Power Loss Minimization in Transmission System using Particle Swarm Optimization and Salp Swarm Algorithm

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Abstract **–**Physical features of network components result in energy and power losses when electrical energy is transported from generating facilities to end consumers via transmission and distribution networks. Electrical energy transmission by physical methods has some losses that cannot be totally avoided. Many possibilities exist to increase the energy efficiency of both current and future networks. Increasing efficiency necessitates putting in place procedures that go above and beyond the acknowledged norms of the activity. Network losses may be reduced by a variety of methods that are both practical and technological. TCSC (Thyristor Controlled Series Compensator) power loss reduction framework using metaheuristic approaches is presented in this research. IEEE-14, IEEE-33, and IEEE-57 bus test systems employ PSO and Salp Swarm Algorithm (SSA) to locate the best position for the TCSC. On the basis of active and reactive power losses, a performance evaluation is carried out.

Keywords – Active power, FACTS, PSO, Reactive power SSA, TCSC**.**

I. INTRODUCTION

For this purpose, flexible compensators affect the voltages at nodes, the series impedance of lines, and/or the phase angles of the system. The FACTS acronym stands for "Flexible Alternating Current Transmission System," and it refers to devices that improve power transfer capacity between a consumption point and a generation point by activating semiconductor elements. Translated in either case. Controlling both active and reactive power flows, while the latter is more important, is a common goal.

By their inherent capacity to operate intermittently across short and recurring time periods, the FACTS control reagents in power systems outperform more conventional approaches because of their reliance primarily on the fluctuation of system demand.

Short circuit, loss of load or group, opening of line, etc. may cause an acceleration or slowdown of mechanical and electrical powers, which may lead to a loss of synchronisation between one or more generating groups. For the network to return to a stable state of operation, the rotor angles fluctuate until they are protected by the adjustment systems.

Electricity use fluctuates regularly due to scheduling, weather, and other factors such as public holidays, weekends, and other special occasions (strikes, sporting events, etc.). Designing the electrical system with this in mind, the whole chain of production, transportation, and distribution to customers has been integrated. When storing a lot of energy in electrical form, it's necessary to create the same amount of electricity that is required to be consumed; we also know that there are limits to the production groups' technological capabilities, which leads us to a non-linear issue.

This has led to a growing interest in figuring out the most cost-effective ways to distribute the electricity generated by power plants. Because of its significance in electric power, this process has been studied since 1928, as shown by the large number of publications on the topic. This topic has been tackled using a variety of approaches and algorithms, with positive outcomes. Losses and operational restrictions of production groups have been included in later updates to the original concept, which was originally constructed without these considerations. Algorithms based on marginal costs are used to arrive at their ultimate forms:

- Costs of fuel and the efficiency of their use.
- Costs of operation and upkeep.
- Prohibited operating limits and operating zones.
- Response gradients for each unit.
- In addition, there may be transmission losses (penalty factors).
- Budgetary restraints.

The efficiency of these algorithms has been shown, however the time component has also been shown to be a drawback. The move to a market that is more dynamic, quick, and efficient has been made possible thanks to the development of "smart grids." When it comes to forecasting consumption, load distribution, and Economic Dispatching, neural networks are being employed more and more in the research of electrical networks. The usage of neural networks avoids the drawbacks of conventional approaches, such as wasted time, as well as the different non-linear and random aspects that may be taken into consideration.

II. Control of Transits

Distribution of energy in a mesh interconnection network is mostly determined by the location of loads.

- The location of manufacturing groups in operation.
- International trade.
- The location of the mechanism of compensating for reactive energy.
- Transportation infrastructure impedances.

It is via these energy transfers that clients are linked, and it uses the lines and transport cables to distribute energy in inversely proportion to their resistance. It's a predilection towards the "shortest road," if you will. The current that runs through the structures creates this energy flow. The more energy flowing through, the stronger the currents will be. When a structure is activated by a flaw, these intensities may rise. Although this structure will be referred to as supporting the initial passage, the phenomena of transfer of charge will take place.

Playing mostly on two factors ensures that transits are regulated:

Topology of the Network: Operation diagrams may be modified to alter the network impedance (e.g., creating lengthy waits to raise network impedance, or working to lower it) and distribution of production sources (e.g., distributing production sources more evenly).

Production Programs: As the dispatcher adjusts the group's production plans, he or she manipulates the allocation of production resources against demand. Customers must be lost as a last resort when all other options have failed. With the aid of driving and simulation tools and a given topology, it is possible to assess the transits in each of the facilities in accordance with the accepted production schedule and the location costs.. It is also feasible to determine the value of transits in the remaining works if a transport structure or production is triggered [3] [4].

III. State of the Art

Distribution losses account for a considerable percentage of power losses in electric networks. Power losses in distribution networks are estimated to be 14 percent of the total amount of power transferred. A combination of these losses and the deregulation of the energy market forced distribution firms to take the issue of losses in distribution networks very carefully before investing in the building of additional lines in order to boost transmission of electric power

Voltage drops and power losses can only be reduced by limiting the passage of strong reactive components of the line current in this line design, since the demand for active power is incompressible. The use of shunt capacitor batteries, the topic of the current disclosure, is highly recommended for compensating reactive energy. Even if batteries and capacitors are installed, the underlying issue (the circulation of large reactive currents) will not be resolved.

The selection of the capacitor bank's power, its position, and even the duration it will stay in line if it is an adaptive compensation is all part of the optimization of reactive energy compensation. However, these decisions must be made such that the least amount of power is lost and a better voltage profile is achieved while still bringing in an economic benefit. Both electrical and economic considerations must be taken into account when deciding the objective function to use. Everyone working on reactive energy compensation has to focus on one thing: the so-called economic return function (saving function). As a result, unlike all the writers who dealt with an issue of concern, this article will focus on the objective function of minimising reactive power losses, which is achieved via the installation of capacitor banks.

Aiming for lower power losses, a more uniform voltage profile, and higher line throughput means determining battery capacities and locations.

The answer to the issue of reactive energy compensation optimization cannot be isolated from that of power flow.

Reactive energy compensation in distribution lines, i.e. calculating the size and position of capacitor banks in order to minimise power losses in the line, has been the subject of several studies. Analytical methods, numerical programming methods, heuristics methods, and intelligence and meta-heuristics methods are all types of heuristics.

Several methods for improving the flow of electricity across distribution networks have been developed in the last several decades. It's not feasible to include all of the projects that have been completed in this area, therefore simply a few examples will suffice. Mahmoudi et al. [5] in 2018 came up with a solution to the issue of power flow in radial and weakly meshed networks. Meshing causes meshes to be disrupted, resulting in the creation of fictional nodes with negative loop counts and power flows. Consideration is given to a model of load that has a constant impedance. A approach for solving recursive relations based on scanning up and down the line was presented in [6] by Bhullar et al. in 2017. Iterative methods have also been presented by

Ghatak et al. [7] in 2017. Equivalent circuit theory is used to find the stability factors of the tension, which needs the knowledge of the nodes' tensions and consequently the solution of the flow of charge to be known in order to determine these factors. One of the most popular methods for iterating through radial and weak-mesh networks has been suggested by Mary and her colleagues in 2017 [8]. Afterwards, he breaks the grids of the network, establishing artificial nodes, the number of which is equal to the number of loops, and where the forces that circulate are negative.

Sweeping the line up and down determines the tensions and phases of the nodes back at the origin. It sets all nodes' tensions to the source's relative value of one, which serves as the starting tension for all nodes. On the basis of Yang and colleagues [9]'s work, massive three-phase lines may be solved using a formulation and method. Sweeping up and down the line is the solution method. Pathak et al. [10] will publish a technique in 2018 that uses the evaluation of basic algebraic expressions. Nodes are first set to a relative value of -1 in order to get an idea of how much strain they can handle. In order to compute voltages at the nodes, it calculates the load current and branch current. Different load models were studied by Parihar et al. [11] in 2017 to see how they affected convergence of the power flow technique As a result, a piece of software dubbed "distriflow" was created to analyse the power flux in any radial distribution network, no matter the number of busbars. In distribution networks with numerous power sources, Babu et al. [12] devised a technique for estimating power flow in 2016 [12]. We will use the same approach we described in reference [8] to find a solution. As a means of issue solving, the network is seen as a single point of contact. Power is injected at the spots where the other sources are connected to imitate them (negative powers). Similarly, Fazio et al. [13] in 2018 developed an iterative technique in which the nodes' tensions are believed to be equal to the voltage source's tensions (1 pu). Before calculating branch currents and node tensions, they provided the geometry of the branch-to-node incidence matrix. They presented the difference between the tensions of two subsequent iterations as a criteria of convergence.

IV. PROPOSED METHODOLOGY

A. Thyristor Controlled Series Compensator (TCSC)

Power flow in transmission lines may be controlled by a series compensation using this device. In order to change the power flow, a TCSC modifies the line's impedance by connecting capacitors or inductors in series with the circuit itself. To validate the inherent inductive effects of transmission lines, capacitive compensation is the most often employed.

The Thyristor-based TCSC has an advantage over traditional stabilizers in that it does not experience failures due to mechanical stress, unlike conventional stabilizers.

X TCSC variable reactance, which represents the compensator's inductive or capacitive capacitance across the line, is connected in series with the line impedance to replicate a TCSC in a transmission line, as illustrated in Figure 1.

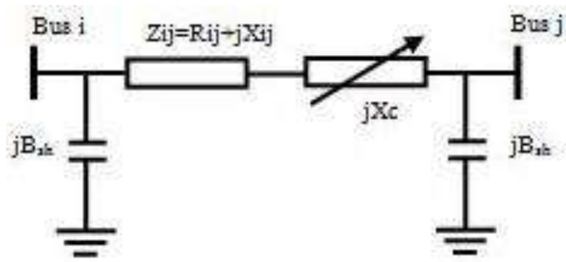

Figure 1: Schematic for a Transmission Line with a TCSC Compensation Device

B. Modeling of TCSC

At steady state, the compensator is able to flexibly switch between reactance levels. Limits for the oscillation of the reactance are proposed in order to prevent overcompensation of the line (1).

$$-0.8\, X_L \leq X_{TCSC} \leq 0.2\, X_L\ p.u. \qquad (1)$$

Various studies have recommended varying upper and lower limits for capacitive and inductive factors, but a trend toward higher capacitive factors and lower inductive factors is consistent.

In order to be employed in a power flow, the model must be placed in a line impedance with the built-in transformer reactance. The compensator's effect on reactance is shown in this picture using the variation equation (2).

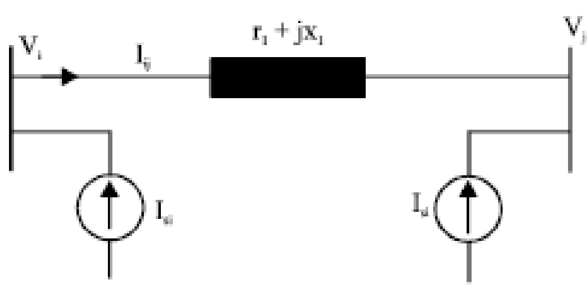

Figure 2: Power injection model of TCSC [15]

$$\Delta y_{i,j} = y_j' - y_{i,j} = \left(G_{i,j}' + jB_{i,j}'\right) - \left(G_{i,j} + jB_{i,j}\right) \qquad (2)$$

Where

$$G_{i,j} + jB_{i,j} = \frac{1}{Z_{i,j}} \qquad (3)$$

$$G_{i,j} = \frac{r_{i,j}}{r_{i,j}^2 + x_{i,j}^2},\ G_{i,j} = \frac{-x_{i,j}}{r_{i,j}^2 + x_{i,j}^2} \qquad (4)$$

$$G_{i,j}' = \frac{r_{i,j}}{r_{i,j}^2 + \left(x_{i,j} + x_{TCSC}\right)^2},\ G_{i,j}' = \frac{-\left(x_{i,j} + x_{TCSC}\right)}{r_{i,j}^2 + \left(x_{i,j} + x_{TCSC}\right)^2} \qquad (5)$$

According to function (3), the existence of the compensator causes a change in admittances, which, in turn, affects the admissions matrix in the mean, indicating (6).

$$Y'_{BUS} = Y_{BUS} + \begin{bmatrix} 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & \Delta y_{i,j} & 0 & \cdots & 0 & -\Delta y_{i,j} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ 0 & -\Delta y_{i,j} & 0 & \cdots & 0 & \Delta y_{i,j} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ & Col-i & & \ldots & Col-j & & \end{bmatrix} \begin{matrix} \\ Row-i \\ Row-j \\ \\ \end{matrix} \quad (6)$$

Equations representing power flow between bars may be developed for both active and reactive power flow, with the inclusion of the compensator, using the admittance variation created by the compensator series.

C. Algorithm of TCSC

There are two considerations that need to be taken into account when modelling and simulating compensator algorithms: the modelling involves defining the variations that introduce the compensators, and if this value is subject to change as the iterative method evolves, this must be taken into account when simulating.

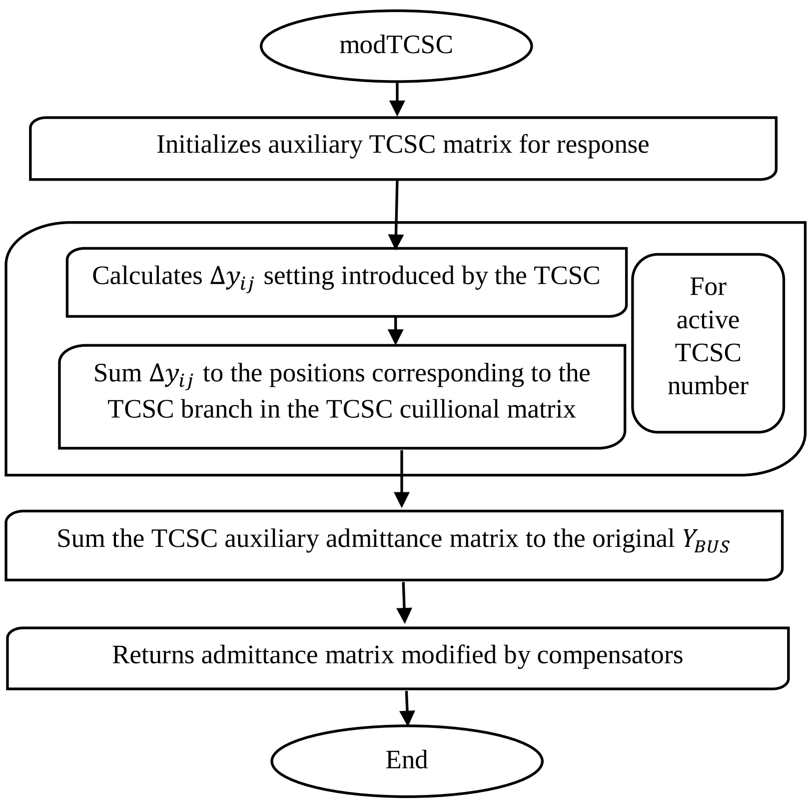

Figure 3: Algorithm of TCSC

The "modTCSC" function may have an inductive or capacitive behaviour, and it modifies the admittance matrix shown in the top part by a magnitude proportional to the same serial admittance of the branch.

A TCSC position vector, a TCSC information matrix, the system admittance matrix without TCSC, and the dimensions of the admittance matrix are all inputs to the method for TCSC adjustments.

It is important to note that the location of the compensator in the software used to compute power flow must be in line with the factors that affect it.

Therefore, its location must go after computing an admittance matrix without compensators and does not depend on any parameter that changes during iterations such as voltage, it is not necessary to place it within the iterative method's loop. TCSC changes serial admittance of a system branch in this case.

As a precautionary measure, the "modTCSC" function is only activated if the "State of operation in each compensator" column has a value of one or zero. This conditional is used for all three types of compensators in this document, and the column is used to indicate whether a compensator is active or inactive in an extension or bar.

D. Problem Formulation

The distribution networks and the strong currents that circulate through them have received significant attention in an effort to limit their intensities and thus improve the quality of energy supplied to consumers in order to reduce power losses, low power factor, and degradation of the voltage profile. Installing batteries or shunt capacitors, which operate on the reactive components of branch currents, is the most recommended method if the network has not been altered. There must be a judicious use of capacitor banks, so that the quality of the energy may be increased without requiring large expenditures that would increase the amount of energy used.

1. Active Power Losses Reduction

Reduced power losses owing to battery "k" are equal to active power losses in the network before and after capacitor bank installation. It is denoted by the symbol:

$$\Delta P_k = P_{av_k} - P_{ap_k} \tag{7}$$

Where,

P_{av_k} Pre-compensation loss of active energy.

P_{ap_k} in order to account for compensating for power losses.

2. Reactive Power Losses Reduction

When a battery is put at node "k" of a distribution line, the difference in reactive power losses between losses before and after the installation of batteries in the capacitors is measured. It is denoted by the symbol:

$$\Delta Q_k = Q_{av_k} - Q_{ap_k} \tag{8}$$

Where,

Q_{av_k} indicates the loss of reactive power prior to compensating.

Q_{ap_k} denotes the compensation-induced losses in reactive power.

E. Optimal Location using Particle Swarm Optimization (PSO)

As we'll call them in the future, "particles," these random and homogenous people wander through the research hyperspace and each represents a possible answer to the problem at hand.

In addition to being able to interact with the other particles in its immediate vicinity, each particle retains a memory of the best solution it has visited. This information tells the particle to return to its best solution while also mimicking the solutions in its immediate neighbourhood, which is what it does.

The collection of particles will generally converge to the global optimal solution to the issue discussed from local and empirical optimums.

A particle swarm is characterized by:

- The number of particles in the swarm, noted nb.
- The maximum speed of a particle, denoted $\vec{v}_{max}$
- The topology and size of a particle's neighborhood that defines its social network.
- The inertia of a particle, noted Ψ.
- The confidence coefficients, noted ρ_1 and ρ_2, which weight conservative behavior (the tendency to return to the best solution visited) and panurgism (the tendency to follow the neighborhood)

A particle is characterized, at time t, by:

$\vec{x}_i(t)$: at position in the search space.

$\vec{v}_i(t)$: its speed.

$\vec{x}_{pbest_i}$: the position of the best solution through which it went.

$\vec{x}_{vbest_i}$: the position of the best known solution in its vicinity.

$pbest_i$: the fitness value of its best solution.

$vbest_i$: the fitness value of the best known solution in the neighborhood.

Algorithm of PSO:

INPUTS: $0 < \rho < 1$

repeat

for $i = 1$ ***until*** nb ***do***

if $F(\vec{x}_i) > pbest_i$ ***then***

$pbest_i = F(\vec{x}_i)$

$\vec{x}_{pbest_i} = \vec{x}_i$

end if

$\vec{v}_i = \vec{v}_i + \rho(\vec{x}_{pbest_i} - \vec{x}_i)$

$\vec{x}_i = \vec{x}_i + \vec{v}_i$

end for

until *(one of the convergence criteria is met)*

F. Optimal Location using Salp Swarm Algorithm (SSA)

A transparent barrel-shaped body identifies it as a Salpidae species. In terms of how it feels, it has a remarkable similarity to a jellyfish. They pump water through their bodies like jellyfish in order to drive themselves forward. Research on these species is in its beginning stages since it is difficult to transfer and sustain them in a laboratory environment. Among salps' most remarkable characteristics is their herd behaviour, which this article examines. Whenever a huge population of salps congregates in the deep ocean, it's usual to see salpa chains in the area. Though no one knows for sure yet, some experts believe it's a technique to increase mobility and the efficiency of food searching [20].

There are two types of people in society: leaders and followers, as shown by chained salpa. In order to keep the herd under control, the herd's leader must be at the top of the chain at all times. One distinct food source is sought by every herd. Following is an example of a formula for updating leader salp's position by food source:

$$x_j^1 = \begin{cases} TF_j + c_1\big(c_2\big(ub_j - lb_j\big) + lb_j\big) & c_3 \geq 0 \\ TF_j - c_1\big(c_2\big(ub_j - lb_j\big) + lb_j\big) & c_3 < 0 \end{cases} \quad (9)$$

Step m is the current one, while M represents the total number of steps done. Suppose that M is 100. Random numbers are used to create the coefficients c 1 and c 2 [0, 1] in all circumstances. Each salpin changes its position as the equation follows the path.

V. SIMULATION RESULTS

The graphs below show the outcomes of the experiment:

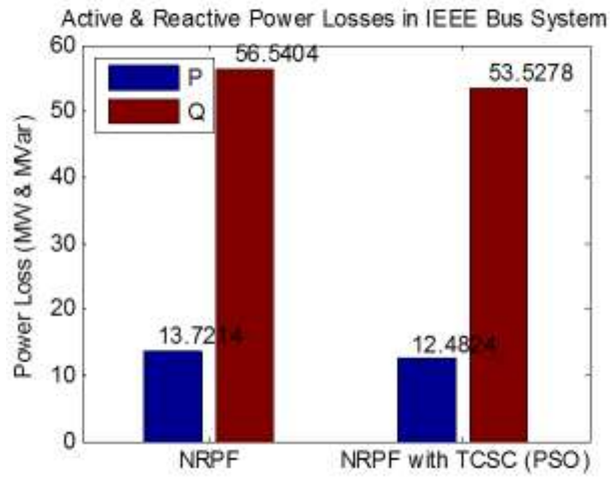

Figure 4: IEEE-14 bus system's active & reactive power losses by PSO optimization

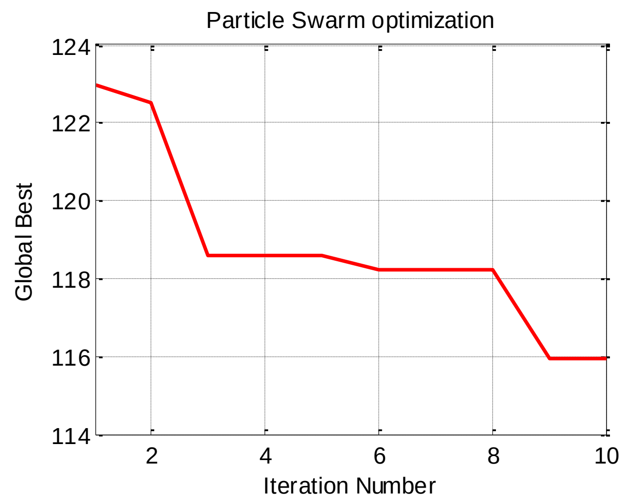

Figure 5: PSO iteration graph

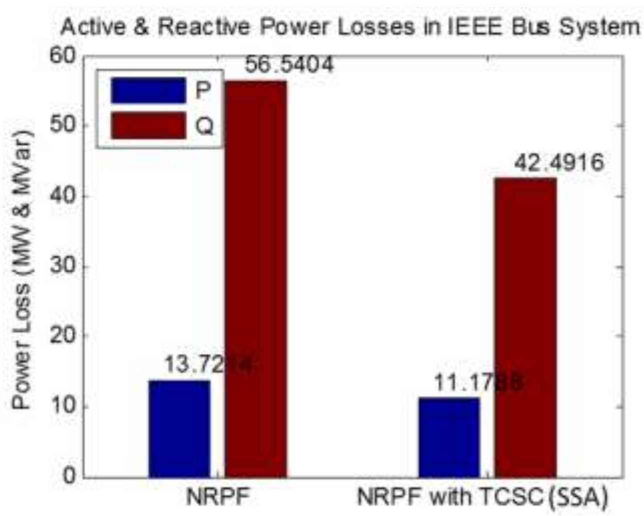

Figure 6: IEEE-14 bus system's active & reactive power losses by SSA optimization.

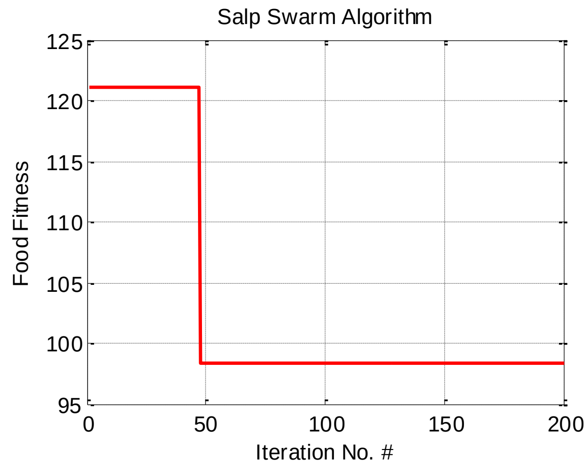

Figure 7: SSA-iteration grap

Table 1: Comparative analysis for active power loss and reactive power loss

Bus Test System	NRPF		NRPF-TCSC-PSO		NRPF-TCSC-SSA	
	Active Power (P) (MW)	Reactive Power (Q) (MVar)	Active Power (P) (MW)	Reactive Power (Q) (MVar)	Active Power (P) (MW)	Reactive Power (Q) (MVar)
IEEE 14 bus test system	13.7214	56.5404	12.4824	53.5278	11.11788	42.4916
IEEE 33 bus test system	17.8162	69.4087	8.6497	35.504	14.5309	51.9566
IEEE 54 bus test system	19.0564	87.4032	18.3042	84.648	18.5278	81.9868

VI. Conclusion

For both technological and financial reasons, reactive energy compensation is a crucial procedure. FACTS devices, the most efficient, or capacitors linked by circuit breaker, which are slower but have shown their effectiveness in an industrial context may be used to implement this method of energy conservation. Individual or worldwide compensation might be included in the package. In order to maximise the economic cost or return function, the appropriate battery size is calculated. Reactive power losses have been included in this objective function since the installation of batteries minimises both the active and reactive losses. Batteries are put one after the other, which means that the optimal power found by deriving the objective function is merely a starting value from which it is determined a standard size accessible on the market that fulfils the limitations of the issue. Finally, this final limitation replaces the stress on the tension that cannot be solved if the minor limits are taken into account. " This comparative research models and simulates in the MATLAB environment. PSO and SSA algorithms were used to conduct a performance evaluation of the optimum position of TCSC. Compared to Particle Swarm Optimization devices, the Salp Swarm Algorithm performs better.

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