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MITIGATION OF CONGESTION USING TCPAR FACTS CONTROLLER

Abstract: *Modern society is heavily dependent on electricity. Consistent efforts are being made to continuously upgrade the power system to meet the ever increasing demand of electrical power. However, installation of generating plants, transmission and distribution systems is a costly affair. With the increasing demand of power, transmission lines are overloaded or congested. Also due to the line outages, other healthy lines become congested. Many FACTS Controllers are available, which can be applied for mitigation of the congestion in the lines. In this research paper, authors have used Thyristor Controlled Phase Angle Regulator (TCPAR) FACTS Controller to mitigate congestion. The authors have mathematically analyzed the efficacy of the TCPAR FACTS controller. TCPAR FACTS Controller is implemented on two different power systems i.e. IEEE 5-Bus Test system and IEEE 9-Bus Test system and results are obtained.*

Keywords: *congestion management, TCPAR FACTS controller, IEEE 5-Bus Test system, IEEE 9-Bus Test system.*

1. Introduction

Congestion in the electrical transmission system is one of the serious technical problems. It can be defined as the condition when excess of power through the transmission line flows, i.e. it is more than the physical limit of the lines. Managing the congestion is the pertinent solution of this problem. And if congestion is not managed, many problems like electricity charges increase; reliability and stability of the power system decrease. It can occur because of line outages, higher load demand, etc. The main objective for managing congestion is to take sufficient actions to relieve congestion in the power transmission system and as a result increasing the power transfer capabilities (Rajalakshmi et al., 2011). The congestion can be reduced or fully mitigated without affecting the economy and extending the system, by placing various Flexible AC Transmission Systems (FACTS) Controllers on the congested lines when line outages occur due to fault or any other reason.

In recent years, FACTS Controllers have been in use to enhance the power transfer capability and minimization of system losses. In (Hingorani & Gyugyi, 2000; Padiyar, 2007; Acha et al., 2012) authors have briefly explained the working and applications of TCSR FACTS Controller along with other FACTS Controllers.

In (Acharya & Mithulananthan, 2007) authors explain that FACTS controllers make it possible to use circuit reactance, voltage magnitude and phase angle as controls to redistribute line flow and regulate voltage profile. FACTS controllers provide proven technical solutions to address these new operating challenges being faced today.

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TCPAR FACTS Controller is a FACTS Controller which can control the power flow in the transmission lines by managing the phase angle of sending-end bus voltage in clockwise or receiving-end bus voltage in anti-clockwise direction. It plays an important role in increasing the load-ability of the existing system, by controlling the congestion in the power system. This FACTS Controller can be used to regulate the power flow in the tie-lines of interconnected power system. A sensitivity based approach has been used by S. N. Singh et. al. in (Singh & David, 2001) for the optimal location of Thyristor Controlled Series Capacitor (TCSC), and TCPAR was proposed for mitigating congestion.

The congestion in the transmission lines and application of the various FACTS Controllers used to mitigate the congestion were discussed in (Gupta et al., 2017; Kumar & Kumar, 2020; Yusoff et al., 2017; Pillay et al., 2015; Gandoman et al., 2018; Siddique et al., 2019; Aslam et al., 2018a,b; Okeke & Zaher, 2013; Grunbaum et al., 2010; Siddiqui & Deb, 2016).

TCPAR FACTS Controller has been presented for relieving congestion in this research paper. Authors have taken the idea of mitigating congestion by using TCPAR FACTS Controller from (Lima et al., 2003; Aouzellag et al., 2012; Rao et al., 2014; Rajderkar & Chandrakar, 2009) and implemented it on the power system. Generally TCPAR FACTS Controller is mostly applied for varying phase shift, so that line current can be regulated, as a result increases load-ability of the existing power system. While the authors couldn't trace many research papers related to mitigation of congestion by using TCPAR FACTS Controller.

This research paper consists of many sections like motivation behind this research is explained in section 2. TCPAR FACTS Controller has been applied by the authors in two different transmission systems, i.e. IEEE 5-Bus Test system and IEEE 9-Bus Test system for detailed analyses and to validate the results which are explained in detail in section 3. In section 4 procedure of the application of TCPAR FACTS Controller in the transmission line, to mitigate congestion, has been explained in detail. Finally, in sections 4 and 5 result and conclusion have been made respectively. This work may open new avenue of research in electrical engineering related to the mitigation of congestion.

2. Motivation for research

In this research paper, TCPAR FACTS Controller has been used to mitigate congestion. TCPAR FACTS Controller has been applied to two different transmission systems and a detailed analysis has been done for finding the effect on the congestion caused due to line outages. Motivation for the research has been mentioned below:

TCPAR is FACTS Controller that can control power flow in transmission lines of power system by regulating the phase angles of the bus voltages of congested lines. FACTS controller like TCPAR FACTS Controller can be used to regulate the power flow in the tie-lines of interconnected power system. It can be seen from the following phasor diagram of bus voltages of a line as shown in Figure 1.

V_{12} is the line voltage drop, which is equal to

$$V_{12} = I * \sqrt{R_L^2 + X_L^2} \quad (1)$$

It shows that

$$I \, \alpha \, V_{12} \quad (2)$$

In order to reduce the line current; the line voltage drop V_{12} must be reduced. It can be achieved by shifting O1 phasor clockwise. The process will reduce the value of phasor V_{12}, and hence, reduces the current. In this way, congestion can be mitigated. R_L and X_L is the resistance and reactance of the line

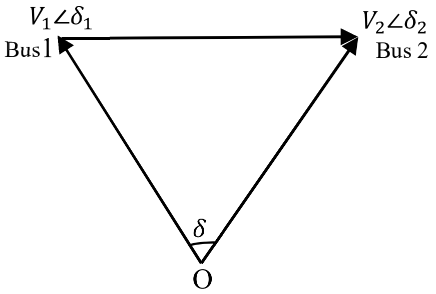

Figure 1. Phasor diagram of voltage and phase angle between two buses

3. Analysis of TCPAR FACTS Controller on IEEE 5-Bus Test system and IEEE 9-Bus Test system

Two different transmission systems have been used in this research paper, and are explained in brief as below:

IEEE 5-Bus Test system: Figure 2 shows the single line diagram of IEEE 5-Bus Test system (Kumar Roy, 2011). It consists of one slack bus numbered 1 and loads are connected to all bus except bus 1. It has total seven transmission lines. Parameters given here are in per unit (pu) format on 60Hz frequency, base voltage is rated at 230kV and base power is 100MVA. It has total 1.65MW of active power load and 0.45MVAR of reactive power load. The minimum and maximum limits of voltage magnitude and phase angle are considered to be 0.95pu to 1.1pu and -45° to 45° respectively.

By using line data and bus data (shown in appendix), the actual values of reactance and susceptance were calculated.

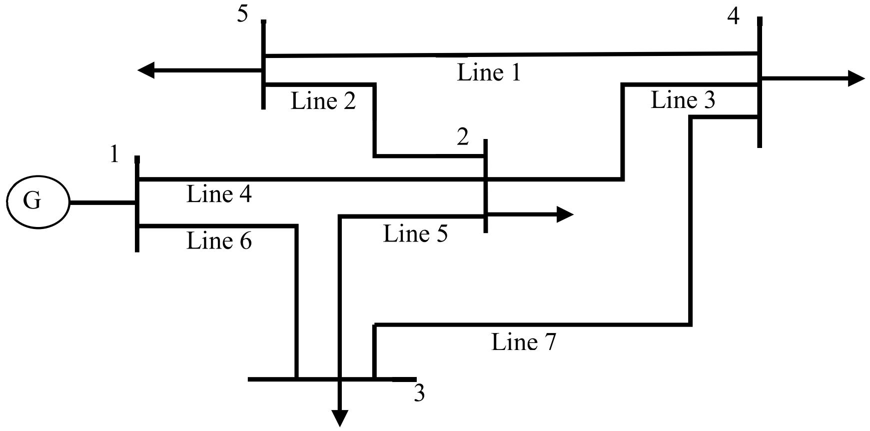

Figure 2. Single line diagram of IEEE 5-Bus Test system

Table 1. Actual values of resistance, reactance and susceptance of IEEE 5-Bus Test system

N_s	N_r	R	X	B	R_1	R_0	L_1	L_0	B_1	B_0
1	2	0.02	0.06	0.06	0.2214	0.6644	0.001763	0.00529	$6.30e^{-9}$	$1.89e^{-8}$
1	3	0.08	0.24	0.05	0.4852	1.4557	0.00386	0.01159	$2.87e^{-9}$	$8.62e^{-9}$
2	3	0.06	0.18	0.04	0.4698	1.4096	0.00374	0.01122	$2.97e^{-9}$	$8.912e^{-9}$
2	4	0.06	0.18	0.04	0.4698	1.4096	0.00374	0.01122	$2.97e^{-9}$	$8.912e^{-9}$
2	5	0.04	0.12	0.03	0.4429	1.3288	0.003526	0.01058	$3.15e^{-9}$	$9.4516e^{-9}$
3	4	0.01	0.03	0.02	0.2712	0.8138	0.00215	0.00647	$5.14e^{-9}$	$1.543e^{-8}$
4	5	0.08	0.24	0.05	0.4852	1.4557	0.00386	0.01159	$2.87e^{-9}$	$8.628e^{-9}$

Where N_s is sending end bus, N_r is receiving end bus, R is resistance, X is reactance, B is susceptance, R_1 and R_0 are positive and zero sequence resistances, L_1 and L_0 are positive and zero sequence inductances, B_1 and B_0 are positive and zero sequence capacitances respectively.

With the help of Table 1, simulink model was developed. Model of IEEE 5-Bus Test system was simulated in MATLAB as shown in Figure 3. Table 2 provides coloured representations of different components of Simulink Model.

Table 2. Colour representation of various components of Simulink Model

S.No	Colour of representation	Component
1)	Magenta	POWERGUI
2)	Yellow	3-phase load
3)	Red	3-phase buses
4)	Light Blue	3-phase transmission line
5)	Green	3-phase generator

Bus voltages and angles were calculated by performing load flow analysis of the following Simulink Model, later on, current in each line was calculated by following formula:

$$I_{12} = Y_{12} * \left((V_1 \cos \delta_1 + jV_2 \sin \delta_1) - (V_1 \cos \delta_2 + jV_2 \sin \delta_2) \right) \qquad (3)$$

,where, I_{12} is the current in the Line (1-2), Y_{12} is the admittance of Line (1-2), V_1 is the voltage of sending end Bus 1 and V_2 is the voltage of receiving end Bus 2 from Figure 3.

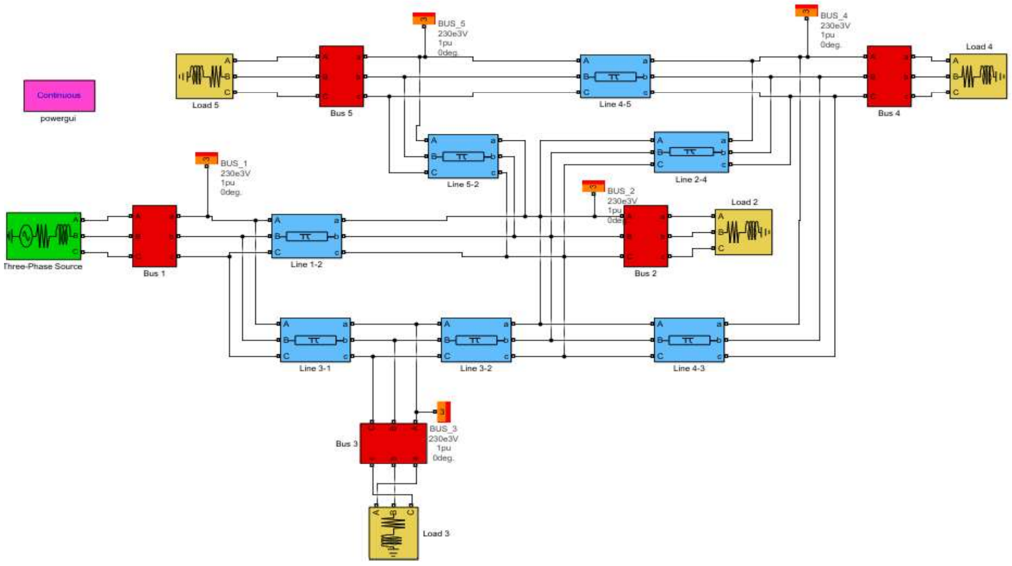

Figure 3. Simulink model of IEEE 5-Bus Test system

For analysis, different combinations of line(s) outages were studied one by one. Due to these outage(s), the line(s) becomes out of service. After outage's analysis, Table 3 was constructed in which currents in all lines for pre and post outages are shown.

Table 3. Values of currents in various line(s) with and without outage(s) for IEEE 5-Bus Test system

S.No.	Pre- Line Outage current	Post - line outage(s)	Post line outage current in pu	Post line outage current in %
1.	I_{L1}(4-5) = 0.0094	(2-5)	0.0260	**276%**
2.	I_{L3}(2-4) = 0.0097	(3-4)	0.0415	**427.8%**
3.	I_{L5}(2-3) = 0.0015	(4-5)	0.0051	**340%**
		(2-4)	0.00415	**277.28%**
		(1-2)	0.1801	**12006.6%**
		(1-3)	0.0200	**1233.5%**
4.	I_{L7}(3-4) = 0.0675	(1-2)	1.1433	**1693.8%**
		(2-3)	0.2155	**319.28%**

Now, look at the most congested line, line 5 which is having highest percentage of congestion when the line outage (1-2) took place. For the line current $I_{L5(2-3)}$ equal to 0.1801pu (in percentage 11906.6%), line (2-3) is the most congested line of the system. Hence, some FACTS Controllers are to be applied on it to mitigate congestion.

IEEE 9-Bus Test system: Figure 4 shows the single line diagram of IEEE 9-Bus Test system (Afolabi et al., 2015). It consists of one slack bus numbered 1. It consists of 8 load buses, which are connected to load and 2 generator buses which are connected to generators. Buses 5 and 8 act as both load and generator buses because they are connected to generators and loads. It has total eleven transmission lines. Parameters given here are in pu format on 60Hz frequency, base voltage is rated at 11kV and base power is 100MVA. It has total 345 MW of active power load and 235 MVAR of reactive power load. The minimum and maximum limits of voltage magnitude and phase angle are considered to be 0.95pu to 1.1pu and -45° to +45° respectively.

From system data Tables (given in appendix), the pu values were converted into actual values as explained earlier in the procedural steps and then simulink model was developed from the single line diagram. Table 4 shows conversion of pu values into actual values. Now, by using this data, simulink model has to be developed.

Table 4. Actual values of resistance, reactance and susceptance after calculating

N_s	N_r	R	X	B	R_1	R_0	L_1	L_0	B_1	B_0
1	2	0.018	0.054	0.009	0.001241	0.00372	9.88e-^{6}	2.964e-^{5}	1.1247e-^{6}	3.3743e-^{6}
1	4	0.015	0.045	0.0076	0.001233	0.003699	9.817e-^{6}	2.945e-^{5}	1.1323e-^{6}	3.397e-^{6}
2	3	0.018	0.056	0	-	-	-	-	-	-
3	9	0.02	0.06	0	-	-	-	-	-	-
4	5	0.013	0.036	0.006	0.001344	0.004032	9.879e-^{6}	2.963e-^{5}	1.1246e-^{6}	3.3738e-^{6}
4	6	0.02	0.066	0	-	-	-	-	-	-
5	6	0.06	0.03	0.0056	0.007035	0.021106	9.335e-^{6}	2.8e-^{5}	1.1902e-^{6}	3.5706e-^{6}
5	7	0.014	0.036	0.006	0.001447	0.004343	9.879e-^{6}	2.963e-^{5}	1.1246e-^{6}	3.3738e-^{6}
6	9	0.01	0.05	0	-	-	-	-	-	-
7	8	0.032	0.076	0	-	-	-	-	-	-
8	9	0.022	0.065	0	-	-	-	-	-	-

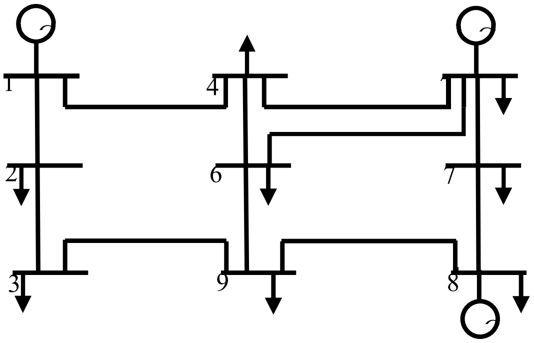

Figure 4. Single line diagram of IEEE 9 – Bus Test system

Representation of different colours in different blocks shown in Figure 5 below has been already explained in the Table 2. Same notation is used in this system also.

Now detailed study about various contingencies in the system and the effect of line outages on the system will be undertaken along with various techniques for their mitigation.

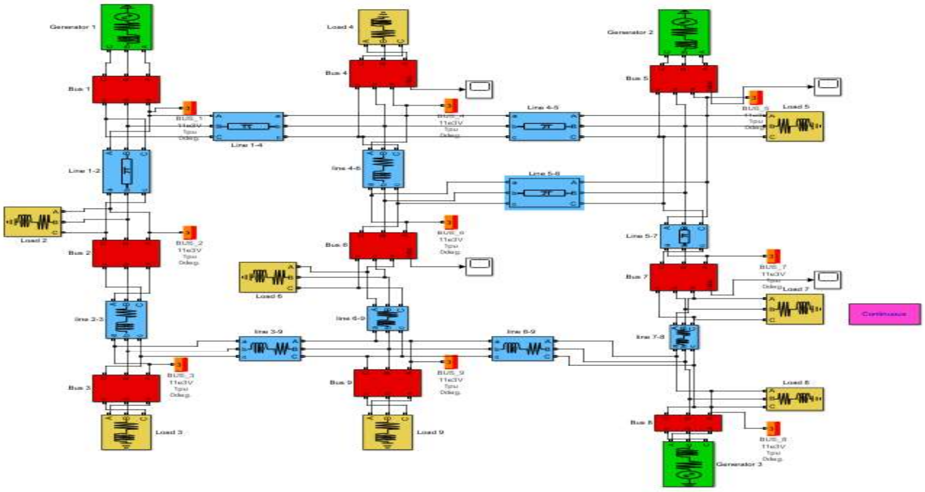

Figure 5. Simulink model of IEEE 9-Bus Test system

Table 5. Values of current in various line(s) with and without outage(s) for IEEE 9-Bus Test system

S.No.	Pre- Line Outage current	Post - line outage(s)	Post line outage current in pu	Post line outage current in %
1.	I_{L1}(1-2) = 0.4854	(1-4)	1.6717	**344.30%**
2.	I_{L2} (2-3) = 0.3743	(1-4)	1.5719	**419.95%**
3.	I_{L4}(3-9) = 0.1034	(1-2)	0.4187	**404.93%**
		(2-3)	0.3006	**290.71%**
		(1-4)	1.3722	**1227.07%**
4.	I_{L5}(4-6) = 0.3564	(5-6)	0.8795	**246.77%**
5.	I_{L6}(6-9) = 0.2712	(1-4)	1.1529	**425.11%**
		(5-6)	1.0975	**404.68%**
		(7-8)	0.66085	**243.67%**
6.	I_{L9}(8-9) = 0.3164	(7-8)	0.8256	**260.93%**

4. Results

Once the congestion current of each line was calculated, TCPAR FACTS Controller was implemented to these two systems to mitigate congestion.

In general, phase shifting is obtained by adding a perpendicular voltage phasor in series with a phase voltage. This phasor is derived from the other two phases by shunt connected transformers as shown in Figure 6. The phase angle of the resultant voltage is made variable with a variety of power electronic devices. Such electronic devices or controllers can provide phase shift in either direction, thus controlling the voltage in bi-directional manner.

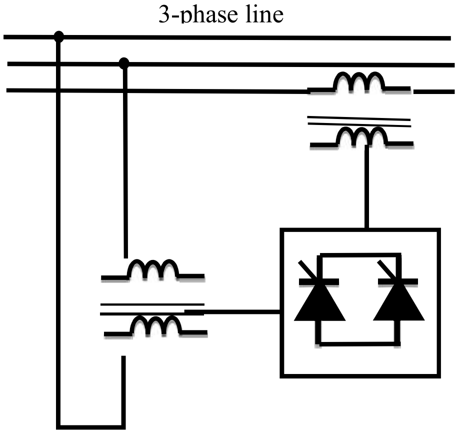

Figure 6. Single line diagram of Thyristor Controlled Phase Angle Regulator FACTS Controller

A possible arrangement for phase angle control is shown schematically in Figure 7(a) with the corresponding phasor diagram in Figure 7(b). For relatively small angular variations, the resultant angular change is approximately proportional to the injected voltage, while the voltage magnitude remains almost constant. However, for large angular variations, the magnitude of the system voltage will significantly increase and for this reason, is often referred to as quadrature booster transformer. The voltage magnitude could be maintained independent of the angular adjustment by a more complex winding arrangement. Nevertheless, because of its relative simplicity, the quadrature booster transformer arrangement has typically been used in conventional phase shifting applications.

After load flow study with outage of various line(s), it was found that some line(s) were facing congestion.

For all the lines, which are congested, TCPARs FACTS Controller has been designed according to the requirement i.e. the original phase angle difference between sending-end and receiving-end buses.

Before designing the TCPAR FACTS Controller, the percentage of reduction of congestion should be calculated as:

$$\text{Percentage of reduction of congestion} = 100 - \left(\frac{I_C}{I_T} * 100\right)\% \quad (8)$$

where, I_C is the value of congestion current as calculated in the Table 3 & I_T is the line current calculated with the application of TCPAR FACTS Controller. Here, let us discuss one case for analysis purpose.

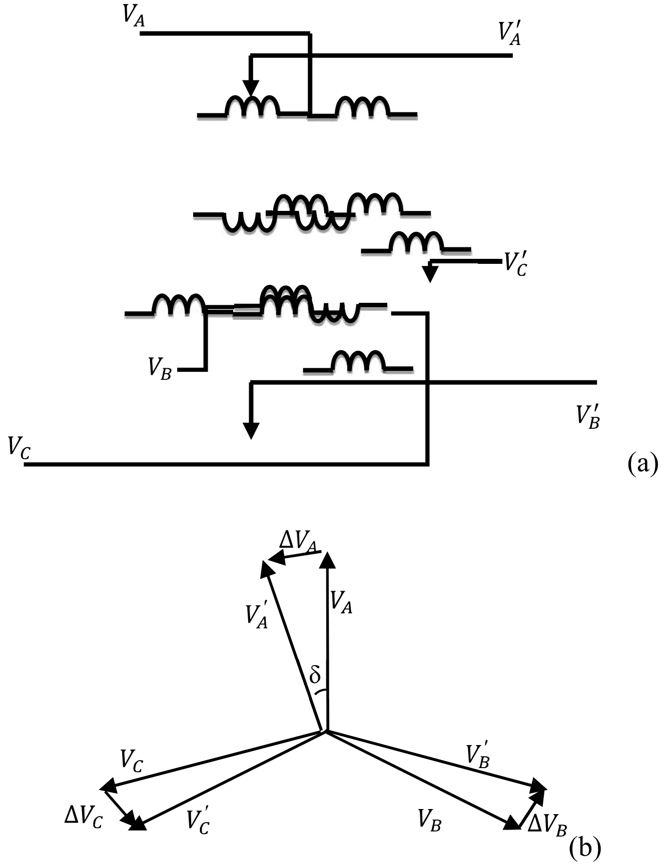

Figure 7. (a), (b):- Concept and basic implementation of Phase Angle Regulator along with its phasor diagram

Case 1:- Elimination of congestion in the line (4-5) for the outage of the line (2-5) in IEEE 5-Bus Test system

The values of voltage and phase angle have been calculated in simulink model by load flow analysis. To connect TCPAR FACTS Controller in series in the line (4-5) to mitigate congestion for the outage of line (2-5), following data is given:

= 1.0721∠-0.28

V_5 = 1.0778∠-0.46

(9)

Y_{45} = 1.25 – 3.75j

I_C = 0.026

Now, phase of bus 4 shifts in clockwise direction towards bus 5 as shown in Figure 8 below. And then, calculate the value of current I_T with the help of equation (3).

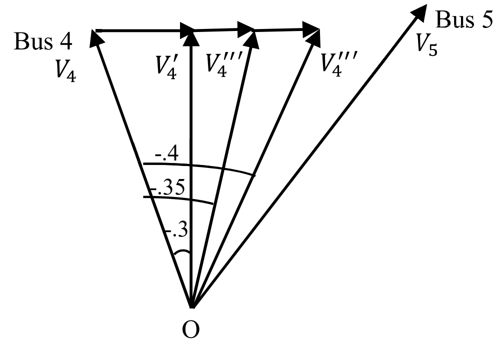

Figure 8. Shifting of Phase of bus 4 towards bus 5

Table 6. Values of phase shifting of V_4 for elimination of congestion

S.No	Phase shift of V_4 in clock-wise direction	I_T	% of reduction in congestion
1.	-0.3°	0.0254	2.3% reduction
2.	-0.35°	0.0239	8.02% reduction
3.	-0.4°	0.0229	11.69% reduction

It can be concluded that TCPAR FACTS Controller is not effective in mitigating congestion in the line (4-5) for the outage of the line (2-5), even the angle shifts from -0.28° to -0.4°; the percentage of reduction in congestion is only by 11.69%.

Similarly, different cases were analyzed and Table 7 is constructed for IEEE 5-Bus Test system and IEEE 9-Bus Test system respectively.

Table 7. Values of phase shifting for elimination of congestion in different line(s) for IEEE 5-Bus Test system

S.No.	Congested line's number	Line's number suffering Outage	I_c	Bus voltage ∠ Phase angle	Phase shift in clockwise direction	I_T	**% of reduction in congestion**
1.	(4-5)	(2-5)	0.026	$V_4 = 1.0721\angle{-0.28}$ $V_5 = 1.0778\angle{-0.46}$	-0.3°	0.0254	**2.3%**
					-0.35°	0.0239	**8.02%**
					-0.4°	0.0229	**11.69%**
2.	(2-4)	(3-4)	0.0415	$V_2 = 1.0706\angle{-0.23}$ $V_4 = 1.0778\angle{-0.40}$	-0.3°	0.03917	**5.6%**
					-0.35°	0.03826	**7.79%**
3.	(2-3)	(4-5)	0.0051	$V_2 = 1.0689\angle{-0.20}$ $V_3 = 1.0697\angle{-0.23}$	-0.22°	0.0043	**15%**
		(1-2)	0.1801	$V_2 = 1.1453\angle{-1.86}$ $V_3 = 1.1136\angle{-1.21}$	-1.3°	0.1769	**1.75%**
					-1.5°	0.1712	**4.9%**
					-1.7°	0.1678	**6.7%**
		(1-3)	0.02	$V_2 = 1.073\angle{-0.29}$ $V_3 = 1.0763\angle{-0.39}$	-0.34°	0.0181	**9.4%**
					-0.38°	0.0173	**13.03%**
4.	(3-4)	(1-2)	1.1433	$V_3 = 1.1136\angle{-1.21}$ $V_4 = 1.1471\angle{-1.90}$	-1.5°	1.0883	**4.8%**
					-1.7°	1.0666	**6.7%**
		(2-3)	0.2155	$V_3 = 1.0657\angle{-0.16}$ $V_4 = 1.0722\angle{-0.27}$	-0.2°	0.2096	**2.6%**
					-0.25°	0.2059	**4.4%**

It can be concluded from above Table 7 that using TCPARs FACTS Controller in the line to mitigate congestion is not effectively successful. Congestion can only be removed up-to 13%, which is not sufficient to mitigate even in small power system like IEEE 5-Bus Test system. Now, let us observe whether TCPAR FACTS Controller can successfully mitigate congestion in IEEE 9-Bus Test system.

From the Table 8, it was observed that when we apply TCPAR FACTS Controller to another system larger than previous system, then also congestion does not mitigated fully, although, it has been observed that it is reduced up-to 15%. Hence, it can be said that TCPAR FACTS Controller is not as effective to mitigate congestion completely.

Table 8. Values of phase shifting for elimination of congestion in different line(s) for IEEE 9-Bus Test system

S.No.	Congested line's number	Line's number suffering Outage	I_c	Bus voltage ∠ Phase angle	Phase shift in clockwise direction	I_T	**% of reduction in congestion**
1.	(4-5)	(2-5)	0.026	$V_4 = 1.0721\angle{-0.28}$ $V_5 = 1.0778\angle{-0.46}$	-0.3°	0.0254	**2.3%**
					-0.35°	0.0239	**8.02%**
					-0.4°	0.0229	**11.69%**
2.	(2-4)	(3-4)	0.0415	$V_2 = 1.0706\angle{-0.23}$ $V_4 = 1.0778\angle{-0.40}$	-0.3°	0.03917	**5.6%**
					-0.35°	0.03826	**7.79%**
3.	(2-3)	(4-5)	0.0051	$V_2 = 1.0689\angle{-0.20}$ $V_3 = 1.0697\angle{-0.23}$	-0.22°	0.0043	**15%**
		(1-2)	0.1801	$V_2 = 1.1453\angle{-1.86}$ $V_3 = 1.1136\angle{-1.21}$	-1.3°	0.1769	**1.75%**
					-1.5°	0.1712	**4.9%**
					-1.7°	0.1678	**6.7%**
		(1-3)	0.02	$V_2 = 1.073\angle{-0.29}$ $V_3 = 1.0763\angle{-0.39}$	-0.34°	0.0181	**9.4%**
					-0.38°	0.0173	**13.03%**
4.	(3-4)	(1-2)	1.1433	$V_3 = 1.1136\angle{-1.21}$ $V_4 = 1.1471\angle{-1.90}$	-1.5°	1.0883	**4.8%**
					-1.7°	1.0666	**6.7%**
		(2-3)	0.2155	$V_3 = 1.0657\angle{-0.16}$ $V_4 = 1.0722\angle{-0.27}$	-0.2°	0.2096	**2.6%**
					-0.25°	0.2059	**4.4%**

5. Conclusion

At the outset, authors had an assumption that TCPAR FACTS Controller would be effective in mitigating the congestion to a great extent. But after the detailed analysis it has been found that TCPAR FACTS Controller is not an effective FACTS Controller to mitigate congestion, yet in some cases, it is useful to mitigate congestion from the line. Hence, it can be said that TCPAR FACTS Controller is partially effective in reducing congestion current of the line.

It is partially successful FACTS Controller because the difference in bus voltage magnitudes is significant. Hence, flow of current is always there in the line due to which congestion remains in the line even after applying it to the congested line.

But TCPAR FACTS Controller is effective to use to mitigate congestion when both the buses have identical voltage magnitudes. If both the buses have identical magnitudes, then we are getting even 83% reduction in congestion. This can be explained by assuming one example.

Suppose V_A is the voltage magnitude of bus 1 and V_B is the voltage magnitude of bus 2. Even, if the phase angle difference becomes zero, the current flows in the line due to line drop V_{AB} as shown in Figure 9.

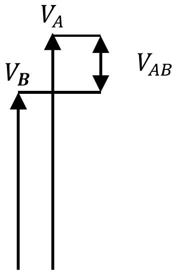

Figure 9.Current flows in the line due to line drop V_{AB}

<u>For IEEE 5-Bus Test system</u>: - Let us assume one case i.e. Elimination of congestion in the line (4-5) for the outage of the line (2-5)

Assume the values of voltage magnitude in bus 4 and 5 will same. Hence, it will

$$\left.\begin{array}{l} V_4 = 1.0721\angle\text{-}0.28 \\ V_5 = 1.0721\angle\text{-}0.46 \end{array}\right\} \quad \begin{array}{l} Y_{45} = 1.25 - 3.75j \\ I_C = 0.0133 \end{array} \qquad (10)$$

Table 9. Effect of phase shift by TCPAR FACTS Controller on the congestion

S. No	Phase shift of V_4 in clock wise direction	I_T	% of reduction in congestion
1.	-0.3°	0.0117	12 % reduction
2.	-0.35°	0.0080	39.84% reduction
3.	-0.4°	0.0044	62.38% reduction
4.	**-0.43°**	**0.0022**	**83.35% reduction**

It can be concluded that TCPAR FACTS Controller is more effective in mitigating congestion in the line (4-5) for the outage of the line (2-5), when the voltage magnitudes of both the buses are same.

Author's efforts couldn't be fruitful—it is the research, sometimes it gives good results sometimes researchers fail.

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Appendix

The bus data and line data of IEEE 5-Bus Test system and IEEE -9 Bus Test system has been given in Tables 10-13. The coding used for buses is: 0-Load bus (PQ Bus), 1-Slack Bus (Swing Bus) and 2- Generator bus (PV Bus).

Table 10. Bus data of IEEE 5-Bus Test system

Bus No	Bus Code	Voltage Magnitude	Angle Degree	Load		Generator		Injected		
				MW	MVAR	MW	MVAR	Qmin	Qmax	MVAR
1	1	1.06	0	0	0	0	0	0	0	0
2	0	1	0	0.20	0.10	0.4	0.3	0	0	0
3	0	1	0	0.45	0.15	0	0	0	0	0
4	0	1	0	0.40	0.05	0	0	0	0	0
5	0	1.0	0	0.60	0.15	0	0	0	0	0

Table 11. Line code of IEEE 5-Bus Test system

Bus Ns	Bus Nr	R (pu)	X(pu)	1/2B(pu)	1 for Line code or tap setting value
1	2	0.02	0.06	0.03	1
1	3	0.08	0.24	0.025	1
2	3	0.06	0.18	0.02	1
2	4	0.06	0.18	0.02	1
2	5	0.04	0.12	0.015	1
3	4	0.01	0.03	0.01	1
4	5	0.08	0.24	0.025	1

Table 12. Bus data of IEEE 9-bus Test system

Bus No	Bus Code	Voltage Magnitude	Angle Degree	Load		Generator		Injected		
				MW	MVAR	MW	MVAR	Qmin	Qmax	MVAR
1	1	1.03	0	0	0	0	0	0	0	0
2	0	1	0	10	5	0	0	0	0	0
3	0	1	0	25	15	0	0	0	0	0
4	0	1	0	60	40	0	0	0	0	0
5	2	1.06	0	10	5	80	0	0	0	0
6	0	1	0	100	80	0	0	0	0	0
7	0	1	0	80	60	0	0	0	0	0
8	2	1.01	0	40	20	120	0	0	0	0
9	0	1	0	20	10	0	0	0	0	0

Table 13. Line code of IEEE 9-Bus Test system

Bus Ns	Bus Nr	R (pu)	X(pu)	1/2B(pu)	1 for Line code or tap setting value
1	2	0.018	0.054	0.009	1
1	4	0.015	0.450	0.0076	1
2	3	0.018	0.560	0.0	1
3	9	0.020	0.600	0.0	1
4	5	0.013	0.036	0.006	1
4	6	0.02	0.066	0.0	1
5	6	0.06	0.030	0.056	1
5	7	0.014	0.036	0.006	1
6	9	0.01	0.05	0.0	1
7	8	0.032	0.076	0.0	1
8	9	0.022	0.065	0.0	1