitive lines. With the sensitive indices computed for each type of the FACTS devices,

The TCPAR should be placed in a line ***-k*** having largest absolute value of the sensitivity factor. Additional criteria can also be used while deciding the optimal placement of TCPAR should not be placed with generating transformer, even though the sensitivity is the highest.

IV. SIMUULATION RESULTS

The proposed method has been tested on modified IEEE 30 bus system, which consists of six generators and 41 transmission lines. The generator and transmission-line data relevant to the system are taken from IEEE standard 30 bus system. The slack bus bar voltage was fixed to its specified value of 1.0 p.u. It is assumed that the limits of the phase shifting angles of TCPAR's were taken as ±**30^0.** Fig 3 shown line 1-2 is overloaded by 105%.

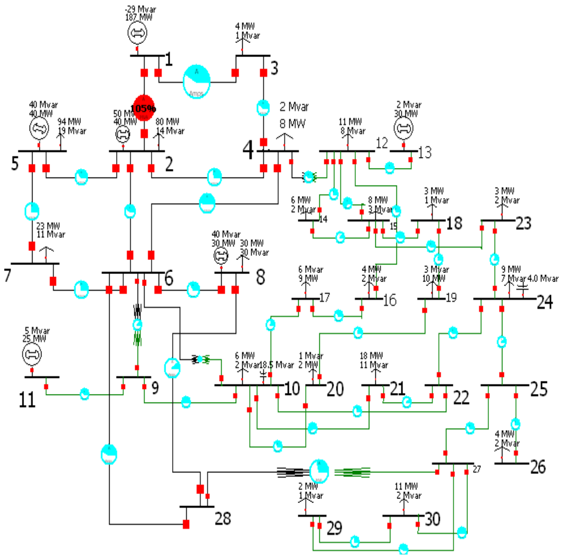


Fig 3: Modified IEEE 30 bus system in which line 1-2 is congested

The increase of losses is more in those lines that are highly loaded as compare to lightly loaded lines. Again the increase of real power flows in the line increase the loss at that line The power flow and losses can be reduced with help of TC-PAR using negative phase shift.

Sensitivity factor for heavily loaded lines are presented in Table1. Table 1 shows that the placement of TCPAR in line 2-4 is most sensitive as compare to other lines This absolute value of sensitivity indicates that phase angle shift of the TCPAR should be negative. The placement of TCPAR in line 2-4 will reduce the loading of line1-2.The best location of TCPAR is line2-4.

TABLE 1: Sensitivity Factor for different location of TC-PAR

Sr no	Lines in which TCPAR is placed (i-j)	Sensitivity factor	Phase shift 3
1	2-4	613.9	12
2	2-6	562.5	11
3	1-3	-81.2	-5
4	2-5	-61.3	-15

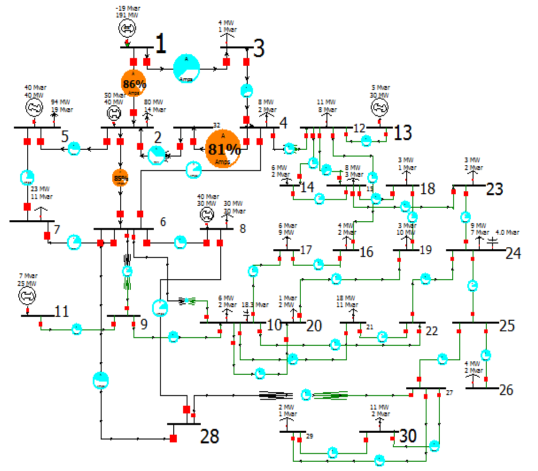


Fig 4: Modified IEEE 30 bus system with TCPAR is placed in line 2-4

Initially line 1-2 is most sensitive having overloading 105% but when TCPAR is placed in line 2-4 having a phase shift of 12 degrees it decrease to 86% as shown in fig.4.

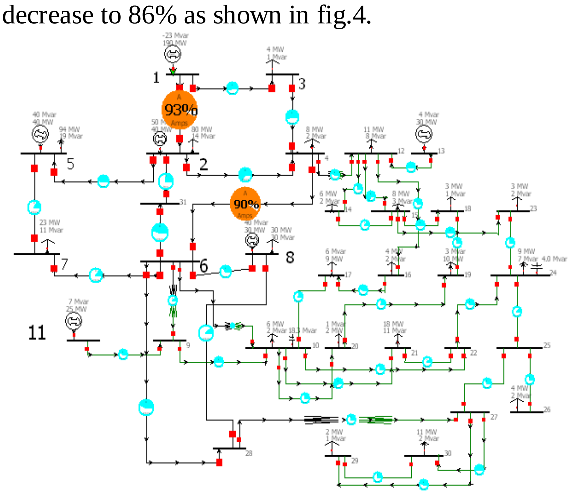


Fig 5: Modified IEEE 30 bus system with TCPAR is placed in line 2- 6

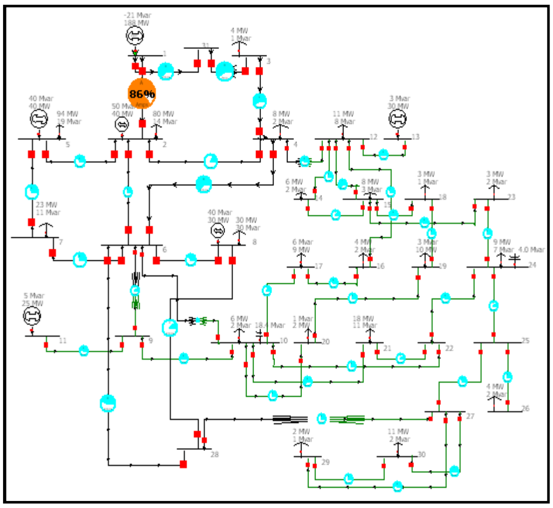
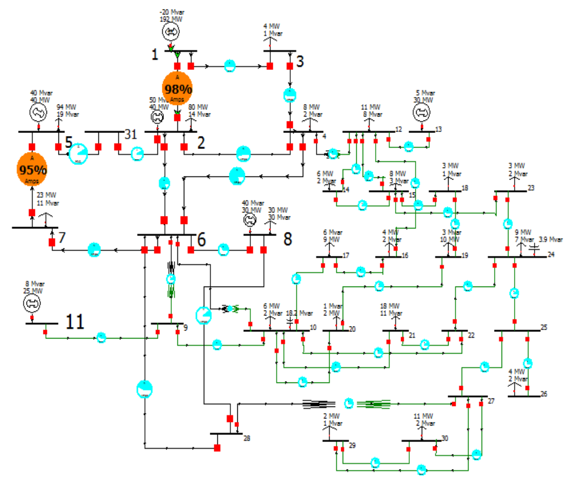


Fig 6: Modified IEEE 30 bus system with TCPAR is placed in line1-3.

In fig.5, when TCPAR is placed in line 2-6 having a phase shift of 11 degrees it decrease to 93%. Similarly Fig 6 and fig 7 shows the third and fourth location of TCPAR placement as per table 1. The TCPAR having the high ability to reduce losses, control steady-state power flow , maximize line utilization, consequently increase system capability and improve reliability. Therefore, it can be utilized to enrich the flexibility of the existing power networks.



V. CONCLUSIONS

In this paper, a sensitivity-based approach has been developed for determining the optimal placement of TCPAR . In a congested system, the optimal locations of TCPAR can be effectively decided based on the real power flow performance index sensitivity factors which indicates the reduction of the total system real power loss **and** will also improve the system voltage profile. TCPAR should be placed in a line 2-4 having largest absolute value of the sensitivity factor. The effectiveness of the sensitivity method has been tested on Modified IEEE 30 bus system by using Power World Simulator Software version 12.0.

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