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OPTIMAL POWER FLOW OF POWER SYSTEM WITH THYRISTOR CONTROLLED SERIES COMPENSATION USING MOTH FLAME OPTIMIZATION WITH LOCATIONAL MARGINAL PRICE

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ABSTRACT

Consideration of transmission line capacity and the optimal power flow (OPF) determines the locational marginal price (LMP), which in turn determines the performance and profitability of a producing unit. Reducing the total cost of the generators can lead to a drop in the market price of electricity. It is recommended to use numerical and repetition-based approaches for solving power flow equations due to their nonlinear nature. In order to achieve the ideal power flow at an affordable price, this paper employs a Moth Flame Optimization (MFO) to solve the equations. We then enhance the MFO's structure to make it more effective at performing the simultaneous calculations of power passing through transmission lines. One FACTS tool that has been utilized to overcome this problem is the Thyristor Controlled Series Compensation (TCSC). Lastly, the proposed MFO algorithm would include the following parameters in its output: bus voltages, line losses, produced power, total generating expenditures, and generator profits. Testing the proposed method on the IEEE 57-BUS network also shows that it improves upon the OPF problem.

Keywords: locational marginal price; optimal power flow; moth flame optimization; thyristor Controlled Series Compensation (TCSC).

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1. INTRODUCTION

Electric service engineering has entered a new era, marked by competition between service-owned and sovereign authorities and long-standing power dynamics. Some licenses are close to each other. From countryside to countryside, and by growth a brief market where numerous consumers buy least client pricing power. This improved use of market pressures, new dealer support and confidence growing contemporary power model and finance system power deal corporation union has increased electric load organize transmission. Competent usage of market-situation transmission organization label change in transmission association Dealings usually disputes shared plan problem 1990s electric value output will be linked.

The goal is to promote financial competence in the use of electric power organizations. Transmission of financial data from connected electric power facilities. Networks provide a typical discussion starter for well-organized power markets. Besides description, financial send out maximize low Plant usability affects pay rates. Transmission constraints Locational Marginal LMP is the low price of providing the next electric power surge at a bus considering generating marginal cost and physical transmission system aspects.

Competitiveness among market actors facilitates power trade. It will boost industrial production and lower electricity costs for all consumers [1]. Market players like power producers Deregulated energy markets benefit customers and system operators. However, Energy market difficulties include generating loss, line outages, etc. [2, 3]. The Transmission systems are widely used due to electric market restructuring. for electricity trading. To integrate in a deregulated system, needs suitable formulation between regulatory entities like pool operators and system managers. This study emphasizes the latter of these difficulties. We study pool, bilateral, and multilateral dispatch coordination and construct mathematical models. How forward and real-time dispatch works when all three modalities coexist is addressed [4].

Producing and distributing companies' agreements cause transmission congestion in deregulated electricity systems globally. Transmission line congestion may be handled in deregulated energy networks for safe and economical operation. FACTS devices lower power flow across lines so they all stay below limitations. In overloaded lines, series-connected Thyristor Controlled Switched Capacitor (TCSC) devices are installed to ease system congestion [5]. Energy power flows must be estimated and improved in an electrical generating system. Locating Flexible Alternating Current Transmission Systems (FACTS) devices and improving power transmission line Available Transfer Capability (ATC) is crucial. It reduces system congestion and boosts power [6].

Calculating locational marginal price (LMP) is crucial for evaluating generation unit performance and profit. This relies on transmission line capacity and optimal power flow (OPF) to minimize generator costs, alleviate transmission line congestion, and lower market electricity prices [7]. Risk-based locational marginal pricing (RLMP) is a novel power market clearing method developed in this study. The risk-based security-constrained economic dispatch model generates the RLMP by modeling system security risk [8]. This study introduces two methods for placing series FACTS devices in deregulated energy markets to minimize congestion. Like the sensitivity factor-based strategy, the suggested strategies prioritize and narrow the solution space. The suggested methods use LMP differences and congestion rent, respectively [9]. Congestion in transmission lines might make it difficult to dispatch all planned power in a deregulated energy market. An Interline Power Flow Controller (IPFC) may enhance system stability and load by reducing system loss and power flow in severely laden lines. This study suggests using a Disparity Line Utilization Factor and Gravitational Search method to optimize IPFC placement and manage transmission line congestion [10]. We present single-objective and multi-objective optimization methods for optimal choice, location, and size of Static Var Compensators (SVC) and Thyristor Controlled Series Capacitors (TCSC) in deregulated power systems to reduce branch loading (congestion), voltage stability, and line losses [11]. This research introduces an effective approach for optimizing FACTS device locations for congestion management by modifying device characteristics. Using FACTS devices for congestion control involves a two-step process. To improve the network, first determine the ideal device placement and then optimize the control parameters [12]. After defining irrigation efficiency equations, hierarchical analysis developed goal function coefficients for all irrigation efficiencies in SWDC model. All irrigation efficiency formulae depend on input discharge [13]. Many recent research optimized furrow irrigation control settings. These experiments either optimized just complete irrigation status or not all infiltration parameters. This study uses MS Visual Basic (VB) programming to calculate the optimal soil water distribution curve equation [14]. Model training and forecasting utilize 42 and 5 years of monthly discharges from the 47-year period. The RMSE metric was used to compare static and dynamic artificial neural network models. Starting with data from October 1960 to September 2002, the finest static and dynamic neural network topologies are identified [15]. We also derive special initialization of a solution using IPFC and GUPFC. In addition, an impedance compensation approach is presented to address the numerical instability or numerical difficulties of IPFC and GUPFC models with low coupling transformer impedances or transformer-less controllers [16]. Multi-transmission lines are controlled by an IPFC in this work. However, IPFC installation in the transmission line is difficult. The suggested technique uses tabu search (TS) algorithm and artificial neural network (ANN) to discover the optimal IPFC installation sites in a multi-transmission line system [17]. Due to transmission corridor congestion, a deregulated energy market may not be able to dispatch all contractual power transactions. Environmental, right-of-way, and economic issues prevent power transmission network growth, thus power system reorganization must unleash transmission system potentials [18]. This work introduces a reliable and efficient meta-heuristic technique for congestion issue solving. This study proposes using the firefly algorithm (FFA) to reduce transmission network congestion in a pool-based energy market by rescheduling producers using active power [19]. Reference [20] proposes enhanced harmony search to tackle transmission expansion planning with adequacy-security issues in deregulated power systems. Zhuang and Galiana performed simulated annealing (SA) on unit commitment [21]. Jang *et al.* [22] proposed a computationally simple random search technique (RSM) for optimization issues. Firefly algorithm (FFA), a meta-heuristic inspired by fireflies [23], is becoming more popular in practically all fields of science and technology for optimization. Reference [24] solved non-linear design issues using FFA. FFA was used in Reference [25] to improve transmission system control variables for actual power loss and voltage stability limit. Reference [26] designs a Smith predictor controller for integration and unstable delay processes using the modified FFA. The current study proposes FFA for power network rescheduling to reduce congestion.

Many optimization and congestion management approaches have been suggested to reduce congestion cost and loss in transmission networks, according to a literature review. However, the approach may be improved to reduce transaction curtailment, loss, and rescheduling expenses. This study introduces UPFC with Moth Flame Optimization (MFO) to manage transmission network congestion.

In this paper, generating scaling factor (GSF) was used to prevent congestion in minimum local points and calculate the power flow for each change in control variables. If the algorithm violates line capacity, it exits this optimal point and continues to find the best response. It decreases convergence speed, makes power flow actual, and costs less than previous ways. A 24-h power flow on an IEEE 57-Node network was performed after the MFO algorithm introduction. The generator profit was computed by estimating the power price using UMP or LMP and comparing it to economic dispatching (ED) and quadratic programming using Lagrangian coefficients.

2. PROBLEM FORMULATION

The optimum power dispatch model in the deregulated energy market aims to minimize deviation from contract power transactions for market utilities. Simultaneously, operational equality and inequality requirements must be met for uninterrupted transactions.

2.1 Objective Function

OPF aims to reduce active power generation expenses. The active power-based cost function of each producing unit is shown by this quadratic curve. Add each generator's cost function to get the system's goal function.

$$F_c = \min(\sum_{i=1}^{ng} a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \quad (1)$$

2.1.1 Equality constraints

Production should minimize cost while meeting power demand and transmission losses. So power flow equations are equivalent limitations.

$$\sum_{i=1}^{N} P_G = \sum_{i=1}^{N} P_{Di} + P_L \quad (2)$$

$$\sum_{i=1}^{N} Q_{Gi} = \sum_{i=1}^{N} Q_{Di} + Q_L \quad (3)$$

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2.1.2 Inequality constraints

OPF limits vary according on power system equipment and dependability. Uneven constraints in buses connecting to power and producing units are usually high and low voltage. Generation restrictions include generator active power, transmission line capacity, TCUL tap adjustment, and phase shift. Limitations of unequal issue variables: Generator-powered buses have high and low active power. The voltage, watt and wattles power and upfc limits are shown below.

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max} \tag{3}$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \tag{4}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \tag{5}$$

$$B_{upfc}^{min} \leq B_{upfc} \leq B_{upfc}^{max} \tag{6}$$

3. ELECTRICITY MARKET PRICE CALCULATION

After calculating OPF and line power flow, we may compute the electricity market price using two approaches. The first technique (UMP) uses power flow data without congestion, calculating electricity prices from the overall cost of functioning generators. Each node will have an equal power tariff. The next process (LMP) is used when one or more transmission lines are at capacity and the power cost for each node will vary based on generator output.

3.1 UMP Price

Consider the IEEE 30-BUS network's generation units to determine the generators' ultimate cost for the minimal producing power:

$$\mathrm{MC_i}(\mathrm{P_i^{min}}) = \frac{\mathrm{dF_i}(\mathrm{P_i^{min}})}{\mathrm{dP_i^{min}}}\left(\frac{\$}{\mathrm{MWh}}\right), \mathrm{i} = 1,2,3,6,8 \tag{7}$$

Power price (π) will be determined by the cost of the more expensive generator since employing the cheaper generator would result in losses and be unfeasible. Electricity costs are based on generators' lowest power to keep prices low.

$$\pi = \max\left(MC_i\left(P_i^{min}\right)\right)\left(\frac{\$}{MWh}\right) \tag{8}$$

3.2 LMP Price

The power price at network locations will be different if transmission line capacity hits its limit since producers cannot employ their full generation capacity. This is termed locational marginal pricing. LMP implies adding a 1-MW excess load using the cheapest generators that can generate without exceeding transmission line limits. Therefore, LMP may be calculated by considering generators that are not at their limitations. Final generators are ones with some capacity left. Thus, LMP in buses with final generators equals their ultimate cost. LMP of nodes devoid of generators or whose generators have surpassed their maximum will also rely on buses with a final generator. Final-generator buses

$$\pi_i = LMP_i = MC_i(P_i), P_i^{min} < P_i < P_i^{max}, P_i \neq P_i^{min}, P_i \neq P_i^{max}, i \in \{1,2,3,6,8\} \tag{9}$$

Final generator buses are indicated by i. Finally, Figure-1 displays the flowchart of all stated steps with green blocks representing algorithm outputs.

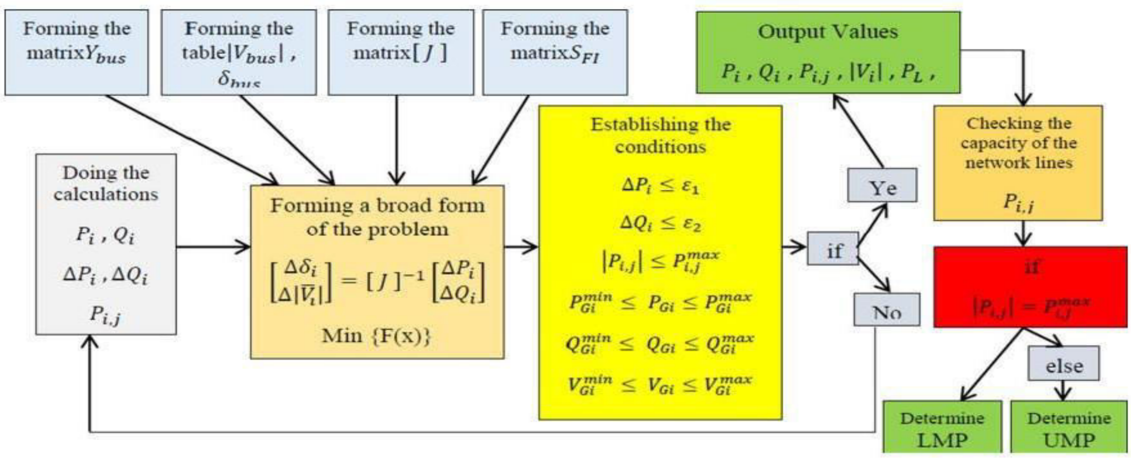

Figure-1. Block diagram of the stages.

4. MOTH FLAME OPTIMIZATION

This is a method of optimisation with roots in the natural world. The algorithm's design was inspired by the moths' method of navigating at night. The moths fly at a steady angle towards the moon. Moths often fly in spiral patterns around lights. The multi-objective function's solution is assumed to be represented by the moths. One of the parameters of the issue is the spatial distribution of the moths. The following is a summary of the mathematical models of moth behavior: In light of these constraints, we

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describe the logarithmic spiral used by the MFO method flow diagram shown in Figure-2, as where S is the spiral function, Mi is the i^{-th} moth, and F_j stands for the j^{-th} flame.

$$M_i = S(M_i, F_I) \tag{9}$$

$$S(M_i, F_I) = D_i.e^{bt}.\cos(2\pi t) + F_j \tag{10}$$

Di is the distance between the ith moth and the jth flame, b is a constant used to define the shape of the logarithmic spiral, and t is a random number in the interval [-1, 1].

$$D_i = \left|F_j - M_i\right| \tag{11}$$

Where M_i is the i^{th} moth for the j^{th} flame and D_i is the distance between them.

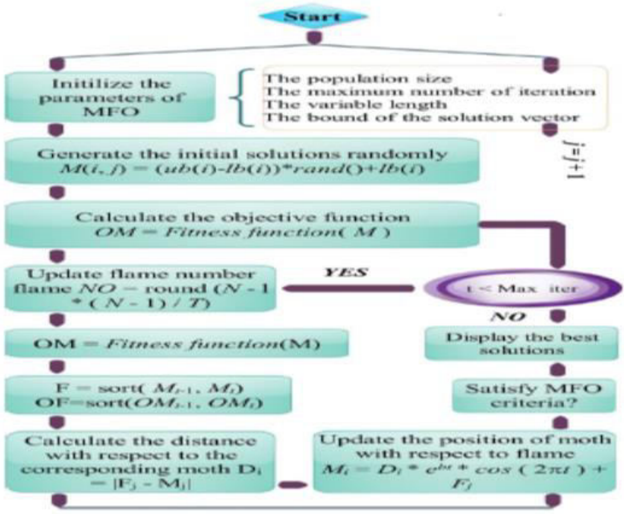

Figure-2. Flow chart of moth flame algorithm.

5. RESULTS AND DISCUSSIONS

Figure-3 depicts an IEEE- 57 node network with 80 lines of transmission, six PV nodes, one slack bus, and the remaining load nodes. Currently, UPFCs are only being installed on load buses. Solar and wind power replace the final two remaining thermal generators at bus 9 and bus 12.

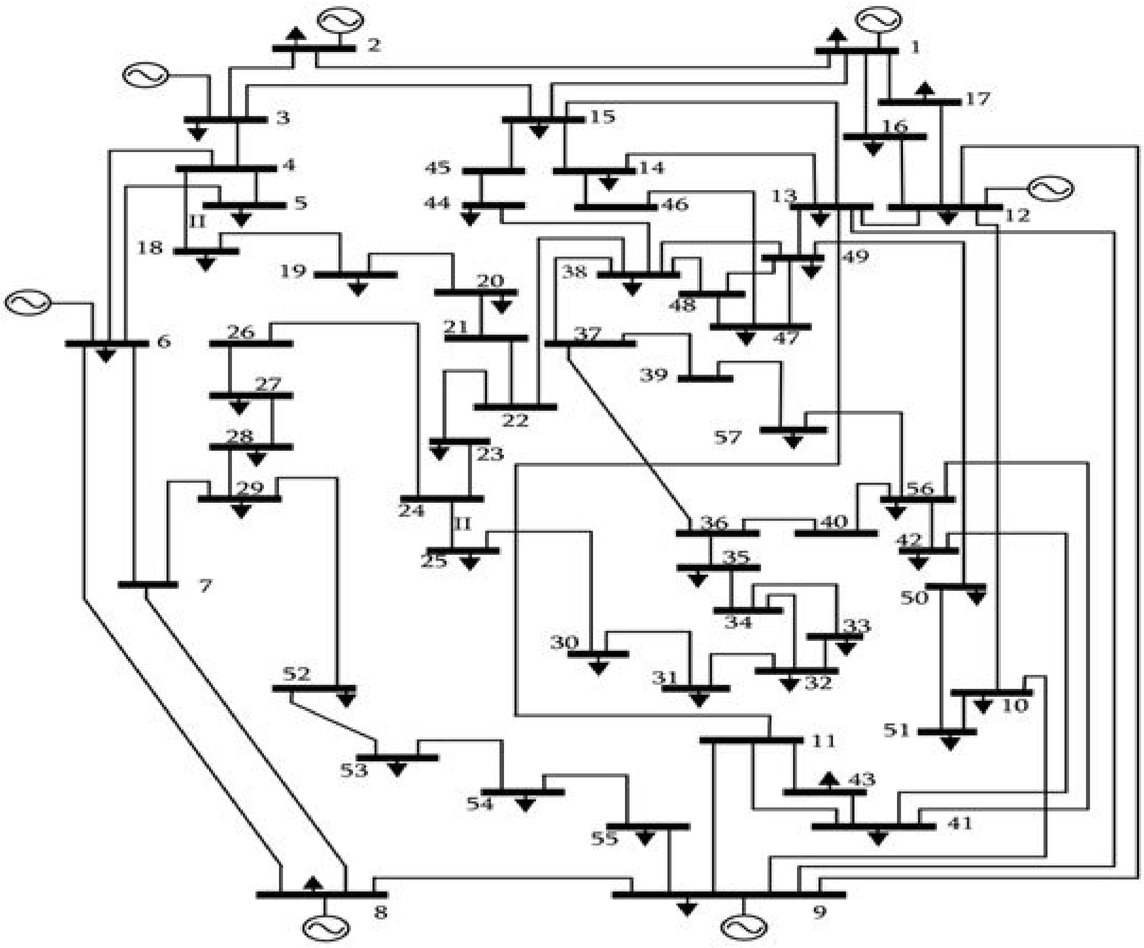

Figure-3. IEEE 57 bus transmission system.

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There is research being done on the generator reallocation for the IEEE-57 node network. The OPF is carried out for functions with a single goal, and then the multi-objective function optimization is carried out thereafter. The outcomes of both optimizations have been compared. The variable LMP stands for the locational marginal price, the variable UMP stands for the uniform marginal price, and the variable GSF stands for the generation scaling factor. MFO is an abbreviation for the algorithm for moth flame optimization. Table-1 indicates the OPF in 24h using MFO. Table-2 shows the Calculations for profits of generators in MFO technique.

Table-1. MFO outcome from OPF in one day.

Hour	P1	P2	P3	P6	P8	P9	P12	PD	Cost of production	Loss	Market Price (UMP or LMP)
1	88.63	1.3013	6.098	1.399	19.2367	200	376.1	683.28	3116.2	9.4881	UMP
2	35.145	0.0678	10.67	0.014	123.13	200	410	768.66	3920.1	9.6	UMP
3	49.634	0.0053	15.22	0.026	153.97	200	410	819.12	5212	9.69	UMP
4	19.812	100	7.378	0	128.78	200	410	854.04	7711.4	11.1	UMP
5	73.81	0.2182	20.94	0.021	210.37	200	410	905.34	7775.4	11.83	UMP
6	46.378	100	16.06	1	180.084	200	410	939.54	1001	12.071	UMP
7	96.17	0.055	32.59	0.006	262.46	200	410	987.96	1035.21	13.99	UMP
8	104.21	0.015	32.59	0.005	292.39	200	410	1024.9	11171	14.29	UMP
9	113.12	8.91	31.05	0.079	310.12	200	410	1059.1	12500	15.031	UMP
10	138.5	31.78	46.17	1.117	296.87	200	410	1110.3	15001	15	UMP
11	133.59	13.787	44	9.753	367.31	200	410	1161.6	16511.23	16.812	UMP
12	122.81	47.512	45.69	7.936	378.46	200	410	1195.8	17910	17.71	LMP
13	138.5	31.78	46.17	1.117	296.87	200	410	1110.3	15001	15	UMP
14	113.12	8.91	31.05	0.079	310.12	200	410	1059.1	12500	15.031	UMP
15	104.21	0.015	32.59	0.005	292.39	200	410	1024.9	11171	14.29	UMP
16	46.378	100	16.06	1	180.084	200	410	939.54	1001	12.071	UMP
17	19.812	100	7.378	0	128.78	200	410	854.04	7711.4	11.1	UMP
18	46.378	100	16.06	1	180.084	200	410	939.54	1001	12.071	UMP
19	104.21	0.015	32.59	0.005	292.39	200	410	1024.9	11171	14.29	UMP
20	138.5	31.78	46.17	1.117	296.87	200	410	1110.3	15001	15	UMP
21	104.21	0.015	32.59	0.005	292.39	200	410	1024.9	11171	14.29	UMP
22	104.21	0.015	32.59	0.005	292.39	200	410	1024.9	11171	14.29	UMP
23	19.812	100	7.378	0	128.78	200	410	854.04	7711.4	11.1	UMP
24	35.145	0.0678	10.67	0.014	123.13	200	410	768.66	3920.1	9.6	UMP

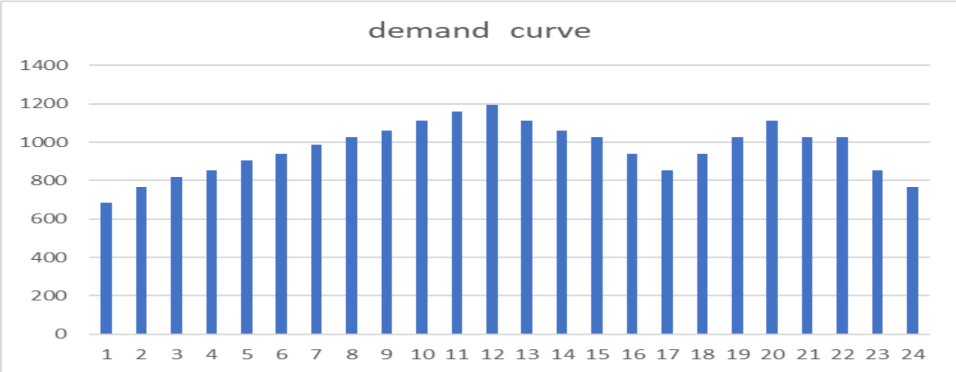

Figure-4. Network's power demand.

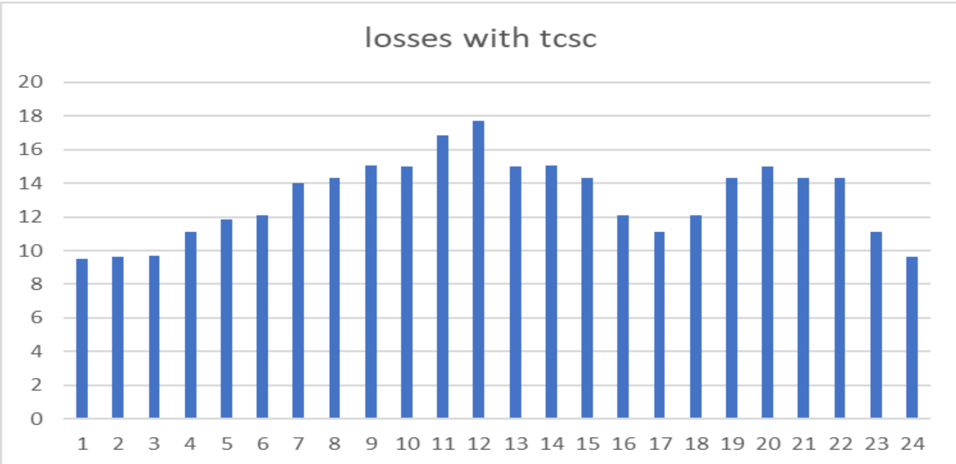

Figure-5. Generation production and transmission losses in the MFO approach.

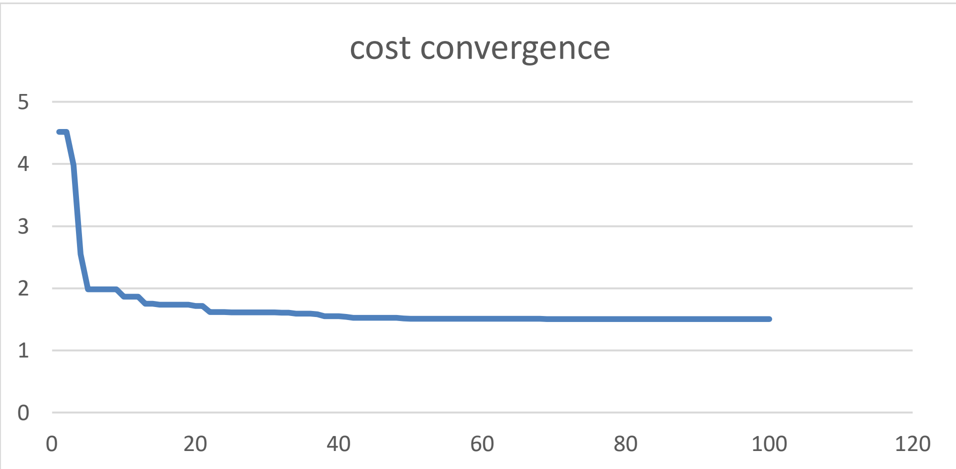

Figure-6. MFO approach cost convergence.

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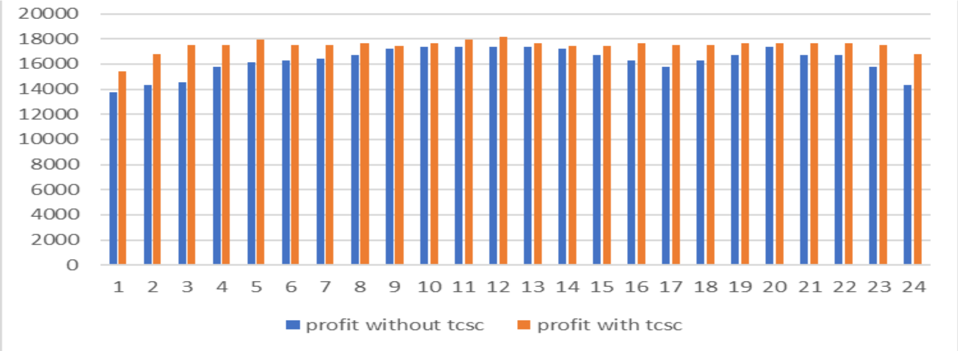

Figure-7. Generation cost profit between with and without TCSC.

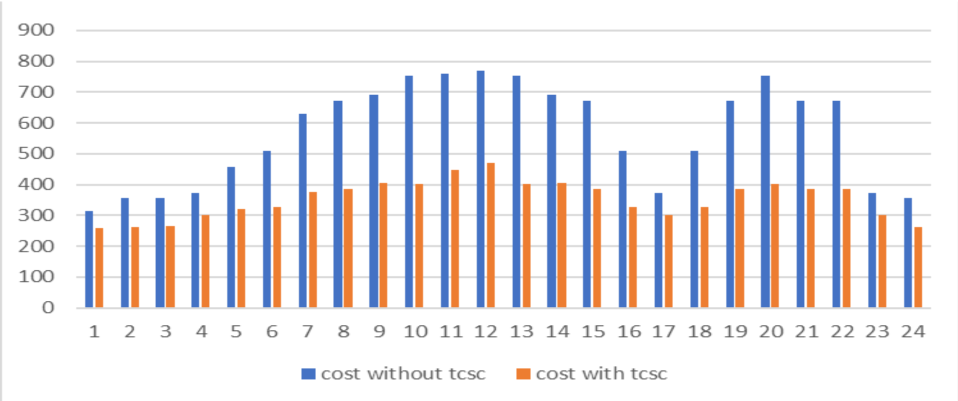

Figure-8. Generation loss cost between with and without TCSC.

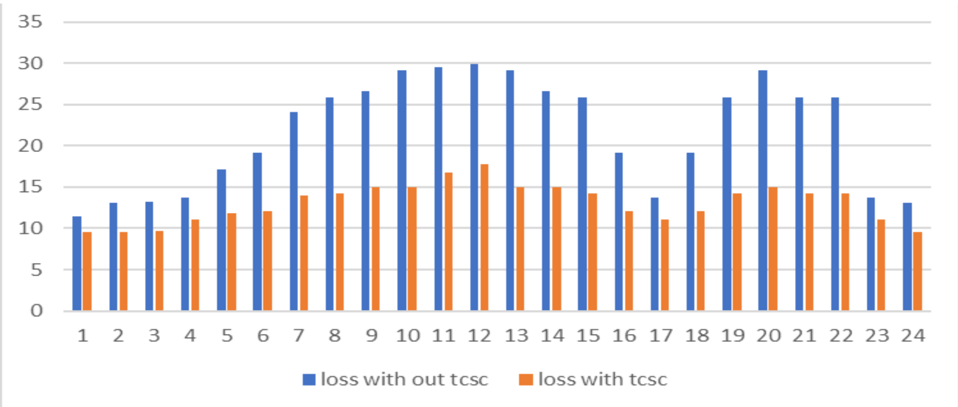

Figure-9. Generation losses between with and without TCSC.

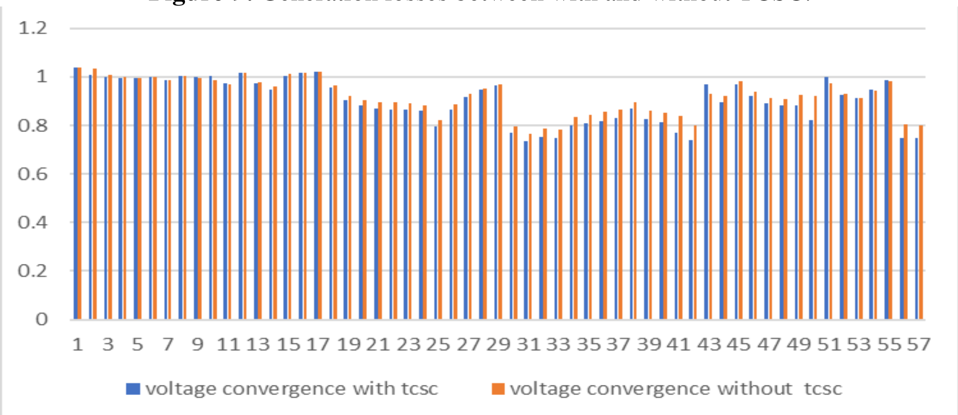

Figure-10. Voltage convergence with and without TCSC.

Table-2. Estimates of generator earnings using the MFO technique.

Hour	P1	P2	P3	P6	P8	P9	P12	Loss cost	Total profit of generators	pi
1	1872.2	10.394	161.44	11.15	530.4	1200	1594.3	258.681	5121.159	48
2	888.22	0.5423	270.4	0.114	3111	1200	6057.4	261.64	11266.13	48
3	1198.6	0.0424	368.24	1.148	3785	1200	6057.4	264.034	12346.31	48
4	524.27	700	192.97	0	3238	1200	6057.4	301.239	11611.15	48
5	1644.1	1.7448	476.65	16.13	4908	1200	6057.4	320.39	13983.6	48
6	1131.7	700	385.2	8	4322	1200	6057.4	326.68	13478.01	48
7	1975.1	0.4399	646.99	0.046	5820	1200	6057.4	376.532	15323.22	48
8	2075.2	0.1127	646.99	0.04	6289	1200	6057.4	384.274	15884.46	48
9	2174.4	70.486	628.38	0.632	6548	1200	6057.4	403.338	16276.26	48
10	2389.5	244.14	759.83	8.924	6356	1200	6057.4	402.54	16613.15	48
11	2355.6	108.48	748	77.07	7290	1200	6057.4	448.811	17387.31	48
12	2268.3	357.51	757.54	62.86	7418	1200	6057.4	471.59	17649.67	LMP
13	2389.5	244.14	759.83	8.924	6356	1200	6057.4	402.54	16613.15	48
14	2174.4	70.486	628.38	0.632	6548	1200	6057.4	403.338	16276.26	48
15	2075.2	0.1127	646.99	0.04	6289	1200	6057.4	384.274	15884.46	48
16	1131.7	700	385.2	8	4322	1200	6057.4	326.68	13478.01	48
17	524.27	700	192.97	0	3238	1200	6057.4	301.239	11611.15	48
18	1131.7	700	385.2	8	4322	1200	6057.4	326.68	13478.01	48
19	2075.2	0.1127	646.99	0.04	6289	1200	6057.4	384.274	15884.46	48
20	2389.5	244.14	759.83	8.924	6356	1200	6057.4	402.54	16613.15	48
21	2075.2	0.1127	646.99	0.04	6289	1200	6057.4	384.274	15884.46	48
22	2075.2	0.1127	646.99	0.04	6289	1200	6057.4	384.274	15884.46	48
23	524.27	700	192.97	0	3238	1200	6057.4	301.239	11611.15	48
24	888.22	0.5423	270.4	0.114	3111	1200	6057.4	261.64	11266.13	48

6. CONCLUSIONS

Through the use of the metaheuristic algorithm MFO, the OPF problem as well as the locational marginal price (LMP) are resolved and calculated in this paper. In the event that the minimum point that is attained does not satisfy the prerequisites for the generation of flow power in the network, the process will be repeated until the prescribed circumstances are satisfied. The power of generating units, network losses, bus voltage, generation cost, and power moving via lines are the outputs of the recommended method. We could also calculate the market price of electricity and the profit of generators by studying the capacity of lines. In addition, we could compute the profit of generators. The results of the simulation illustrate the effectiveness of the MFO algorithm, which has resulted in reduced losses, reduced processing time, reduced producing costs, and an OPF that is better in accordance with the actual situation.

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