IMPACT OF THYRISTOR CONTROLLED PHASE ANGLE REGULATOR ON POWER FLOW

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ABSTRACT

Due to increased loading or severe faults in power system results into stressed power system, it will arise the situation in which system does not remains in secure operating region. Therefore, it is the first aim to make methodology to bring power system again into secure operating region. If there will be an unavailability of proper methodology to bring the system into secure region it leads to unstable power system. Similarly in power system the severe faults results into voltage collapse and it decreases the voltage limits which leads overloading of lines. This condition can be overcome by two options i.e. by reconstruction of power system or adjusting the line parameters. In modern days Flexible AC Transmission System (FACTS) are used which controls different parameters of the power system and makes power system stable & improves its performance. Among the FACTS devices the Thyristor Controlled Phase Angle Regulator (TCPAR) plays an important role in increasing load ability of power system. In this paper, we are concentrating mainly on the TCPAR characteristics i.e. which controls the power flow in transmission line by regulating the phase angle of the bus voltage. This can be done firstly by determining the optimal location of TCPAR device in IEEE-14 bus system. Thus by OPF results in MATLAB the effect of injecting TCPAR in system can be studied.

Key words: FACTS, TCPAR, OPF, Optimal location of TCPAR, MATLAB.

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1. INTRODUCTION

FACTS devices control one or more of the parameters to improve system performance by using placement and coordination of multiple FACTS controller. It achieve significant
improvements in operating parameters of power systems such as small signal stability, security of power system, transient stability etc. In this project, we are concentrating on determining the optimal location of the TCPAR device in a system. The impact of injecting TCPAR in the system can be studied by using MATLAB. The TCPAR is a device that can control power flow in transmission lines by regulating the phase angle of bus voltage. TCPAR plays an important role in increasing load ability of existing system & controlling congestion in network. It can be used to regulate the power flow in tie-lines of interconnected power system. TCPAR can be thought of essentially the same as conventional phase-shifter with a fast phase-angle regulation capability.

In [1], in this paper, an optimization – based methodology is introduced to identify locations of a series connected FACTS device. Due to which there is increase in the maximum megawatt power transfer. Authors designed & implemented OPF software for integration of steady state FACTS models. This results helps in evaluating effectiveness of series FACTS device in maximizing network transfer capability. In [2], this paper introduced the GENETIC ALGORITHM to seek optimal location of multi-type FACTS devices in a power system by considering following parameters:- The location of device, their types & their values. Four different kinds of FACTS controllers TCSC, TCVR, TCPST & SVC are used & modelled for steady-state studies by 118-bus power system. However, results shows that the simultaneous use of several kinds of FACTS devices was most efficient solution to increase system load ability. It also observed that a maximum number of FACTS devices beyond which this load ability cannot be improved. In [3], optimally located facts devices SVC, TCSC & TCPAR on ‘REAL TIME PRICES’ has been studied. Authors designed a ‘Mixed Integer Nonlinear Programming’ (MINP) for optimal placement of FACTS devices by calculating Active & Reactive power Marginal Prices. The impact of placing FACTS devices on Marginal Prices & social Welfare is observed. On conclusion, it is observed that there is improvement in RPMP obtained with SVC and with TCSC & TCPAR significant improvement in APMP can be observed. In [5], this paper presents comparison of various methods used for optimizing the location of TCSC and various FACTS devices. Sensitivity based approach has been used to decide optimal location of FACTS devices. Three indices obtained in this work:- Line loss sensitivity indices, total system loss sensitivity indices, real Power flow performance indices. These techniques mainly implemented on 5-bus system & IEEE-14 Bus system by considering following common approach: - Active power loss on transmission line in which a device is proposed to install, Total system real power loss, the real power flow performance index.

The main objective is to enhance the power flow after injecting the TCPAR device. Impact of injecting TCPAR in the system can be determined and its result can be observed. The optimal location of TCPAR can be obtained by real power flow performance index and sensitivity analysis can be done. Thus to find optimal location of the TCPAR an IEEE-14 bus system is implemented. First of all study of optimal power flow of IEEE-14 bus system an Newton-raphson method is used in matlab software and then programming can be done.

2. MODELING OF TCPAR

The TCPAR is equipment that can control power flow in transmission lines of power system by regulating the phase angle of the bus voltage. Environment restrictions usually restrict opportunities of reinforcement through the consideration of new routes. In such a situation, Flexible AC Transmission System (FACTS) controllers such as TCPAR play an important role in increasing load ability of the existing system and controlling the congestion in the network. FACTS device like TCPAR can be used to regulate the power flow in the tie-lines of interconnected power system. When TCPAR is equipped with power regulator and frequency
based stabiliser it can also significantly influence the power flow in the transient states occurring after power disturbances. Basic injection model of TCPAR is shown below.

![Static representation of TCPAR](image1)

**Figure 1** Static representation of TCPAR

![Injection model of TCPAR](image2)

**Figure 2** Injection model of TCPAR

In Fig. 2 which line-k is connected between bus-i & bus-j thus real power ($P_{ij}$) and reactive power ($Q_{ij}$) without injecting TCPAR is given as:

$$P_{ij} = |V_i|^2 Y_{ij} \cos(\theta_i + \delta_i - \delta_j) - |V_j|^2 Y_{ij} \cos \theta_j$$  \hspace{1cm} (1)

$$Q_{ij} = |V_i|^2 Y_{ij} \sin \theta_i - |V_j|^2 Y_{ij} \sin(\theta_i + \delta_j - \delta_i) - \frac{|V_j|^2 Y_{ij}}{2}$$  \hspace{1cm} (2)

where, $V_i$ and $\delta_i$ are the voltage magnitude and angle at bus-i. $Y_{ij}$ and $\theta_{ij}$ are magnitude and angle of $ij$ th element of $Y_{bus}$ matrix. $Y_{sh}$ is the full line charging admittance of line-k.

As shown in Fig. 1 in the TCPAR by the process of adding & subtracting a variable voltage component in perpendicular to phase voltage the phase shift is obtained [4]. In Fig.1 it shows that the TCPAR effect can be obtained by the series injected voltage source $V_T$ & current $I_T$. Therefore bus voltage changes from $V_i$ to $V'_i$ corresponding to the shift angle $\alpha$ and is given as:

$$\frac{V'_i}{V_i} = e^{j\alpha} \hspace{1cm} (3)$$

$$V'_i = V_i (1 + j \tan \alpha) \hspace{1cm} (4)$$

$$V_T = j \tan \alpha \hspace{1cm} (5)$$

Where, $k = \cos \alpha$ is the transformation coefficient of the voltage magnitude.

Ignoring losses in TCPAR the relationships between current is given as:

$$V_i I'_i = V'_i I'_i \hspace{1cm} (6)$$

$$I'_i = \frac{e^{j\alpha}}{k} I_i \hspace{1cm} (7)$$

$$I_i = I_T + \dot{I}_0 \hspace{1cm} (8)$$

$$I_T = -j I'_i \text{ tan} \alpha$$  \hspace{1cm} (9)
Similarly, Power flow equations can be given as,
\[ S_{ij} = P_{ij} + jQ_{ij} \] (10)

As shown in fig.2 the injected model of the TCPAR thus the injected active and reactive power is given as,
\[ P_y = |V|^2 g_y \cos(\theta_y) - |V|^2 b_y \sin(\theta_y) \] (11)
\[ Q_y = |V|^2 g_y \sin(\theta_y) - |V|^2 b_y \cos(\theta_y) \] (12)

where \( t = 1/\cos \alpha \).

\[ P_{ij} = -V_i^2 T^2 g_y - V_i V_j T (g_y \sin \delta_y - b_y \cos \delta_y) \] (13)
\[ Q_{ij} = V_i^2 T^2 b_y + V_i V_j T (g_y \cos \delta_y + b_y \sin \delta_y) \] (14)
\[ P_{ij} = -V_j^2 V_j T (g_y \sin \delta_y + b_y \cos \delta_y) \] (15)
\[ Q_{ij} = -V_j^2 V_j T (g_y \cos \delta_y - b_y \sin \delta_y) \] (16)

3. SOLUTION TECHNIQUE

As we know that there are different techniques for obtaining the optimal location of FACTS device such as:- Sensitivity approach , Line outage distribution factor , Genetic algorithm, Particle swarm optimization. In this paper firstly the OPF can be obtained from MATLAB programming with N-R method without FACTS device & by injecting TCPAR device in one by one each line of the IEEE-14 bus system again OPF is obtained and after that sensitivity factor of each line can be calculated manually.

4. REAL POWER PERFORMANCE INDEX

The severity of system loading under normal and contingency cases can be described by a real power flow performance index (PI) [4]. The sensitivity factor with respect to parameter of TCPAR can be given as:-
\[ PI = \sum_{m=1}^{N} \frac{w_m}{2n} \left( \frac{P_{im}}{P_{im}^{max}} \right)^2 \] (17)

Where, \( P_{im} = \) Real power flow

PI will be small when all lines are within limits & reach a high value when there are overloads. It provides a good measure of severity of line overloads for a given state of power system

5. SENSITIVITY METHOD

In complicated systems it is difficult to determine the optimal location of the FACTS devices by running the OPF of the system. Hence sensitivity method is used to determine the suitable location of the FACTS device.

The real power flow PI sensitivity factor with respect to TCPAR is given as:-
\[ \alpha_i^2 = \frac{\partial PI}{\partial \phi_i} = \sum_{m=1}^{N} w_m P_m \left( \frac{1}{P^{max}_m} \right)^4 \frac{\partial P_m}{\partial \phi_i} \] (18)
6. MATLAB PROGRAMMING

First of all programming is done to find out the OPF without FACTS device i.e. by N-R method. In input files all IEEE-14 bus standard data is to be consider from the data sheet. Thus in output we can get real & reactive power at sending & receiving end and $Y_{bus}$.

As shown in fig.3& 4 the screenshots of matlab programming script. It shows the input loaded files of bus data and line data. The data of these input files is refer from the IEEE-14 bus standard data. The output of the programme without FACTS device is given as:-
Similarly after injecting the TCPAR in one by one in each line it gives impact on OPF. e.g. if TCPAR is placed on line 1 then its impact on power and $Y_{bus}$ is given as:

$\begin{align*}
T_P & = -1.4633 - 0.2102i \\
T_Q & = -0.7534 + 6.1813i \\
0.3913 & = 2.3462i \\
-2.1417 & = -8.4799i \\
7.2225 & = -3.5751i \\
4.3931 & = -3.5939i \\
1.6392 & = -10.5161i \\
7.5354 & = 5.1002i \\
0.0009 & = -0.5007i \\
0.0242 & = -0.9901i \\
0.2351 & = 1.6909i \\
0.1027 & = -0.9023i \\
-0.0229 & = 0.0155i \\
-1.3631 & = -1.5216i \\
0.0053 & = -6.4524i \\
0.0000 & = 3.7686i \\
-0.1111 & = -0.2172i \\
0.0892 & = 5.5656i \\
-0.0151 & = -0.9911i \\
0.1366 & = 0.1307i \\
3.5313 & = -6.8623i
\end{align*}$

Figure 6 Power and $Y_{bus}$ Output after Injecting TCPAR in line 1.

As shown in Fig.6 the impact of TCPAR on power flow and $Y_{bus}$. As the first row of $Y_{bus}$ gets modified and rest matrix is same. In this way TCPAR is placed in each line and OPF is obtained.

7. RESULT

As seen from matlab programming section the TCPAR shows its impact on line in which it is placed. Thus from these outputs the sensitivity factor can be calculated manually for the optimal location of TCPAR. It can be calculated from the OPF outputs of without FACTS and with FACTS device by applying equation (17) & (18). The result is shown below in tabular form:

<table>
<thead>
<tr>
<th>LINE K</th>
<th>FROM BUS i to j</th>
<th>$G_{ij}^*jB_{ij}$</th>
<th>PHASE SHIFT $\Phi$</th>
<th>SENSITIVITY FACTOR</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-2</td>
<td>-0.79+j6.18</td>
<td>10</td>
<td>655.1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1-5</td>
<td>-0.50+j3.01</td>
<td>10</td>
<td>-418.76</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>2-3</td>
<td>-1.03+j4.57</td>
<td>10</td>
<td>-267.17</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>2-4</td>
<td>-0.72+j3.46</td>
<td>9.13</td>
<td>-399.86</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>2-5</td>
<td>-0.74+j3.56</td>
<td>11.5</td>
<td>-485.86</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 7 Sensitivity Factor in tabular form

As shown in figure.7 the most sensitive line is line “5” i.e. bus “2-5” which is the optimal location of the TCPAR device. At this line after placing of TCPAR it gives its best operational work.

8. FUTURE SCOPE

As seen in result the optimal location of the TCPAR device is found out by using performance index in line “5”. In future if TCPAR device is injected on line 5 the power flow will increase & voltage magnitude is also increased dynamically. After that the results of programming are verified with matpower results.

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