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Design and Implementation of Power System Optimization Using Particles Swarm Algorithms

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***Abstract*—** This study aims to develop a power system optimization simulation environment for one of Electrical Supply Grid in Peshawar Region where theoretical, calculated and collected data is used and proposes enhancements in the distribution system as per the results of the simulation of the Particle Swarm Optimizer and Newton Rhapson Algorithm on it. The simulation framework is cross-evaluated on the IEEE-30 Bus bar system and compared with eminent researches in this field. The results are plotted and tabulated first as a comparison and then as a proposed model for Peshawar Region's selected substations and the involved grid.

***Keywords*—** PSO, Optimal Power Flow, Particle Swarm Optimization, Grid Optimization, Reactive Dispatch.

I. Introduction

The aim of power flow study is to ensure that the power grid is stable, safeguarded and secure while transmitting power from production to consumer. At the same time, economical transmission of power is also an important factor, which is also ensured during the power flow study. An electrical engineer has the responsibility on both sides, power production as well as on maintenance side to carryout different approaches to minimize struggles while achieving a certain amount of power producing in a power production house while ensuring lowest possible power losses. Optimal power flow plays a very important role in managing different aspects of modern power systems such as load estimation, calculating ATC (Available Transfer Capability) unit commitment, fuel purchase scheduling etc. The problem at hand is termed as Economic Load Dispatch in which the power produced is transmitted or dispatched to the consumer side of the grid ensuring minimum power production costs as well as minimum power losses in the dispatch. This is ensured in a greater ration by the arrangement of components in the grid as well as the strategic placement of Compensators, Transformers and as well as the arrangement of transmission lines and distribution system.

Usually for ELD problem solution a mathematical programming is used which is based on different optimization techniques such as gradient method, lambda iteration [1][2][3][4] and [5] and many more.

This research covers the power losses study which is a class of problems in the OPFA (Optimal Power Flow Analysis). There are various techniques to solve the problem and numerous other techniques are coming out. One of these various techniques is Particle Swarm Optimization (PSO). PSO is best known for its simplicity and better outcomes and is used in this project because it really fulfils all the criteria of our problem. As compared to other techniques PSO provides very good results and consume less time for solution. In contrast with its competitors such as Genetic Algorithm and Ant Colony Algorithm PSO has little issues to address.

The paper is organized as follows.

Section I comprises of general introduction. Section II discuss literature review. Section III have materials and methdology. Section IV have implementation. Section V have evaluation and section VI have conclusion.

II. Literature Review

There are many simple and intelligent methods to address complex and unnatural ELD. Some of these methods are genetic algorithm (GA) [6] & [7], evolutionary programming (EP) [8] & [9], dynamic programming (DP), hybrid EP, tabu search[11], adaptive Hopfield neural network (AHNN), neural network (NN), particle Swarm Optimization (PSO) [15], [16], [17] and [18] etc.

Other methods like gradient method and lambda iteration or [1], [2] and [3] can also be used for computing Economic Load Dispatch calculations but they are not practically applicable in the consumer market. Although they are fast. Of many intelligent methods in use, genetic algorithm is applied to solve the Optimal Power Flow in real time [6] and [7]. Evolutionary algorithm and tabu search methods help solving some problems [8], [9] and [11] while ANN (Artificial neural network) solves optimization problem. Most people use swarm behaviour to solve the optimum dispatch problem and unit commitment as well. Although these are uncertain. In case of ELD, as this is a practical problem, it needs modification in accordance with the problem at hand.

These methods are basically iterative techniques which based on problem territory and limits of time execution can search optimal solutions globally let alone local optimal solutions. These are common-cause searching methods based on those principles which are taken from genetic and evolution mechanisms witnessed in nature and living beings. The advantage of these methods is that they search solutions space completely and carefully. But the main problem with these methods is their sensitivity towards their choice of

Parameters. In all these intelligent methods Particle Swarm Optimization (PSO) is a rather simple technique and has some ensuring results when applied to a problem such as ELD or OPF. The calculation time required to perform a PSO is less as compared with other known techniques and gives out standard results that are interpreted easily.

Heuristics is a type of approach used in mathematics for solution of problems that relate to Polynomial Hard category. In literature, typical approaches of heuristics include Genetic Algorithms, but they are not confined to it or Bee programming and Particle Swarm Algorithm [13],[14],[15],[16],[17],[18].. Using these algorithms OPF problems have been tested and optimized and results are found to be better than previously used mathematical approaches for analysis.

Details of Certain Prominent methods are given in the following topics.

a. Particle Swarm Optimization

There are a large number of computational techniques already which are originated from biological systems. Such as genetic algorithm is pictured from human evolution; artificial neural network is human brain model in simplified form. One of these biological systems is social system. Social system is based on the collective behavior of simple personals interacting in between themselves and their environment. This is also called a swarm intelligence. [19].

Particle swarm optimization (PSO) is a technique based on stochastic optimization developed by Dr. Kennedy and Dr. Ebehart [16] in the year 1995. The inspiration came from bird flocking. This technique has a lot of similarities with computational techniques like Genetic Algorithms. The algorithm computes local and global optimum values of the given objective function by finding values that pass the criteria of local or global maxima or minima (depending on the problem formulation) and saving the results temporarily until next swarm finds better values. But PSO, unlike GA, has no evolution operators for instance mutation and crossover. In computational intelligence field, there are two well-known methods inspired from swarm, Particle swarm optimization (PSO) and Ant Colony Optimization (ACO). ACO is inspired by ant behavior. Later it was understood that it can be used as an optimizer model. The Optimizer Model in PSO includes a few terms such as Swam - a population not well organized but moving in random directions that tend to attain a common optimum value, Personal Best - the position of an individual particle associated with it, yielding highest fitness factor in its best position, Global Best - the best position of any particle it has attained by visiting a point having best possible fitness factor of all the swarm.

b. Genetic Algorithm

Inventor of Genetic Algorithm is John Holland, who first invented GAs in 1960s. later on GAs were developed at the University of Michigan in the year 1970 with the help of his students and colleagues. This algorithm is inspired from Darwin theory of evolution and mostly used for optimization purposes. [19]

In Genetic Algorithm, a set of values is initiated randomly in correspondence with a specific set of constraints already defined by the nature of the problem or mentioned explicitly in the problem. These variables are then passed through a set of different tasks, such as evolution, mutation, crossover in which the most fit in the population of children survives slowly and gradually. Which then tend to fulfil best child criteria in the problem space. This process of children generation and evolving for best child in the space continues until the stopping criteria is reached, which may be different for example, a certain number of iterations.

Genetic Algorithm has three genetic operators, (1) Selection, (2) Crossover and (3) Mutation

c. Selection

Function of this operator is to select a chromosome from the population for the purpose of reproduction. The chromosome with higher fitness factor has the highest probability of being selected. There are many methods of chromosome selection for parents to crossover. [19] They are listed as:

- Steady-state selection
- Rank selection
- Tournament selection
- Boltzmann selection
- Roulette-wheel

Crossover

Crossover operator swaps genetic values between two parent strings. It selects a random point and swaps sub-sequences between two chromosomes before and after the locus, which creates two offspring. [19]. For example, the strings 1000 01100111 and 1110 0001 0011. This operator copies biological recombination of two single chromosome organisms (haploid). There is possibility of both, single bit crossover as well as two-bit crossover. In two-bit crossover, the binary digit swap at two chosen points.

d. Mutation

In the final step, the two individuals produced by cross over operation will now undergo mutation operator in order to form a new generation. Mutation operator alters some bits at random locations on a given chromosome. Suppose the string 1100 1001 1000 is to be mutated in its next position will results in 1110 1001 1000. There is an equal chance for every bit to be mutated in a string in an agreement with its biological correspondence and with a probability factor. Usually this factor is very less, e.g. 0.001. In case of 100% mutation all the bits will be inverted in a chromosome. [19].

Mutation operator maximize GA's ability to search for approximate optimal solution for any given problem by making sure that each new population is very different than the previous. This is a confirmation that the solution space used and formulated after the problem definition is searched as a whole rather than in a few selected space for generating the new population.

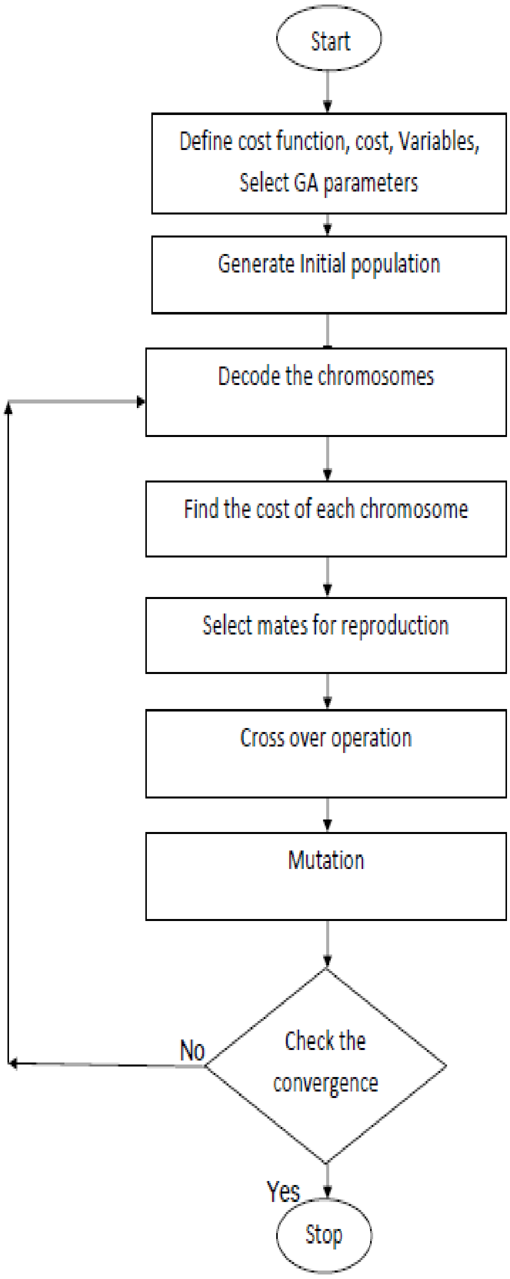

Figure II-1 Genetic Algorithm Process Flow Chart

e. Lambda Iteration

Lambda iteration is another method used for solving optimization problems. In this method lambda is introduced as a variable which is used to solve constraint optimization. This is also called Lagrange multiplier. Lambda is easy to solve through solution systems of equation. The equations are solved by the method of iteration so that all inequality constraints in each trial are satisfied.

- Select an appropriate value for λ(0). This value should confirm to the limitation that it will represent the largest incremental intercept for the generating cost such that it should be at least more than the largest intercept of the incremental cost of different generators.
- Next step is to find out the total generating power of each generating unit
- The equality constraint given below should be satisfied

$$Pd = \sum_{n=1}^{n} Pn$$

- If step (c) is not satisfied increment λ and repeat. [19]

f. Artificial Neural Network

Artificial neural network (ANN) is basically a study pattern that is inspired from brain, or we can call it a simple model of brain. Most prioritized method to train ANN is the back-propagation algorithm. A lot of efforts have been made by the researchers in order to be able to apply evolutionary computations (EC) for developing some of the features of artificial neural networks. Three main features of neural networks have been put into test by EC methodologies, those are: network architecture (includes network topology and transfer functions), network connections weights and the last one is network learning algorithms. [19]. Maximum work done on the evolution of Artificial Neural Networks covers network weights and topological structure, which are encoded in Gradient Algorithm as chromosomes.

This algorithm works by learning about the problem and solution space in each iteration. As the number of iterations and data input is increased and progresses, to does the algorithm's learning of the nature of the problem. After sufficient iterations, the algorithm develops relationships between the inputs and the outputs and the solution is represented as an optimized equation.

The best feature about ANN is its learning capabilities by which it steers its learning curve towards the solution as required by the problem type. Although it has started to emerge in the recent 2 decades, this algorithm has promising results.

III. MATERIALS AND METHOD

In all types of power flow analysis, the mutual admittance that comprises the bus admittance matrix is important. The modeling starts by considering total admittance of the charging line on each feeding bus Y so that the NxN matrix i.e. the bus admittance can be calculated. Mathematically it can be represented by:

$$Y_{ij} = |Y_{ij}|\angle\theta_{ij}$$

This can also be rewritten as:

$$|Y_{ij}|cos\theta_{ij} + j|Y_{ij}|sin\theta_{ij}$$
$$or$$
$$G_{ij} + jB_{ij}$$

θ_{ij} is used to represent the voltage phase angle between ith and jth bus.

The voltage of a bus i is given alternatively as:

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$$V_i = |V_i|\angle\delta_i$$
$$or$$
$$V_i = |V_i|(cos\delta_i + jsin\delta_i)$$

Here δ_i is the ith generator's rotor angle.

Now the net power injected to the network by the ith generator is given as:

$$P_i - jQ_i = V_i * \sum_{n=1}^{N} Y_{in}V_n$$

Here N is the total number of Lines, i is the number of bus being calculated and Y_{in} denotes the elements of bus Y. Also Q_i is reactive power while P_i is the real power at ith bus. The current injected to the network is calculated as shown below:

$$\sum_{n=1}^{N} Y_{in}V_n = I_i = Y_{i1}V_1 + Y_{i2}V_2 + \cdots ... + Y_{iN}V_N$$

Particle Swarm optimization (PSO) is a population based algorithm in which each particle is considered as solution in the multimodal optimization space. There are several types of PSO proposed but here in this work very simplest form of PSO is taken to solve the Optimal Power Flow problem. The particles are generated keeping the constraints in mind for each generating unit as well as the transmission lines and relevant components. When Optimal Power Flow problem considered it can be classified in two different ways.

- Optimal Power Flow without considering the transmission line losses
- Optimal Power Flow considering the transmission line losses.

Both of these techniques have been covered previously in literatures references [16], [17] & [18].

IV. Implementation

In this study, the following substations have been selected for optimization routine. The reason for their selection is simple, they are in the nearest vicinity of Peshawar District and are inside the PESCO Network. All of these substations are 132kV and a

1. Dalazak
2. Jamrud
3. Hayatabad
4. Mattani
5. Peshawar City
6. Peshawar Uni
7. Peshawawr Industrial
8. Peshawar Cantt
9. Peshawar Forte
10. A R Baba
11. Sakhi Ch
12. Shahi Bagh
13. Shahi Bagh New
14. Warsak
15. Warsak P

Step a) The analysis of the selected power grid is done using the Newton Rhapson Algorithm to find out the total transmission losses in the existing network.

Step b) In the next step, PSO is initialized with the parameters shown below:

Population Size	10
Max Iterations	3000
Inertia Weight (w)	0.9,0.4
Acceleration Constants	C1=C2=1.98
Convergence Criteria	0.000001

Step c) The Objective Function for minimization contains power loss calculation for the transmission lines according to [1][14][2][3]:

$$P_l = \sum_{i=0}^{n}\sum_{i=1}^{N} P_{Gi}B_{ij}P_{ij} + \sum_{i=1}^{N} B_{Oi}P_I + B_{OO}$$

And each generating unit, the cost function is calculated as:

$$F_ip_i = ca_i + b_ip_i + ap_i^2$$

And the price factor if cost is also needed by:

$$\lambda = \frac{df_i}{dp_i} = a_ip_{gi} + b_i$$

Then the objective function can be combined and shown to be:

$$F_i = ca_i + b_ip_i + ap_i^2 + \lambda(p_l + p_d - \sum_{i=1}^{n} p_{gi})$$

Step d) The PSO algorithm follows its routine and calculates the optimum values for the grid parameters. The parameters mainly contain power flow in each transmission line.

Step e) The results are saved and forwarded to Newton Rhapson for validation of power flow matrices. The Newton's Method calculates the power flow and line losses among various other information and validates the parameters for practical application.

The results of the experimentation are explained in the next section.

V. Evaluation

The Bus data according to each substation is given in the table below:

Bus No.	Type	Pd	Vm	Va	Vmax	Vmin
1	3	1.03	1.034	0.705	1.06	0.95
2	1	0.99	1.002	0.628	1.06	0.95
3	1	1	1.036	0.633	1.06	0.95
4	1	1.03	1.092	0.681	1.06	0.95
5	1	1.02	1.032	0.809	1.06	0.95
6	1	0.99	1.024	0.621	1.06	0.95
7	1	0.99	1.035	0.617	1.06	0.95
8	1	0.98	1.045	0.636	1.06	0.95
9	1	1.03	1.007	0.692	1.06	0.95

10	1	1.03	1.009	0.686	1.06	0.95
11	1	0.99	1.018	0.779	1.06	0.95
12	1	0.99	1.083	0.701	1.06	0.95
13	1	1.05	1.027	0.711	1.06	0.95
14	1	1.01	1.096	0.717	1.06	0.95
15	1	1.01	1.006	0.722	1.06	0.95

The Branch Data of the Network is shown below:

From Bus	To Bus	R	X
1	12	0.021	0.008
2	3	0.004	0.001
2	6	0.006	0.002
2	8	0.010	0.004
2	15	0.017	0.006
4	5	0.017	0.007
5	7	0.012	0.004
5	10	0.006	0.002
5	12	0.001	0.000
6	7	0.005	0.002
8	**15**	0.019	0.007
9	12	0.012	0.004
11	12	0.026	0.010
11	15	0.023	0.009
12	13	0.009	0.003
12	14	0.017	0.006
12	15	0.0277	0.010
14	15	0.0107	0.004

The Newton Rhapson Algorithm Generates the System Summary for State Estimation of the network as shown in the table as follows:

Bus No.	V Mag	V Ang	PG (MW)	QG (MVAR)	PL (MW)	QL (MVAR)
1	1.000	0.000	14.16	0.02	-	-
2	0.995	-0.122	-	-	0.99	0
3	0.995	-0.122	-	-	1.00	0
4	0.998	-0.055	-	-	1.03	0
5	0.998	-0.052	-	-	1.02	0
6	0.995	-0.124	-	-	0.99	0
7	0.994	-0.125	-	-	0.99	0
8	0.995	-0.123	-	-	0.98	0
9	0.998	-0.053	-	-	1.03	0
10	0.998	-0.053	-	-	1.03	0
11	0.996	-0.083	-	-	0.99	0
12	0.998	-0.051	-	-	0.99	0
13	0.998	-0.053	-	-	1.05	0
14	0.998	-0.054	-	-	1.01	0
15	0.995	-0.107	-	-	1.01	0

There are 18 Branches in the network stated above, the details of branching is shown below:

Br #	Bus i	Bus j	From Bus		To Bus	
			P	Q	P	Q
1	1	12	14.16	0.02	-14.13	-0.01
2	2	3	1.00	0	-1.00	0
3	2	6	1.98	0	-1.98	0
4	2	8	0.98	0	-0.98	0
5	2	15	-4.95	0	4.95	0
6	4	5	-1.03	0	1.03	0
7	5	7	0.00	0	0	0
8	5	10	1.03	0	-1.03	0
9	5	12	-3.08	0	3.08	0
10	6	7	0.99	0	-0.99	0
11	8	15	0.00	0	0	0
12	9	12	-1.03	0	1.03	0
13	11	12	-6.96	0	6.97	0.01
14	11	15	5.97	0	-5.96	0
15	12	13	1.05	0	-1.05	0
16	12	14	1.01	0	-1.01	0
17	12	15	0.00	0	0	0
18	14	15	0.00	0	0	0

For these Branches, tranmission losses are calculated as follows:

Br #	Bus i	Bus j	P Loss	Q Loss
1	1	12	0.032	0.01
2	2	3	0	0
3	2	6	0	0
4	2	8	0	0
5	2	15	0.003	0
6	4	5	0	0
7	5	7	0	0

Br #	Bus i	Bus j	P Loss	Q Loss
8	5	10	0	0
9	5	12	0	0
10	6	7	0	0
11	8	15	0	0
12	9	12	0	0
13	11	12	0.010	0
14	11	15	0.006	0
15	12	13	0	0
16	12	14	0	0
17	12	15	0	0
18	14	15	0	0
		TOTAL	**0.052**	**0.02**

The total Power Losses n the network are estimated by Newton Rhapson as 32.57 kW.

The particle Swarm Optimization Algorithm runs and finds the best configuration of the network such that the power losses are minimized and the network can be optimized.

After PSO run, the data generated is passed to Newton Rhapson and the new configuration is tested for validity in terms of power flow. This can take from 5 iteration upto 100 collectively while the PSO algorithm by itslef iterates 3000 times, thus a total of minimum 15000 to a maximum of 300,000 Iterations are run to find the best optimized configuration of the network.

The result of the runs are shown in the table as a new better configuration for Bus parameters below:

Bus No.	V Mag	V Ang	PG (MW)	QG (MVAR)	PL (MW)	QL (MVAR)
1	1.000	0.000	14.15	0.02	-	-
2	0.996	-0.080	-	-	0.99	0
3	0.996	-0.081	-	-	1.00	0
4	0.997	-0.057	-	-	1.03	0
5	0.998	-0.054	-	-	1.02	0
6	0.997	-0.074	-	-	0.99	0
7	0.997	-0.068	-	-	0.99	0
8	0.996	-0.082	-	-	0.98	0
9	0.998	-0.053	-	-	1.03	0
10	0.998	-0.055	-	-	1.03	0
11	0.998	-0.056	-	-	0.99	0
12	0.998	-0.051	-	-	0.99	0
13	0.998	-0.053	-	-	1.05	0
14	0.996	-0.088	-	-	1.01	0
15	0.996	-0.086	-	-	1.01	0

And the results of the new configuration as branch data which is optimized and better than the existing grid parameters are shown below:

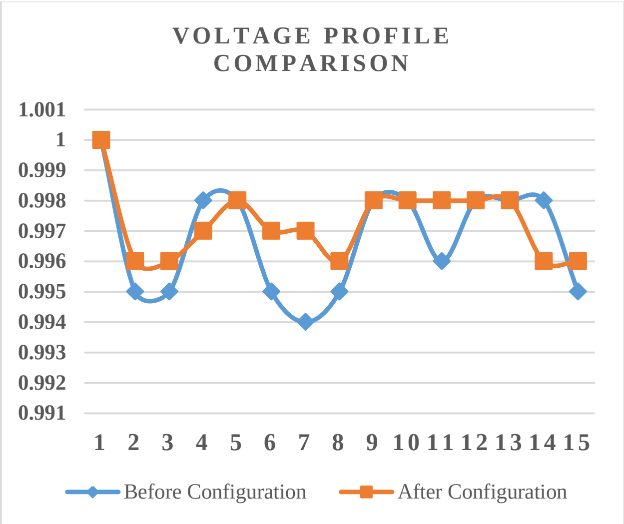
Br #	Bus i	Bus j	From Bus		To Bus	
			P	Q	P	Q
1	1	12	14.15	0.02	-14.12	0
2	2	3	1.00	0	-1.00	0
3	2	6	-4.99	0	4.99	0
4	2	8	0.98	0	-0.98	0
5	2	15	2.02	0	-2.02	0
6	4	5	-1.03	0	1.03	0
7	5	7	6.98	0	-6.97	0
8	5	10	1.03	0	-1.03	0
9	5	12	-10.1	0	10.06	0
10	6	7	-5.98	0	5.98	0
11	8	15	0.00	0	0	0
12	9	12	-1.03	0	1.03	0
13	11	12	-0.99	0	0.99	0
14	11	15	0	0	0	0
15	12	13	1.05	0	-1.05	0
16	12	14	0.00	0	0	0
17	12	15	0.00	0	0	0
18	14	15	-1.01	0	1.01	0

For these new configuration Branches, tranmission losses are calculated as follows:

Br #	Bus i	Bus j	P Loss	Q Loss
1	1	12	0.032	0.01
2	2	3	0	0
3	2	6	0.001	0
4	2	8	0	0
5	2	15	0.001	0
6	4	5	0	0
7	5	7	0.005	0
8	5	10	0	0
9	5	12	0.001	0
10	6	7	0.002	0
11	8	15	0	0

Br #	Bus i	Bus j	P Loss	Q Loss
12	9	12	0	0
13	11	12	0	0
14	11	15	0	0
15	12	13	0	0
16	12	14	0	0
17	12	15	0	0
18	14	15	0	0
		TOTAL	**0.042**	**0.02**

The comparison of the voltage profiles before and after configuration is shown below:



The power losses in the network before configuration are 32.2757 kW and the power losses after configuration are 28.7186 kW. A total of 11.029% decrease in the power losses have been observed and achieved. The algorithm took 3.12 seconds to reconfigure the network.

CONCLUSION

The particle swarm optimization has various applications in numerous fields of science and has proven to be the best solver in problems related to power in engineering fields. In this project, a selected 132KV grid of PESCO has been taken and its state estimation has been done on Newton Rhapson Method. After that the data is fed through PSO using the MATPOWER toolbox. The network losses are calculated before and after the optimization of the network on PSO algorithm and the losses has been found to decrease by 11.029% in just a few iterations (20 to be precise). The network is reconfigured on the results obtained from Newton Rhapson State estimation done on the results of the PSO and the voltage profile and power losses are compared. The results are groundbreaking and the proposed network model can be implemented by NTDC for minimizing losses in the network.

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