Optimal Power Flow of Power System with Static VAR Compensator using Moth Flame Optimization with Locational Marginal Price

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Abstract: The determination of a generation unit's locational marginal price (LMP), which depends on our understanding of transmission line capacity and optimal power flow (OPF) based on reality, is crucial to evaluating the performance of the unit and determining its profit. Minimising the total cost of the generators will lower the price of electricity on the market. Since power flow equations are nonlinear, numerical and repetition-based approaches should be used to solve them. The equations in this paper are solved using a Moth Flame Optimization (MFO), and to enhance the performance of the MFO in its structure, for simultaneous calculations of power passing through in transmission lines so that by learning about the capacity of transmission lines, in addition to the optimal power flow becoming a reality, the price of electricity is determined using uniform market pricing, or LMP method. The FACTS device used for the problem is Static Var Compensator (SVC). Finally, values for bus voltages, line losses, power injected to buses, power travelling via lines, total generating costs, and generator profits would be included in the output of the proposed MFO algorithm. Additionally, the results of testing the proposed methodology on the IEEE 30-BUS network reveal improvements on the OPF problem.

Keywords: Locational marginal price, Optimal power flow, Moth Flame Optimization.

1. INTRODUCTION

India is an overpopulated nation with growing power demand. The deregulation of the power industry has further increased the pressure on the transmission corridors in the country. Consequently, optimization of power flow has gained immense importance in the power world. At the same time, the use of FACTS devices in the AC transmission system is the only cost-effective solution to match the high efficiency of the HVDC systems. Power systems are often used under stable sinusoidal settings with three balanced phases. For power system operators in such a system, knowledge of power flow along lines and voltages in various buses is crucial. Power flow studies seek to understand how generated power is distributed on network lines and to establish the voltage of buses, among other things. Voltages, currents, active and reactive powers, power losses, power exchange between various power systems, generation and consumption balance within the system, transmitted powers, and other features discovered through measuring current and voltage in various parts are among the power flow parameters currently being studied.

The node voltage approach, which is the most suitable method in many power system evaluations, is utilised in power flow calculations. This approach generates a number of intricate algebraic equations based on the nodes' currents, which we may solve to determine the nodes' voltages if we know the nodes' currents. Because these equations are nonlinear, however, they need be solved numerically and repeatedly. Both the Newton-Raphson method and the Gauss-Seidel method are frequently used to solve these equations. Power flow studies are the foundation of power system design and analysis, and carrying out these studies is crucial for scheduling and maximising utilisation amongst power firms [1]. Optimal power flow (OPF) is typically used for research on how to fix overloads in transmission lines, control of transmission systems, assessing available transmission capacity (ATC), managing line congestion, pricing of active and reactive power, and locational marginal price (LMP). In OPF, control variables are chosen so that the goal variable is minimised while also establishing a number of equal and unequal constraints, such as control and utilisation limitations, through the use of power flow equations. The objective function in this series is the sum of the costs of all the generators, the control variables are the active powers that the generators create, and the state variables are the voltages of the buses' domain and angle. The minimum and maximum limits of control variables, the minimum and maximum bus voltage, and the maximum transmission powers of lines are other examples of uneven restrictions [2, 3].

The optimal power flow problem is solved using a variety of traditional optimisation techniques, including linear programming [4], quadratic programming [5, 6], gradient and Lagrange methods, as well as a variety of artificial intelligence (AI) techniques, including particle swarm optimisation (PSO) [9–13], differential evolution (DE) [14], and ant colony optimisation (ACO) [15 Following the MFO algorithm, a 24-hour power flow was carried out on an IEEE 30-BUS network, and ultimately, the profit of the generators was calculated by determining the electricity price through LMP, and the results are compared with and without SVC.

2. PROBLEM FORMULATION

In addition to limiting the output of active and reactive power from generators, bus voltage, capacitor/shunt reactor, transformer tap adjustment, and power flow of gearbox lines, OPF aims to ensure optimal system performance. OPF, which is an important problem in the economic evaluation of power systems and can be characterised as an optimisation problem with an objective function and some constraints, has limitations due to the physical laws governing gearbox systems, the production and use of energy, and the capabilities of the equipment.

2.1 Objective Function

Minimising the overall cost of active power generation is the main objective in the development of OPF. Additionally, each generation unit's cost function, which is shown as a quadratic curve, depends on the active power it generates. The cost functions of each generator are then added to obtain the system's objective function.

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

in which ng is the number of generation units which include slack bus, Pgi is the generation active power in bus number i, and a, b, and c are the coefficients of the cost function for each generator.

2.1.1 Equality constraints:

Production is equal to both the power demand and the transmission losses when the cost function is minimised. Power flow equations are therefore viewed as equal limitations.

$\sum_{i=1}^{N} P_{Gi} = \sum_{i=1}^{N} P_{Di} + P_L$

Where i=1,2,3,.......,N and N = no. of. Buses

$$\sum_{i=1}^{N} Q_{Gi} = \sum_{i=1}^{N} Q_{Di} + Q_L$$

Where i=1,2,3,.......,Nand N = no. of. Buses

P_L is total active power losses

Q_L is total reactive power losses

P_{Gi} is the active power generation at bus i

P_{Di} is the power demand at bus i

2.1.2 Inequality constraints:

The uneven constraints of OPF are a reflection of both the reliability-related and physical equipment limitations of the power supply. High voltage limitations in buses connected to power and generation units and low voltage limitations in buses connected to power are the two most prevalent types of uneven limits. Limitations on generation include the maximum and minimum active power produced by generators, the transmission lines' maximum capacity, and restrictions on tap adjustment and phase shift. Problem variables with unequal restrictions include: In buses with generators, active electricity is produced in high- and low-frequency bands.

2.1.3 Voltage limits for generator buses:

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

Where Gi=1, 2, 3,.......,ng and ng = no. of. Generator buses

2.1.4 Real power generation limits:

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

Where Gi=1, 2, 3,......,ng and ng= no. of. Generator buses

2.1.5 Reactive Power generation limits:

Reactive power injection in buses with VAR compensators and high- and low-band reactive power generation in buses with generators

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

2.1.6 SVC Limits

$$B_{svc}^{min} \leq B_{svc} \leq B_{svc}^{max}$$

3. CALCULATING THE MARKET PRICE OF ELECTRICITY

There are two ways to determine the market price of electricity after doing OPF calculations and determining the power flow in the lines. In the first technique (UMP), power flow data are collected in a fashion that does not entail any congestion, and as a result, the cost of all operational generators is used to determine the price of energy. Additionally, in this scenario, the cost of electricity will be the same for each bus. When one or more transmission lines have surpassed their capacity, the second technique (LMP) is used. In these cases, the price of power for each bus will not be the same and should be determined based on the output of generators.

3.1 UMP price :

In this case, the minimum generation power obtained is used to calculate the final cost of the units; taking into account the information of generation units of the IEEE 30-BUS network, the final cost of the generators for the minimum generating power will be as follows:

$$\mathrm{MC}_i\left(P_i^{\min}\right) = \frac{\mathrm{d}F_i\left(P_i^{\min}\right)}{\mathrm{d}P_i^{\min}}\left(\frac{\$}{\mathrm{MWh}}\right), \quad i = 1, 2, 3, 6, 8$$

The final cost of the more costly generator will be used to establish the power price (π) in this situation because if the price was set based on the cost of the less expensive generator, keeping the more expensive generators running would be unreasonable. Additionally, in order to maintain a low market price, the cost of electricity is set based on the generators with the lowest generation capacity.

$$\pi = \max\left(\mathrm{MC}_i\left(P_i^{\min}\right)\right)(\$/\mathrm{MWh})$$

3.2 LMP price

Locational marginal pricing, or LMP, is the practise of charging different amounts for electricity in different parts of a network when the transmission lines' capacity is at its limit and it is not possible to utilise all of the generators' available output. In actuality, LMP entails putting a surplus 1-MW load in place using the least expensive generators that can produce without going against the restrictions of the transmission line. As a result, a method of determining LMP involves focusing on generators that have not yet reached their upper or lower limitations. These generators, or those with some of their capacity still available, are referred to as last generators. LMP in buses with final generators will therefore be the same as the final cost of these types of generators. The LMP of buses with a final generator will also affect the LMP of other buses without generators or with generators that have reached their generation limit.

For buses that have a final generator

$$\pi_i = \mathrm{LMP}_i = \mathrm{MC}_i(P_i), \quad \forall P_i^{\min} < P_i < P_i^{\max}, \quad P_i \neq P_i^{\min},\ P_i \neq P_i^{\max},\ i \in \{1, 2, 3, 6, 8\}$$

Here, i is an indicator for buses that have a final generator. Finally, Fig. 1 shows the flowchart of all the defined stages in which green blocks are the outputs of the proposed algorithm.

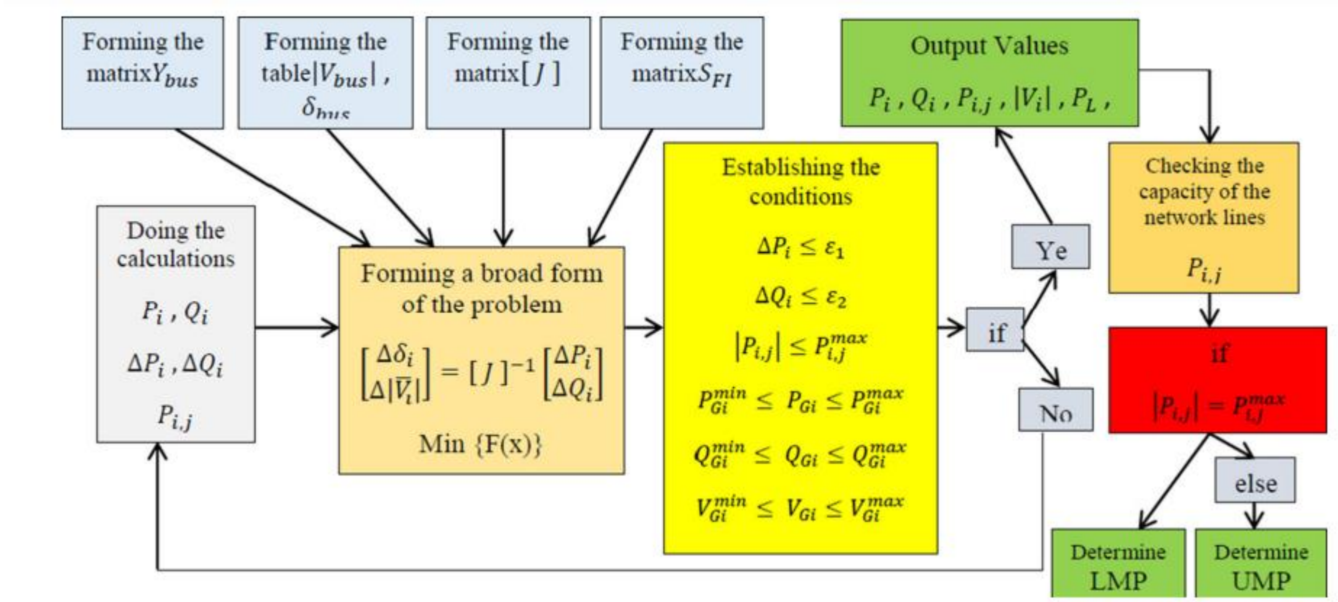

Fig. 1 Block diagram of the proposed strategy

4. MOTH FLAME OPTIMIZATION

It is an optimization concept inspired by nature. The moths' nighttime navigation strategy served as inspiration for the algorithm. The moths move at a constant inclination to the moon. The moths also have a propensity to circle the lights in a spiral motion. It is presumed that the moths symbolize the multi-objective function's solution. The moths' location in the space is one of the problem's variables. The mathematical modelling of the Moths' behavior is as mentioned below:

Where S is the spiral function, M_i is the i-th moth, Fj denotes the j-th flame, and In light of these considerations, we define the MFO algorithm's logarithmic spiral as follows:

$$M_i = S(M_i, F_j)$$

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

Where Di denotes the separation between the i-th moth and the j-th falme, b is a constant used to specify how the logarithmic spiral will look, and t is a random value between the range [-1,1] and is given by:

$$D_i = | F_j - M_i |$$

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

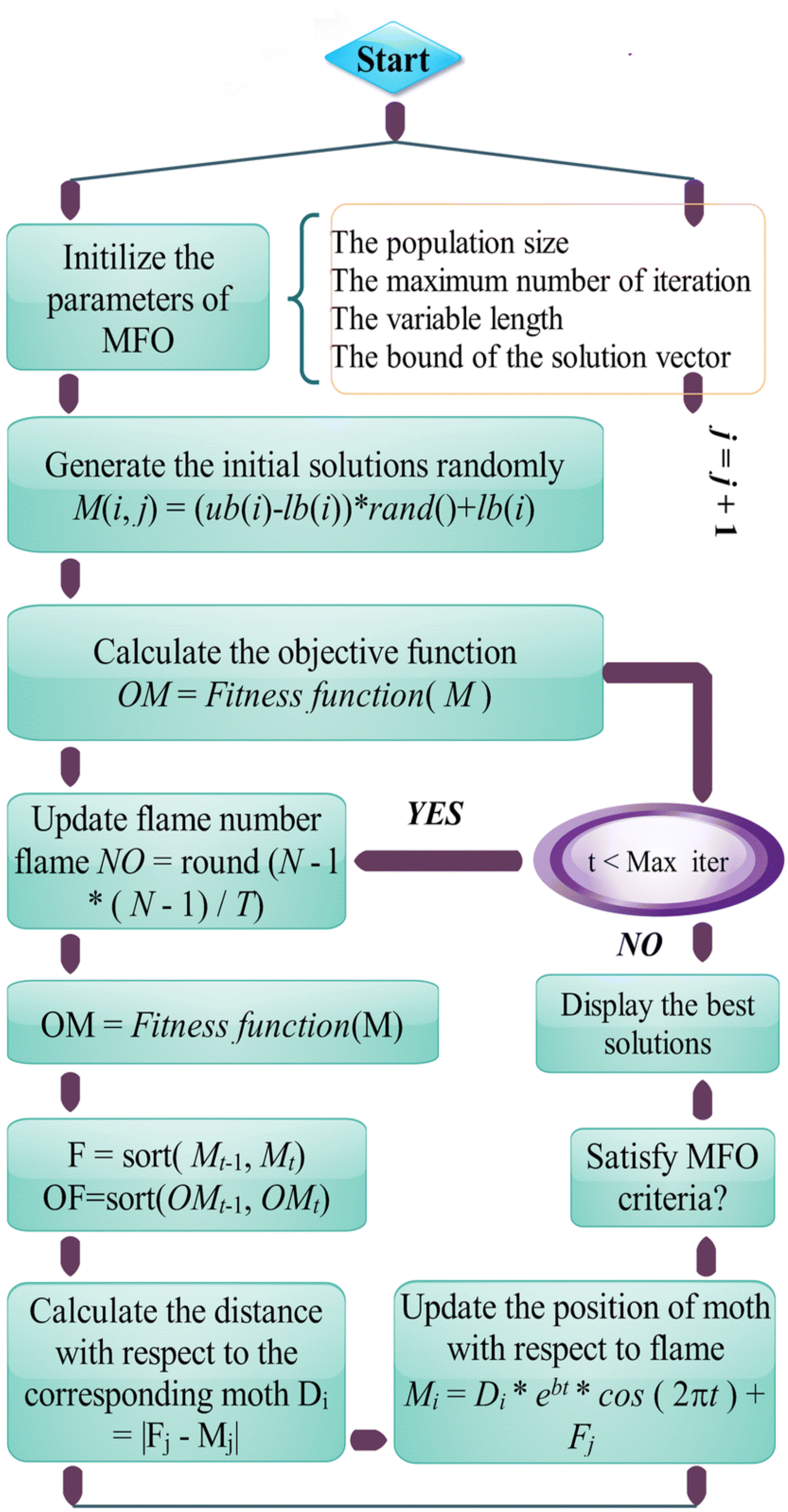

Figure 2: Flow Chart of Moth Flame Algorithm

5. RESULTS AND DISCUSSION

An IEEE 30 bus system with 41 transmission lines, 5 PV buses, one slack bus and remaining load buses have been shown in Fig. 1. Only load buses have been considered for SVC placement. The last two thermal generators at bus 23 and 27 are replaced with solar and wind generators respectively.

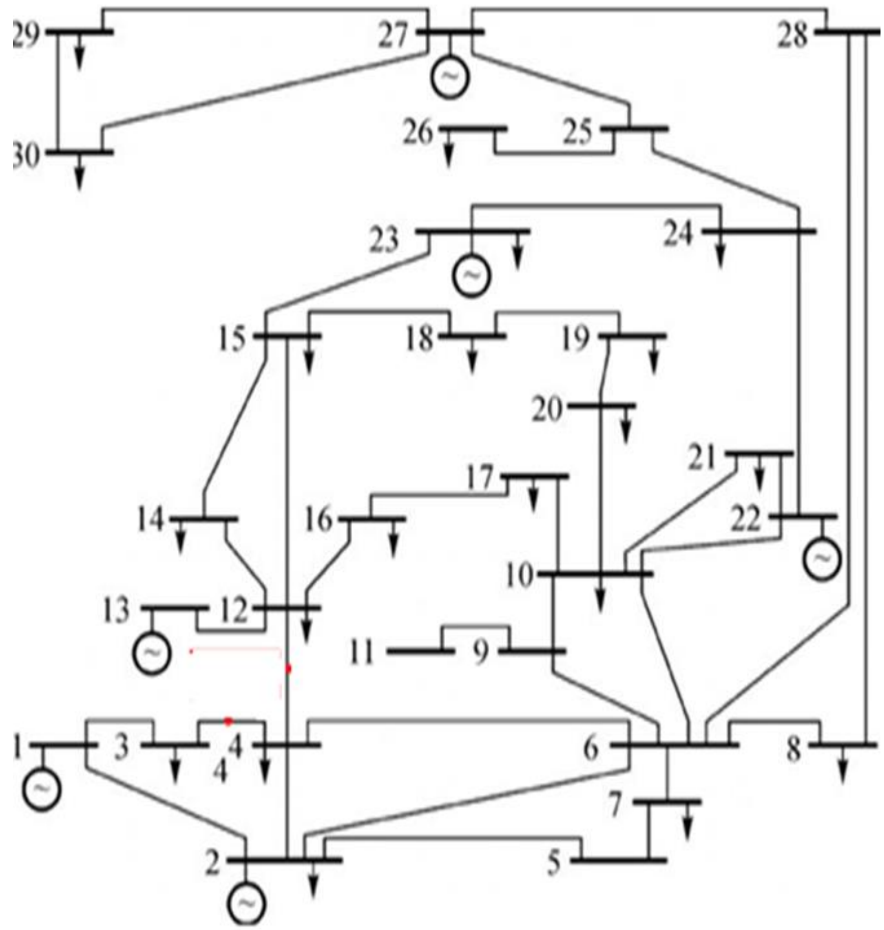

Fig. 3 Modified IEEE 30 Bus Transmission System

The generator reallocation for IEEE-30 bus system is studied. The OPF is performed for single objective functions followed by the multi-objective function optimization and the results have been compared. LMP represents the Locational marginal price, UMP represents the uniform marginal price, GSF represents the generation scaling factor.MFO represents the moth flame optimization technique.

5.1 Results without SVC Device

Figure 4 it shows the results without svc device between time in hours to the power in MW with respect to x axis and y axis. It is observed that in 12th hour demand of the supply is more so it is called peak hour. Demand of the supply is varied with respect to hours in a day.

Table 1 shows the results from implementing the proposed algorithm, along with the amount of injected power, network losses, overall cost of production, and price of electricity for a 24-hour period. The 36 MW capacity of Line 2-3, which had achieved its maximum capacity at 12 o'clock, is one of this network's constraints, according to the results. As a result, the pricing for this hour will be determined using LMP, and Table 6 provides LMP values for various buses.

Fig 2 shows network losses in MFO method with respect to time during peak hour only losses are more losses are going to be increased with respect to load.

From the results obtained, the generation capacity of generators and the electricity flowing through lines. Using MFO, we can accurately connect changes in the power injected to buses to the power flowing through lines. Additionally, negative power columns show that the direction of power in that line has been reversed. Thus, taking into account the outcomes of lines 3–4, power is shifted from bus 4 to bus 3, which is another factor contributing to the bus generator 2's reduced power output.

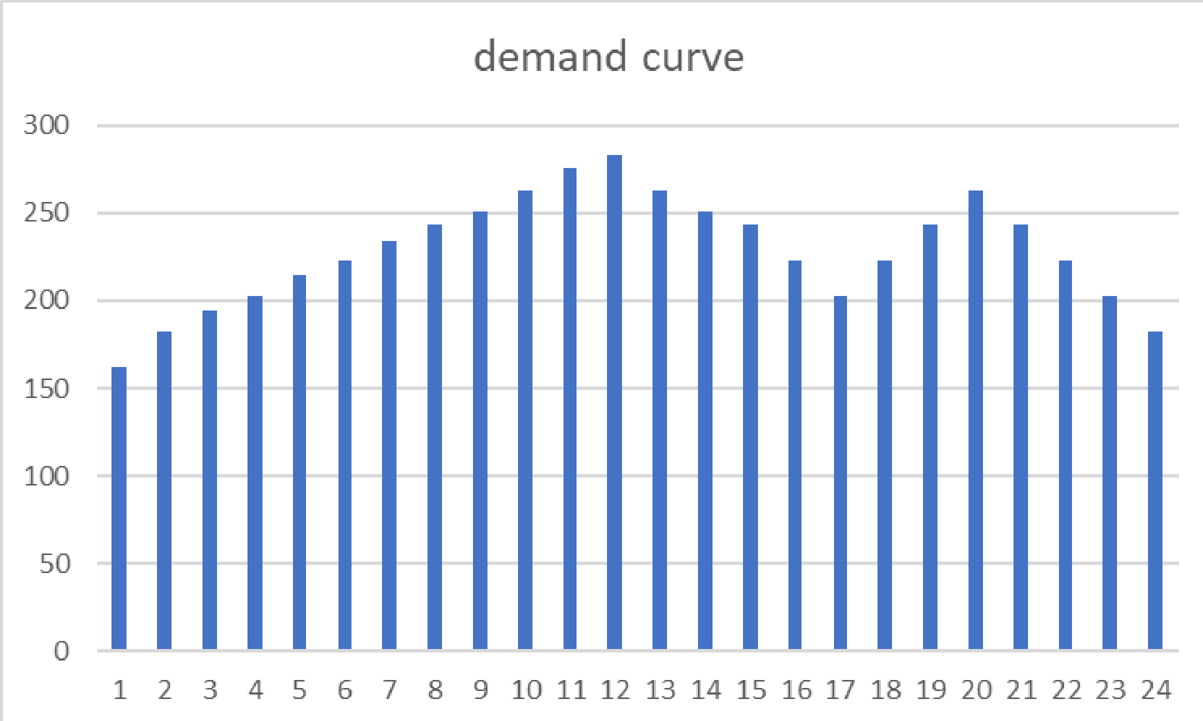

Fig. 4 Network's power demand

Table 1 Results from OPF in 24 h

HOUR	MFO									
	P1	P2	P5	P8	P11	P13	PD	LOSS	Cost of production	Market Price(UMP or LMP)
1	56.6	20.29	15	10	35	30	162	4.99	230.57	UMP
2	73.95	24.377	15	10	35	30	182.18	6.33	283.88	UMP
3	84.32	26.87	15	10	35	30	194.12	7.09	317.37	UMP
4	91.939	28.72	15	10	35	30	202.4	8.268	342.69	UMP
5	101.634	31.092	15	10	35	30	214.5	8.311	375.96	UMP
6	108.907	32.9	15.63	10	35	30	222.6	9.86	403.12	UMP
7	117.905	35.148	16.46	10	35	30	234.1	10.369	437.795	UMP
8	129.017	39.143	17.84	10	35	30	243	18.106	486.84	UMP
9	133.33	39.192	17.729	10	35	30	251	14.25	499.5	UMP
10	142.48	41.573	18.45	10.95	35	30	263.1	15.347	540.47	UMP
11	150.047	43.49	19.03	14.6	35	30	275.3	16.88	584.68	UMP
12	300	20	15	20.238	35	30	283.4	36.8	1.08E+03	LMP
13	128.8	80	24.7	14.02	10	30	263.13	24.3	684.864	UMP
14	133.23	40.6	18.41	13.123	35	30	251	19.43	516.82	UMP
15	129.017	39.143	17.84	10	35	30	243	18.106	486.84	UMP
16	113.34	34.9	16.18	10	35	30	222.6	16.9	423.35	UMP
17	79.75	30.98	32.26	10	35	30	202.4	15.59	385.05	UMP
18	113.34	34.9	16.18	10	35	30	222.6	16.9	423.35	UMP
19	129.017	39.143	17.84	10	35	30	243	18.106	486.84	UMP
20	128.8	80	24.7	14.02	10	30	263.13	24.3	684.864	UMP
21	129.017	39.143	17.84	10	35	30	243	18.106	486.84	UMP
22	113.34	34.9	16.18	10	35	30	222.6	16.9	423.35	UMP
23	79.75	30.98	32.26	10	35	30	202.4	15.59	385.05	UMP
24	74.55	24.45	15	10	35	30	182.16	6.84	285.601	UMP

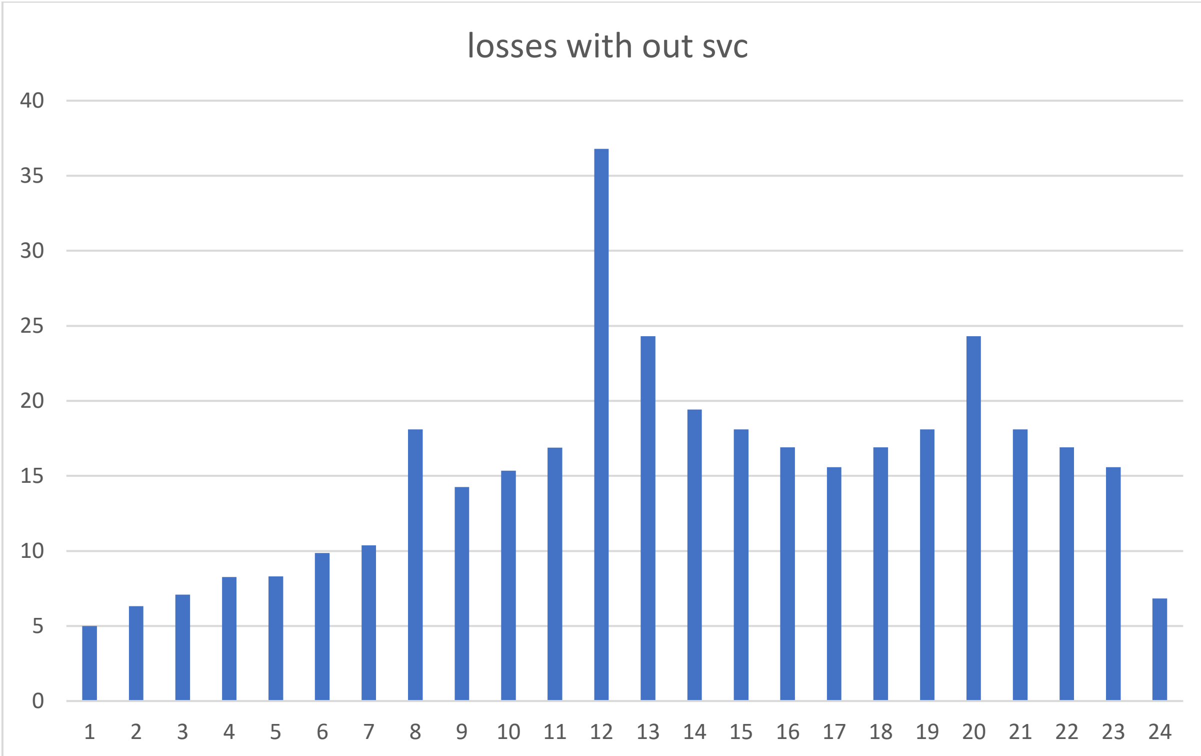

Fig. 5 Generation power and network losses in MFO method

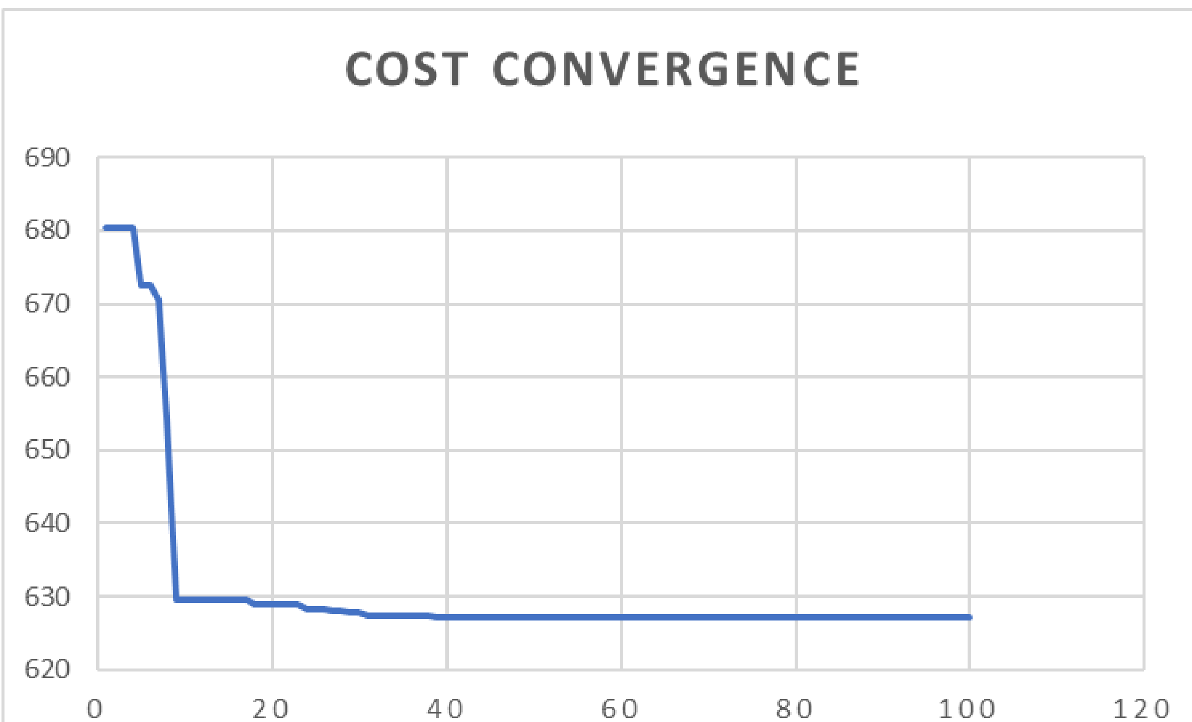

Fig. 6 cost convergence in MFO method

Table 2 LMP values for network buses

HOUR	MFO																													
	LMP																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
12	0.227	0.095	0.016	0.268	0	0.18	0.115	0	0.018	0	0.2113	0	0.0736	0.095	0.09	0.131	0.173	0.146	0.16	0.1	0	0.013	0.173	0.146	0.162	0.1	0	0.051	0.02	

Table 3 Calculations for profits of generators in MFO method

Hour	MFO								
	P1	P2	P5	P8	P11	P13	Loss cost	Total profit of generators	pi
1	1459.5	525.4	390.94	246.6	844.3	727.5	130	4064.24	28
2	1902.2	629.3	390.94	246.6	844.3	727.5	164.4	4576.4	28
3	2165.66	59.65	390.94	246.6	844.3	727.5	184.16	4250.4	28
4	2358.7	739.4	390.94	246.6	844.3	727.5	214.5	5092.94	28
5	2603.7	799.2	390.94	246.6	844.3	727.5	215.8	5396.4	28
6	2789.5	844.6	406.75	246.6	844.3	727.5	256	5603.25	28
7	3013.3	901.016	427.4	246.6	844.3	727.5	269.19	5890.92	28
8	3292.03	10268	461.79	246.6	844.3	727.5	469.5	5370.07	28
9	3400	1001.8	458.7	246.6	844.3	727.5	369.74	6309.16	28
10	3628.6	1060.9	476.9	270.013	844.3	727.5	398.13	6610.07	28
11	3816.8	1108.5	491.18	359.5	844.3	727.5	435.74	6912.08	28
12	7462.5	518	390.9	497.5	844.3	727.5	486.7	6.95E+03	LMP
13	3286.5	1988	628.7	345.36	247.5	727.5	629.5	6594.06	28
14	3397.4	1037	475.8	323.35	844.3	727.5	505.18	6300.17	28
15	3292	1000.6	461.7	246.6	844.3	727.5	469.5	6103.2	28
16	2898.6	894.8	420.5	246.6	844.3	727.5	438.3	5594	28
17	2049.6	796.43	805.9	246.6	844.3	727.5	404.4	5065.93	28
18	2898.6	894.8	420.5	246.6	844.3	727.5	438.32	5594	28
19	3292	1000.6	461.79	246.6	844.3	727.5	469.52	6103.2	28
20	3286.5	1988	628.7	345.35	247.5	727.5	629.5	6594.06	28
21	3292	1000.6	461.79	246.6	844.3	727.5	469.5	6103.2	28
22	2898.6	894.81	420.5	246.6	844.3	727.5	438.3	5594	28
23	2049.6	796.43	805.9	246.6	844.3	727.5	404.4	5065.93	28
24	1917.5	631.36	390.9	246.6	844.3	727.5	177.6	4580.56	28

5.2 Results with SVC

Table 4 Results from OPF in 24h

HOUR	MFO									
	P1	P2	P5	P8	P11	P13	PD	LOSS	Cost of production	Market Price(UMP or LMP)
1	55.68	20	15	10	35	30	162	3.6812	227.381	UMP
2	73.43	23.855	15	10	35	30	182.18	5.1132	281.2	UMP
3	83.2	26.18	15	10	35	30	194.12	5.27	312.58	UMP
4	90.04	27.81	15	10	35	30	202.4	5.4361	335.09	UMP
5	99.97	30.208	15	10	35	30	214.5	5.62	368.666	UMP
6	107.208	31.936	15	10	35	30	222.6	6.54	393.64	UMP
7	116.29	34.125	15.75	10	35	30	234.1	7.0374	428.025	UMP
8	123.246	35.73	16.215	10	35	30	243	7.29	454.317	UMP
9	130.1	37.37	16.68	10	35	30	251	8.165	480.95	UMP
10	139.64	39.953	17.35	10	35	30	263.1	8.82	519.78	UMP
11	144.11	42.072	18.03	15.18	35	30	275.3	9.1	560.325	UMP
12	157.12	43.9	18.55	10	35	30	283.4	11.191	590.8.	LMP
13	140.1737	39.872	17.294	10.451	35	30	263.13	9.6	522.49	UMP
14	130.1	37.37	16.68	10	35	30	251	8.165	480.95	UMP
15	123.246	35.73	16.215	10	35	30	243	7.29	454.317	UMP
16	107.208	31.936	15	10	35	30	222.6	6.54	393.64	UMP
17	90.04	27.81	15	10	35	30	202.4	5.4361	335.09	UMP
18	107.208	31.936	15	10	35	30	222.6	6.54	393.64	UMP
19	123.246	35.73	16.215	10	35	30	243	7.29	454.317	UMP
20	140.1737	39.872	17.294	10.451	35	30	263.13	9.6	522.49	UMP
21	123.246	35.73	16.215	10	35	30	243	7.29	454.317	UMP
22	107.208	31.936	15	10	35	30	222.6	6.54	393.64	UMP
23	90.04	27.81	15	10	35	30	202.4	5.4361	335.09	UMP
24	73.96	23.9	15	10	35	30	182.16	5.711	282.674	UMP

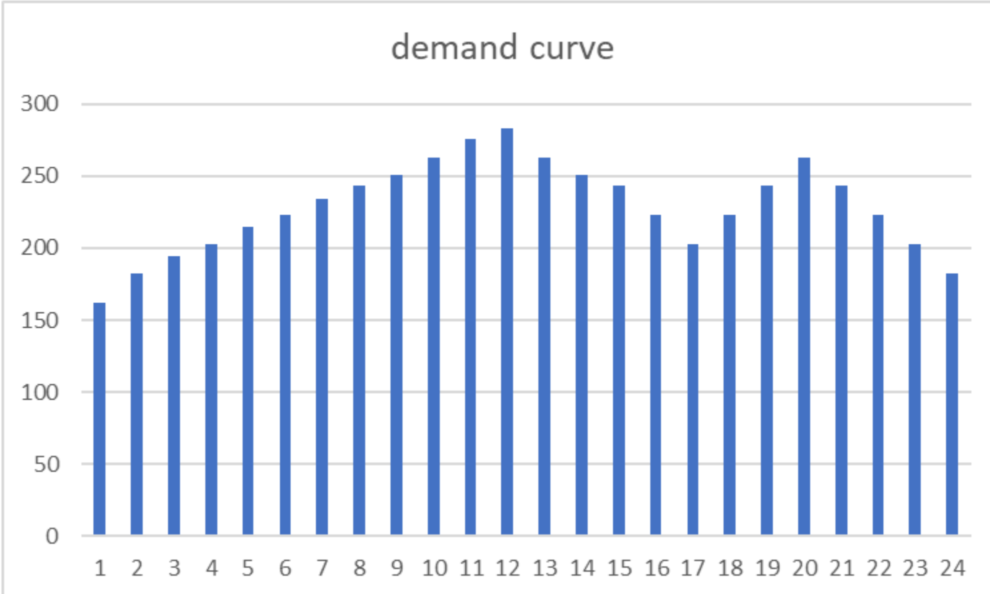

Fig. 7 Network's power demand curve

Table 5 Calculations for profits of generators in MFO method

Hour	MFO								
	P1	P2	P5	P8	P11	P13	Loss cost	Total profit of generators	pi
1	1436.06	518	390.937	246.666	844.375	727.5	95.63	4067.9	28
2	1888.96	616.25	390.937	246.666	844.375	727.5	132.84	4581.84	28
3	2137.12	675.231	390.937	246.666	844.375	727.5	136.916	4884.9	28
4	2310.63	716.47	390.937	246.666	844.375	727.5	141.23	5095.57	28
5	2561.74	776.99	390.937	246.666	844.375	727.5	146.002	5402.206	28
6	2744.3	820.472	390.937	246.666	844.375	727.5	169.88	5604.37	28
7	2972.82	875.403	409.746	246.666	844.375	727.5	182.788	5893.722	28
8	3147.43	915.572	421.37	246.666	844.375	727.5	189.341	6113.572	28
9	3319.128	956.524	432.92	246.666	844.375	727.5	212.06	6315.053	28
10	3557.518	1020.834	449.63	246.666	844.375	727.5	229.03	6617.49	28
11	3668.982	1073.362	466.5	373.784	844.375	727.5	236.285	6918.21	28
12	3992.54	1118.65	479.344	246.666	844.375	727.5	290.47	7.12E+03	LMP
13	3570.83	1018.81	448.262	257.752	844.375	727.5	249.26	6618.269	28
14	3319.128	956.524	432.97	246.666	844.375	727.5	212.06	6315.053	28
15	3147.43	915.572	421.37	246.666	844.375	727.5	189.341	6113.572	28
16	2744.308	820.472	390.93	246.666	844.375	727.5	169.88	5604.37	28
17	2310.638	716.47	390.93	246.666	844.375	727.5	141.2308	5095.57	28
18	2744.3	820.472	390.93	246.666	844.375	727.5	169.88	5604.37	28
19	3147.43	915.572	421.3722	246.666	844.375	727.5	189.341	6113.572	28
20	3570.83	1018.819	448.262	257.752	844.375	727.5	249.26	6618.269	28
21	3147.43	915.57	421.37	246.666	844.375	727.5	189.341	6113.572	28
22	2744.308	820.47	390.93	246.666	844.375	727.5	169.88	5604.37	28
23	2310.638	716.47	390.93	246.666	844.375	727.5	141.23	5095.57	28
24	1902.44	617.379	390.93	246.666	844.375	727.5	148.364	4580.926	28

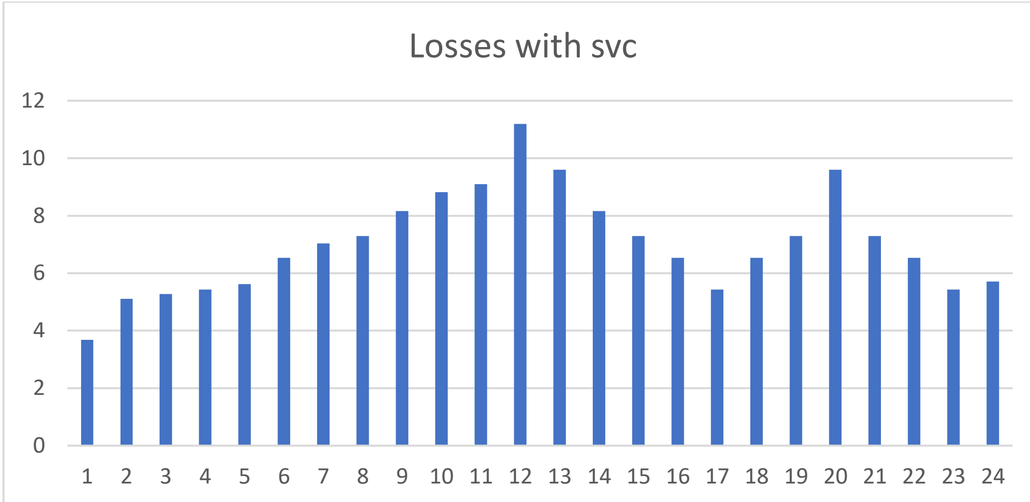

Fig. 8 Generation power and network losses in MFO method

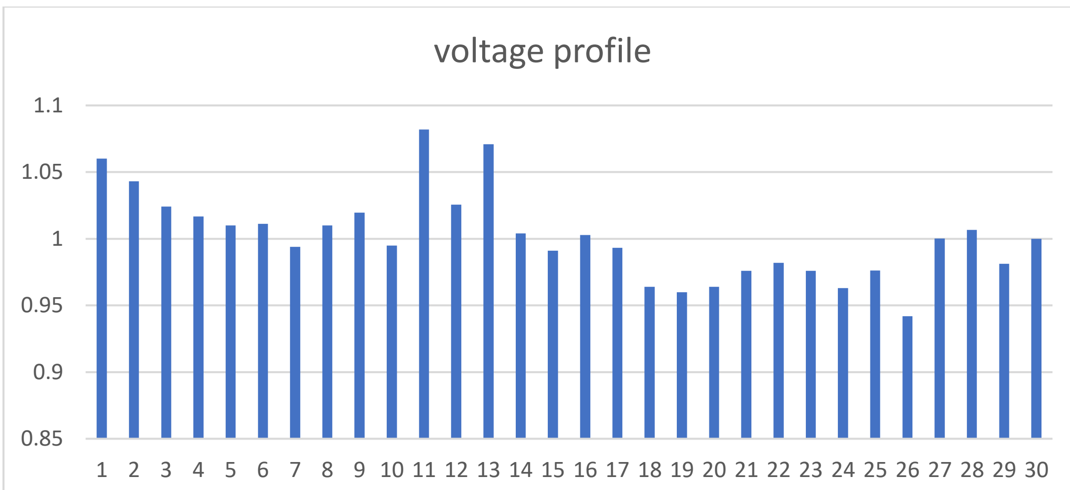

Fig. 9 voltage profile in MFO method

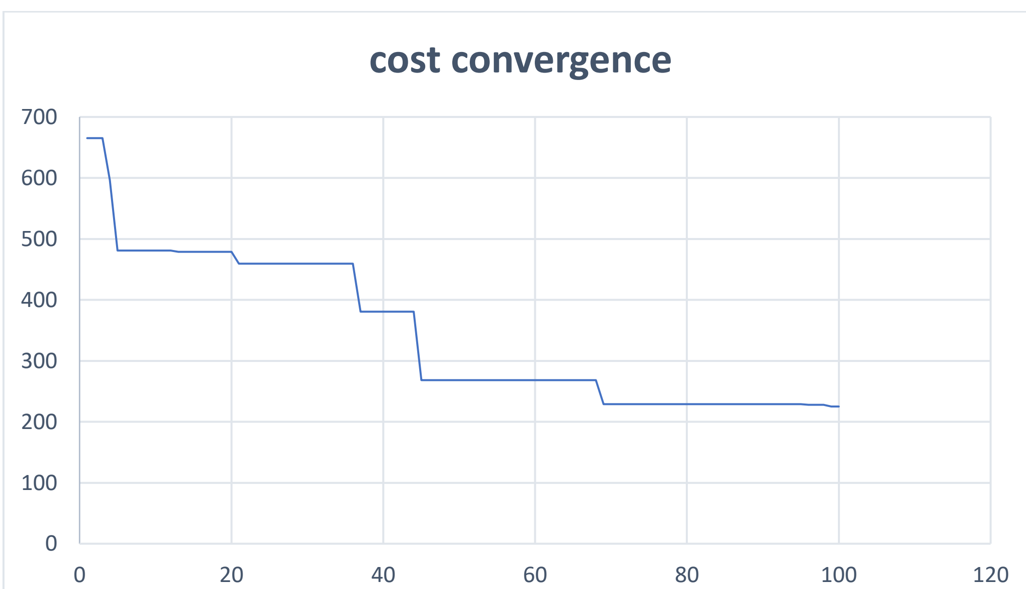

Fig. 10 cost convergence using MFO method

Fig 7 shows demand of the supply with respect to time. Table 4 shows the results with FACTS device, SVC and it is observed that the losses and cost of the production going to be decreased as compared to Table 1. Fig 8 shows the results of network losses in MFO losses are reduced by placing svc in system as compared to Fig 5. Figure 9 shows the voltage profile of the 30-bus system and it is drawn between voltage and demand of the supply. Fig 10 shows the cost convergence of svc system it also reducing cost of the system as compared without facts devices system.

5.3 Comparison without and with SVC

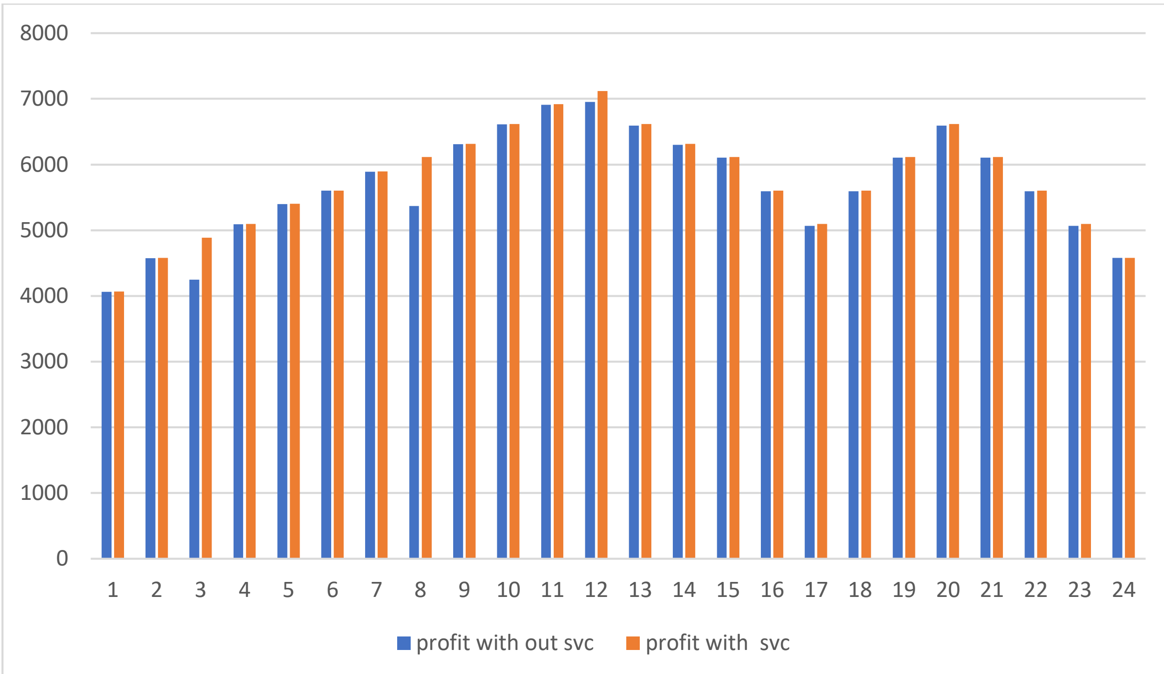

Fig. 11 Generation cost profit between with and without svc

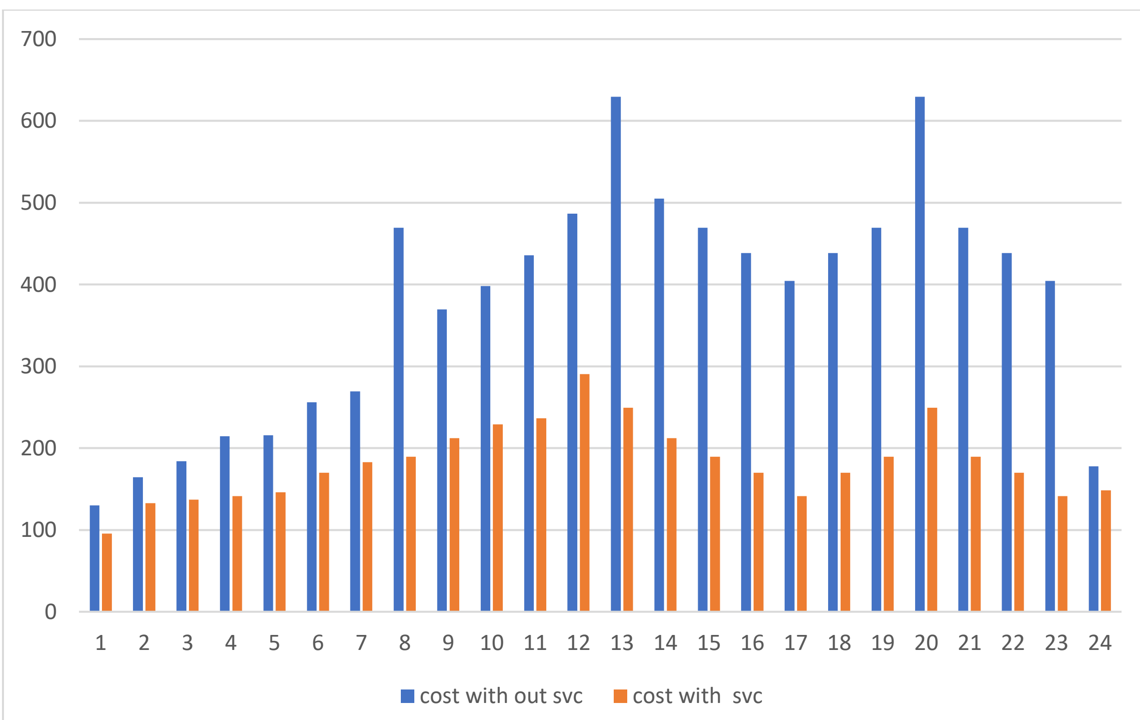

Fig. 12 generation loss cost between with and without svc

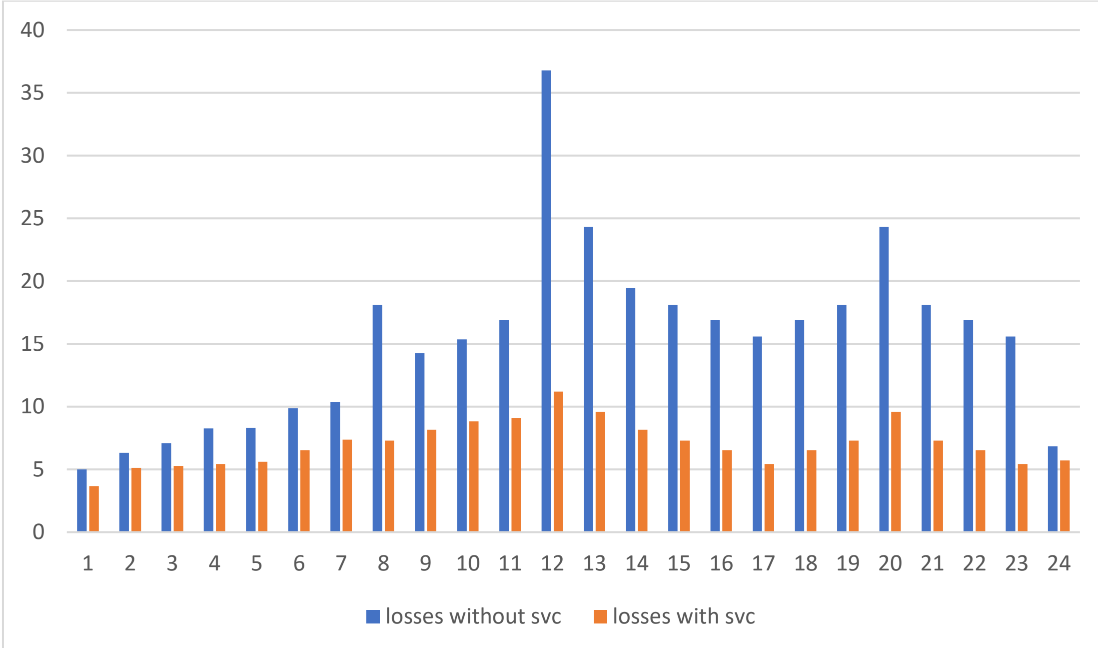

Fig. 13 generation losses between with and without svc

Fig 11 shows the profit between with and without svc, by placing svc profit of the system increased it represented with colour red. Fig 12 shows the loss cost with and without svc, in svc loss cost is reduced as compared to without svc. during peak hour loss cost is more in without svc. In svc loss cost is less so that the total profit of the system going to increased. Fig 13 shows the losses with svc and without svc losses are less in svc system as compared to the without svc system.by reducing the losses in system efficiency of the system is improved as compared to without svc system. Fig 14 shows voltage convergence between with and without svc by placing svc voltage profile is almost constant it is near to unity and above the unity as compared to without svc system.

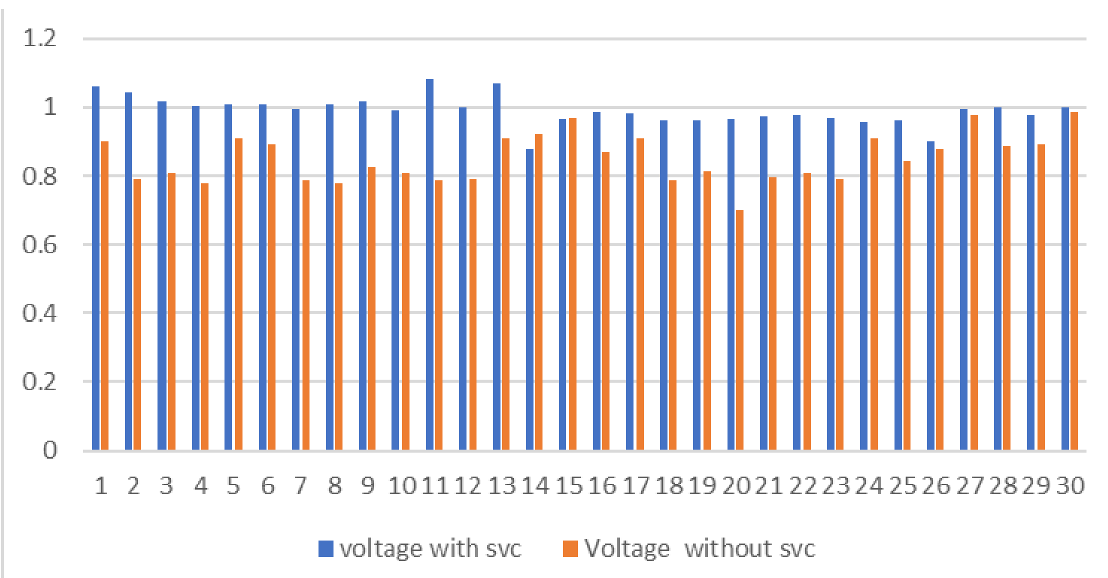

Fig. 14 Voltage convergence with and without svc

6. CONCLUSION

The OPF problem and the locational marginal price (LMP) are solved in this article using the metaheuristic algorithm MFO. Check each variable's minimum point against the requirements for establishing flow power in the network simultaneously, and if necessary, repeat the operation if necessary. The suggested algorithm will ultimately produce the power of the generation units, network losses, bus voltage, generation costs, and power moving through lines. By examining the capacity of the lines, we may also determine the market price of energy and the profit made by the generators. The MFO algorithm has demonstrated correct performance in simulations, as evidenced by its ability to provide reality-based OPF and reduce losses while processing data quickly and at a reasonable cost.

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