International Journal of Computer Applications (0975 – 8887)

Volume 72– No.5, May 2013

Stability Enhancement with SVC

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ABSTRACT

This paper deals with Power flow, which is necessary for any power system solution and carry out a comprehensive study of the Newton- Raphson method of power flow analysis with and without SVC. Voltage stability analysis is the major concern in order to operate any power system as secured. This paper presents the investigation on N-R power flow enhancement of voltage & angle stability with & without FACTS controllers such as Static Var Compensator (SVC) device. The Static Var Compensator (SVC) provides a promising means to control power flow in modern power systems. In this paper the Newton-Raphson is used to investigate its effect on voltage profile and angle stability with and without SVC in power system. Simulations have been implemented in MATLAB Software and the IEEE 57-bus system has been used as a case study. Simulations investigate the effect of voltage magnitude and angle with and without SVC on the power flow of the system. This survey article will be very much useful to the researchers for finding out the relevant references in the field of Newton-Raphson power flow control with SVC in power systems.

General Terms

MATLAB Software Toolbox, Newton-Raphson method, Power flow, Power flow with SVC FACTS Controller Algorithm, Reactive Power Compensation.

Keywords

Newton-Raphson method, Power flow, SVC FACTS Controller, Reactive Power Compensation.

1. INTRODUCTION

As the power systems are becoming more complex it requires careful design of the new devices for the operation of controlling the power flow in transmission system, which should be flexible enough to adapt to any momentary system conditions. The operation of an ac power transmission line is generally constrained by limitations of one or more network parameters and operating variables by using FACTS[3] technology such as SVC (Static Var Compensator), the bus voltages, line impedances, and phase angles in the power system can be regulated rapidly and flexibly. N-R power flow is very important tool for the analysis power systems and it is used in operational and planning. The main objective of power flow is calculating unspecified bus voltage angles and magnitudes.

The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents. Flexible Alternating Current Transmission System (FACTS) is static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability. It is generally power electronics based device. The FACTS devices can be divided in three groups, dependent on their switching technology: mechanically switched (such as phase shifting transformers), thyristor switched or fast switched, using IGBTs. While some types of FACTS, such as the phase shifting transformer (PST) and the static VAR compensator (SVC)[4] are already well known and used in power systems, new developments in power electronics and control have extended the application range of FACTS[6].

This paper presents the performance of Newton-Raphson power flow analysis for IEEE-57bus system with and without SVCC FACTS controller and verifies the voltage & Angle Stability of a power system.

2. NEWTON-RAPHSON POWER FLOW APPROACH

Load-flow studies are very common in power system analysis. Load flow allows us to know the present state of a system, given previous known parameters and values. The power that is flowing through the transmission line, the power that is being generated by the generators, the power that is being consumed by the loads, the losses occurring during the transfer of power from source to load, and so on, are iteratively decided by the load flow solution, or also known as power flow solution. In any system, the most important quantity which is known or which is to be determined is the voltage at different points throughout the system. Knowing these, we can easily find out the currents flowing through each point or branch. This in turn gives us the quantities through which we can find out the power that is being handled at all these points [2].

Let F(x) be a nonlinear function of (x)
Where (x) = a set of variables
If F(x) is expanded in terms of Taylor’s series up to terms containing first derivatives only around an initial set of points x_o , F (x) can be written as:

$$F(x) = F(x_o) + F(x_o)'(\Delta x) \tag{1}$$

Where

$F(x_o)$ = Value of the function at, x_o

$F(x_o)'$ =First partial derivatives of F (x) at x_o

Δx = Changes in the values of variables

At the optimum, Kuhn-Tucker conditions are to be, satisfied, implying that:

$$F(x)' = F(x_o)' + F(x_o)''(\Delta x) = 0 \qquad (2)$$

Where

$F(x_o)''$ = Hessian of F(x) at x_o

After rearranging,

$$(\Delta x) = -\left[F(x_o)''^{-1} F(x_o)' \right] \qquad (3)$$

$$x_i^{(k+1)} = x_i^{(k)} + \Delta x_i^{(k)} \qquad (4)$$

Equations (3) arid (4) are the basic relations for the development of second order Newton formulation.

3. POWER FLOW CONTROL

The power transmission line can be represented by a two-bus system ―k and ―m in ordinary form. The active power transmitted betweens bus nodes k and m is given by [2, 9]:

$$P = \frac{V_m V_k \sin(\delta_k - \delta_m)}{X} \qquad (5)$$

Where $V_m \& V_k$ are the voltages at the nodes, $\delta_k - \delta_m$ the angle between the voltages and X the line impedance. The power flow can be controlled by altering the voltages at a node, the impedance between the nodes and the angle between the end voltages [5]. The reactive power is given by:

$$P = \frac{V_k^2}{X} - \frac{V_m V_k \cos(\delta_k - \delta_m)}{X} \qquad (6)$$

4. STATIC VAR COMPENSATOR

Basically, the SVC consists of a thyristor-controlled reactor (TCR) in parallel with a capacitor bank. The firing-angle control of thyristor enables the SVC to have very fast response. It provides fast reactive power compensation, improves the bus voltage profiles, increases system stability margin and damps power system oscillations [4, 5, 9, 12].

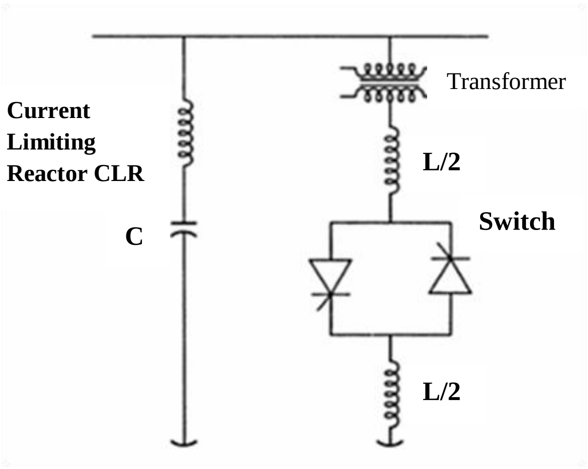

Fig 1: A basic schematic for an SVC

Reactive power [7] compensation is necessary for voltage regulation, stability enhancement and for increasing power transmission capability [2, 12]. Both the STATCOM and the SVC have been used to provide variable shunt reactive compensation [1]. They provide rapidly controllable, automatic variable shunt compensation at the appropriate buses in the power system [4]. Moreover, these devices can be placed in the network more easily than the generating units without any danger of the increasing the faults. The two most popular configuration of this type of shunt controller are the fixed capacitor (FC) with a thyristor controlled reactor (TCR) and the thyristor switched capacitor (TSC) with TCR. Among these two setups, the second (TSCTCR) minimizes stand-by losses; however from a steady-state point of view, this is equivalent to the FC-TCR. In this paper, the FC-TCR structure is used for analysis of SVC which is shown in figure 1. The TCR consists of a fixed reactor of inductance L and a bi-directional thyristor valve that are fired symmetrically in an angle control range of 90° to 180°, with respect to the SVC voltage.

4.1 Operating Principle

The current through the reactor can be regulated by closing the thyristor switch at any point between 0º to 90º from the start of the voltage wave. When the switch closes at 0º, a full current wave passes through the reactor. This reactor current, as per design, is higher than the capacitor current at the line voltage. The two currents are in phase opposition, giving a resultant, which is inductive. The SVC [9, 10] is operating in the inductive mode. As we advance the firing angle, the inductive current wave form shrinks and the current reduces. Beyond the matching point, the resultant of the two currents is capacitive. The following three important features to be noted:

1. Since the inductive current comes in a truncated form, it brings in harmonics, which are a regular feature here.

2. The thyristors are self-commutating, that is, the inductive will be off, at the end of the current wave by itself.

3. Under a static operation, the regulation is of an instant type and can jump from a high capacitive output to a high reactive output with a time lag of hardly a few cycles, if required by the power system.

Let us refer to the basic schematic of an SVC as shown in Figure2

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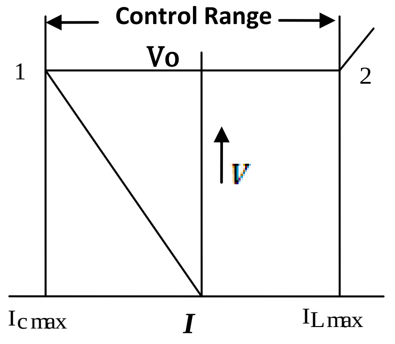


Fig 2: Operating Control Range of SVC

The reactive power output of the reactive is higher than that of the capacitor, at rated voltages on both. The reactor output is regulated. If the system is overloaded and requires capacitive current support the reactor current is reduced below that of the capacitor current so that the net outflow from the SVC is capacitive. The maximum capacitive current, that the SVC provides, is $I_{c\max}$ with the reactor current falling to zero. The system changes to light load conditions and the system voltage rises. Some reactive current has to be added to hold down the system voltage, SVC [11] then counter-balances the capacitive current fully and produces a resultant lagging current. It reaches $I_{c\max}$, which the SVC can produce. Please note that under this condition, the SVC is producing a resultant current of $I_{l\max} - I_{c\max}$ beyond point 2, the system voltage will keep on rising. The control range of the voltage with the SVC lies between points 1-2.

4.2 Characteristic of SVC

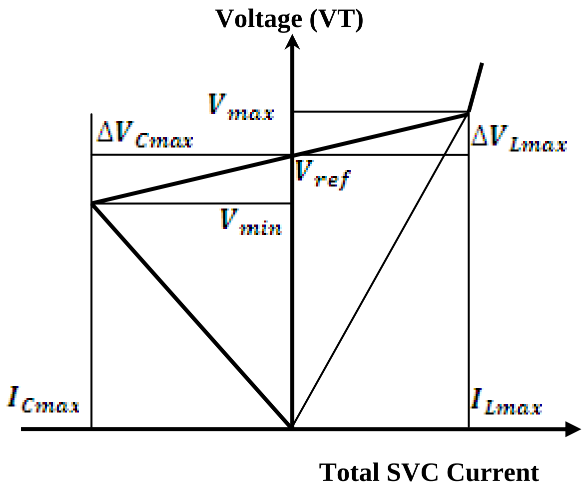


Fig 3: V-I characteristics of SVC

A typical terminal voltage versus output current of a static Var compensator with a specific slope is shown in Fig.5.In most applications, the static Var compensator [12] is not used as a perfect terminal voltage regulator, but rather the terminal voltage is allowed to vary in proportion with the compensating current. This regulation slope is defined as:

$$\text{Slope} = \frac{\Delta V_{c\max}}{I_{c\max}} = \frac{\Delta V_{L\max}}{I_{L\max}} \qquad (7)$$

The regulation slope allows:

- To extend the linear operating range of the compensator
- To improve the stability of the voltage regulation loop
- To enforce automatic load sharing between static Var compensator as well as other voltage regulating devices.

The voltage at which the static compensator neither absorbs nor generates reactive power is the reference voltage V_{ref} (Fig.5).In practice, this reference voltage can be adjusted within the typical range of ±10%.The slope of the characteristic represents a change in voltage with compensator current and therefore, can be considered as a slope reactance X_{SL}. The SVC response to the voltage variation is, then, determined from:

$$V_T = V_{ref} + X_{SL} * I_{svc} \qquad (8)$$

5. SVC Power Flow Model

Two SVC models are presented in this section. These models differ from the usual representation of SVC [10] as a voltage source. They are based on the concept of variable susceptance. These are the shunt variable susceptance model and the firing-angle model, where the SVC variables are combined with bus voltage magnitudes and angles of the network for obtaining power flow solution. These SVC models are presented in the following sub-sections.

5.1 Shunt Variable Susceptance Model

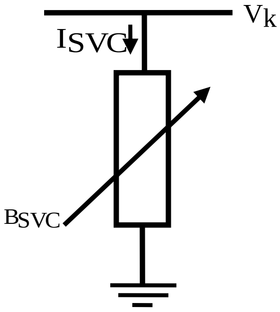


Fig 4: Variable shunt Susceptance model of SVC

In practice the SVC can be seen as an adjustable reactance with either firing-angle limits or reactance limits. The equivalent circuit shown in Figure 4. is used to derive the SVC nonlinear power equations and the linearised equations required by Newton's method. With reference to Figure 4, the current drawn by the SVC [2] is

(9)

Here the reactive power, which the SVC draws, is given by –

$$Q_{I_{SVC}} = Q_k = -V_k^2 B_{SVC} \qquad (10)$$

This is also the reactive power which is injected at bus k. The linearised equation of the SVC is given below by Equation (11) where the equivalent susceptance, B_{SVC} appears as a state variable –

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^i = \begin{bmatrix} 0 & 0 \\ 0 & Q_k \end{bmatrix}^i \begin{bmatrix} \Delta Q_k \\ \Delta B_{SVC} / B_{SVC} \end{bmatrix}^i \qquad (11)$$

According to Equation (11), the variable shunt susceptance, B_{SVC} is updated at the end of iteration (i) as given below:

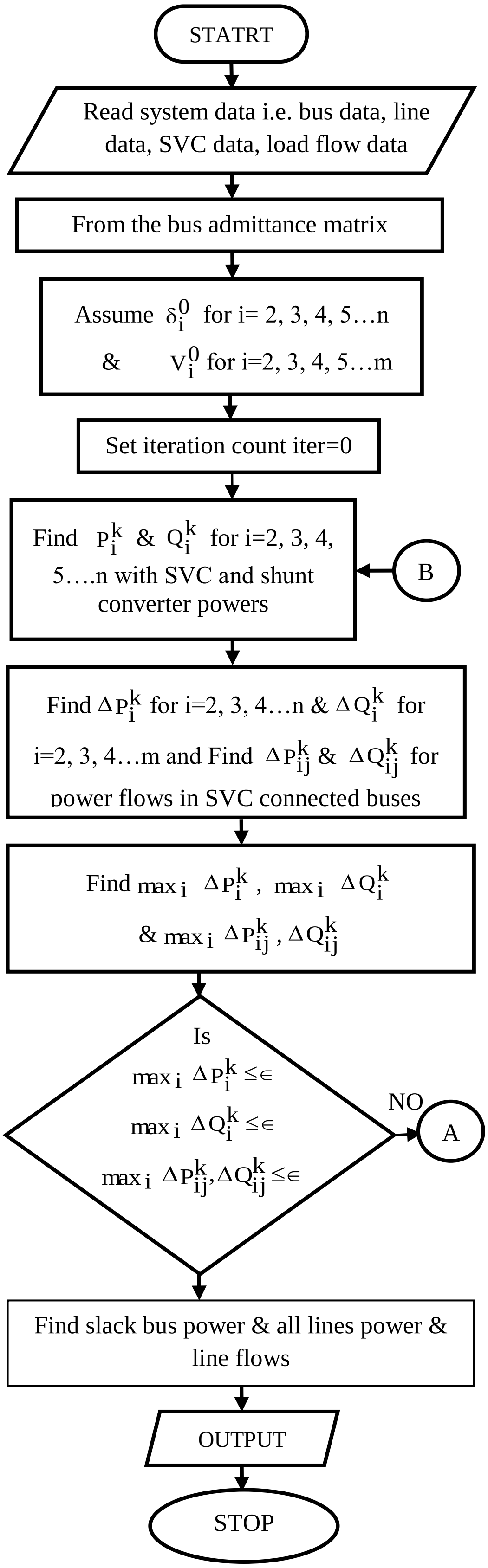
$$I_{SVC} = B_{SVC} V_k \qquad B^i_{svc} = B^{i-1}_{svc} + \left(\frac{\Delta B_{svc}}{B_{svc}}\right)^i B^{i-1}_{svc}$$

(12)

The total SVC susceptance is represented by this varying susceptance, which is necessary to maintain the nodal voltage at the prescribed magnitude. When the SVC susceptance has been computed, the firing angle required for this compensation can be determined.

5.2 Firing Angle Model

An alternative SVC model, which circumvents the additional iterative process, consists in handling the thyristor-controlled reactor (TCR) firing angle α as a state variable in the power flow formulation 13]. The variable α will be designated here as α_{SVC} to distinguish it from the TCR firing angle α used in the TCSC model. The positive sequence susceptance of the SVC, given by [2, 13]



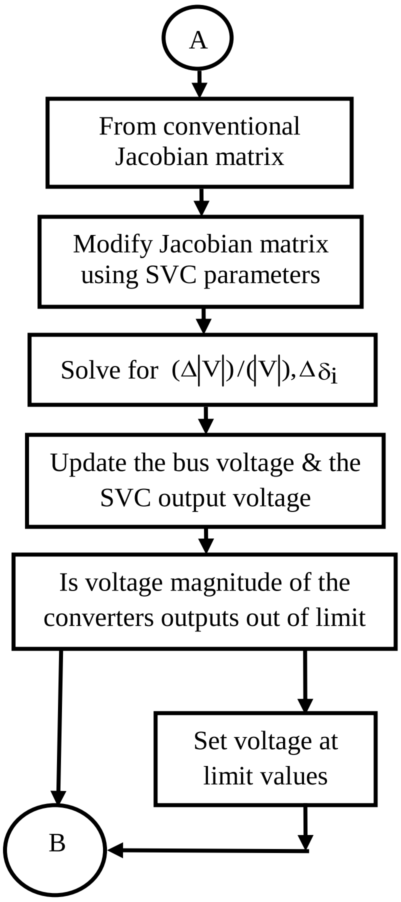


Fig 5: Flowchart of Power flow with SVC

$$I_{svc(1)} = jB_{svc}V_{(1)} \tag{13}$$

Where

$$B_{svc} = B_C - B_{TCR} = \frac{1}{X_C X_L}\{X_L - \frac{X_C}{\pi}[2(\pi-\alpha)+\sin 2\alpha]\}$$

$$X_L = \omega L \quad X_C = \frac{1}{\omega c} \tag{14}$$

$$Q_k = \frac{-V_k^2}{X_C X_L}\{X_L - \frac{X_C}{\pi}[2(\pi-\alpha_{svc}) + \sin(2\alpha_{svc})]\} \tag{15}$$

From Equation (15), the linearised SVC equation is given as

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2V_k^2}{\pi X_L}[\cos(2\alpha_{svc}) - 1] \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \Delta\alpha_{svc} \end{bmatrix} \tag{16}$$

At the end of iteration (i), the variable firing angle α_{SVC} is updated according to

$$\alpha_{SVC}^{(i)} = \alpha_{SVC}^{(i-1)} + \Delta\alpha_{SVC}^{(i)} \qquad (17)$$

6. SIMULATION & RESULTS

This paper is presented in the concept of voltage stability of IEEE-57 bus system i.e. voltage & angle magnitude for Newton-Raphson power flow and SVC. SVC connected for IEEE-57 bus system in bus number-41.Then the voltage magnitude lies between 0.95-1.05 P.U.

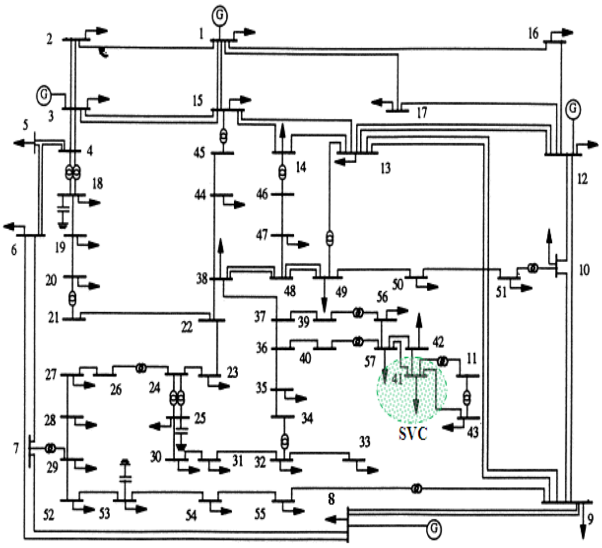


Fig 6: IEEE 57 bus System with SVC

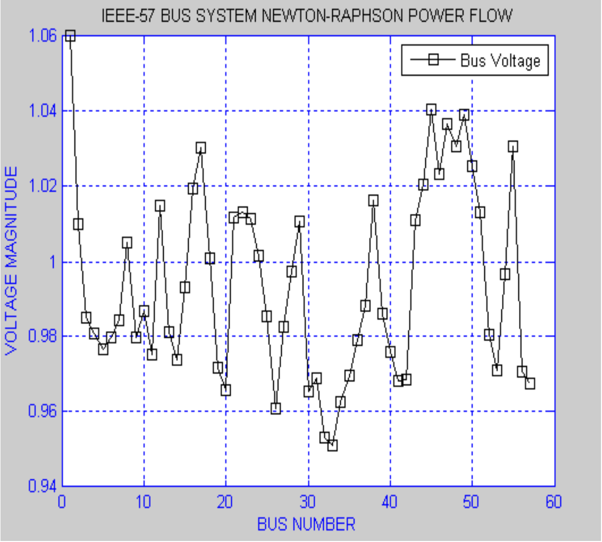


Fig 7: IEEE 57 bus System N-R power flow Voltage Profile

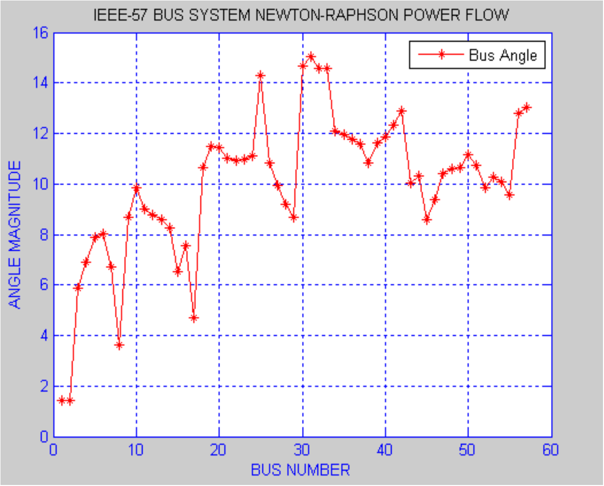


Fig 8: IEEE 57 bus System N-R power flow Angle Profile

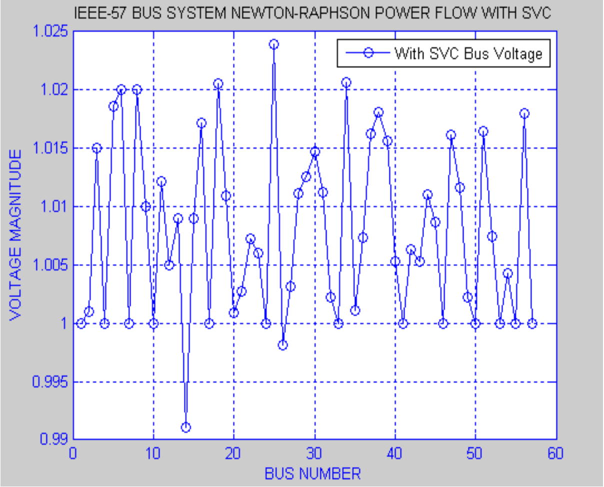


Fig 9: IEEE 57 bus System N-R power flow with SVC Voltage Profile

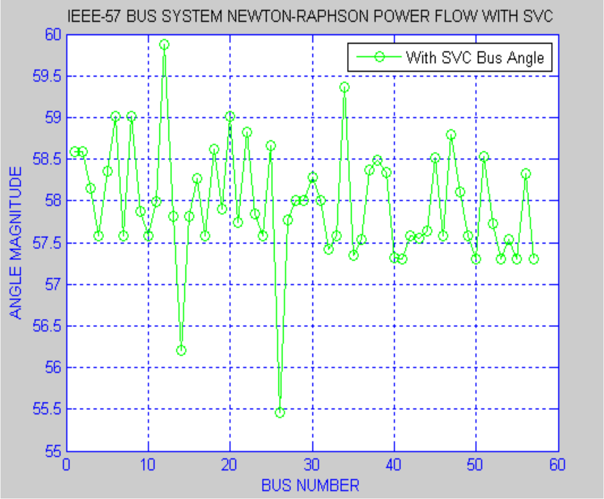


Fig 10: IEEE 57 bus System N-R power flow with SVC Angle Profile

Table 1. MATLAB Output of IEEE-57 bus system voltage & angle magnitude of N-R Power flow SVC

BUS NO	V (P.U)	ANGLE (DEGREE)	Vsvc (P.U)	ANGLE (DEGRE)
1	1.0600	01.4067	1.0000	58.5876
2	1.0100	01.4067	1.0010	58.5876
3	0.9850	05.8615	1.0150	58.1552
4	0.9765	06.9149	1.0000	57.5876
5	0.9800	07.9008	1.0186	58.3607
6	0.9844	08.0353	1.0200	59.0147
7	1.0050	06.7305	1.0000	57.5876
8	0.9800	03.6456	1.0210	59.0147
9	0.9867	08.6756	1.0100	57.8687
10	0.9752	09.8352	1.0000	57.5876
11	1.0150	09.0009	1.0122	57.9938
12	0.9811	08.7864	1.0050	59.8741
13	0.9737	08.5663	1.0090	57.8089
14	0.9932	08.2373	0.9911	56.2116
15	1.0193	06.5271	1.0090	57.8089
16	1.0304	07.5757	1.0172	58.2735
17	1.0010	04.7206	1.0000	57.5876
18	0.9716	10.6655	1.0205	58.6137
19	0.9658	11.4934	1.0109	57.9009
20	1.0116	11.4429	1.0039	59.0077
21	1.0130	11.0236	1.0027	57.7446
22	1.0115	10.9344	1.0072	58.8276
23	1.0016	10.9695	1.0060	57.8492
24	1.0250	11.0921	1.0000	57.5876
25	0.9610	14.3136	1.0239	58.6630
26	0.9826	10.8536	0.9981	55.4670
27	0.9973	09.9570	1.0031	57.7632
28	1.0320	09.2087	1.0111	58.0007
29	1.0106	08.6627	1.0126	58.0032
30	0.9656	14.6520	1.0147	58.2832
31	0.9691	15.0383	1.0112	58.0020
32	0.9535	14.5732	1.0022	57.4245
33	0.9509	14.5954	1.0000	57.5876
34	0.9625	12.1091	1.0207	59.3709
35	0.9695	11.9452	1.0011	57.3483
36	0.9791	11.7686	1.0073	57.5345
37	0.9882	11.5585	1.0163	58.3766
38	1.0162	10.8433	1.0181	58.4807
39	0.9860	11.6063	1.0156	58.3345
40	0.9761	11.8678	1.0053	57.3206
41	0.9681	12.3211	1.0000	57.2976
42	0.9687	12.8993	1.0063	57.5876
43	1.0111	10.0297	1.0053	57.5485
44	1.0206	10.3286	1.0110	57.6427
45	1.0407	08.5923	1.0087	58.5146
46	1.0235	09.3932	1.0000	57.5876
47	1.0367	10.4307	1.0161	58.7887
48	1.0307	10.5784	1.0116	58.1072
49	1.0391	10.6397	1.0022	57.5876
50	1.0255	11.1493	1.0000	57.2976
51	1.0131	10.7458	1.0165	58.5337
52	0.9807	09.8370	1.0074	57.7209
53	0.9712	10.2848	1.0000	57.2976
54	0.9965	10.0918	1.0043	57.5431
55	1.0308	09.5643	1.0000	57.2958
56	0.9708	12.8084	1.0180	58.3284
57	0.9674	13.0325	1.0000	57.2976

7. CONCLUSION

This paper consists of various aspects, regarding voltage and angle profile of Newton-Raphson power flow analysis for IEEE-57 bus system with and without SVC has been presented and the importance to maintain voltage profile and angle stability improvement has been discussed. There by the reactive power compensation was successfully done in the particular transmission whenever it is required. The power flow and the voltage profile in various transmission lines along with and without the placement of SVC in a specific transmission line is obtained in order to improve the system performance. Hence the themes of the paper to maintain voltage stability and angle enhancement have been successfully achieved with the incorporation of SVC.

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