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Sustainability Energy System in Power Network Using Particle Swarm Optimization.

Adeniyi.D. Adebayo[1], *Okafor Joyce Odu*[2]

[1]Electrical And Electronic Engineering, Federal University Otuoke, Bayelsa State, Nigeria adebayoad@fuotuoke.edu.ng
[2]Electrical And Electronic Engineering, Federal University Otuoke, Bayelsa State, Nigeria odujp@fuotuoke.edu.ng

ABSTRACT

Minimizing line losses in electrical power networks is critical for boosting system efficiency, stability, and economic operation. The goal of this research is to determine how to reduce transmission line losses in an electrical power network by using Particle Swarm Optimization (PSO). Transmission line resistance causes line losses, which raise operating expenses, waste energy, and compromise system dependability. Due to the intricate and nonlinear structure of power systems, traditional techniques for loss minimization frequently encounter difficulties. PSO's simplicity, computing efficiency, and capacity to identify global optima make it a useful method for resolving these optimization issues. It draws inspiration from the social behavior of fish schools and bird flocking. In this study, control variables such generator voltages, transformer tap settings, and reactive power compensation devices are adjusted using PSO to optimize the reactive power distribution and voltage profile within the network. The performance of PSO is compared with traditional optimization techniques, and the suggested methodology is tested on a typical IEEE bus system. The outcomes show that the PSO-based strategy preserves network restrictions, enhances voltage stability, and dramatically lowers active power losses. According to the results, PSO is a useful technique for minimizing loss in intricate power systems since it may produce an ideal result in a fair amount of time. This work adds to the current efforts in smart grid technology, where lowering transmission losses is essential to creating energy systems that are efficient and sustainable. PSO integration with other metaheuristic algorithms will be the main focus of future research in order to improve solution robustness and convergence speed.

KEYWORDS: Optimization, line losses, grid, energy system, transmission, distribution, network

INTRODUCTION

An essential component of a nation's economic growth is energy. Of all the energy types, electrical energy is the most significant. The utilization of electricity is essential to a contemporary, intelligent civilization. Any country's national planning process must priorities electrical energy production, transmission, and distribution operations due to the energy's vital role in the country's social and economic growth. In fact, the greater a nation's per capita electrical energy consumption, the better its population's standard of life. Thus, a country's electrical energy consumption per capital determines its degree of growth. The strategic planning of power plants to meet the demands of the power network load is a crucial and important topic in power systems. Because transmission lines link the power network's substations and generating facilities, engineers are particularly interested in analysing, calculating, and minimizing transmission losses. The aforementioned subjects have been the subject of much inquiry (Adewumi, 2017).

The most significant kind of energy in the contemporary world is unquestionably electrical energy. It is the lifeblood that propels the economy of every nation or culture and provides a feeling of fulfillment to the typical person. For power plants to distribute their energy to end users, transmission and distribution lines are necessary. This conveyed energy does not, however, come without losses (Adewumi and Adedeji, 2016).

Nigeria's national grid, which runs at 330kV or 132kV, makes electricity transmission easier. The transmission grid establishes a robust network that all load centers may access by connecting all power plants. It transmits produced electricity from power plants to major load centres via a network of cables supported by steel towers that connect transformer stations. (Onyeji, I.; Ogujor, E. O.; Nwankwo, A. U., 2012).

In the context of supplying energy to end consumers, losses are the quantity of power pumped into the transmission and distribution systems that users do not pay for. The magnitude of these losses may serve as a stand-in for the efficiency of electrical power systems. Almost all electric power networks, whether in developed or developing nations, have line losses during the transmission of energy. (Ogujor, E. O., Nwankwo, A. U., & Onyeji, I., 2012)

To lessen these losses, electrical engineers have researched a range of technological methods throughout time. In order to lower line losses in electric power networks, this research investigates the use of algorithm-based particle swarm optimization (Adewumi, 2017).

MATERIALS

Power losses during operation and the cost of transmission towers and wires sometimes limit the available transmission capacity (Glover et al., 2010). A common barrier to the economical distribution of energy is transmission capacity. For customers at all voltage levels to get reliable electric energy supplies in a deregulated economy, an effective electric grid is necessary.

Growing demands on electric energy transmission and the need to provide access to consumers and producing companies have resulted in recent trends towards worse supply quality and reduced security. The FACTS technology has the potential to alleviate some of these issues by enabling utilities to improve grid reliability and maximise the performance of their transmission systems. An optimum power flow (OPF) method was proposed to minimise energy losses in the network while preserving the operational voltage and temperature restrictions of the network by using FACTS devices for reactive power regulation.

The idea of optimum power flow was put out in the early 1960s as an extension of conventional economic dispatch to determine the best control variable configurations given various constraints. The term "OPFs" refers to a broad category of network optimisation problems. To overcome OPF concerns, a variety of approaches have been proposed.

The generic OPF problem is defined as follows: $g(x, u) = 0$ and/or $h(x, u) \leq 0$ indicate nonlinear equality constraints (power flow equations), while $h(x, u)$ represents nonlinear inequality constraints on the vectors x and u. The goal of the problem is to minimize the general objective function $F(x, u)$ while satisfying the constraints. The reactive power output of generators intended for bus voltage management, as well as the magnitudes and phase angles of the bus voltages, are the dependent variables contained in the vector x. Along with fixed impedances, line parameters, uncontrolled active and reactive powers for generators and loads, reference bus angles, and other fixed parameters are also included in the vector x. When minimizing costs is the primary objective, it is typically necessary to minimize active power losses.

The losses target is often formulated based on the following assumptions:

* Loss minimization is performed after cost minimization. As a result, the active power generation rates, excluding slack bus generation, are maintained at their ideal levels.

* The control state variables are transformer tap ratios and generator bus voltages. Phase-shifting transformer angles and shunt reactance are maintained at their rated values.

* During optimization, transformer tap ratios are handled as continuous variables. They are then repeated after being adjusted to the closest tap position.

* Restrictions on the real and imaginary components of the complex voltage drop between the lines are used to roughly control current flows.

Restrictions for contingencies are disregarded. The objective function for active power losses described mathematically The total of the active power losses in each branch and transformer determines the power system's minimization.

Numerous optimization methods and techniques exist, however they are only suitable for specific kinds of situations. Therefore, in order to choose the best solution strategy, it's critical to be able to determine the task features. Different minimization techniques with differing computational requirements, convergence qualities, etc., are used for each task class. The mathematical properties of the objective function, the constraints, and the control variables are used to categorize optimization problems. The nature of the objective function is likely the most crucial feature.

Natural selection and genetics serve as the foundation for the optimization technique known as particle swarm optimization (PSO). This approach can look for many solutions simultaneously. In the first stage, PSO creates random initial particles. Next, it updates the particles using velocity vectors until a process stop condition is met. Determining how an achieved solution is good involves the test function computation. Numerous power engineering issues have been solved with PSO, such as the placement of UPFCs and the optimization of their parameters for potential load increases, the placement of distributed generation, and the optimization of their sizes in relation to the cost of electricity for customers or economic dispatch.

Because a population of random solutions is used to initialize the system, particle swarm optimization and genetic algorithms share this characteristic. But each possible solution (referred to as a particle) starts out with a random velocity and travels across the n-dimensional space of the problem. PSO has proven to be quite effective in resolving a variety of engineering issues. The duties can be completed swiftly and easily with its implementation. A lot of work has been put into determining the best STATCOM design and where to put it using the PSO approach during the last few years. The following is a useful summary of contemporary optimization methods that can be applied in the field: particle swarm optimization with the STATCOM optimal placement.

Transmission and distribution systems' electric power losses are mostly determined by the elements (power lines, transformers) in the system, their specifications, and their operating status at the time. As for elements models, the losses are mostly caused by series resistances (by flowing currents) and partially by shunt resistances (by operating voltage). If one only considers the series resistances, the total active power losses in a distribution system can be calculated as follows: Active power losses increase operating expenses and reduce the effectiveness of energy transfer to consumers.

Ploss = R* I2

where Ii denotes the current flowing through branch i, Ri is the resistance of branch i, and n is the total number of branches in the system. The terminal stage of the electricity system is the distribution network that consumers terminate. Utilities and consumers are equally impacted by potential distribution network issues. The voltage loss that needs to be decreased in order to maintain the voltages at load sites within acceptable bounds is one of these issues. When using long-distance lateral radial feeders or feeding heavy loads, the voltage loss issue could occur. As a result, the voltage at each system node needs to be managed. The voltage control is typically reactive power control. Thus, lowering the node voltages and reactive power leads to a decrease in power loss. The distribution systems are outfitted with several voltage-controlling devices in order to optimize voltage and regulate reactive power.

The STATCOM compensator, which uses IGBT (insulated gate bipolar transistors) as dependable high-speed switching elements and a pulse-width modulation-based control approach, is based on a VSC (Voltage Source Converter) design (Figure 1). A voltage source that is totally programmable, matching the system voltage in phase and frequency, and whose amplitude can be swiftly and continuously adjusted, is the foundation of a voltage stabilization circuit (VSC), which is utilized as a reactive power control tool.

STATCOM Connection Principle

In the event of asymmetrical loads, STATCOM can balance the system, improve power quality, and offer dynamic voltage support for the grid. This improves the ability of the wires to transmit power and promotes system availability. Transmission lines with reactive power may lower system losses, and the grid's power factor can rise when reactive power flow is dynamically balanced. STATCOM may be thought of as a voltage source with an impedance Z that can provide both active and reactive power to the grid point to which it is connected (Capitanescu and Martinez, 2011). The following case study's primary goal is to use the Particle Swarm Optimisation approach to minimise line losses in the grid and determine the optimal location for the STATCOM compensator.

Methods of Research

The given information does not disclose the research methodologies employed in this study. However, it is noted that the Particle Swarm Optimisation (PSO) method is used in the power grid to reduce line losses. PSO is a computer technique that repeatedly attempts to improve a potential solution in respect to a certain quality metric in order to optimise a problem. Drawing inspiration from the behaviour and movement of swarms of fish or birds, the approach treats each swarm member as a particle that moves over the search space in search of the optimal answer.

The problem and the objective function must be defined before applying PSO to this study. The aim function in this situation is to minimize the line losses in the electricity system. The network configuration, the characteristics of the elements (power lines, transformers), and the condition of operation at the moment characterize the problem. The formula Ploss = R * I^2, where R is the power line resistance and I is the current flowing through it, can be used to determine the active power losses in the system, which are mostly produced by the power lines' series resistances.

The next step is to initialize the swarm of particles with random placements and velocities. Every particle is a possible solution to the issue, and its location is a collection of control factors that dictate how the power grid functions, including the reactive power output of the generators, the tap ratios of the transformers, the voltage magnitudes and angles of the buses, and so on. The direction and magnitude of the particles' movement in the search space are determined by their velocities.

Following startup, the algorithm goes into an iterative loop, with evaluation, update, and selection being the three primary phases in each iteration. The evaluation stage finds the best solution so far by calculating the objective function for each particle. The particles' locations and velocities are modified in the update stage in accordance with both their individual and the swarm's experiences. The following equations are used to accomplish this:

v_i(t+1) = w * v_i(t) + c1 * r1 * (p_i - x_i(t)) + c2 * r2 * (p_g - x_i(t))

x_i(t+1) = x_i(t) + v_i(t+1)

where w is the inertia weight, c1 and c2 are the cognitive and social learning coefficients, r1 and r2 are random numbers between 0 and 1, p_i is the best position that particle i has found thus far, and p_g is the best position that the swarm has found thus far.

The best solution obtained thus far is compared against the current solution in the selection step, and the best one is chosen for the following iteration. When a stopping criterion—such as a minimum improvement in the objective function or a maximum number of iterations—is satisfied, the algorithm comes to an end.

To validate the suggested approach, a case study is done on a power system using a STATCOM compensator. The goal is to use the PSO algorithm to reduce line losses in the grid and determine the optimal placement for the STATCOM compensator. The outcomes are contrasted with those attained by employing different optimization strategies, like gradient-based approaches and genetic algorithms.

RESULT

Procedures for Data Development

A power system with 14 nodes and two voltage levels—400 kV and 220 kV—was taken into consideration in this study. The 400 kV level applied to the first five nodes, and the 220 kV level to the remaining nodes. The slack bus was assigned to node 1. Three-phase control transformers with a tap changer on the secondary side of ±11x1.13% connected the various voltage levels (Figure 1).

Diagram of the power system showing the various voltage levels and regions

The 400 kV voltage level's generating/load area is represented by the blue region, the 220 kV voltage level's generating/load housing estate is represented by the green area, and the industrial area is represented by the red area.

Data on each node's line impedance, generation capacity, and load demand were gathered in order to examine the power system. The load flow analysis was then carried out using the data to ascertain the actual and reactive power flows on each line, as well as the voltage magnitude and angle at each node. The Newton-Raphson method, a popular iterative technique for solving nonlinear equations, was applied to the load flow analysis (Kundur, 1994).

Various operating situations, including regular operation, backup plans, and ideal power flow, were tested for the load flow study. While the contingency scenarios took into account the loss of a line or a generator, the normal operating scenario presumed that all lines and generators were in operation.The goal of the ideal power flow scenario was to reduce the system's power loss while meeting all operational requirements, including voltage and line flow limitations.

The performance of the power system under various operating situations was then assessed using the load flow analysis data. Line loads, power loss, and voltage profile were among the performance metrics. The power loss was computed as the total of the actual power losses on all lines, and the voltage profile was evaluated based on the voltage magnitude and angle at each node. The percentage of the line's thermal limit was used to evaluate the line loading.

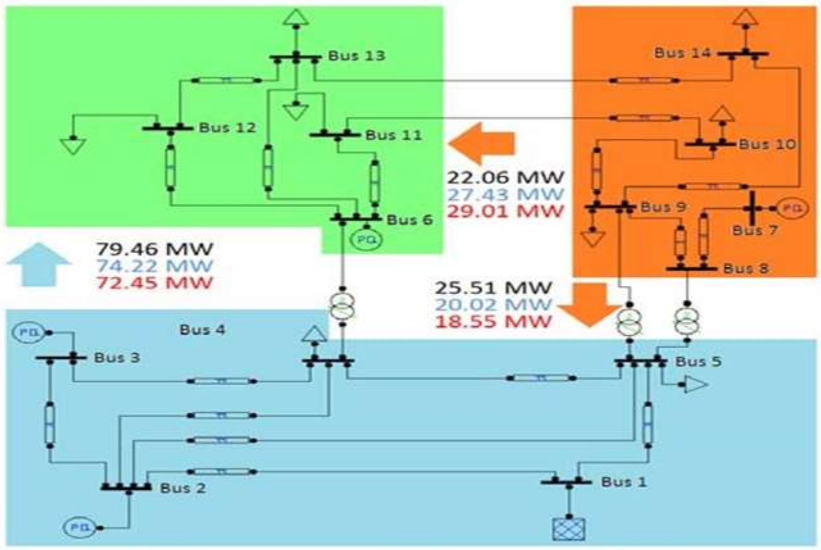


Fig. 1: Power system with 14 nodes

In the present research we formulate four main experiments:

1) Network operational parameter calculation without optimisation.

2) Network operational parameter calculation after optimisation: Optimisation was done to lower the system's overall active power losses both with and without STATCOM.

3) Generator source outage simulation: scenarios were progressively computed both with and without STATCOM when sources were supposed to be out of commission. In each instance, it was assumed that the outage was limited to a single source. Since node 1 is a balancing node, we did not take the outage into account. In every instance, the optimisation was carried out to lower the network's overall active power losses while maintaining all operational constraints within allowed deviations.

4) Since the line between nodes 8 and 9 is the second most overloaded line for the voltage level 220 kV (the line between nodes 7 and 8 is the most overloaded line for the level 220 kV), simulating the line disconnection between those nodes was taken into consideration. However, the disconnection of that line resulted in a similar state as was mentioned in case 3, namely the disconnection of the source at node 7. The goal was to minimise the network's overall active power losses while maintaining any operational limits within allowed deviations.

Simulation Results

Reactive powers on generators and taps on tap-changing transformers in the absence of STATCOM are the study's control variables. In situations involving STATCOM, the reactive power produced or consumed by the system is a control variable. Every simulation was run using the Particle Swarm Optimisation technique in the MATLABTM software.

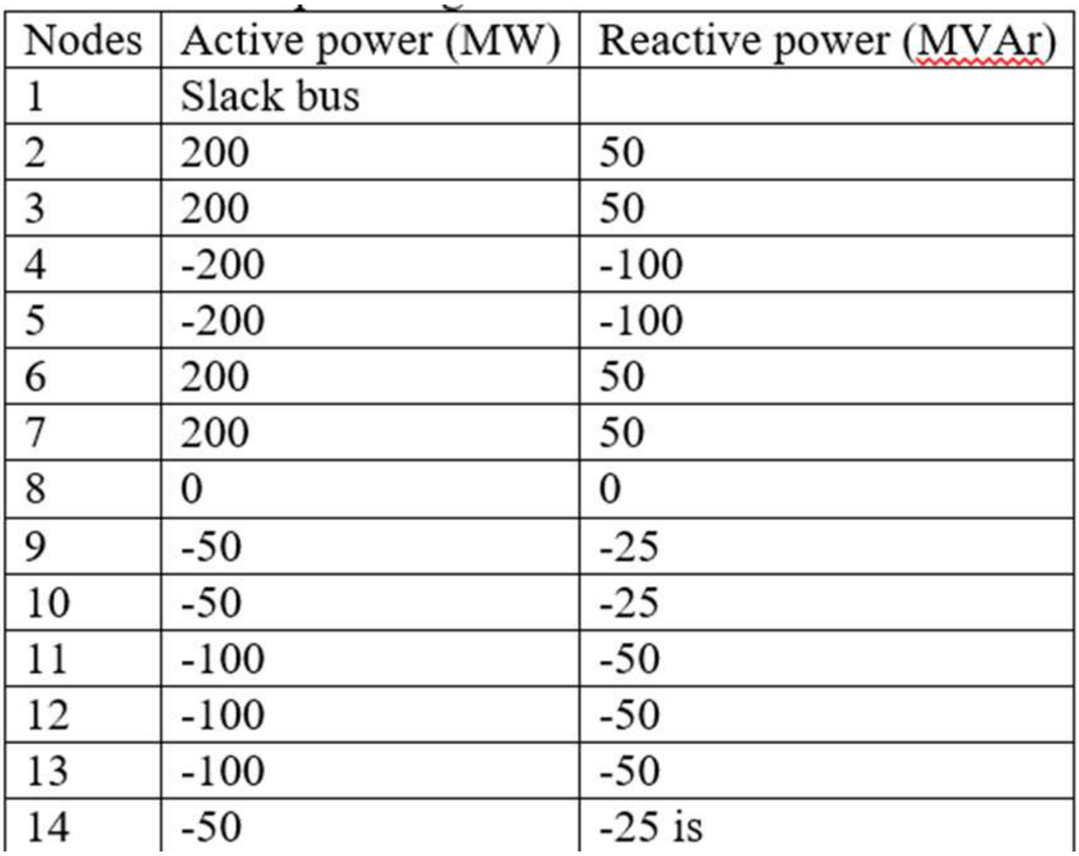
All estimates took into account the following operating limitations:

* The nodes' maximum allowable voltage variations are 5% for both voltage levels.

* Maximum and lowest reactive power that the generators can provide: the generators can provide up to 50 MVAr more than the conventional values shown in Table I. Negative numbers indicate active power consumption and inductive mode, whereas positive values indicate active power production and capacitive mode. Tap transformers establish the maximum and lowest values; the transformer control range is 202.3 to 241.4 kV. This approach always selects the closest value of the adjustable transformer since it does not provide a continuous change of regulated voltage.
* All transmission lines have thermal limitations: the highest allowable current for 400 kV lines is 2000 A, whereas the maximum allowable current for 220 kV lines is 860 A.

* Maximum / minimum possible supplied / consumed reactive power using STATCOM: ±100 MVAr.

Table I – Active and reactive powers generated / absorbed at nodes

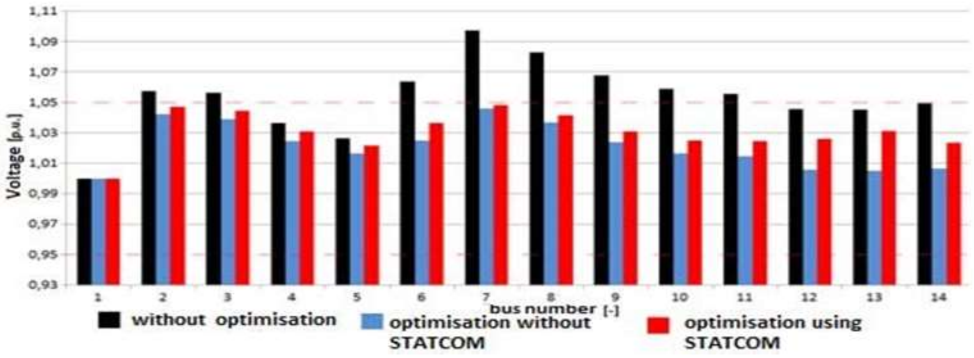


Nodes	Active power (MW)	Reactive power (MVAr)
1	Slack bus	
2	200	50
3	200	50
4	-200	-100
5	-200	-100
6	200	50
7	200	50
8	0	0
9	-50	-25
10	-50	-25
11	-100	-50
12	-100	-50
13	-100	-50
14	-50	-25 is

Three types of experiments were performed:

In Experiment 1, we managed STATCOM to obtain the lowest active power losses without using any optimisation techniques. 9.09 MW was the total active power loss. In Figure 3, the dark hue represents the simulation findings for this instance. As shown, the voltages are not within acceptable bounds.

Experiment 2: To minimise active power losses in the network under consideration, we used the optimisation approach in this instance. With and without STATCOM, we ran two simulations. Figs. 3 and 4 show the simulation results for these two conditions. Red indicates the status after optimisation using STATCOM, while blue indicates the situation following optimisation without STATCOM. The state with STATCOM had a total active power loss of 7.81 MW, whereas the state without STATCOM experienced 8.51 MW.



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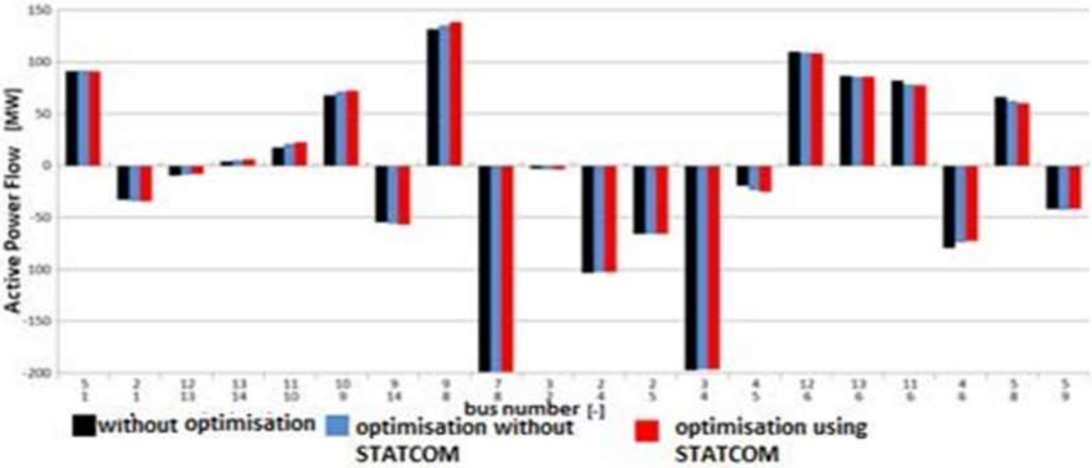

Fig. 2: Active power flow in all lines

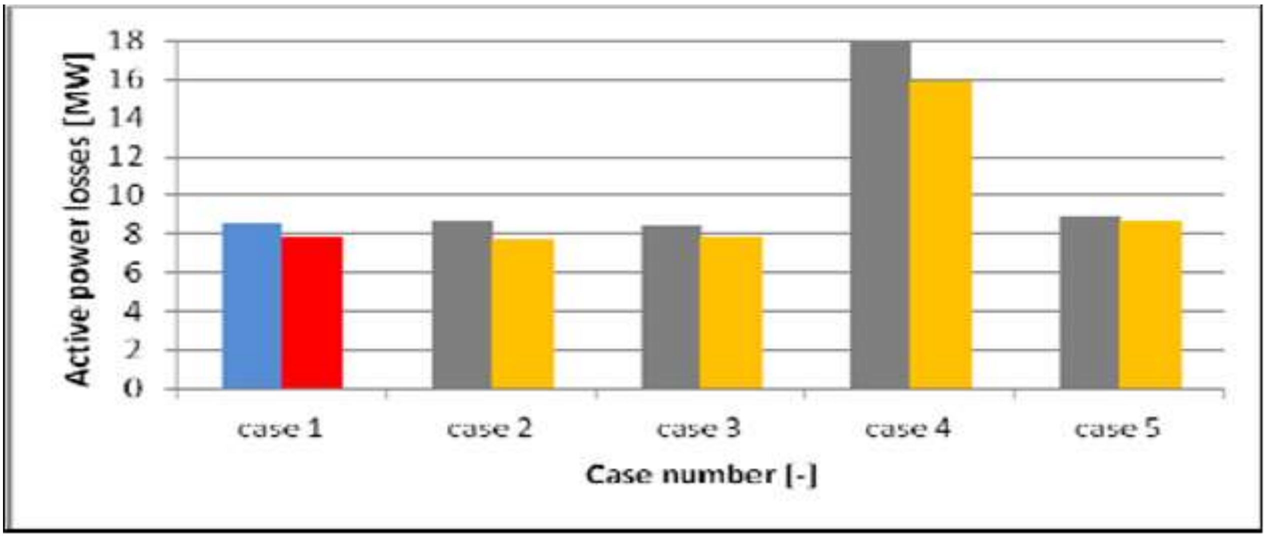

Fig. 3: Active power losses for all five cases with and without STATCOM

Experiment 3: In this instance, we looked at creating outages from sources (cases 2 to 5): scenario 1: Optimisation (complete without turning off): this scenario shows the simulation results from experiment 2. Subsequently, four optimisation procedures were carried out to minimise active power losses in the event of a producing source failure, both with and without STATCOM (orange and grey, respectively).

The second scenario is optimisation (turn off generator 2).

In the third case, optimisation (turn off generator 3) Optimisation in Case 4 (turn off generator 6) The fifth case is optimisation (turn off generator 7). The findings of experiment 3, as previously mentioned, are shown in Fig. 3 and Table II for the states with and without STATCOM. The bus number to which STATCOM was linked is shown in Table II, together with the quantity of reactive power that STATCOM contributed to or consumed from the network.

Table II - Simulation results for all five cases

Case	Active power losses [MW]		Bus number [-]	Reactive power [MVAr]
	without STATCOM	with STATCOM		
1	8,51	7,81	13	93,79
2	8,65	7,76	2	-99,99
3	8,48	7,94	2	-99,99
4	17,97	15,93	12	99,93
5	8,94	8,60	13	62,35

Experiment 4 – in this scenario we cut off the line between the nodes 8 and 9. In the first scenario the simulation was done without STATCOM (green color). The second instance involves the connection of STATCOM (purple).

Figure 6 illustrates that using STATCOM may result in reduced active power losses when compared to the scenario without STATCOM. Positioned at node 13, STATCOM provided 87.589 MVAr of reactive power. Figure 7 displays the voltage profile for both states, and Figure 8 shows the variations in the active power flow in each line for both states.

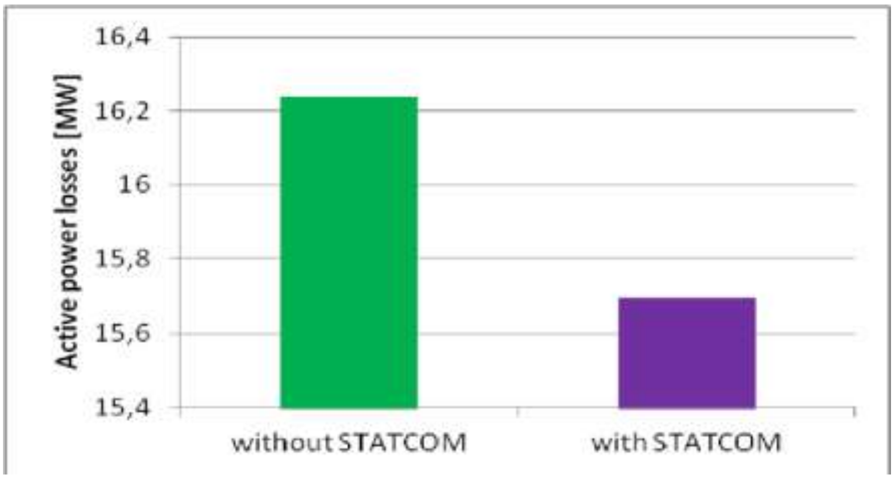

Fig. 4: Active power losses (line 8-9 is switched off)

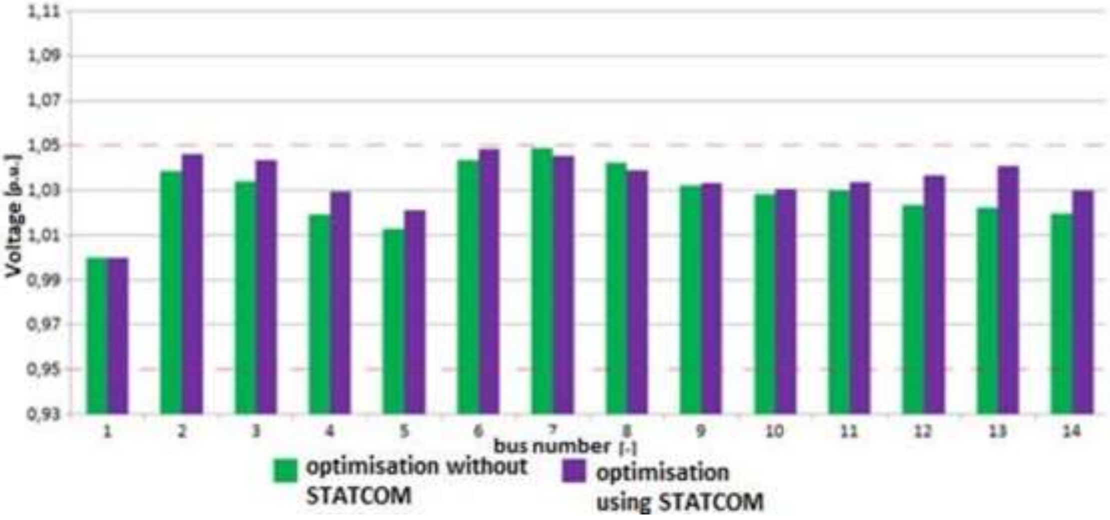

Fig. 5: Voltage profile (line 8 – 9 is switched off)

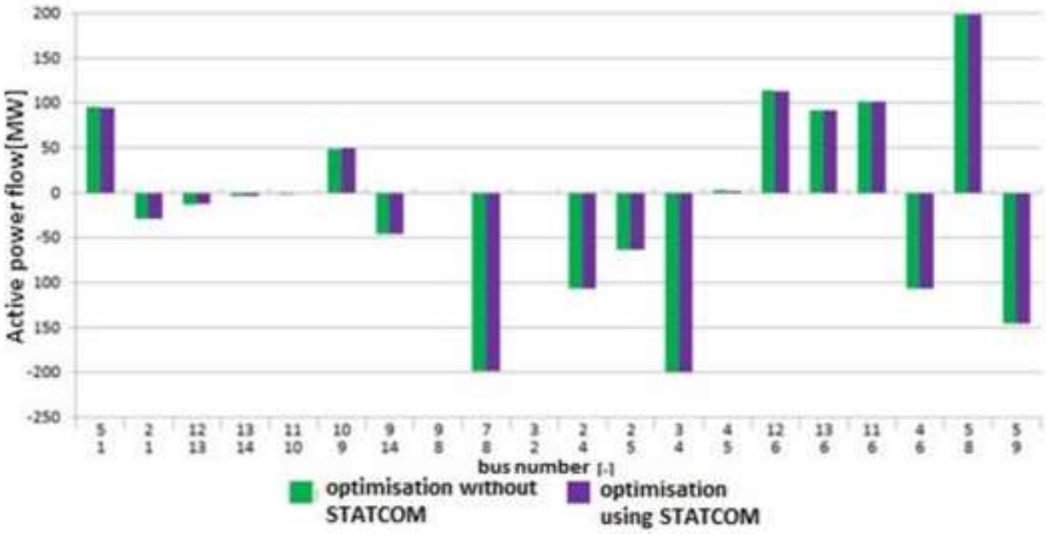

Fig. 6: Active power flow in all lines (line 8-9 is switched off)

CONCLUSION

This study examines the theoretical and practical implications of using Particle Swarm Optimisation (PSO) in electric power networks to reduce line losses. In order to minimise active power losses and control voltage, the research made use of the Static Synchronous Compensator (STATCOM) and additional Flexible AC Transmission System (FACTS) devices. Presented is the concept and evolution of using STATCOM for optimisation. STATCOM provides active power consumption management and enhances power quality. Applications that need correction for a variable load voltage may benefit from this effect. It would improve power stability and lessen the likelihood of line losses caused by such sources.Not only does STATCOM reduce active line losses, but it also enables us to control the voltage at the node to which this device applies.

The simulation results presented in this research give information for STATCOM design and implementation in power networks. The use of PSO showed how the technique might enhance power networks' performance and selected criteria.

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