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Voltage Stability Augmentation using Shunt FACTS

Sushil Kumar Gupta, Sanjay Kumar, Rhea Srivastava, Chelliboyina Prasanna Lakshmi, Megha Raj Lakshmi

Abstract*: With the ever increasing demand of power, the major concern that has aroused is the problem of voltage instability. Due to voltage instability several major power system failures and blackouts occur. Voltage stability thus becomes a necessity. For this FACTS devices like SVC, STATCOM, etc. are used. Load Flow analysis and Continuation Power Flow Analysis is done to identify the weak buses and FACTS devices are installed in these weak buses to enhance the voltage stability. This paper presents a network formulation of IEEE 30 Bus test system using MATLAB and PSAT software and then comparing the effect of SVC and STATCOM for voltage stability enhancement.

Keywords: voltage stability, PSAT, CPF, FACTS

I. INTRODUCTION

Voltage stability plays a vital role in power system stability. Voltage collapse is a state where upon loading, voltage control dynamics become improper. At a specified operating state, if loading voltage does not reach post equilibrium quantities of disturbance, voltage instability occurs. The main aim of attaining system stability is to transfer power smoothly on sudden load increase. In maintaining the load stability, dynamic power flow methods are used for accurate analysis and taking measures to keep the system in stable state and function evenly. Ultimately, voltage stability involves regularizing overall phenomenon including mechanical proceedings. Voltage stability is an important aspect because voltage instability may result into severe power system failures, blackouts, etc. Varied number of methods like conventional power flow, continuation power flow, modal analysis, index method is being executed to analyze the stability of voltage in any system [1]. CPF method is generally applied in dynamically operated system to look for nearness for bifurcation of saddle nodes [2]. Thereafter various solutions and techniques are being proposed to combat the problem of voltage instability and regulation [3]. For these solutions to come into action, the root cause of voltage instability needs to investigate first. Imbalance in reactive power is found to be associated with voltage instability [4]. This can be overcome by bringing forth reactive power compensation, primarily focusing on injecting the same [5]. This can adroitly be done by FACTS devices such as SVC, STATCOM. The notion of FACTS devices was first brought forward by Hingorani [6]. FACTS are said to be efficient enough in compensating reactive power and refine voltage stability, control power flow and improve transmission capacities of power system [7]. SVC is a shunt type FACTS device and it comprises of combination of controllers which either absorb or inject reactive vars as per the system requirement [8], and STATCOM whose compensation augments steady state voltage margin of power capability [9]. With the help of power losses through the system most appropriate location of SVC have been found and voltage stability under different load factors are studied [10]. In [11], line stability voltage indices are used to choose the best possible location for the same. PSAT [12] is a MATLAB tool box used for analyzing and controlling electrical power system. Using PSAT [13] we identify the weak buses where the FACTS devices need to be installed to maintain stability of the IEEE-30 bus test system. PSAT analysis is performed with the help of Newton-Raphson method where it provides simple and instant result for the complex calculations involved. P-V curves are plotted for the buses that are more sensitive to the voltage collapse both before and after compensation is done by using SVC and STATCOM. The difference in the voltage stability caused by SVC and STATCOM has been shown using the static report in PSAT analysis.

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* Correspondence Author
Sushil Kumar Gupta*, Electrical Engineering Department, National Institute of Technology, Jamshedpur, Jharkhand, India. Email: skgupta.ee@nitjsr.ac.in
Sanjay Kumar, Electrical Engineering Department, National Institute of Technology, Jamshedpur, Jharkhand, India. Email: sanjay.ee@nitjsr.ac.in
Rhea Srivastava, Electrical Engineering Department, National Institute of Technology Jamshedpur, Jharkhand, India. Email: rhea0904@gmail.com
Chelliboyina Prasanna Lakshmi, Electrical Engineering Department, National Institute of Technology, Jamshedpur, Jharkhand, India. Email: prasanna17101998@gmail.com
Megha Raj Lakshmi, Electrical Engineering Department, National Institute of Technology, Jamshedpur, Jharkhand, India. Email: pgmlg0528@gmail.com

II. MATHEMATICAL FORMULATIONS

The mathematical notation of flow of reactive power using the depicted model as in Fig 1 is given here [14].

A. Reactive Power Flow

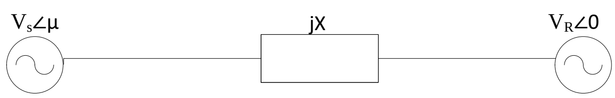

Fig. 1. A system's equivalent model

In the given transmission line,
V_S= per phase voltage of generator side
V_R = per phase voltage of load side
I = transmission line current per phase
μ = power angle
P = Real power

X = Transmission line reactance per phase
Q_S = Reactive power of sending end
Q_R = receiving end reactive power

$$I = \frac{V_S}{X}\angle(\mu - 90^\circ) - \frac{V_R}{X}\angle - 90^\circ \quad (1)$$
$$P = R_e[V_r I^*] \quad (2)$$
$$P = \frac{V_S V_R}{X}\sin\mu \quad (3)$$
$$Q_R = I_m[V_R I^*] \quad (4)$$
$$Q_R = \frac{V_S V_R \cos\mu - V_R^2}{X} \quad (5)$$
$$Q_S = I_m[V_S I^*] \quad (6)$$
$$Q_S = \frac{V_S^2 - V_S V_R \cos\mu}{X} \quad (7)$$

From the above equations we can observe that reactive power flow is mainly controlled by the difference between generator side voltage and load side voltage. The flow of reactive power is from load end to generator end under loading conditions. Due to this, the reactive power that the line generates becomes more (due to the shunt capacitance) in comparison to the reactive power that the line absorbs (due to series inductance) and hence reactive power is supplied to the load end.

B. Continuation Power Flow (CPF)

Power flow analysis is done to get voltage magnitude and angles for every bus in the given power system for a specific load and generator's voltage and real power. Post this the reactive and active power flow in individual line can be determined analytically.

The voltage stability limit is known as the critical point where the Jacobian matrix becomes singular in conventional power flow. To counter this problem CPF analysis is adopted which uses predictor iteration and corrector steps. The given Fig. 2 illustrates that the predictor step starts from point A and the estimate solution is obtained from the tangent of triangle ABC. Then by using the conventional power flow method, the corrector step determines the solution.

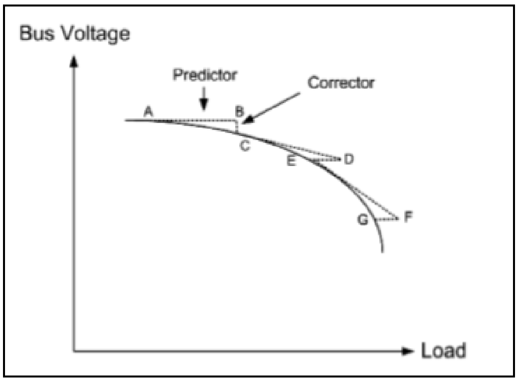

Fig. 2. Graph Showing Predictor and Corrector Step of CPF

The load flow equations containing loading factor (λ_p) can be expressed as [9]

$$F(\mu, V, \lambda_p) = 0 \quad (8)$$

where,
λ_p = the loading factor
μ= bus voltage angle's vector, and
The load flow equation as in the Newton Raphson method is illustrated as:

$$P_i - \sum_{j=1}^{N} Y_{ij} V_i V_j \cos(\mu_i - \mu_j - \theta_{ij}) = 0 \quad (9)$$

$$Q_i - \sum_{j=1}^{N} Y_{ij} V_i V_j \sin(\mu_i - \mu_j - \theta_{ij}) = 0 \quad (10)$$

Taking the load factor (λ_p), the new load flow equations can be expressed as:

$$P_{Li} = P_{Lo} + \lambda_p(K_{Li} S_{\Delta base}\cos\phi_i) \quad (11)$$
$$Q_{Li} = Q_{Lo} + \lambda_p(K_{Li} S_{\Delta base}\sin\phi_i) \quad (12)$$

where
P_{Li} , Q_{Li}= the active and reactive power respectively
K_{Li}= load varying constant at bus i, and
$S_{\Delta base}$= the required power to provide necessary scaling of λ_p.

(a) Predictor Step:

To adjust the state variables, this step uses linear approximation method
Taking the derivative of both sides of equation (1), we get

$$F_\mu\, d\mu + F_v\, dv + F_\lambda\, d\lambda = 0 \quad (13)$$

$$\begin{bmatrix} F_\mu & F_v & F_\lambda \end{bmatrix} \begin{bmatrix} d\mu \\ dV \\ d\lambda \end{bmatrix} = 0 \quad (14)$$

(b) Corrector Step:

The load flow equations are selected by:

$$\begin{bmatrix} F(\mu, V, \lambda) \\ x_k - \eta \end{bmatrix} = 0 \quad (15)$$

where
x_k = the state variable selected as continuation parameter at k iterative and
η= the predicted value of x_k

C. Static VAR Compensator (SVC)

By using SVC, the parameters of the power system is maintained and controlled by adjusting its output to exchange capacitive and inductive current. Schematic diagram of a SVC is given in Fig. 3.

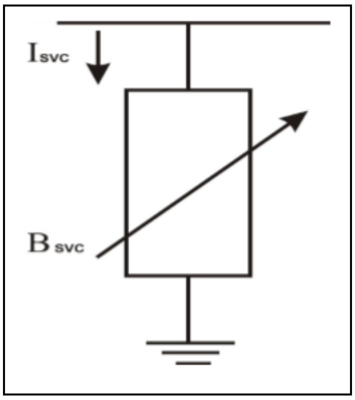

Fig.3. Schematic Diagram of SVC

The SVC draws the current, $I_s = jB_s V_i$ (16)
The SVC draws reactive power which is injected at bus i that is given as

$$Q_s = V_i^2 B_s \quad (17)$$

B_s = The susceptance of SVC
V_i = The voltage at bus i

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D. STATCOM

Static Synchronous Compensator (STATCOM) is one of those FACTS devices whose main purpose is to compensate reactive power by providing continuous reactive power during voltage variations which helps in stability of the grid. Transformer, Capacitor and Voltage Source Converter (VSC) are the main paths of STATCOM. Model circuit of STATCOM is given in Fig. 4.

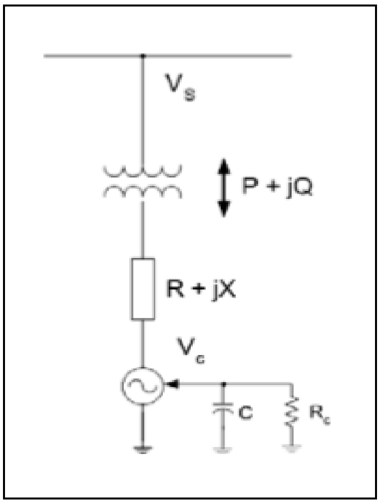

Fig.4. Model Circuit of STATCOM

The steady state equation is represented as

$$V_{d.c.} = \frac{P}{CV_{d.c}} - \frac{V_{d.c}}{R_cC} - \frac{R(P^2+Q^2)}{CV^2V_{d.c}} \quad (18)$$

The injected A.C power at bus has the following form:

$$P = V^2G - kV_{d.c.}VG\cos(\theta-\alpha) - kV_{d.c.}B\sin(\theta-\alpha) \quad (19)$$

$$Q = -V^2B - kV_{d.c.}VB\cos(\theta-\alpha) - kV_{d.c.}G\sin(\theta-\alpha) \quad (20)$$

Here,
G = STATCOM's conductance
B = STATCOM's susceptance

III. METHODOLOGY

A. PSAT

As the name implies, PSAT serves the purpose of analyzing the power system with the benefits of toolbox which is easy to access. PSAT also enables the functions related to different power flows engaged. When compared to other MATLAB toolbox, PSAT provides wide range of features that makes power system analysis achieved with less effort and more accurate. The usage of PSAT for the modeling of the test bus system and its analysis is shown in the flowchart given in Fig. 5.

B. IEEE 30 test bus system

The IEEE test system being examined is 30 Bus Test System which comprises of one slack bus, five generators at 2,5,8,11,13 buses and remaining buses are said to be load buses. It has 41 lines. Using PSAT the model of IEEE 30 bus test system which was made is shown in Fig. 6.

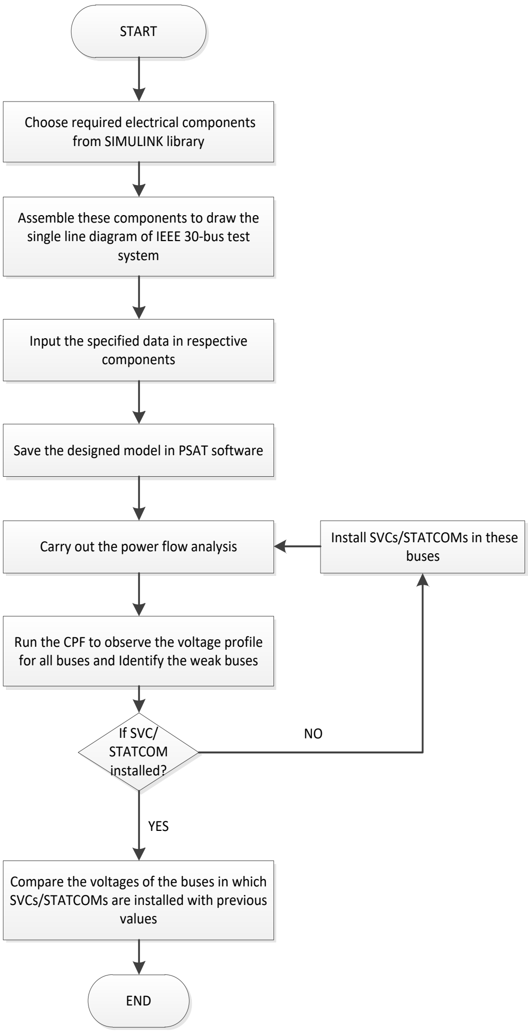

Fig.5. Flowchart depicting the procedure.

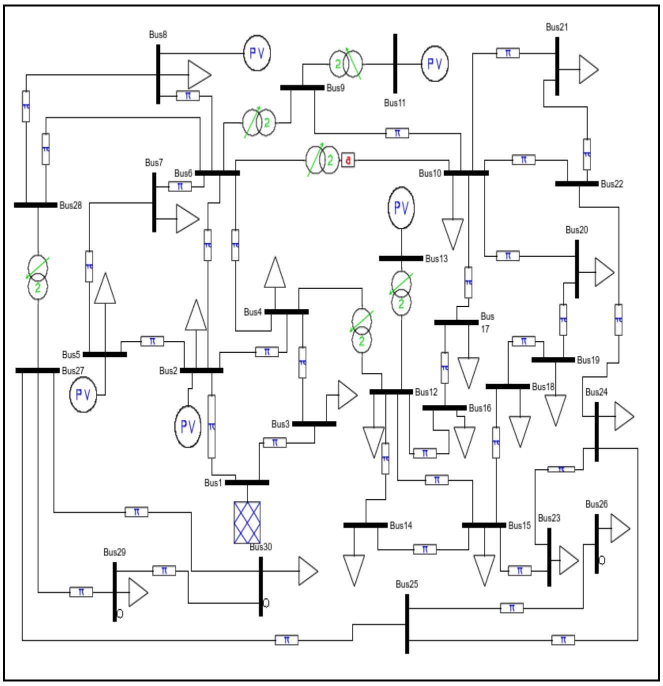

Fig.6. Standard Model of the IEEE 30 bus test system.

IV. RESULT AND DISCUSSION

The Load flow solution using Newton-Raphson method in IEEE-30 bus test system is obtained by using PSAT. The power flow analysis was done and the following voltage profile graph was obtained.

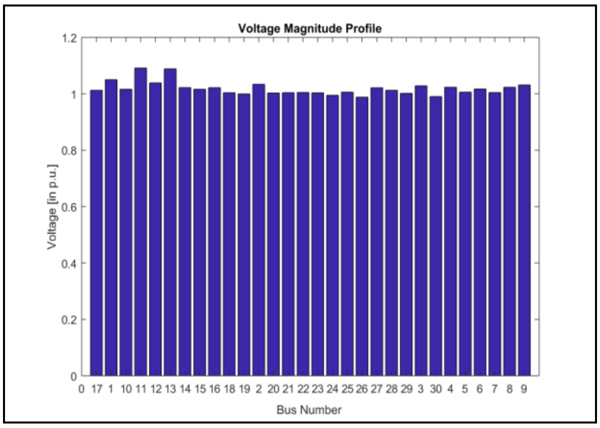

Fig.6. Voltage profile of IEEE 30 bus test system using Power Flow.

The CPF analysis was done and the obtained voltage profile graph is presented in the Fig. 7. From the graph it is clear that the voltages at buses 26, 29 and 30 are comparatively lower, hence SVC is put at these locations. We also compared the voltage profile after incorporating STATCOM at buses 26 and 30. Since STATCOM is more efficient than SVC, so two STATCOMs were sufficient in improving the voltage profile of the test system.

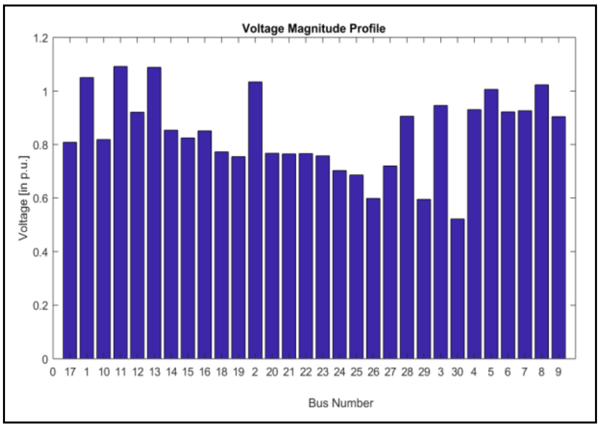

Fig.7. Voltage profile of IEEE 30 bus test system using Continuation Power Flow.

The voltages of Bus no. 26, 29 and 30 without FACTS and voltages with SVC and optimal value of susceptance for SVC are given in the Table I. The obtained optimum value of susceptance was within the specified range which was selected to be [0.9 0.0]. The maximum value of λ (loading parameter) without FACTS is 2.942 and with FACTS is 3.8739. Hence, it can be seen that the loading parameter improves with the installation of FACTS devices.

The voltages of Bus no. 26 and 30 without FACTS and voltages with STATCOM and optimal value of current and voltage for STATCOM are given in the Table II. The obtained optimum value of STATCOM current is within the specified range which was chosen to be [0.2 0.1].

Table I. Result of Various Parameters Using SVC

Bus No.	Voltage (in p.u.) without FACTS	Voltage (in p.u.) with SVC	Optimum Value of Susceptance (in p.u.)
26	0.59865	0.86469	0.61632
29	0.59514	0.9207	0.40428
30	0.5219	0.89581	0.47122

Table II. Result of Various Parameters Using STATCOM

Bus No.	Voltage (in p.u.) without FACTS	Voltage (in p.u.) with STATCOM	Optimum Value of Current (in p.u.)	Optimum Value of Voltage (in p.u.)
26	0.59865	1.0315	0.17391	1.0227
30	0.5219	1.0344	0.17391	1.0248

The voltage of the weak buses i.e. 26, 29 and 30 resulted in PV graph as in Fig. 8. At the location of weak buses SVCs were installed and there was a prominent increase in the voltage as shown in Fig. 9. Installation of two STATCOMs at buses 26 and 30 were sufficient in increasing the three weak buses as is depicted in Fig. 10.

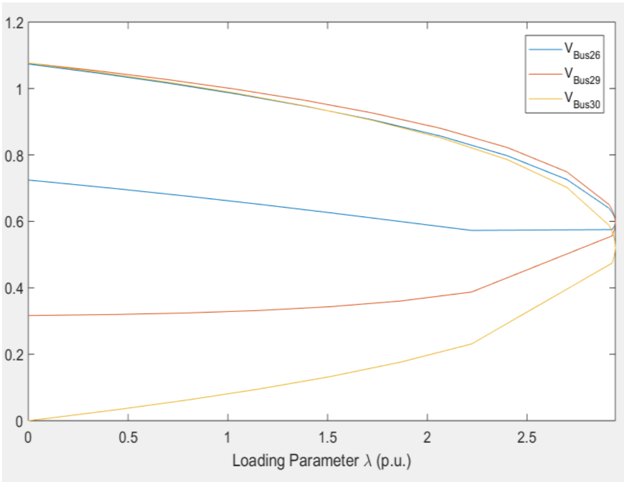

Fig.8. P-V Graph without FACTS

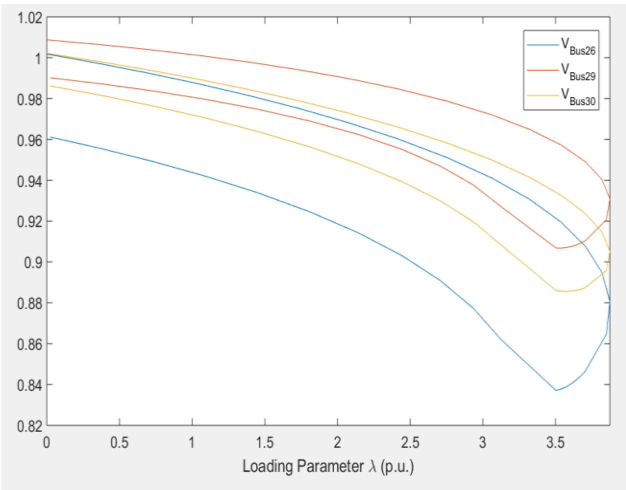

Fig.9. P-V Graph with SVC

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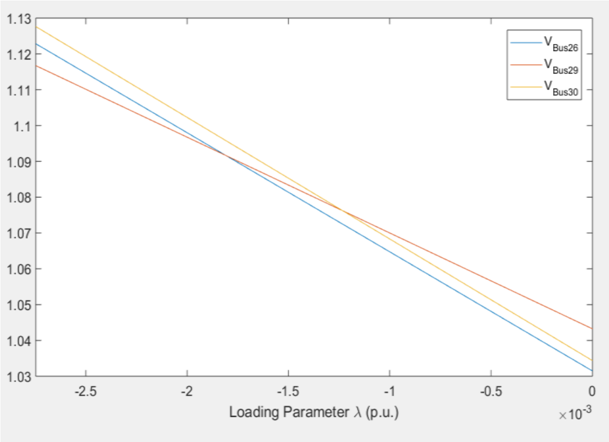

Fig.10. P-V Graph with STATCOM

The active power flow of the lines before installation of SVC is shown in Fig. 11. After installing SVC into the test bus system the active power flow augments which is quite evident from the graph in Fig. 12.

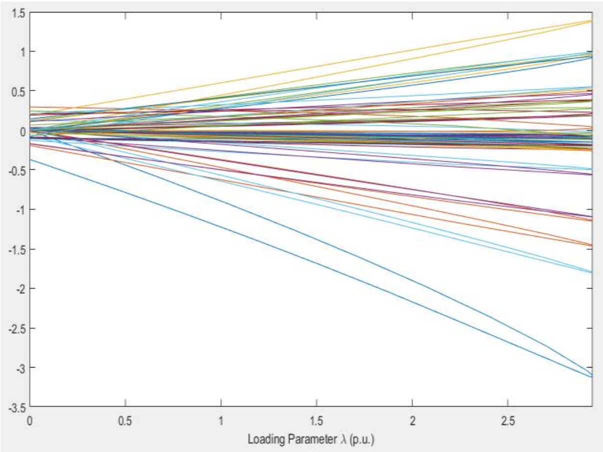

Fig.11. Active Power flow without SVC

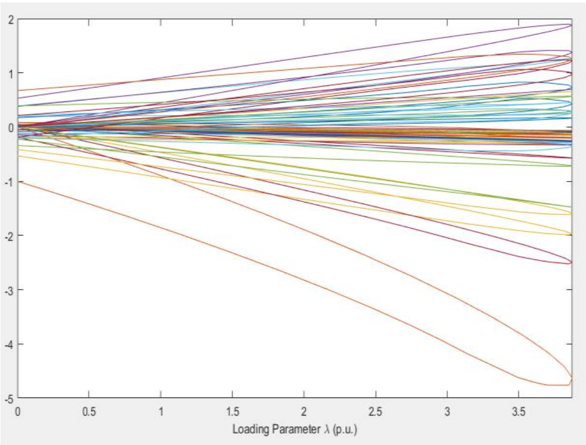

Fig.12. Active Power flow with SVC

V. CONCLUSION

The paper shows the voltage stability assessment of IEEE 30 bus test system done by SVCs and STATCOM using MATLAB and PSAT software. For the improvement of voltage stability, weak buses those are needed to be enhanced are distinguished by the dint of PSAT software and gradually the outcome of voltage profiles are presented in succession to the incorporation of shunt FACTS devices. The result depicts that STATCOM is more efficient than SVC in stabilizing the voltage of the test system.

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AUTHORS PROFILE

Sushil Kumar Gupta born on 1st January, 1964 at Hajipur of Bihar state in India. He passed B.Sc(Engg.) in Electrical Engineering from MIT, Muzaffarpur in 1985, M.Tech in Electrical Engineering with Power System Specialization from NIT, Jamshedpur in 1988. Currently, he is working as Associate Professor in the Electrical Engineering Department, NIT Jamshedpur, Jharkhand. and pursuing Ph D in the area of Power System at NIT Jamshedpur. His area of interests are Load Flow Studies, Reactive Power Management, and Congestion Management using FACTs Devices.

Sanjay Kumar born on 5th June, 1980. He received his B. Tech degree from N.I.T. Jamshedpur in 2006, M. Tech from N.I.T. Patna in 2010, Ph D from IIT (ISM) Dhanbad in 2016. He is having more than five years of teaching experience. Currently, he is working as Assistant Professor in the Department of Electrical Engg. Jharkhand, India.

Rhea Srivastava born on 9th April 1997. She is an undergraduate student currently pursuing her B. Tech (hons.) in Electrical and Electronics Engineering from National Institute of Technology Jamshedpur, Jharkhand, India.

Chelliboyina Prasanna Lakshmi born on 17th October 1998. She is an undergraduate student currently pursuing her B. Tech(hons.) in Electrical and Electronics Engineering from National Institute of Technology Jamshedpur, Jharkhand, India..

Megha Raj Lakshmi born on 25th June 1997. She is an undergraduate student currently pursuing her B. Tech(hons.) in Electrical and Electronics Engineering from National Institute of Technology Jamshedpur, Jharkhand, India.