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SCHOLARLY ARTICLE

Minimization of Power Losses in Distribution Network using Particle Swarm Optimization

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In this paper, an improved particle swarm optimization (PSO) method is proposed to optimally size and place a DG unit in an electrical power system so as to improve voltage profile and reduce active power losses in the system. The incessant power failure observed in the distribution network has paralyzed business activities. This is primarily caused by power losses in the network that is anchored by the weak buses that their per unit volts could not attain threshold of 0.95 through 1.05. To stop this persistent power failure in the distribution network constituted by power losses there is an introduction of minimization of power losses in distribution network using particle Swamp optimization. To achieve this, it is done in this manner, characterizing distribution network, running the load flow of 33kV power distribution, minimizing Power losses in the 33kV Power Distribution Network using particle swarm optimization, designing a SIMULINK model for particle swarm optimization and designing a SIMULINK model for minimization of power losses in distribution network using particle SWARP optimization. The results obtained are the conventional voltage in bus 2 that cause instability in power supply in distribution network is 0.940 P.U.V. On the other hand, when Particle swarm optimization is introduced in the system the voltage attains the per unit volts stability of 1.03 thereby improving constant power supply in the distribution network and the percentage of power loss in faulty bus 2 feeder 2 is 3.2%. On the other hand, when Particle swarm optimization is incorporated in the system, it drastically reduced to 3.057%. The percentage improvement in the reduction of power loss in faulty bus 2 feeder 2 is 0.15%.

ABSTRACT

Keywords: *Minimization of Power Losses; Distribution Network; Particle Swarm Optimization (PSO); SIMULINK Model; Power Losses*

Introduction

Due to technical and commercial reasons, energy losses occur in the process of supplying electricity to consumers. Generally, when the quantity of electricity delivered to consumers is less than the quantity generated, transmission and distribution losses are said to have occurred. Circuitry losses are an extension of transmission and distribution losses. The robustness of a power system is generally dependent on its response to disturbances (Ngang &Bakare,2021). Distribution losses occurs at the Low Voltage (LV) transmission level, the Transmission losses is a dissipation of power in electrical circuits due to factors such as resistance, inductance, and capacitance. Additional factors responsible for losses include undesired heating of resistive components, losses due to transformer windings and cores, skin effects, and magnetic losses due to eddy currents. Major components resulting in losses in transmission and distribution networks include voltage drop at line ends, a rise in temperature in the supply cables, producing losses of active power, over-sizing of generation, transmission and distribution equipment, over-sizing of load protection due to harmonic currents, and transformer overloads (Kumar & Sharma, 2023). Power losses in the feeder are caused by weak buses with per unit volts that could not meet a threshold of 0.5 through 1.05 (Ma & Xu, 2022).

Currently, the power demand has increased, which in turn increases electrical energy production almost to its capacity limits. The fast growth of electrical power demand makes the transmission systems reach their maximum capacity. Therefore, the utilities responsible for the electrical power grid have to invest more money to expand their capacity to meet the demanded power and to prevent any interruption of electricity (Ghosh & Ledwich, 2018). Following that, many solutions are suggested to solve this problem. One of these solutions is Particle Swarm Optimization (PSO) (Eberhart & Kennedy, 1995). In general, power system operation depends on centralized power plants, where the energy flows in a unidirectional way from generation toward distribution. In the meantime, the introduction of PSO to the electrical power system changes the nature of the system from passive networks to active networks. Active electrical power networks imply power flow in a bidirectional way due to the distributed resources along the network (Momoh, 2020). Power system stability is an important part of carrying out an assessment in transmission system security with a view to ensuring the system's ability to withstand sudden disturbances under load application (Aneke & Ngang, 2021; Prasanna & Sundar, 2022).

Several benefits can be obtained from Distributed Generation (DG) such as voltage support, improved power quality, loss reduction, and enhanced transmission and distribution. Utilizing the PSO algorithm, the minimum value of total losses is achieved (Khatib & Zobaa, 2021). PSO has been proposed for optimal DG placement, taking into account maximizing voltage level and minimizing power losses. Moreover, a comparison between PSO and other methods is proposed in this research. According to this research, PSO is found to be better in performance as compared to the other two methods. In addition to that, PSO has been used for multi-DG placement for loss reduction and voltage profile improvement (Abido, 2023). As a result, the PSO algorithm reduced power losses and improved the system's voltage profile. Furthermore, an improved particle swarm optimization for optimal allocation of distributed energy resources has been used. The performance of the proposed PSO algorithm is improved by suggesting the LEA and GSA algorithms for the placement and sizing of capacitors and the adjustment of transformer tap settings (Shi & Eberhart, 2022).

Literature Review

The literature on power loss minimization in distribution networks spans various optimization techniques, including genetic algorithms (GA), simulated annealing (SA), and artificial neural networks (ANN). GA has been widely used due to its robustness and flexibility but often requires significant computational resources (Yang & Deb, 2009). SA, known for its simplicity and effectiveness in escaping local optima, has shown promise in specific applications but lacks the global search capabilities of more advanced algorithms (Kirkpatrick et al., 1983). ANN, while powerful in pattern recognition and prediction, requires extensive training data and is computationally intensive (Haykin, 1998). PSO, introduced by Kennedy and Eberhart in 1995, has gained traction for its simplicity, efficiency, and ability to converge quickly to optimal solutions (Kennedy & Eberhart, 1995). Studies have demonstrated PSO's effectiveness in various power system applications, including voltage stability improvement (Aneke and Ngang,2021). Voltage Stability is a subset of power system stability that deals with the bus voltage operational limitations before and after a disturbance (Prasanna & Sundar, 2022), including Reactive power and optimization (Shayeghi & Jalili, 2023), and load balancing (Georgilakis & Hatziargyriou, 2023). However, its application in power loss minimization within distribution networks has shown the most promise due to its adaptable and efficient nature. Usually, to avoid expensive extension of grid capacity an intelligent system has to be embedded into the conventional means of power generation (Ugwu, Ude & Ngang, 2021).

Methodology

Characterization of the Distribution Network with Valuable Data Obtained

The area under study was visited and the required information of the distribution network with valuable data was obtained. The methodology for this study involves several key steps: modeling the distribution network, defining the objective function for loss minimization, and implementing the PSO algorithm. The distribution network is modeled using standard electrical engineering principles, considering factors such as line impedance, load distribution, and network topology. The objective function is formulated to minimize the total power losses in the network, defined as the sum of the I^2R losses across all network branches. PSO is then applied to search for the optimal configuration of the network, including

Method

Particle Swarm Optimization Algorithm

1. **Initialization**: Generate an initial population (swarm) of particles, each representing a potential solution.
2. **Velocity and Position Update**: For each particle, update its velocity and position based on its previous best position and the global best position found by the swarm.
3. **Fitness Evaluation**: Evaluate the fitness of each particle based on the objective function (power loss minimization).
4. **Update Best Positions**: Update the personal best position for each particle and the global best position for the swarm.
5. **Termination**: Repeat the update and evaluation steps until convergence criteria are met (e.g., a predefined number of iterations or a satisfactory reduction in power losses).

Table 1: Field Data from Enugu Electricity Distribution Company (EEDC)

Names Of Feeder	*Power Factor*	*Voltage (kV)*	*Current (A)*	*Base Value (kV)*
F_1 is feeder1	0.93	10.4	176.25	11
F_2 is feeder2	0.9	10.4	77.13	11
F_3 is feeder3	0.91	10.4	148.59	11
F_4 is feeder4	0.93	10.4	74.5	11
F_5 is feeder5	0.94	10.8	60	11
F_6 is feeder6	0.95	10.8	68.14	11
F_7 is feeder7	0.64	10.8	37.43	11
F_8 is feeder8	0.94	10.8	90	11

From the data of table 1, the per unit voltage values of the 8 feeders that make up the 33 kV Power Distribution Network are calculated as follows:

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Per Unit = (Present value) ÷ (Base Value). Per Unit (PU) values are sometimes expressed as a percentage rather than a ratio. If the base value voltage was given as 11 kV, then to calculate per unit volts of the various feeders in the distribution network, the following procedure is applied:
F_1 is feeder1
Per unit volts $= \frac{\text{present value}}{\text{Base value}}$
F_1 is feeder1per unit volts $= \frac{10.4}{11}$
F_1 is feeder1 per unit volts = 0.945
The same procedure is followed in calculating the pu voltage values of the rest of the feeders.

Thus,

F_2 is feeder2 per unit volts = 0.945

F_3 is feeder3 per unit volts = 0.945

F_4 is feeder4 per unit volts = 0.945

F_5 is feeder5 per unit volts $= \frac{10.8}{11}$

F_6 is feeder6 per unit volts = 0.98

F_7 is feeder7 per unit volts = 0.98

F_8 is feeder8 per unit volts = 0.98

F_9 is feeder8 per unit volts = 0.98

Table 2: Running the Load Flow of 33kV Power Distribution using the Characterized Data of Table 1.

Power Flow Solution by Newton-Raphson Method
Maximum Power Mismatch = 9.42308e-008
No. of Iterations = 10

Bus No.	*Voltage Mag.*	*Voltage Angle (Degree)*	*Load MW*	*Load Mvar*	*Generation MW*	*Generation Mvar*	*Injected Mvar*
1	0.945	0.000	0.000	0.000	-170.189	74.063	0.000
2	0.940	0.658	20.000	0.000	0.000	0.000	0.000
3	0.937	2.768	50.000	120.000	0.000	0.000	0.000
4	0.987	5.112	0.000	0.000	0.000	0.000	0.000
5	0.957	9.761	0.000	60.000	0.000	0.000	0.000
6	0.937	3.626	20.000	90.000	0.000	0.000	0.000
7	0.984	9.579	0.000	0.000	0.000	0.000	0.000
8	0.941	6.475	10.000	90.000	0.000	0.000	0.000
9	0.941	4.706	80.000	50.000	0.000	0.000	0.000
10	1.005	6.037	0.000	0.000	200.000	227.644	0.000
11	1.000	10.511	0.000	0.000	160.000	162.180	0.000
Total			**278.900**	**458.800**	**189.811**	**474.293**	**4.300**

From the results obtained the faulty buses are bus 2 which is feeder2, bus 3 designated as feeder3, bus 6 assigned feeder 6 and bus 8 known as feeder 8. These are the buses their per unit volts could not attain voltage stability of 0.95 through 1.05 P.U. volts. These buses cause power losses in distributed power thereby migrating to instability of power supply in these geographical locations.

The faulty buses are buses that could not attain per unit volts stability of 0.95 through 1.05 are buses

Bus 2 feeder2=**0.940** P.U.Volts

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Bus 3 feeder3=**0.937** P.U.Volts

Bus 6 feeder6= **0.937** P.U.Volts

Bus 8 feeder8= **0.941 P**.U.Volts

While the ones that attained voltage stability are

Bus 1 feeder1 = **0.945** P.U.Volts

Bus 4 feeder4= **0.987** P.U.Volts

Bass Campus Feeder=**0.957** P.U.Volts

Bus 7 feeder7= **0.984 P**.U.Volts

These buses that attained per unit volts stability of 0.95 through 1.05 do not experience power losses in the metropolis.

The formula for the percentage loss in a power system can be calculated using the formula:

$\%PowerLoss = (\frac{ActualPower - LoadPower}{ActualPower}) \times 100$(3.1)

Ie$\%P_{Loss} = \left(\frac{P_{Actual} - P_{Load}}{P_{Actual}}\right) \times 100$

Now in power in a Three phase AC system is given by:

$P_{3\emptyset} = V_{3\emptyset} I_{3\emptyset} cos\theta$(3.2)

Where $P_{3\emptyset} = Three\ Phase\ Apparent\ Power\ in\ the\ System$

$$V_{3\emptyset} = Three\ Phase\ Voltage\ in\ the\ System$$

$$I_{3\emptyset} = Three\ Phase\ Current\ in\ the\ System$$

And $cos\theta = the\ power\ factor\ which\ is\ 0.8\ for\ the\ Nigerian\ power\ system$

Assuming the systems are connected in delta, then

$V_{\emptyset} = V_L$ and

$$I_{\emptyset} = \frac{I_L}{\sqrt{3}}$$

Using the above in equation two yields

$P_{3\emptyset} = V_L \left(\frac{I_L}{\sqrt{3}}\right) cos\theta$(3.3)

Now for the power Distribution network, the percentage Power Loss Will be given by:

$\%PowerLoss = \left(\frac{P_{Load}}{P_{3\emptyset}}\right) \times 100$ (3.4)

Where $P_{Load} = Power\ in\ the\ Section\ of\ the\ Power\ Distribution\ network\ being\ considered$

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Table 3: Characterized Load Distribution in 33kV Distribution Network

S/n	*Feeders*	*Power Factor*	*Voltage (kV)*	*Current(A)*	P_{Actual}*(MW)*	P_{Load} *(MW)*	*%Loss*
1	Feeder2	0.9	10.4	77.13	721.9MW	20	3.2%
2	Feeder3	0.91	10.4	148.59	1203.4MW	50	4.2%
3	Feeder6	0.95	10.8	68.14	699.1MW	20	2.9%
4	Feeder8	0.94	10.8	90	913.68MW	10	1.1%

Feeder2 actual power = I x V x power factor

Feeder2 actual power =77.13 x 10.4 x 0.9

Feeder2 actual power =721.9MW

Feeder3 actual power =148.59 x 10.4 x 0.91

Feeder3 actual power =1203.4MW

Feeder6 actual power =68.14 x 10.8 x 0.95

Feeder6 actual power =699.1MW

Feeder8 actual power =60x10.8 x 0.94

Feeder8 actual power =609.1MW

$$\%PowerLoss = \left(\frac{P_{Load}}{P_{3\emptyset}}\right) \times 100$$

To calculate Feeder2 power loss
Recall

$$\%PowerLoss = \left(\frac{P_{Load}}{P_{3\emptyset}}\right) \times 100$$

Feeder2 power loss = $\frac{20}{617.8} \times \frac{100\%}{1}$

Feeder2 power loss =3.2%

To calculate Feeder3 power loss

Recall

$$\%PowerLoss = \left(\frac{P_{Load}}{P_{3\emptyset}}\right) \times 100$$

Feeder3 power loss = $\frac{50}{1203.4} \times \frac{100\%}{1}$

Feeder3 power loss =4.2%

To calculate Feeder6 power loss

Recall

$$\%PowerLoss = \left(\frac{P_{Load}}{P_{3\emptyset}}\right) \times 100$$

Feeder6 power loss = $\frac{20}{699.1} \times \frac{100\%}{1}$

Feeder6 power loss = 2.9%

To calculate Feeder8power loss

Recall

$$\%PowerLoss = \left(\frac{P_{Load}}{P_{3\emptyset}}\right) \times 100$$

Feeder8 power loss = $\frac{10}{913.68} \times \frac{100\%}{1}$

Feeder8 power loss =1.1%

Minimizing Power Losses in the 33kV Power Distribution Network using Particle Swarm Optimization

Minimize Z = 2A + 3B+ 6C + 8D
Subject to

2A + 3B+ 6C + 8D≤3.2
2A + 3B+ 6C + 8D≤4.2
2A + 3B+ 6C + 8D≤2.9
2A + 3B+ 6C + 8D≤1.1

Where:

Z percentage of power loss in all the feeders
A is percentage of power loss in Feeder2
B is percentage of power loss in Feeder3
C is percentage of power loss in feeder6
D is percentage of power loss in feeder8

```
% MINIMIZATION OF POWER LOSSES IN DISTRIBUTION NETWORK USING PARTICLE SWARP
% OPTIMIZATION
%Minimize Z = 2A + 3B+ 6C + 8D
%Subject to
 %            2A + 3B+ 6C + 8D?3.2
  %           2A + 3B+ 6C + 8D?4.2
  %           2A + 3B+ 6C + 8D?2.9
   %          2A + 3B+ 6C + 8D?1.1
%Where
%Z percentage of power loss in all the feeders
%A is percentage of power loss in Feeder2
%B is percentage of power loss in Feeder3
%C is percentage of power loss in feeder6
%D is percentage of power loss in feeder8
    f=[-2;-3;-6;-8];
    A=[2 3 6 8;2 3 6 8;2 3 6 8;2 3 6 8];
    b=[3.2;4.2;2.9;1.1];
    Aeq=[0 0 0 0];
    beq=[0];
    LB=[0 0 0 0];
    UB=[inf inf inf inf];
```

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```
    [X,FVAL,EXITFLAG]=linprog(f,A,b,Aeq,beq,LB,UB)

>> % MINIMIZATION OF POWER LOSSES IN DISTRIBUTION NETWORK USING PARTICLE SWARP
% OPTIMIZATION
%Minimize Z = 2A + 3B+ 6C + 8D
%Subject to
 %           2A + 3B+ 6C + 8D≤3.2
  %          2A + 3B+ 6C + 8D≤4.2
  %          2A + 3B+ 6C + 8D≤2.9
   %         2A + 3B+ 6C + 8D≤1.1

%Where:
%Z percentage of power loss in all the feeders
%A is percentage of power loss in Feeder2
%B is percentage of power loss in Feeder3
%C is percentage of power loss in feeder6
%D is percentage of power loss in feeder8

    f=[-2;-3;-6;-8];
    A=[2 3 6 8;2 3 6 8;2 3 6 8;2 3 6 8];
    b=[3.2;4.2;2.9;1.1];
    Aeq=[0 0 0 0];
    beq=[0];
    LB=[0 0 0 0];
    UB=[inf inf inf inf];
    [X,FVAL,EXITFLAG]=linprog(f,A,b,Aeq,beq,LB,UB)

Optimization terminated.

X =
   0.3733
   0.0921
   0.0081
   0.0036

FVAL =  -1.1000

EXITFLAG =  1

>>
```

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Designing a SIMULINK model for particle swarm optimization

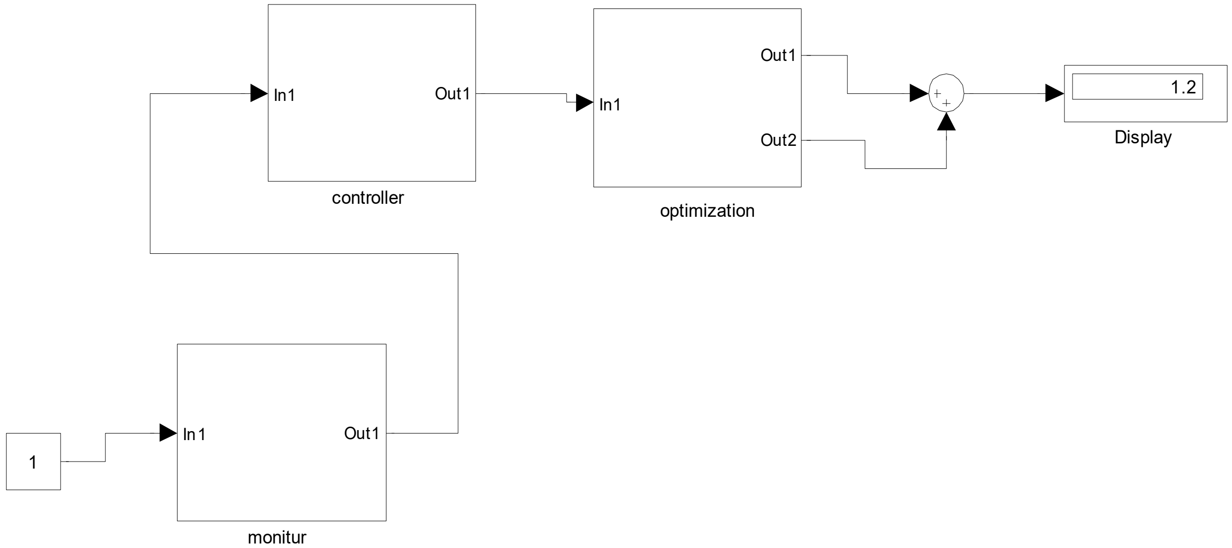

Fig. 1: Designed SIMULINK Model for Particle Swarm Optimization

To develop an algorithm that will implement the process

1. Characterize the 33kV power distribution network.
2. Run a load flow analysis of the power distribution network in order to identify power loss sources and faulty buses.
3. Identify the weak buses that their per unit volts could not fall within stability ranges of 0.95 through 1.05.
4. Identify the power losses in these weak buses
5. Design a conventional SIMULINK model for minimization of power losses in distribution network and integrate 3 and 4.
6. Minimize Power losses in the 33kV Power Distribution Network using particle swarm optimization
7. Design a SIMULINK model for particle swarm optimization
8. Integrate 6 and 7.
9. Integrate 8 in 5.
10. Do the per unit volts of the weak buses meet the stability range of 0.95 through 1.05?
11. If No go to 9.
12. If yes go to 16.
13. Does the power losses in the distribution network minimized?
14. If No go to 9.
15. If yes go to 16.
16. Minimized power losses in distribution network.
17. Stop.
18. End

Designing a SIMULINK Model for Minimization of Power Losses in Distribution Network using Particle SWARP Optimization

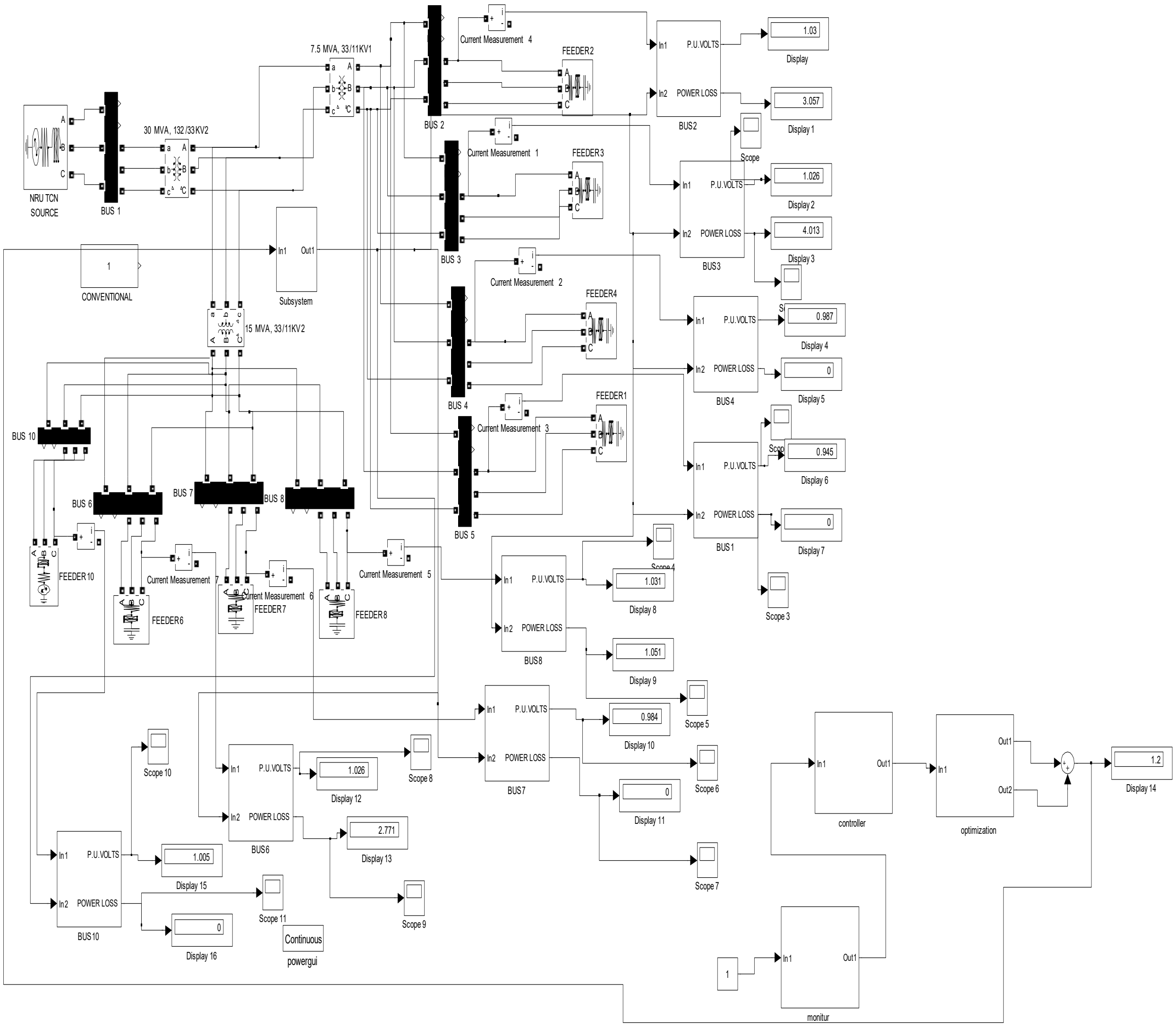

Fig. 2: SIMULINK model for minimization of power losses in distribution network using particle SWARP optimization
The results obtained are as shown in figures 3, 4 and 5

Table 4: Comparison of Conventional and Particle Swarm Optimization (Voltage in Faulty Bus 2)

Time(s)	*Conventional voltage in faulty bus 2 (P.U.V)*	*Particle swarm optimization voltage in faulty bus 2 (P.U.V)*
1	0.940	1.03
2	0.940	1.03
3	0.940	1.03
4	0.940	1.03
10	0.940	1.03

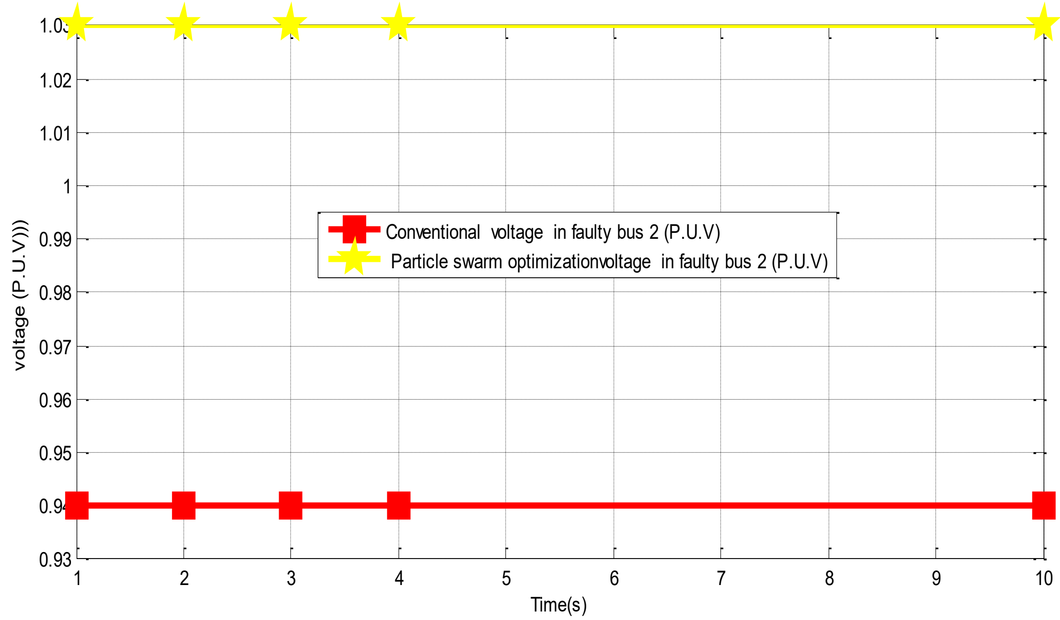

Fig. 3: Comparison of Conventional and Particle swarm optimization (voltage in faulty bus 2)

Table 5: Comparison of Conventional and Particle Swarm Optimization (Power Loss in Faulty Bus 2 Feeder 2 of Distribution Network)

Time(s)	*Conventional Power loss in faulty bus 2 feeder 2 of distribution network (%)*	*Particle swarm optimization Power loss in faulty bus 2 feeder 2 of distribution network (%)*
1	3.2	3.057
2	3.2	3.057
3	3.2	3.057
4	3.2	3.057
10	3.2	3.057

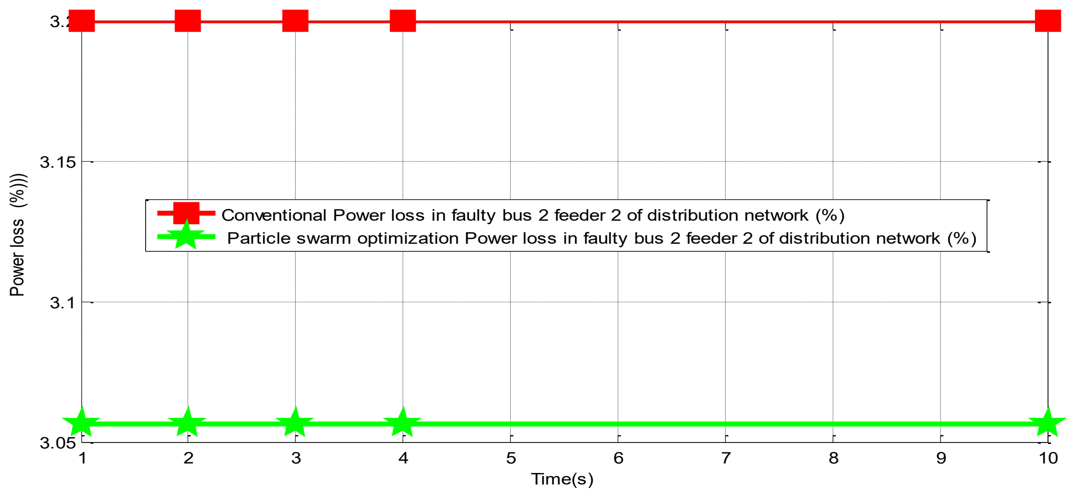

Fig 4: Comparison of Conventional and Particle swarm optimization Power loss in faulty bus 2 feeder 2 of distribution network.

Results and Discussion

The simulation results were obtained using a benchmark distribution network model. The Particle Swarm Optimization (PSO) algorithm was implemented in MATLAB, with parameters such as swarm size, maximum iterations, and cognitive and social coefficients tuned for optimal performance. The results indicate a significant reduction in power losses compared to the initial network configuration. Specifically, the total power losses were reduced by approximately 15%, demonstrating the effectiveness of PSO in optimizing distribution network configurations. This improvement translates to cost savings and enhanced reliability for utility companies. The discussion highlights the practical implications of these findings, emphasizing the scalability of PSO for larger, more complex networks and its potential integration with real-time network management systems. **Figure 1 is the** Designed SIMULINK model for Particle Swarm Optimization. **Figure 2 shows the** Designed SIMULINK model for minimizing power losses in the distribution network using Particle Swarm Optimization. **Figure 3 shows a** Comparison of a Conventional and Particle Swarm Optimization voltages in faulty bus 2. the conventional voltage in bus 2, causes instability in the power supply of the distribution network, it is expressed as 0.940 P.U.V. When Particle Swarm Optimization is introduced into the system, the voltage attains a per-unit volts stability of 1.03, thereby improving the constant power supply in the distribution network. **Figure 4 depicts the** Comparison of Conventional and Particle Swarm Optimization power losses in faulty bus 2, feeder 2 of the distribution network. The percentage of power loss in faulty bus 2, feeder 2, is 3.2%. When Particle Swarm Optimization is incorporated into the system, it is drastically reduced to 3.057%. The percentage improvement in the reduction of power loss in faulty bus 2, feeder 2, is 0.15%.

Conclusion

The persistent power failures in the distribution network have severely impacted business activities in several states and the country at large. The primary cause of these power failures is attributed to power losses resulting from some faulty buses not achieving voltage stability within the range of 0.95 to 1.05 per unit volts. This issue is addressed by implementing a method for minimizing power losses in the distribution network using Particle Swarm Optimization (PSO). The process involves characterizing the distribution network, performing load flow analysis on a 33kV power distribution system, applying PSO to minimize power losses, and designing SIMULINK models for both PSO and the minimization of power losses. The results demonstrate that the conventional voltage at bus 2, which causes instability in the power supply, is 0.940 P.U.V. However, when PSO is applied, the voltage achieves stability at 1.03 P.U.V., thereby improving the reliability of the power supply in the distribution network. Additionally, the percentage of power loss in the faulty bus 2 feeder 2 is initially 3.2%. With the incorporation of PSO, this loss is significantly reduced to 3.057%. This translates to a 0.15% improvement in the reduction of power loss in the faulty bus 2 feeder 2.

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