LOSS MINIMIZATION AND VOLTAGE STABILITY ENHANCEMENT IN POWER SYSTEMS USING STATIC VAR COMPENSATOR AND TAP CHANGING TRANSFORMER

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ABSTRACT

This paper describes the effect of the reactive power compensation by using static var compensator(SVC) and tap changing transformer in minimize losses and maintaining the voltage profile of the power systems. The weakest bus is determined by the sensitivity index method. Then the static var compensator is installed at the weakest bust and reactive power is increased. The tap changing transformer is combined to minimize losses and voltage stability. The proposed method was applied to 14-bus and 30-bus IEEE systems is to show its feasibility and capability. All simulation was done by using the MATLAB version 7.5 programming.

Keywords:
Static var compensator, tap changing transformer, voltage stability, sensitivity index, reactive power compensation.

1.0 INTRODUCTION

Voltage stability can also call "load stability". A power system lacks a capability to transfer an infinite amount of electrical power to the load. The main factor causing voltage instability of the power system is to meet the demands for reactive power in the heavily stressed systems to keep desired voltages. Other factors contributing to voltage stability are the generator reactive power limits, the loads characteristic, the characteristic of the reactive power compensation devices and the action of the voltage control devices.

There are many factors affecting voltage stability of the power system such as insufficient reactive power, voltage dependent loads and load voltage regulating transformers [1]. Reactive power compensation is often the most effective method to improve both transmission capability and voltage stability [2]. One of the techniques is by using the static var capacitors which have been commonly used in transmission and distribution networks.

SVC is a shunt connected static var load whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables. SVC is similar to a synchronous condenser in that it is used to supply or absorb reactive power but without rotating part. It contains the equivalent of automatic voltage regulator system to set and maintain a target voltage level.

A tap changing transformer offer variable control to keep the supply voltage within its limits. It can control the real and reactive power in order to minimize the losses in the power system by altering the magnitude [3].

This project presents the variations of SVC value and tap changing transformer value in minimizing losses and improving voltage stability.

2.0 THEORETICAL BACKGROUND

2.1 Power Flow Analysis

The power flow analysis commonly referred as load flow analysis is very important in power system analysis, planning and designing for the future expansion of power system [5]

There are many techniques of solving a load flow solution of power systems, such as:

i) The GaussMethod

ii) The Gauss-Seidel Method
iii) The Newton Raphson Method
iv) The Fast Decouple Method

The Newton Raphson Method is used to calculate the power flow in this project. This method is very reliable and extremely fast in convergence compared to other methods. The computational time for one of Newton Raphson iteration is about one-seventh times of Gauss Seidel Method. It is not sensitive that cause poor or non-convergence as other load flow methods. The rate of convergence is relatively independent of the system size. For large power systems, this method is found to more efficient and practical [3].

$$P_i=\sum_{j=1}^{n} |V_i|\,|V_j|\,|Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j)$$
....(1)

$$Q_i=-\sum_{j=1}^{n} |V_i|\,|V_j|\,|Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j)$$
...(2)

Equation (1) and (2) constitute a set of nonlinear algebraic equations in terms of the independent variables, voltage magnitude per unit, and phase angle in radians. We have two equations for each load bus, given by (1) and (2), and one equation for each voltage controlled bus, given by equation (2) [3].

2.2 Index Formulation

The voltage stability index was being developed by Abdul Rahman T.K [7]. Consider a line connecting bus i to bus $i+1$.

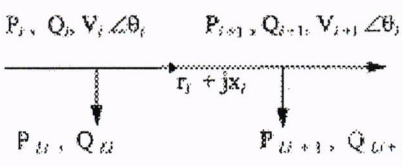

Figure 3.2

Therefore the voltage stability index is given by,

$$L = 4\,[\,V_oV_L\cos(\theta_O-\theta_L) - V_L^2\cos(\theta_O-\theta_L)^2\,]\,/\,V_o^2$$
.... (4)

Where; L = voltage stability index
V_o = open circuit coltage
V_L = load voltage
θ_O = open circuit angle
θ_L = base angle

Since $(\theta_O-\theta_L)$ is very small, $(\theta_O-\theta_L)\approx 1.0$ which can be simplified to

$$L = 4\,[\,V_oV_L - V_L^2\,]\,/\,V_o^2 \quad \text{.............. (5)}$$

L must be kept less than 1.0 to maintain voltage stability. If L exceeds 1.0, the voltage at the referred bus becomes imaginary which indicates that voltage collapse had occurred in the system.

The stability of load buses in a power system for a given loading could be studied by evaluating the voltage stability index L applied to the Thevenin equivalent circuits. To maintain a stable system at load bus i, $L_i \le 1.0$ and bus i is closed to its voltage stability limit i.e critical if Li approaches 1.0.

The sensitivity index (SI) is given by;

$$SI = \frac{\delta L_i}{\delta P_i}$$

$$= \frac{\delta L_i}{\delta V_{Li}} \times \frac{\delta V_{Li}}{\delta P_i} \quad \text{............... (6)}$$

Where;

$$\frac{\delta L_i}{\delta V_{Li}} = [\,4V_o - 8V_L\,]\,/\,V_o^2$$

$\frac{\delta V_{Li}}{\delta P_i}$ comes from inverse Jacobian matrix.

It is noted that for a system, the value of SI shows any changes in active power P will change the value of stability index L most. This SI technique was used to determine the suitable location of SVC and tap changing transformer, where the bus with highest value of SI should be the best location of SVC and tap changing transformer in the system.

2.3 Reactive power compensation concept

2.3.1 Static var compensator (SVC)

SVC is a shunt device which can control the power flow and improve transient stability on power grids. The SVC regulates voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (SVC capacitive). When system voltage is high, it absorbs reactive power (SVC inductive).

Several advantages of installing an SVC at one or more suitable points in the network:

i) Increase transfer capability
ii) Reduce losses while maintaining a smooth voltage profile under different network conditions.
iii) Mitigate active power oscillations through voltage amplitude modulation.

2.3.2 Tap changing transformer

Tap changing transformer can control the reactive var flow so that optimum bus can be determined and reduced line losses. A method of controlling the voltage in the networks make the used of transformers, the turn ratio of which may be change. The general formula for adjustment tap changing transformer is given by the equation (3) [6].

$$t_i^N = t_i^0 + C_i\,(v_i^{reg} - v_i) \quad \ldots\ldots\ldots\ldots(3)$$

Where

t_i = value of tap changing transformer
v_i = voltage change ratio
C_i = direction factor

The presents of a tap changing transformer allows manual change of the turn ratio and the output voltage. Because of the impedance of the lines, the voltage at the receiving end is slightly lower than the voltage at the sending end for most loads [2].

3.0 METHODOLOGY

The study aimed to identify the effect of SVC on the total losses and voltage stability of the power systems. Firstly the test bus was a chosen by running the load flow and sensitivity index without any compensation. The sensitivity index is used to determine the weakest bus. The highest value of sensitivity index will be the reference bus. It is because this reference bus is the most critical in maintaining the stability systems. Hence the SVC will be installed in that weakest bus.

For total loss analysis, the SVC and tap changing transformer is inserted gradually by manual. The losses of each value of SVC and tap changing transformer is recorded until it reached its minimum value. Hence, the final result is being recorded. The flow chart of total loss analysis is illustrated as Figure 3.1.

For voltage stability analysis, the reactive load is being increased until the voltage magnitude is below than 0.6V. When the system is at maximum loads, the suitable value of SVC and tap changing is inserted until the voltage magnitude is greater than 0.6V. Hence, the final result is being recorded. The flow chart of voltage stability is illustrated as figure 3.1

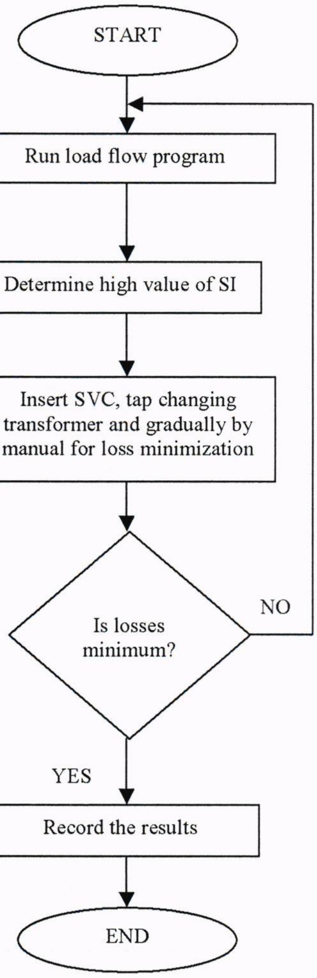

Figure 3.1: Loss Minimization Flow Chart

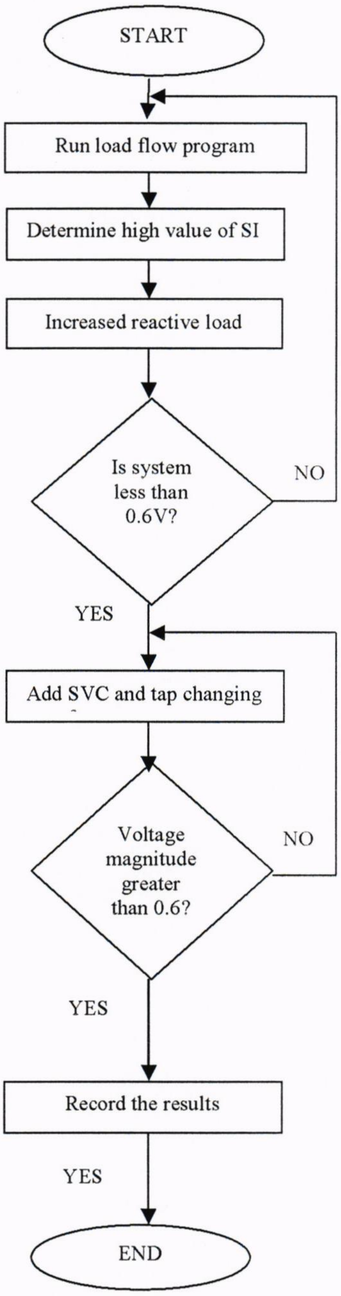

Figure 3.2: Voltage Stability Enhancement Flow Chart

4.0 RESULTS AND DISCUSSION

A test was conducted on the 30-bus and 14-bus IEEE reliability test system. For 30-bus system, it has 6 generator (PV) and 24 load (PQ) busses. For 14-bus system, it has 5 generator (PV) and 9 load (PQ) busses. The single diagram is illustrated as below.

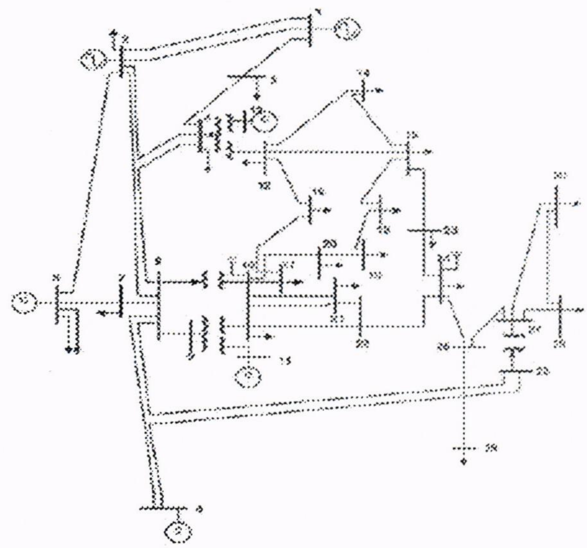

Figure 4.1: IEEE 30-bus sample system

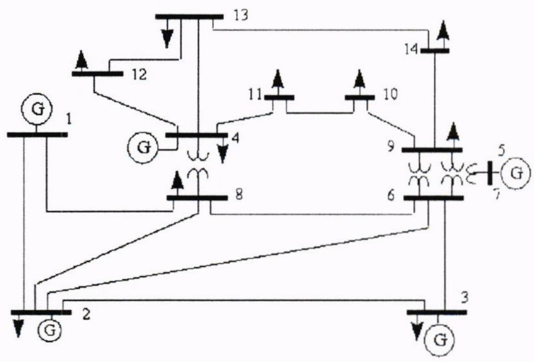

Figure 4.2: IEEE 14-bus system

4.1 Systems performance without SVC

Table 4.1 shows the stimulation result of the load flow diagram without injection of SVC. The total loss is computed.

Table 4.1: Result for total loss without injection of SVC.

	Total Loss	
IEEE System	P (MW)	Q(MVar)
14-Bus	19.058	53.774
30-Bus	17.599	22.244

4.2 Sensitivity index

For 14-bus reliability test system, bus 12 shows the highest value of SI with 0.3008 and for 30-bus reliability test system, bus 4 shows the highest value of SI index with 1.7161. These two buses are chosen as the best location for SVC.

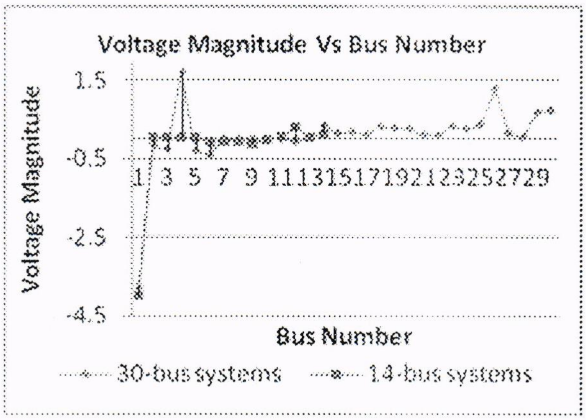

Figure 4.3: SI Index versus Bus Number

4.3 Sizing of SVC and tap changing transformer for loss minimization

For 14-bus systems, Figure 4.4 shows the relationship of total losses with reactive power. The minimum total loss obtained is 18.716MW when the reactive power injected is 14MVar.

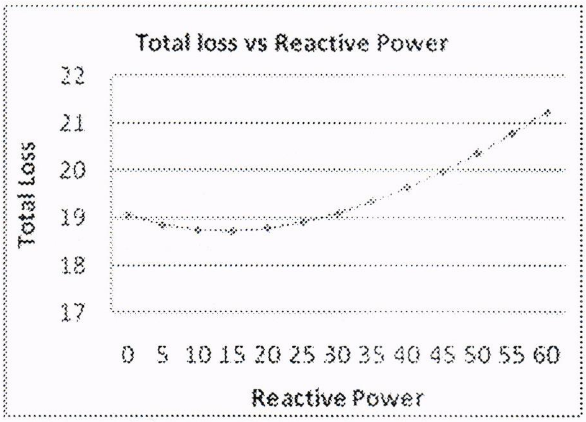

Figure 4.4: Total loss versus reactive power for 14-bus

For 30-bus systems, Figure 4.5 shows the relationship of total losses with reactive power. The minimum total loss obtained is 17.47MW when the reactive power injected is 35MVar.

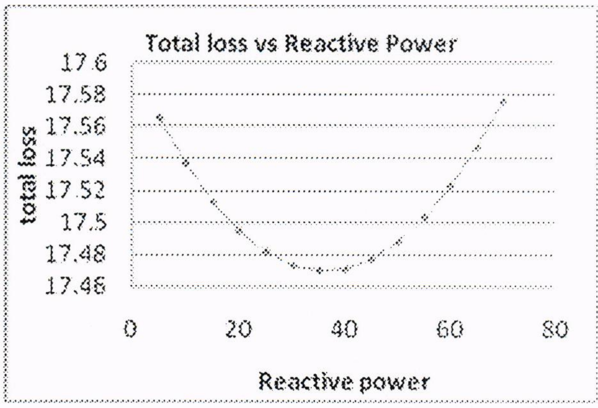

Figure 4.5: Total loss versus reactive power for 30-bus.

The tap changing transformer ratio with minimum loss for 14-bus systems is 1p.u. The result are illustrated in Figure 4.6

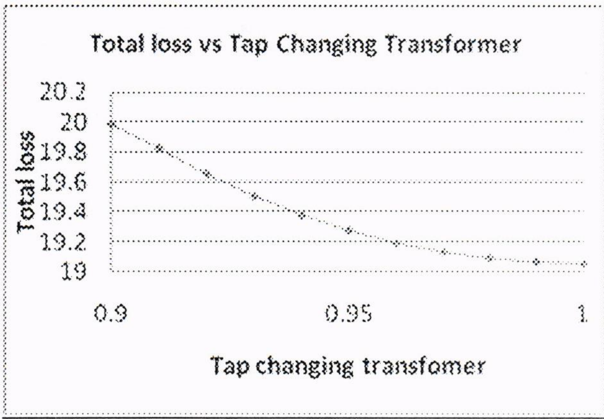

Figure 4.6: Total loss versus tap changing transformer .

For 30-bus systems, there are four busses tap changing transformer one at a time.

Each transformer bus are analyzed to find the best ratio for minimum losses. The results are illustrated as in Figure 4.7 to 4.10.

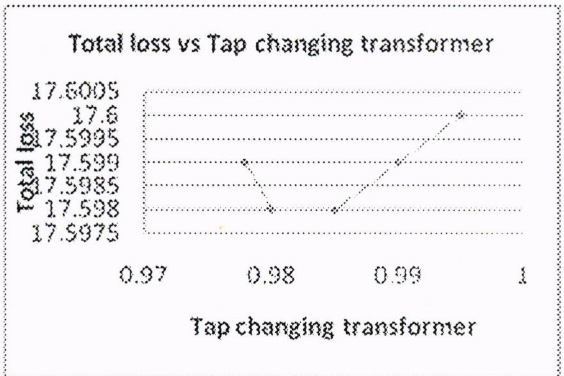

Figure 4.7: Total loss versus tap changing transformer at bus 9.

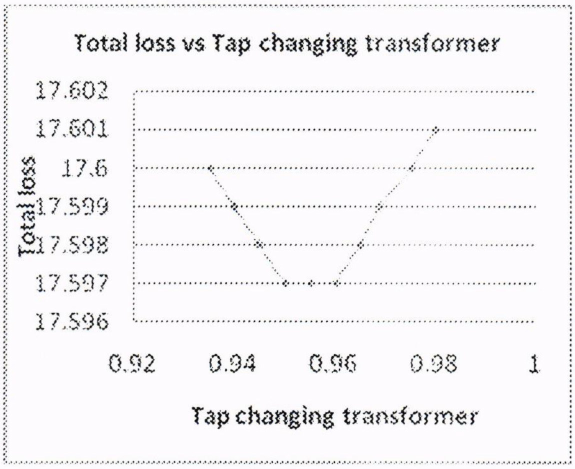

Figure 4.8: Total loss versus tap changing transformer at bus 10.

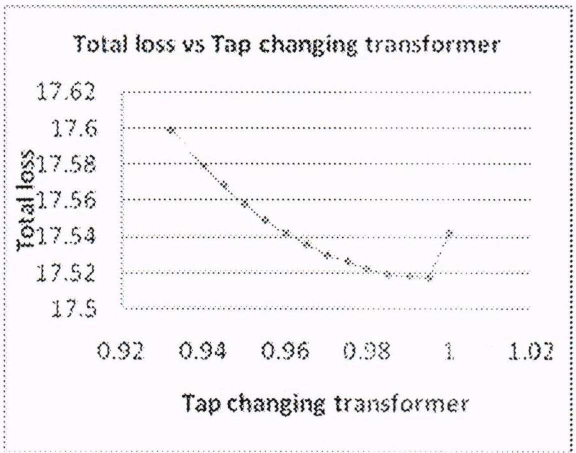

Figure 4.9: Total loss versus tap changing transformer at bus 12.

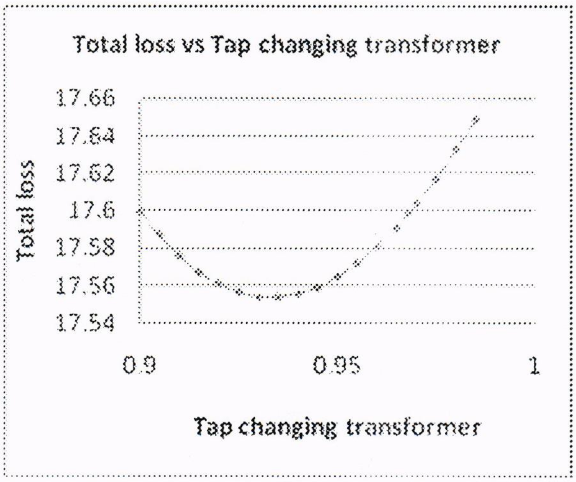

Figure 4.10: Total loss versus tap changing transformer at bus 28.

From the graph above, the suitable size of tap changing transformer of each bus is tabulated in Table 4.2.

Table 4.2: The suitable size of tap changing transformer of each bus.

Bus number	Size of tap changing transformer (p.u)
9	0.985
10	0.96
12	0.995
28	0.935

The system performance with SVC and tap changing transformer for minimizing the total loss is illustrated in Table 4.3 for 14-bus systems and Figure 4.4 for 30-bus systems.

Table 4.3: Systems performance of 14-bus systems with SVC and tap changing transformer

Size of SVC (Mvar)	Size of tap changing transformer (p.u)	Total loss(MW)
0	1.0	19.058
14	1.0	18.716

Table 4.4: Systems performance of 30-bus systems with SVC and tap changing transformer

Size of SVC (Mvar)	Size of tap changing transformer (p.u)	Total loss
0	0.978,0.969, 0.932,	22.244
35	0.985, 0.96, 0.995, 0.935	17.501

4.4 System performance with SVC and tap changing transformer for voltage stability

The systems is said to be unstable when the voltage magnitude is less than 0.6 [2]. For 14-bus systems, the system became unstable when the reactive load equal to 43MVar is injected at bus 12. For the 30-bus systems, the maximum reactive load is 625MVar. The result is illustrated as figure below.

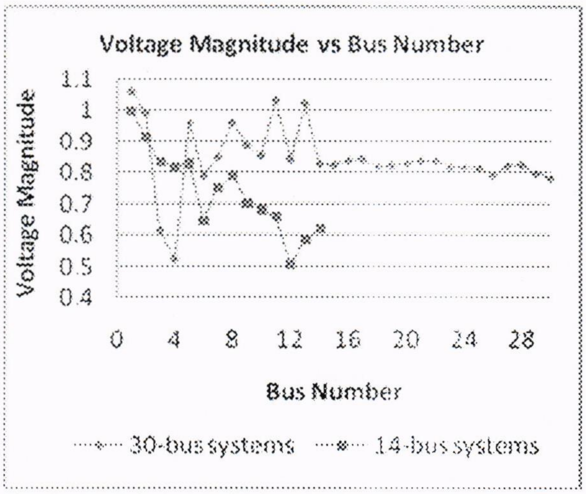

Figure 4.11: Voltage magnitude versus bus number

When injecting the suitable size of SVC and tap changing transformer in 14-bus systems and 30-bus systems, the voltage profile of both systems is being improved. For 14-bus systems, when 14MVar of SVC was injected, the voltage profile was increased to 0.747. This shows 32% of increment towards the stability level. For 30-bus systems, when 35MVar of SVC was injected at bus with the transformer tap ratio of 0.985p.u, 0.96p.u, 0.995p.u and 0.935p.u was injected, the voltage profile was increased to 0.632. This shows 17% of increment towards the stability level. The result is shown in figure below 4.12.

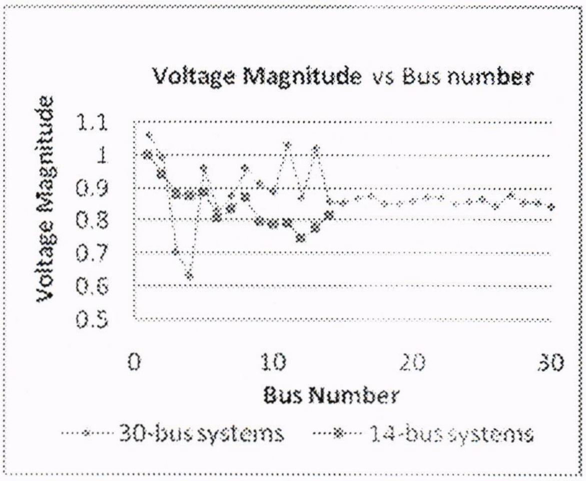

Figure 4.12: System performance with SVC and tap changing transformer for voltage stability

5.0 CONCLUSION

An investigation on reactive power loading and reactive power compensation was carried out for minimum losses and voltage stability. The test was performed on IEEE 14-bus systems and 30-bus systems. The SI index shows that bus 12 is the most sensitive bus of 14-bus systems and bus 4 is the most sensitive bus for 30-bus systems. The size of SVC and tap changing transformer for loss minimization injected at the weakest bus is 14MVar with 1p.u of tap changing transformer for 14-bus systems and 35MVar with 0.985p.u, 0.96p.u, 0.995p.u and 0.935p.u of tap changing transformer for 30-bus systems. The losses had reduced to 1.8% and 21.3% for 14-bus and 30-bus systems respectively. The reactive power loading which causes instability and generates more losses can be reduced by inserting SVC at the weakest bus.

6.0 FUTURE DEVELOPMENT

For future development, Artificial Intelligent such as Genetic Algorithm (GA) could be used to determine the optimal size and location of SVC and tap changing transformer for loss minimization and systems stability in power systems.

7.0 ACKNOWLEDGEMENT

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