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Newton-Raphson Power Flow Models of SVC Optimized by PSO

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Abstract –**Transmission lines consume a considerable amount of power. The necessity of power and its dependency has grown exponentially over the years. The void between limited production and tremendous demand has increased the focus on minimizing power losses. The losses like transmission loss range from the conjecture factors like physical or environmental losses to severe technical losses. The primary factors like reactive power and voltage deviation are significant in stretched conditions and long range transmission lines of powers. The short and medium range of transmission lines accounts for micro-static values of power loss but the transmission losses of vulnerable size are witnessed in long transmission range of more than 100 kilometres. In this paper, we have incorporated Static VAR compensator (SVC) as the FACTS (Flexible AC Transmission System) device to control the power loss in transmission lines. The optimal location SVC is studied on the basis of Particle Swarm Optimization (PSO) technique to minimize network losses. Validation through the implementation on the IEEE-14 and IEEE-30 bus systems shows that the PSO is found feasible to achieve the task.**
Keywords –**FACTS, IEEE-14, IEEE-30, PSO, SVC.**

I. Introduction

Industrialization and population growth are the primary factors for which the consumption of electricity is steadily increasing. It becomes increasingly difficult to get traffic areas to build new transmission lines or distribution. For these reasons, the power companies are seeking to increase the power that can be transported existing lines without compromising reliability and stability. Ideally, we would load them to the limits of the thermal capacity of drivers and use all lines to support the electrical load.

Transport networks and distribution of electric power have so far passive devices. Furthermore, the mesh lines requires more control of power flows. Network complexity also requires safety margins increased so that local disruptions do not cause any instability could spread throughout the transport network. The evolution of the electronic power topologies and their integration in electricity grids has resulted in major improvements on these, such as flexible compensation of reactive power, the continuous monitoring of the voltage busbar, the improving power factor etc.

The static compensator (SVC) based on controllable power electronics components is a device used to keep the voltage steady state and transient within the desired limits. CVS injects or absorbs reactive power in the busbar where it is installed, so as to meet the demand for reactive power load. It allows a flexible and continuous control of the voltage at the busbar.

The correction of the displacement factor is achieved in part by batteries of fixed compensation whose power is limited by the vacuum maximum permissible voltage on the network. In order to adapt the level of compensation for consumption, the fixed part is supplemented by an adjustable device based on a controlled reactance by thyristors. Although simple in principle, this device requires a filtering of low-frequency harmonics with large LC circuits.

II. Problem Statement

The methods of calculating the Load-Flow are extremely important in assessing the state of a power system, are evaluating operation and control, and for future extensions studies [1].

Calculating Load Flow begins by specifying the loads at some nodes, and produces power and the amplitudes of the voltages of the remaining nodes with both, the full description of the system including its impedances. The objective is to determine the complex nodal voltage from which all other amounts as the flow in the lines, currents and losses can be derived.

In mathematical terms, the problem can be reduced to a set of nonlinear equations where the real and imaginary components of the nodal voltages are variable. The number of equations is equal to twice the number of nodes. Nonlinearities can be roughly classified as quadratic kind. The gradient techniques and relaxation techniques are the only methods available for solving these systems [2].

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III. PROPOSED METHOD

Newton-Raphson method is used to find power loss of proposed system. Here we have taken IEEE 14 and IEEE 30 bus systems. The SVC is connected randomly at different buses. The voltage of all buses is heavily affected for the increasing load. The SVC is randomly connected and power flow losses for various buses are calculated to improve the voltage profile and also compensate the reactive power of whole system. Using the Newton Raphson method, the following analysis are made:

- To find base load losses of all buses and also total losses of IEEE 14 and IEEE 30 bus systems.
- To find load losses of all buses and also total losses for different load variation without SVC.
- To find load losses of all buses and also total losses for different load variation with SVC.

Newton-Raphson Method

The Newton Raphson method is the most sophisticated and the most important method for solving load flow studies especially for complex power networks. The Newton Raphson method is based on the Taylor series (sequential linearization) and partial derivatives. The general form of the problem is:

Find x, knowing that, $f(\hat{x}) = 0$

Each $\hat{x}$ estimation, $x^{(v)}$ defines:

$$\Delta x^{(v)} = \hat{x} - x^{(v)} \quad (1)$$

Iteration Index:

The representation of $f(\hat{x})$ by Taylor series gives:

$$f(\hat{x}) = f\left(x^{(v)}\right) + \frac{df\left(x^{(v)}\right)}{dx}\Delta x^{(v)} + \frac{1}{2}\frac{d^{(2)}f\left(x^{(v)}\right)}{dx^{(v)}}\left(\Delta x^{(v)}\right)^2 + \text{Terms of high order}$$

$f(\hat{x})$ is approximated by neglecting all terms except the first two.

$$f(\hat{x}) \approx f\left(x^{(v)}\right) + \frac{df\left(x^{(v)}\right)}{dx}\Delta x^{(v)} \quad (2)$$

This linear approximation is used to solve $\Delta x^{(v)}$

$$\Delta x^{(v)} = -\left[\frac{df\left(x^{(v)}\right)}{dx}\right]^{-1} f\left(x^{(v)}\right) \quad (3)$$

Solve the new estimate of $\hat{x}$

$$x^{(v+1)} = x^{(v)} + \Delta x^{(v)}$$

$$x^{(v+1)} = x^{(v)} - \left[\frac{df\left(x^{(v)}\right)}{dx}\right]^{-1} f\left(x^{(v)}\right) \quad (4)$$

Application of the Newton-Raphson Method in a Power Distribution Problem (Power Flow)

The injected apparent power S in a node can be written as:

$$S_i = V_i I_i^* = V_i\left(\sum_{k=1}^{n} Y_{ik} V_k\right) = V_i \sum_{k=1}^{n} Y_{ik}^* V_k^* \quad (5)$$

Here, admittance,

$$Y_{ik} = G_{ik} + jB_{ik} \quad (6)$$

And nodal voltage

$$V_i = |V_i| e^{j\theta_i} = |V_i| \angle \theta_i \quad (7)$$

$$\theta_{ik} = \theta_i - \theta_k \quad (8)$$

$$e^{j\theta} = \cos\theta + j\sin\theta \quad (9)$$

$$S_i = P_i + jQ_i = V_i \sum_{k=1}^{n} Y_{ik}^* V_k^* = \sum_{k=1}^{n} |V_i||V_k|\, e^{j\theta_{ik}}(G_{ik} - B_{ik}) \quad (10)$$

$$P_i = \sum_{k=1}^{n} |V_i||V_k|\left(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}\right) = P_{Gi} - P_{Di} \quad (11)$$

$$Q_i = \sum_{k=1}^{n} |V_i||V_k|\left(G_{ik}\cos\theta_{ik} - B_{ik}\sin\theta_{ik}\right) = Q_{Gi} - Q_{Di} \quad (12)$$

$$x = \begin{bmatrix} \theta_2 \\ \vdots \\ \theta_n \\ |V_2| \\ \vdots \\ |V_n| \end{bmatrix} f(x) = \begin{bmatrix} P_2(x) - P_{G2} + P_{D2} \\ \vdots \\ P_n(x) - P_{Gn} + P_{Dn} \\ Q_2(x) - Q_{G2} + Q_{D2} \\ \vdots \\ Q_n(x) - Q_{Gn} + Q_{Dn} \end{bmatrix} \quad (13)$$

The first iteration; $v = 0$

Choice of initial values:

As long as: $\left|f\left(x^{(v)}\right)\right| > \varepsilon$ gives,

$$x^{(v+1)} = x^{(v)} - J(x) f\left(x^{(v+1)}\right) \quad (14)$$

$$v = v + 1$$

The most complex part of the Newton-Raphson algorithm is the determination of the matrix and the inverse matrix Jacobean $J(x)$.

$$J(x) = \begin{bmatrix} \frac{\partial f_1(x)}{\partial x_1} & \frac{\partial f_1(x)}{\partial x_2} & \vdots & \frac{\partial f_1(x)}{\partial x_n} \\ \frac{\partial f_2(x)}{\partial x_1} & \frac{\partial f_2(x)}{\partial x_2} & \vdots & \frac{\partial f_2(x)}{\partial x_n} \\ \vdots & & \vdots & \vdots \\ \frac{\partial f_n(x)}{\partial x_1} & \frac{\partial f_n(x)}{\partial x_2} & \vdots & \frac{\partial f_n(x)}{\partial x_n} \end{bmatrix} \quad (15)$$

The Jacobean elements are calculated by calculating the partial derivatives of each function with respect to each variable.

$$f_1(x) = \sum_{k=1}^{n} |V_i||V_k|\left(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}\right) - P_{Gi} + P_{Di} \quad (16)$$

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$$\frac{\partial f_1(x)}{\partial \theta_1} = \sum_{k=1\neq i}^{n} |V_i||V_k| \left(-G_{ik} \sin \theta_{ik} + B_{ik} \cos \theta_{ik}\right) \qquad (17)$$

SVC is applied to reduce power loss.

Static VAr Compensator

The Static VAr Compensator (SVC) is a shunt connected device whose main functionality is to regulate the voltage at a chosen bus by suitable control of its equivalent reactance. A basic topology consists of a series capacitor bank, C, in parallel with thyristor-controlled reactor, L, as shown in Figure 1. In practice the SVC can be seen as an adjustable reactance [3] that can perform both inductive and capacitive compensation. The details about the modelling of the SVC can be found in [4, 5]. The SVC connected at node j is shown in Figure 2.

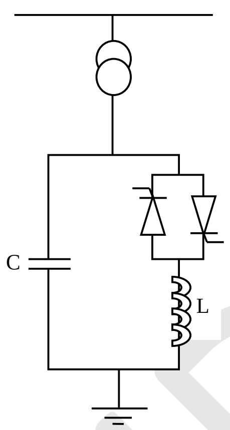

Figure 1: Basic SVC Topology

Figure 3 shows the injection model of the SVC, where I_{jsvc} is the complex SVC injected current at node j, V_i and V_j are the complex voltages at nodes i and j. The reactive power injection in node j is given by:

$$Q_j = -V_j^2 B_{SVC} \qquad (18)$$

Where, $B_{SVC} = B_C - B_L$, B_C and B_L are the susceptance of the fixed capacitor and thyristor controlled reactor, respectively. The reactive power can be transferred into injected current at bus *j* given by:

$$Q_j = jV_j B_{SVC} \qquad (19)$$

Figure 3 shows the SVC control block diagram where V_t is the voltage magnitude at the SVC terminal, V_{ref} is the voltage to be maintained by SVC, K is the gain of the controller, T is the time constant associated with the SVC control action, ΔB_{min} and ΔB_{max} denote the limits to the change of the SVC susceptance and C_{damp} is the signal from the damping controller.

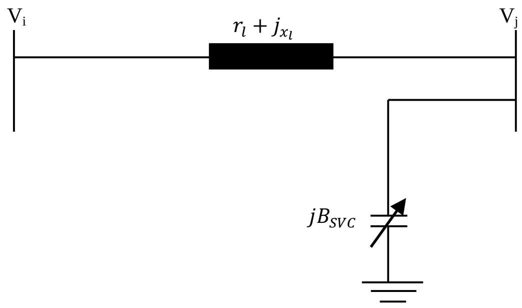

Figure 2: Representation of a SVC

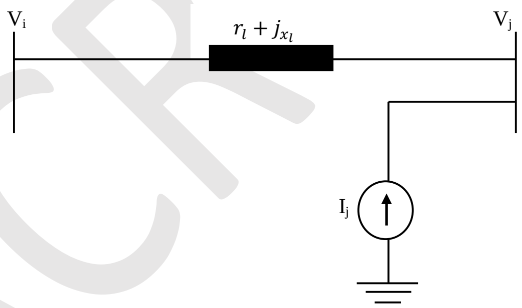

Figure 3: Current injection model of a SVC

In the proposed system, the location of SVC in a particular bus system is decided be Particle Swarm Optimization.

Particle Swarm Optimization

PSO is a technique used to explore the search space of a given problem to find the settings or parameters required to maximize or minimize a particular objective.

The original PSO algorithm was inspired by the social behaviour of biological organisms, specifically the ability of groups of some species of animals to work as a whole in locating desirable positions in a given area, e.g. birds flocking to a food source. This seeking behaviour was associated with that of an optimization search for solutions to non-linear equations in a real-valued search space.

Particle Swarm Algorithm

1. Begin
2. Factor settings and swarm initialization
3. Evaluation
4. g = 1
5. While (the stopping criterion is not met) do
6. for each particle
7. Update velocity

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8. revise place and localized best place
9. Evaluation
10. End For
11. Update leader (global best particle)
12. g + +
13. End While
14. End

The PSO procedure has various phases consist of Initialization, Evaluation, Update Velocity and Update Position.

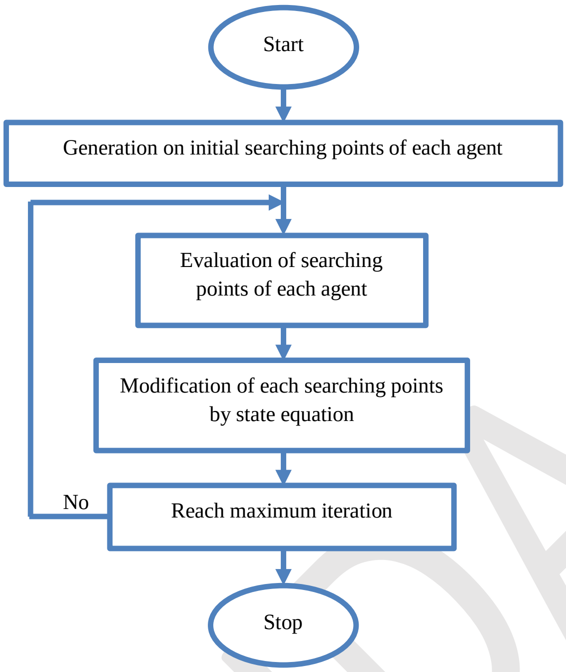

Figure 4: Flow chart of PSO

IV. Simulation And Results

On the IEEE-14 and IEEE-30 bus test systems (shown in Figure 5 and Figure 6) the proposed PSO algorithm technique have been tested. The performance of proposed algorithms has been studied by means of MATLAB simulation.

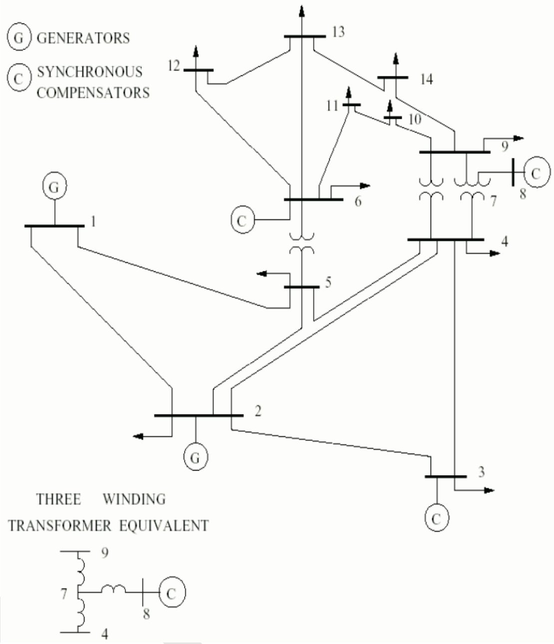

Figure 5: Single line diagram of the IEEE-14 bus test system

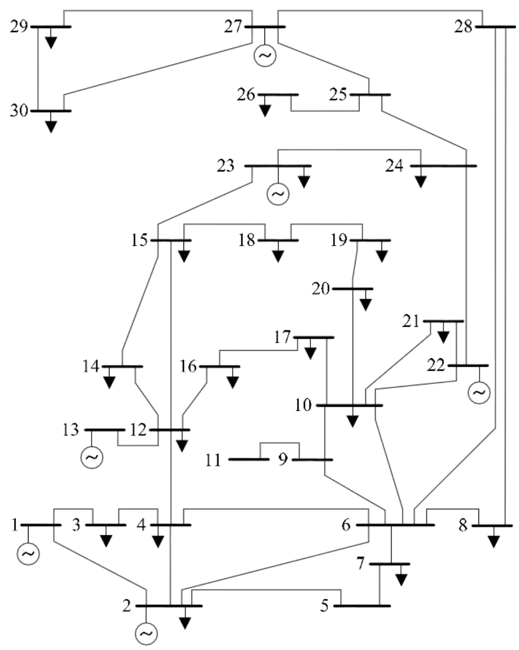

Figure 6: Single line diagram of the IEEE-30 bus test system

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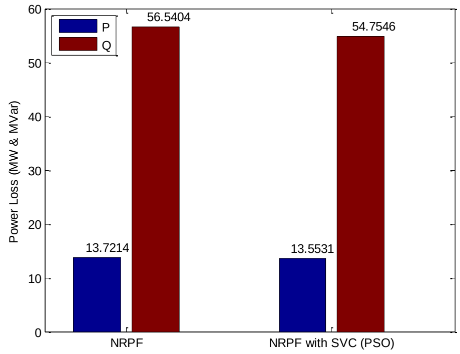

Figure 7: Active & Reactive power losses in IEEE-14 bus system

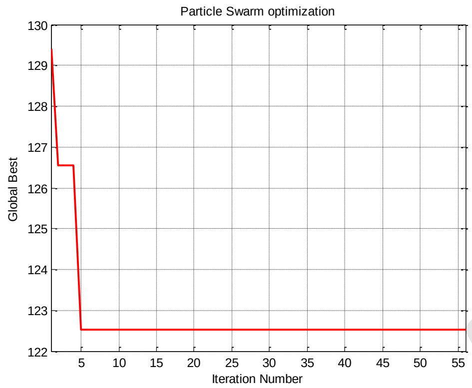

Figure 8: Iteration count for PSO

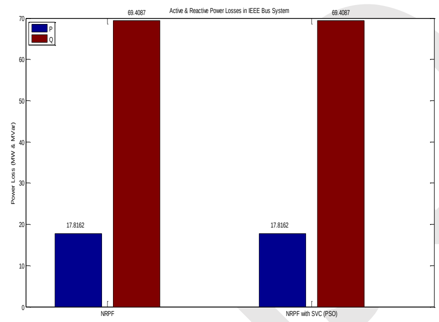

Figure 9: Active & Reactive power losses in IEEE-30 bus system

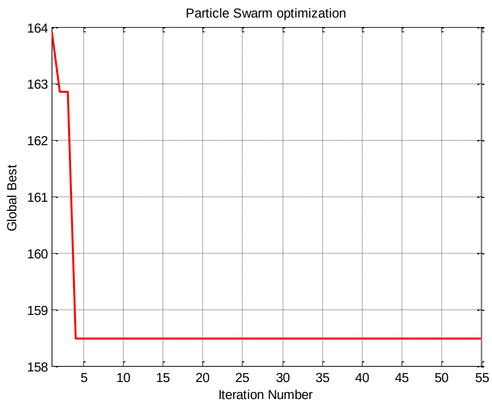

Figure 10: Iteration count for PSO

V. CONCLUSION

In the context of our research for the minimization of Transmission Power Losses by the application of FACTS devices, a comparison is made in the proposed approach. Particle Swarm Optimization is used to optimize the location of SVC using the MATLAB model. The tests were performed taking SVC as the FACTS device. The PSO algorithm has less power losses and much better than the line without SVC device.

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