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Mitigation of Transmission Congestion with Series Controller Facts Devices

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Abstract

Transmission congestion problem is a major issue in transmission network. This work proposed NR (Newton Rapshon) based algorithm for solving transmission congestion problem in PSAT MATLAB environment. NR based evolutionary technique is used for optimum co-ordination of series controllers with imaginary power sources present in transmission network. Here author evaluate voltage stability, real power loss reduction, and running cost by using power flow. Transmission loss magnifies the total system running cost. This paper manages the improvement of VAR power because its optimization is a huge problem in transmission system. The PV curve provides a voltage collapse point and finds the location of weak bus. TCSC (Thyristor controlled series capacitors) and SSSC (static synchronous series compensator) are used in current issue in IEEE-14, 30, 57 bus system. The comparative results between TCSC and SSSC are presented in this work. From obtained result, it is observed that SSSC yields superior results when compared to TCSC in phrase of real power loss and running cost.

Keywords:Real power loss, Newton Rapshon, PSAT, TCSC, SSSC, PV curve, Voltage stability, Running cost, Net saving

Abbreviations: NR, Newton Rapshon; PF, power flow; TCSC, Thyristor controlled series capacitors; SSSC; static synchronous series compensator; CPF , continuous power flow ; PSAT, Power system analysis toolbox; OPF, optimal power flow; ECR, Energy consumption rate; VSC, voltage source converter; DR, demand response; JB, Jacobean matrix; TCR, thyristor controlled reactor.

I. INTRODUCTION

Transmission line congestion management is challenging task. Present scenario of electrical transmission system with continuous increase in electricity demand, control on new transmission line construction, unintentional power flow in line increases the transmission loss, unbalance bus voltage in system and crowding of transmission network. Transmission systems of present power network are reliably crashed into increasingly focused on level because of the ascent in load requests and limitations of developing new lines. This paper deals with the optimization of VAR power because its optimization is a massive issue in transmission system. It wants dynamic control of VAR era by all the accessible imaginary sources inside the frame work. The sources of imaginary power are generators, transformer tap changer, and capacitors. Position of Facts controllers play a crucial role in congestion management, Facts controllers are used the problem of reactive power compensation can be solved. For enhance the maximum load ability facts controllers are used of the transmission system. Facts raises the compliance of the power system, makes it more stable and controllable. Facts controllers can raises the transfer capability in stability limited system by 20 – 30%. Flexible AC transmission system (Facts) was first brought into light by Hingorani [1] in 1998.Power flow control method have been presented by Gothana and Heydt [2]. A brief search for the optimal position of Facts controllers is discussed by Lie and Dang [3]. This paper deals with improvement OP (operational performance) of power system using UPFC Facts devices. The simulation is executed using PSAT in the MATLAB. The area for the situation of UPFC is purposeful utilizing an index termed as NBI (network branch index) [4]. Voltage stability improvement is assessed by extension power flow method present in [5-6]. Installation of Facts devices

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is very crucial issue due to continuous increases electricity demand, it's very economical. In this proposed work presents the minimization of transmission loss and cost using PSO (Particle swarm optimization) and also optimal position of TCSC in [7].Various optimization methods are explained in [8]. Increase in the loadability with Facts devices [9]. In [10] author describes the reactive power compensation. In this paper presented voltage critical point using the load flow JB (Jacobin matrix) [11]. In paper [12] authors have developed in IEEE-57 bus system and restructure in PSAT, authors had brief studied on angle, bus voltage, reactive and real power.in paper [13] aim of this work is to analyse the impacts of Facts controller on voltage stability in power system. PSAT toolbox gives graphical consolidate of power flow analysis, PSAT toolbox detect the most precise node [14].In this paper shows how the improve voltage stability using shunt devices. All the parameter concluded for voltage collapse using the PSAT toolbox in MATLAB and description of weak bus through voltage stability record [16]. [17] In this paper author analyses the position of weak bus. In power system network for maintain the stable voltage. The point of this paper exhibiting a (GA) genetic evolutionary technique based method for management of congestion and to magnifying social welfare utilizing one unit SSSC (Static Synchronous Series Compensator) in a twofold pool advertises based power system. The author is accomplished by ideal finding and sizing one SSSC unit in [19]. Using Facts controller and DR (Demand Response) manages the congestion in transmission line in this proposed work [20-23].

II. MODELING OF SERIES CONTROLLER

Series connected type facts devices inserted in series with the transmission line. TCSC and SSSC are series type Facts controllers. TCSC is variable impedance type controller, it manages the power flow by adjusting the reactance of the system and SSSC is voltage source type converter, it does also reactive power, when line voltage is in phase quadrature within the line current.

(A) Modelling Of TCSC: TCSC is used for solving issues steady state stability, transient stability, voltage stability and dynamic stability in transmission line that's why TCSC is efficient and cost-effective controller. TCSC contains a series capacitor bank shunted by a (TCR) thyristor-controlled reactor for away from of series reactance. TCSC controls the line impedance through the presentation of a thyristor controlled capacitors in arrangement with the line [7]. Fig (1) shows the basic design of the device. Variable impedance of TCSC is expressed as:

$$X''_{pq\,New} = X''_{pq} - X''_{TCSC} \quad (1)$$

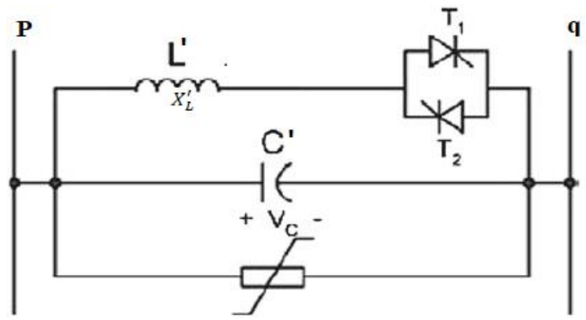

Fig1. Basic structure of TCSC

The essence of the TCSC relies upon the relative reactance of the thyristor branch and capacitor bank. The (W_r') resonance frequency of LC is defined as:

$$X'_c = -\frac{1}{W_n C'} \qquad X'_L = WL'$$

$$W'_r = \frac{1}{L'C'} = W_n\sqrt{\frac{-X'_C}{X'_L}} \quad (2)$$

There are three modes which can be adjusted by TCSC absolute impedance:

Blocking Mode: In this mode pf (power factor) of TCSC in this mode, TCSC have leading PF (Power Factor), so it's operating in pure capacity because thyristor is not triggered.

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By Pass Mode: The thyristor is worked in arranged to $X'_L = X'_c$, the current is in phase with TCSC voltage.

Capacitive Boost Mode: The thyristor is worked in arranged to capacitive mode $X'_c > X'_L$ and then inductive mode $X'_L > X'_c$.

(B) Modelling Of SSSC: SSSC is works like series inductor and capacitor. SSSC is useful for pf (Power Factor) correction, give fast control, and reduces harmonic distortion by active filtering. This device is help to regulate the voltage drop. Coupling transformer is used for connecting VSC (Voltage Source Converter) in series with the transmission line.

The infusion model characterizes the Fact controllers as device that infuses a certain load of real and imaginary power to connecting node, so that the Fact devices are given as PQ element. Here fig (2) displays a model of a transmission line with one SSSC, which is connected between bus p and bus q. All the while steady state operation SSSC can be expressed as a voltage source $V'_{se}\llcorner\Phi'_{se}$. The value of $V'_{se}\llcorner\Phi'_{se}$ is balanced according to the control plot specified. Below Fig shows model of SSSC.

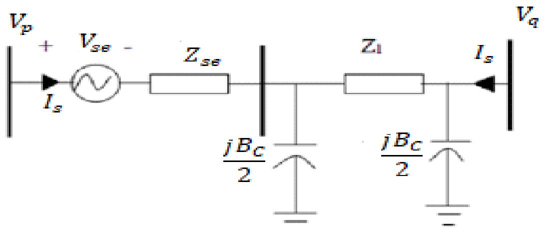

Fig2. Basic structure of SSSC

The injection of real power at bus p and q is given by:

$$P_s'^{\,se} = V_s'\, V_{se}'(1 - \frac{B_c' X_l'}{2}).\frac{\sin(\Phi_s' - \Phi_{se}')}{H'} \quad (3)$$

$$P_r'^{\,se} = -V_r'\, V_{se}' \frac{\sin(\Phi_r' - \Phi_{se}')}{H'} \quad (4)$$

Similarly injection of imaginary power at bus p and bus q is expressed as:

$$Q_s'^{\,se} = -V_s'\, V_{se}'(1 - \frac{B_c' X_l'}{2}).\frac{\cos(\Phi_s' - \Phi_{se}')}{H'} \quad (5)$$

$$Q_r'^{\,se} = V_r'\, V_{se}' \frac{\cos(\Phi_s' - \Phi_{se}')}{H'} \quad (6)$$

where, $H' = X'_{se} - \frac{B'_c X'_{se} X'_l}{2} + X'_l$

III. PROBLEM FORMULATION

In electric power system power flow plays an important role. A multi-target work is developed utilizing NR (Newton Raphson) power flow to find an answer including both the location and estimate of TCSC and SSSC that limits the total power loss and balance or keep up the voltage profile at all buses. A real power loss intensifies the system cost, in the proposed work the various objectives is defined as follow

(A) Improvement of Bus Voltage: It is very essential to oversee healthy voltage profile constantly. The first objective is the minimization of the voltage deviation expressed as:

$$M_2 = \sum_{i=1}^{n1}[U_a - U_{specified}] \quad (7)$$

Where, $U_{specified}$ is the specified bus voltage and $n1$ is the bus no. U_a is the voltage magnitude at a_{th} bus. The analysis of voltage stability is examined by following method:

CPF (Continuous power flow) in toolbox PSAT is used to explore the path of PV curve. CPF (Continuous power flow reduces the merging issue adjacent voltage collapse point and calculation time in PV curve.

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Maintain the voltage stability is main issue in power system. For voltage safety PV curve is most accepted method

(B) Reduction of Real Power Loss: Transmission loss within the system constitutes economic loss, which provides no gain. The loss magnitude ought to the accurately predicted and author used Facts controller to minimize them. Mathematical expression for real power loss minimization is as follows:

$$M_L = P_L \sum_{q=1}^{nl} G_{pq} \left[U_p^2 + U_q^2 - 2U_p U_q \cos(\beta_{pq})\right] \tag{8}$$

Where,

nl = no. of transmission lines

G_{pq} = Conductance of p^{th} and q^{th} bus in transmission line

U_p= bus p^{th} voltage

U_q= bus q^{th} voltage

B_{pq}=Power angle at bus p^{th} and q^{th}

P_L=Real power loss

Because of Transmission loss, redistribution of reactive power in transmission network occurs firstly. So real power loss reduction changes the real power generated by slack bus.

Equality limits: Imaginary and real power equation for nl bus system.

$$Q''_{gp} - Q''_{dp} - U_p \sum_{q=1}^{nl} U'_p [G'_{pq} \sin\phi + B'_{pq} \cos\phi] = 0 \tag{9}$$

Where, i=1, 2, 3……………nl

$$P''_{gp} - P''_{dp} - U'_p \sum_{p=1}^{nl} U'_p [G'_{pq} \cos\phi + B'_{pq} \sin\phi] = 0 \tag{10}$$

Where, =

nl- Total bus number.

P'_{gp} And P'_{dp} is real power generation and p^{th}bus demand respectively

Q'_{gp} And Q'_{dp} is VAR Generation and demand of the p^{th}bus

G'_{pq} is represents transfer conductance of $p^{th}$and q^{th}bus

B'_{pq} Represent the transfer susceptance of p^{th} and q^{th} bus.

Inequality limits: Maximum and minimum limit must be defined for the generator voltage magnitude and reactive power

$$P_{gx,\min} \le P_{gx} \le P_{gx,\max}\text{, x= 1, 2… } M_{PV} \tag{11}$$

Generator bus voltage and reactive power restraints are express as:-

$$Q_{gx,\min} \le Q_{gx} \le Q_{gx,\max}\text{, x= x= 1, 2… } M_{PV} \tag{12}$$

$$U_{gx,\min} \le U_{gx} \le U_{gx,\max}\text{, x= 1, 2, 3………M} \tag{13}$$

Transformer taps limits: maximum and minimum limit

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$t_{x,\min} \leq t_x \leq t_{x,\max}$, x= 1, 2, 3……… (14)

M_{PV} - PV buses locations

M- buses locations

SSSC limit: The maximum and minimum values of SSSC. Voltage V'_{se} and its angle θ'_{se} are comprised as:

$$V'^{\,min}_{sssc} \leq V'_{sssc} \leq V'^{\,max}_{sssc} \quad (15)$$

$$\theta'^{\,min}_{sssc} \leq \theta'_{sssc} \leq \theta'^{\,max}_{sssc} \quad (16)$$

TCSC limit: Output of reactive power limits defined in maximum and minimum limit as given below:

$$Q'^{\,min}_{tcsc} \leq Q'_{tcsc} \leq Q'^{\,max}_{tcsc} \quad (17)$$

$$X'^{\,min}_{tcsc} \leq X'_{tcsc} \leq X'^{\,max}_{tcsc} \quad (18)$$

(C) Minimize Running Cost: The Vars of generator are managed by transformer tap setting system as it does not require additional cost. The main goal of the authors in this work is to lessen congestion in the transmission line using series controller. Minimization of running cost can be asserted as:

Upgrade the value, $M'_o = C'_a + C'_b$ (19)

Where C'_aexpense due to energy loss is and C'_b is expense due to series controller.

$$C'_a = P'_l \times ECR\ (Energy\ consummation\ rate) \quad (20)$$

$$ECR = 0.06 \times 100000 \times 8760. \quad (21)$$

So minimization of optimized value M, minimize the running cost. All the data are taken from [18].

(D) Loss Reduction: reduction of loss in % expressed as:

$$\frac{P_{loss(without\ Facts)} - P_{loss(with\ Facts)}}{P_{loss(with\ Facts)}} \times 100 \quad (22)$$

(E) PSAT

a. PSAT is a toolbox of MATLAB which is open source; it can perform CPF (continuous power flow), PF (Power flow), OPF (Optimal power flow) and small signal stability analysis.
b. PSAT additionally empowers the capacities identified with various power flows locked in.
c. The use of PSAT for the displaying of the test bus framework and its examination is appeared as designing of test bus system.
d. PSAT can designing single line diagram of any power system network.

(F) NR (NEWTON RAPSHON):

This technique builds up with primitive speculations of all load bus angles and bus voltage magnitude and angles at generator buses. For each power balance equations comprised system of equations, higher arrange terms disregarded. The outcomes are a linear arrangement of equations can be gives as:

$$\begin{bmatrix} \Delta\theta' \\ \Delta|V'| \end{bmatrix} = -J \begin{bmatrix} \Delta P' \\ \Delta Q' \end{bmatrix} \quad (23)$$

Here ΔP^' and ΔQ^' are inequality equations:

$$\Delta P'_i = -P'_i + \sum_{k=1}^{nl} |V'|_i\, |V'|_k\, (G'_{ik} * \cos\theta'_{ik} + B'_{ik} * \sin\theta'_{ik}) \quad (24)$$

$$\Delta Q'_i = -Q'_i + \sum_{k=1}^{nl} \partial|V'|_i\, |V'|_k\, (G'_{ik} * \sin\theta'_{ik} + B'_{ik} * \cos\theta'_{ik}) \quad (25)$$

J could be a PD (Partial derivation) known as a jacobian:

$$J = \begin{bmatrix} \frac{\partial \Delta P'}{\partial \theta'} & \frac{\partial \Delta P'}{\partial |V'|} \\ \frac{\partial \Delta Q'}{\partial \theta'} & \frac{\partial \Delta Q'}{\partial |V'|} \end{bmatrix} \quad (26)$$

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The linearized framework of conditions is solve to decide the next value (m+1) of angles and voltage significance dependent on.

$$|V'|^{(m+1)} = |V'|^{m} + \Delta|V'| \quad (27)$$

$$\theta'^{(m+1)} = \theta'^{m} + \Delta\theta' \quad (28)$$

IV. RESULTS AND DISCUSSION

Here (NR) Newton Rapshon algorithm is actualized on distinct bus system using PSAT. Using CPF (Continuous Power Flow) in PSAT we have plotted PV curve for critical bus no. 5, 14 in IEEE 14 bus system. Fig 3(a) shows PV curve on absence of series controller and Fig 3(b) shows PV curve after establishment of series controllers, which enhance the voltage magnitude. Series controller significantly affects the aspect PV curve which enhances the basic point in PV curve.

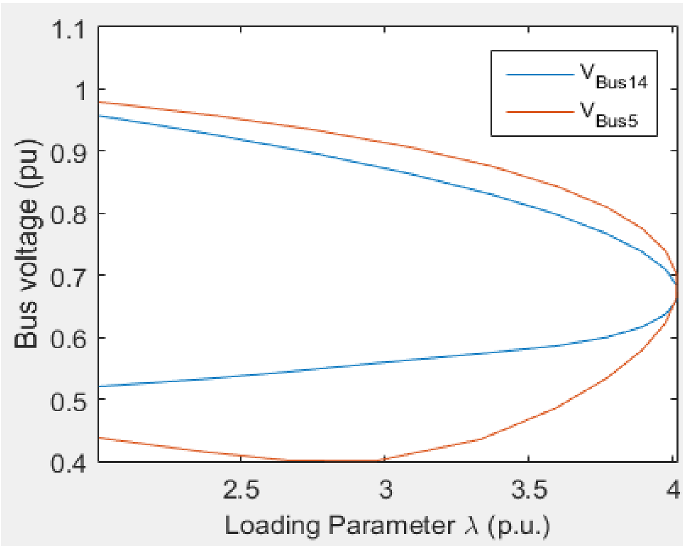

Fig.3 (a): PV Curve before establishment of series controller for IEEE 14 bus system

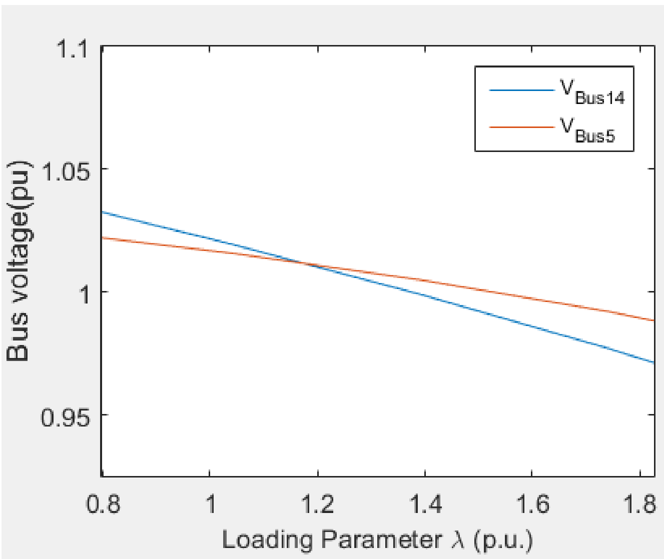

Fig.3 (b): PV Curve after establishment of series controller for IEEE 14 bus system

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Fig 4(a) displays PV curve due to absence of series controller and Fig 4(b) displays PV curve due to presence of series controller and here PV curve plotted for critical bus no.15, 18, and 22 for IEEE 30 bus system

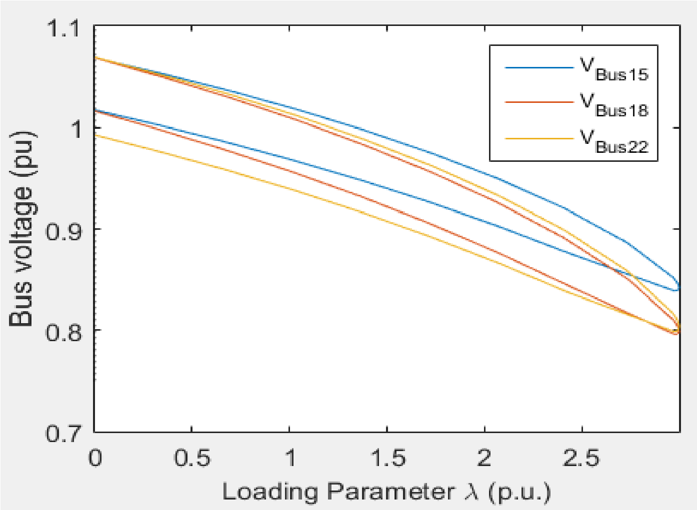

Fig.4 (a): PV Curve before establishment of series controller for IEEE 30 bus system

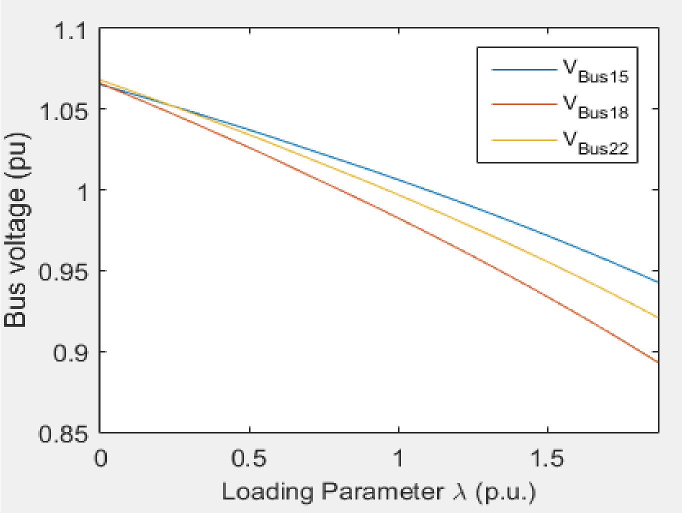

Fig.4 (b): PV Curve after establishment of series controller for IEEE 30 bus system

Similarly, Fig 5(a) displays PV curve due to absence of series controller and Fig 5(b) displays PV curve due to presence of series controller and here PV curve plotted for critical bus no.26, 27, 28 for IEEE 57 bus system.

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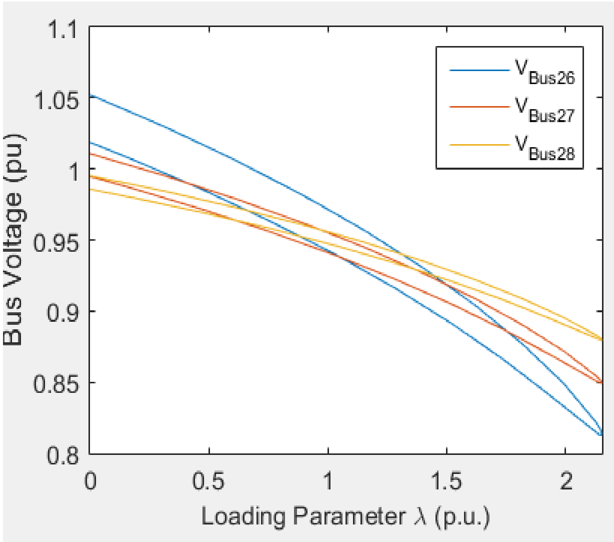

Fig.5 (a): PV Curve before establishment of series controller for IEEE 57 bus system

Bus voltage magnitude of most sensitive buses that access from NR load flow presents in Table 1. It is noticed that the bus voltage enhances after allocation to the proper place in series controllers TCSC and SSSC. Table 2 shows the magnitude of imaginary power with and without series compensation devices allocation by NR technique in distinct test system. We also listed bus no. where series controllers are placed in the middle of the bus. In Table 3 shows comparative analysis the real power loss due to absence and presence of TCSC and SSSC Fact devices. Real power loss before establishment of series controller for test system a, b and c are 0.13541, 0.07268, 0.30748 pu respectively. In Table 4 shows total running cost of system before and after establishment of TCSC and SSSC.

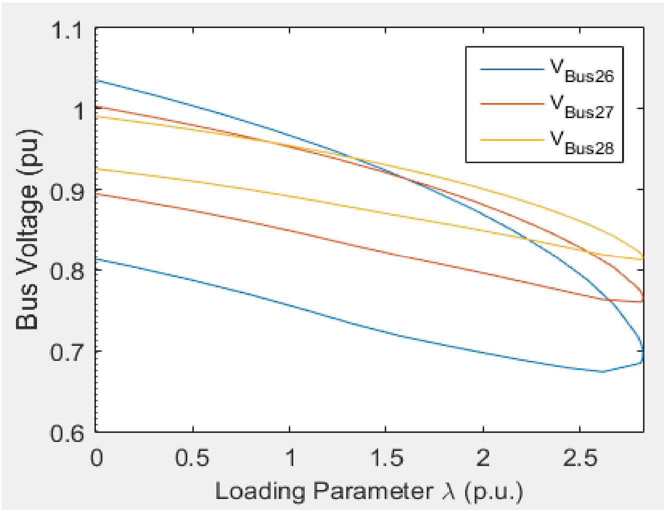

Fig.5 (b): PV Curve after establishment of series controller for IEEE 57 bus system.

In Table 3 presents the result achieved with two different series controller TCSC and SSSC and it is found that real power loss with SSSC is minimum rather than real power loss with TCSC for bus system a, b and c. Real power loss magnifies the total running cost of system so it is clear that running cost with SSSC is minimum rather than TCSC. So SSSC is more economical than TCSC. Table 5 presents reduction of real power loss; in a test system real power loss reduces 49 to 52 %, in b test system real power loss reduces 30 to 38% and c test system real power loss reduces 42 to 49%.

Table 1. Comparative analysis of Bus voltage due to absence and presence of series controller for a, b and c bus system.

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S.N	Bus system	Bus number	Bus voltage due to absence of Facts controller	Bus voltage due to presence of TCSC	Bus voltage due to presence of SSSC
a	57 bus system	6	0.95774	0.97922	0.98139
		8	1.0121	1.0124	1.0128
		14	0.95645	0.95487	0.96227
		42	0.96995	0.97221	1.0029
		52	0.89397	0.98	0.98
		53	0.89241	0.96707	0.96733
b	30 bus system	1	1.0124	1.0193	1.0194
		5	1.0384	1.0391	1.0393
		27	1.0159	1.0161	1.0163
		28	1.0029	1.0036	1.0037
c	14 bus system	2	1.0319	1.035	1.037
		12	1.0496	1.0516	1.055
		14	1.0329	1.0342	1.0366

Table 2. Comparative studies of imaginary power for test system a, b, and c.

S.no.	Bus system	Variables	Imaginary power on absence of Facts controller	Imaginary power on presence of TCSC	Imaginary power on presence of SSSC
a	14 bus system	$Q_{(\mathbf{15-1})}$	0.29907	0.81663	3.4227
		$Q_{(9-8)}$	0.20585	0.84353	6.6508
		$Q_{(\mathbf{14-46})}$	0.38964	0.01409	0.13763
b	30 bus system	$Q_{(\mathbf{2-5})}$	0.0142	0.33217	1.1814
		$Q_{(27-28)}$	0.09957	0.25671	0.76852
c	57 bus system	$Q_{(1-2)}$	0.020607	0.50488	4.0697
		$Q_{(7-8)}$	0.2502	0.63868	5.4826

Table 3. Comparative study of real power loss on absence and presence of Facts controller for test system a, b, and c.

S.no.	Bus system	Real power loss on absence of FACTs controllers (pu)	Real power loss on presence of FACTs controllers (pu)	
			TCSC	SSSC
a	14 bus system	0.13541	0.09048	0.08922
b	30 bus system	0.07268	0.05567	0.05299
c	57 bus system	0.30748	0.21578	0.20668

Table 4. Comparison of total running cost due to absence and presence of Facts controllers for test system a, b, and c.

S.no.	Bus system	Running cost due to energy loss on absence	Running cost using FACTs controllers $\times 10^6$ in ($)	Total saving by FACTs devices $\times 10^6$ in ($)

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		of FACTs controllers (A) $\times 10^6$ in ($)	TCSC(B)	SSSC(C)	TCSC (A-B)	SSSC (A-C)
a	14 bus system	7.097	4.743	4.676	2.355	2.421
b	30 bus system	3.83	2.93	2.785	0.89	1.035
c	57 bus system	16.16	11.341	10.863	4.819	5.297

Table 5. Real power loss reduction at different test system using TCSC and SSSC

S.no.	**Bus system**	**% Loss reduction with TCSC**	**% Loss reduction with SSSC**
a	14 bus system	49.65	51.77
b	30 bus system	30.56	37.16
c	57 bus system	42.49	48.77

V. CONCLUSION

In the prospective work, the author has minimized the transmission congestion by NR (Newton Raphson) algorithm. It is enforced for impressive systematization of series controllers with the other imaginary sources available in framework. At various test system we have presented two type of Facts controller namely TCSC and SSSC for maintain the voltage profile, reduction in real power loss and running cost of the system. PV curve plotted due to absence and presence of series controllers of the weak buses for IEEE 14, 30 and 57 bus system using PSAT simulation. Series controller significantly affects the aspect of PV curve which enhances the basic point in PV curve. The results got to signify critical enhancement in voltage profile and real power loss are reduces 35 to 50%. The result acquired by the SSSC (Static synchronous series compensator) is compared with the result acquired from TCSC (Thyristor controlled series compensator) and it is clear that SSSC is ideal for maintain the voltage stability, reducing the real power loss and running cost for different bus system. SSSC is more economical than TCSC.

VI. FUTURE SCOPE

This proposed work is useful for minimizing the transmission congestion. This work is useful for static voltage stability analysis. Future work should be possible on dynamic voltage stability analysis by considering generator dynamics and dynamic load models. Dynamic analysis can be done for possibilities and positioning can be given for buses and branches. The mitigating the transmission congestion and enhancement in voltage stability by series controller can be observed. The voltage collapse point and also evolutionary techniques can be used to power flow.

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