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A THYRISTOR CONTROLLED SERIES COMPENSATOR BASED OPF FOR SOCIAL WELFARE

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ABSTRACT

The current geopolitical climate has highlighted the significance of maximizing the world's energy potential. The optimal use of available assets lowers the cost of electricity to customers. This study proposes a multi-objective ideal power flow for a composite transmission network with FACTS devices. The multi-objective function used in this work is a novel approach. Objectives include minimizing voltage variance, power loss, and negative social welfare (NSW). New South Wales customers should be delighted with lower electricity bills per unit provided and less loss. This problem was resolved using a Thyristor Controlled Series Compensator (TCSC) FACTS device. Theory was tested using an IEEE 30 bus system. Mouth Flame Optimization Algorithm maximized the objective function. The results are detailed, compared, and assessed.

Keywords: Optimal Power Flow, Negative Social Welfare, Thyristor Controlled Series Compensator, Mouth Flame Optimization Algorithm.

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1. INTRODUCTION

India has a large population and growing electrical demand. Since power deregulation, transmission corridor pressure has increased. The power business now prioritizes power flow optimization. The only way to match HVDC systems' efficiency without breaking the bank is to use FACTS devices in the AC transmission system.

Congestion limits were addressed by M.O. Lawal *et al*. [1] for optimal hydro-thermal power flow. Power flow tracking may identify the generators causing crowded lines and increase their output. Establishing a penalty number for the maximum power of the affected generators reduces congestion. I. Batra *et al*. [2] used the TECM-PSO algorithm (TECM) to non-linear congestion management in a deregulated energy system to improve twin extremity mapping of the chaotic map. The hybrid PSO-APO algorithm by K. Teeparthi *et al*. [3] considers wind and heat generators for emergencies. Power system difficulties have been solved via FACTS devices [4]. Visakha *et al*. [5] devised a plan to deploy a UPFC in a suitable place while anticipating problems. Nusair *et al*. [6] optimized a renewable-system power system utilizing TCSC. For cost savings, authors employed OPF with FACTS devices [7]. Authors conducted OPF for an integrated wind farm system using TCSC and UPFC to minimize costs [8]. Managing power system issues requires proper FACTS device deployment and adjustment. IPFC has solved power system congestion and contingency issues [9, 10]. Due of IPFC's multiple connections, placement must be considered [11]. Voltage index-based contingency analysis is suggested in [12]. Kumar *et al*. [13] suggest IPFC placement using cat swarm optimization to increase voltage stability. Verma *et al*. [14] advised placing FACTS devices there for voltage stability. Research has examined power grid FACTS device regulation [15, 16]. As advocated in [17], placing and sizing FACTS devices for greatest social welfare may decrease load shedding and branch costs and increase the public benefit. Optimizing public good activities seems natural. [18, 19] shown that optimal power flow and FACTS location and size may achieve multi-objective functions.

This study proposes a multi-objective OPF for an integrated power system. Traditional generators, solar array, and wind turbine comprise the transmission network. Losses voltage deviation reduction and welfare improvement are optimization's main aims. A negative social welfare was created to fit the objective function as it is a minimization function.

There were three stages to the completion of the goals. First, an OPF for the MOP has been run on the whole system integration. The ideal location of TCSC in the power system has then been determined using an index. The TCSC is now set up to maximize future success in reaching the goals. At long last, the integrated system has been fine-tuned once again to achieve its goals. The system's resilience has been evaluated using a contingency analysis. The findings have been presented and examined, and they highlight the system's resilience when subjected to erratic inputs. The research makes use of a bus system based on the IEEE 30 standard. The research used an IEEE 30 bus system and an optimization technique called Moth Flame.

2. MOTH FLAME OPTIMIZATION

This is a method of optimization 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 describe the logarithmic spiral used by the MFO method, where S is the spiral function, M_i is the i-th moth, and F_j stands for the j-th flame.

$$M_i = S(M_i, F_I) \quad (1)$$

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

D_i is the distance between the i-th moth and the j-th 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].

$$D_i = |F_j - M_i| \quad (3)$$

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

3. PROPOSED METHODOLOGY

A. Multi Objective Function

Minimizing a multi-objective function that includes the following research goals is being done.

Objective 1- Negative Social Welfare

Increasing the demand side price while decreasing the production side cost maximizes social welfare. The term "social welfare" refers to the net benefit to society as opposed to the net benefit to either consumers or sellers. Since this function minimizes a negative value, it maximizes social welfare.

$$\mathrm{NSW} = \sum_{i=1}^{NG} C_i(P_{Gi}) - \sum_{j=1}^{ND} B_j(P_{Dj}) \quad (4)$$

$$C(P_g) = \sum_{i=1}^{n} a_{gi} P_{gi}^2 + b_{gi} P_{gi} + c_{gi} \quad (5)$$

$$B(P_d) = \sum_{i=1}^{n} a_{di} P_{di}^2 + b_{di} P_{di} + c_{di} \quad (6)$$

Objective 2- Minimization of Power Loss

$$F2 = \sum_{k=1}^{NT} G_{k(i,j)} [\mathrm{V}_i^2 + \mathrm{V}_j^2 - 2 V_i V_j \cos(\delta_{ij})] \quad (7)$$

Where,
V_i, V_j= i,j voltage in p.u.

Objective 3- Voltage deviation minimization:

A good voltage profile can only be achieved by carefully maintaining the voltages and minimizing the voltage collapse that causes the huge voltage spikes.

The voltage deviation reduction goal function is:

$$F_3 = \sum_{i=1}^{N_B} \| V_m - 1 \| \quad (8)$$

Voltage at bus m and number of busses are indicated by V_m and N_b

Constraints-

$$\sum_{i=1}^{NG} P_{Gi} + WP - P_{Loss} - P_L = 0 \quad (9)$$

$$P_{Loss} = \sum_{j=1}^{N_{TL}} G_j [|V_i|^2 + |V_j|^2 - 2|V_i||V_j| \cos(\delta_i - \delta_j)] \quad (10)$$

$$P_i - \sum_{k=1}^{N_b} |V_i V_k Y_{ik}| \cos(\theta_{ik} - \delta_i + \delta_k) = 0 \quad (11)$$

$$Q_i - \sum_{k=1}^{N_b} |V_i V_k Y_{ik}| \sin(\theta_{ik} - \delta_i + \delta_k) = 0 \quad (12)$$

Inequality Constraints

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (13)$$

$$\phi_i^{\min} \le \phi_i \le \phi_i^{\max} \quad (14)$$

$$TL_1 \le TL_1^{\max} \quad (15)$$

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (16)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (17)$$

$$K_{TCSC}^{\min} \le K_{TCSC} \le K_{TCSC}^{\max} \quad (18)$$

B. Proposed Amalgamated Severity Index

Combining the line Voltage stability indicator with the line power flow congestion factor is offered as the basis for TCSC placement.

$$ASI_{lm} = w_1 \times LUF_{lm} + w_2 \times FVSI_{lm} \quad (19)$$

Where,

$$w_1 + w_2 = 1 \quad (20)$$

The two indices for line l_m's weighting factors are w_1 and w_2. Both indices have been given equal consideration in our analysis.

Transmission line congestion is quantified by a metric called the line utilization factor (21) (LUF).

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$$LUF_{ij} = \frac{MVA_{ij}}{MVA_{ij\max}} \tag{21}$$

Where is LUF_{ij} The line's line utilization factor (LUF) in relation to buses i and j

The MVA rating of the line connecting nodes i and j is MVA_{ij} (max).

MVA_{ij} is the line's actual MVA rating between nodes i and j.

To assess line congestion, use the Line Utilization Factor.

The following equation (19) calculates the line-based Fast Voltage Stability Index (FVSI).

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \tag{22}$$

Where Z represents line impedance.

Q_j is the reactive power at bus j, and X is the line reactance.

V_i denotes the bus I voltage magnitude.

An FVSI shows the load's stable operating range. Line stability diminishes with high FVSI. FVSI higher than signals system instability.

C. Stepwise Procedure

The following steps solve the multi-objective OPF problem:

1. Solar and wind power units are installed on selected transmission system buses.
2. The OPF is executed for the multi-objective function.
3. The amalgamated severity index is used to determine the placement of TCSC.
4. The OPF and TCSC optimization are done for the multi-objective function.
5. Performance of contingency analysis tests system robustness.

4. RESULTS AND DISCUSSIONS

Figure-1 depicts an IEEE 30 bus system with 41 transmission lines, 5 PV buses, one slack bus and remaining load buses. Currently TCSCs are only being installed on load buses. Solar and wind power replace the final two remaining thermal generators at bus 11 and bus 13.

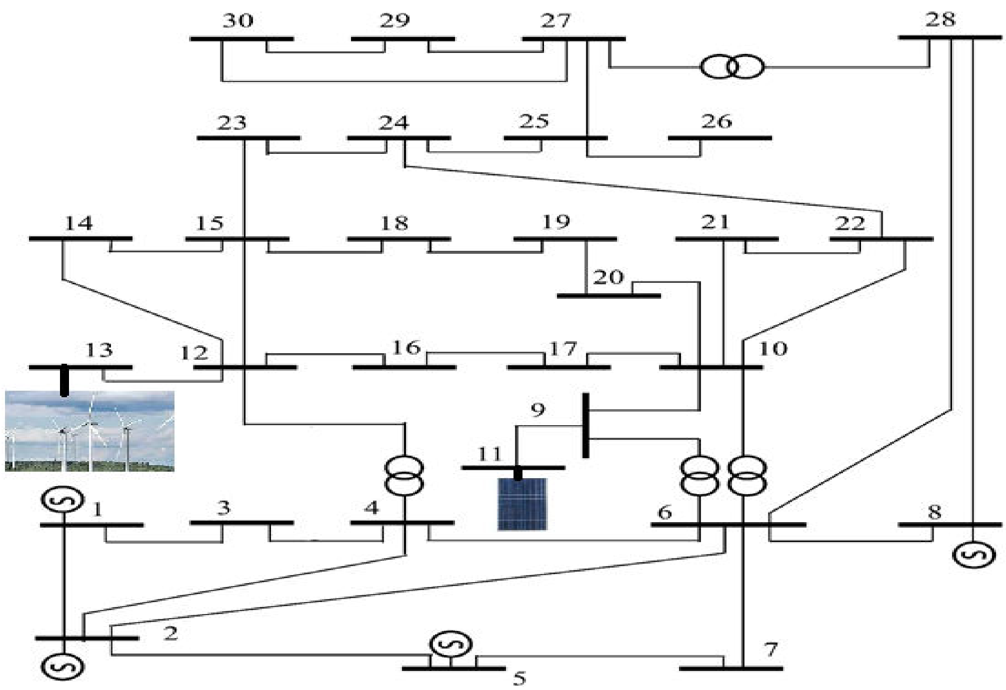

Figure-1. Modified IEEE 30 Bus Transmission System.

Contingencies in line 6-7 and line 2-5 of the IEEE-30 bus system are examined. Table-1 compares single-objective function OPF vs multi-objective function optimization during line 6-7 contingency. OF_1 is Negative Social Welfare, OF_2 Voltage Deviation, OF_3 Active Power Loss, and OF_4 Multi-Objective Optimization. OF_1 achieves the smallest NSW value, OF_2 the minimum voltage variation 1.24 p.u., and OF_3 the least active power loss of 6.93 MW. The multi-objective function delivers relatively optimal values for all four goals. Each aim in this research has equal importance, although the weightage may be modified as needed.

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Table-1. Optimal power flows for various objective functions with contingency at line 6-7 and renewable energy sources without TCSC

S. No	Parameter		OF_1	OF_2	OF_3	OF_4
1	Real power generation (MW)	P_{G1}	154.3438	50.0000	50.0000	50.0000
		P_{G2}	44.8174	80.0000	80.0000	80.0000
		P_{G5}	23.5310	50.0000	50.0000	50.0000
		P_{G8}	10.0000	60.0000	60.0000	45.3488
		P_{Gs}	35.0000	35.0000	35.0000	35.0000
		P_{Gw}	30.0000	30.0000	15.3382	30.0000
2	Total Active power generation (MW)		297.6922	305	290.3382	290.3488
3	Total real power generation cost (Rs/hr)		603.0690	792.5050	792.5050	732.0775
4	Active power Loss (MW)		14.2923	21.6000	6.9382	6.9488
5	Valve point effect (Rs/hr)		632.5021	835.3258	835.3258	774.9769
6	Voltage deviation (p.u.)		2.1441	1.2450	1.2976	1.3033
7	CE (ton/hr)		0.1299	0.0595	0.0595	0.0520
8	FPL		49.4666	49.4666	49.4666	49.4666
9	FPG		603.0690	792.5050	792.5050	732.0775
10	NSW		553.6024	743.0384	743.0384	682.6109
11	Objective function		553.6024	1.2450	6.9382	1.5078e+03

Table-2. Optimal power flows for various objective functions with contingency at line 2-5 and renewable energy sources without TCSC

S. No	Parameter		OF_1	OF_2	OF_3	OF_4
1	Real power generation (MW)	P_{G1}	147.7871	50.0000	50.0000	50.0000
		P_{G2}	43.1013	80.0000	66.9718	66.9718
		P_{G5}	29.4452	50.0000	50.0000	50.0000
		P_{G8}	17.2566	60.0000	60.0000	60.0000
		P_{Gs}	35.0000	35.0000	35.0000	35.0000
		P_{Gw}	30.0000	30.0000	30.0000	30.0000
2	Total Active power generation (MW)		302.5902	305	291.9718	291.9718
3	Total real power generation cost (Rs/hr)		627.6053	792.5050	736.1972	736.1972
4	Active power Loss (MW)		19.1903	21.6000	8.5718	8.5718
5	Valve point effect (Rs/hr)		660.4830	835.3258	782.5105	782.5105
6	Voltage deviation (p.u.)		4.0930	2.3165	2.4942	2.4942
7	CE(ton/hr)		0.1205	0.0595	0.0514	0.0514
8	FPL		49.4666	49.4666	49.4666	49.4666
9	FPG		627.6053	792.5050	736.1972	736.1972
10	NSW		578.1393	743.0390	686.7312	686.7312
11	Objective function		578.1387	2.3165	8.5718	1.7933e+03

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Similar findings were observed during Table-2, line 2-5 contingency. After comparing parameters, line 6-7 contingency is more severe and threatens the system more. Table-3 shows that TCSC is between lines 2-5 based on Severity Index values for all IEEE 30 bus lines.

Table-3. Severity Index values twenty most severe lines of IEEE 30 bus system

RANK	Line Connected		FVSI max Value	Line no with FVSI max	LUF max Value	Line no with LUF max	CILF max Value	Line no with CILF max
	SEB	REB						
1	6	7	0.3367	2-5	0.4549	2-5	0.3958	2-5
2	2	5	0.3615	9-11	0.4363	6-7	0.3080	6-7
3	1	3	0.3689	9-11	0.4015	1-2	0.3072	9-11
4	3	4	0.3669	9-11	0.3876	1-2	0.3062	9-11
5	2	6	0.3564	9-11	0.2699	2-5	0.3013	9-11
6	4	12	0.3561	9-11	0.3059	9-10	0.3011	9-11
7	4	6	0.3525	9-11	0.2774	2-5	0.2994	9-11
8	28	27	0.3512	9-11	0.2999	9-10	0.2988	9-11
9	18	19	0.3418	9-11	0.3384	9-10	0.2943	9-11
10	6	28	0.3405	9-11	0.2538	9-10	0.2937	9-11
11	2	4	0.3431	9-11	0.2514	2-5	0.2928	9-11
12	6	10	0.3383	9-11	0.2749	9-10	0.2926	9-11
13	12	16	0.3368	9-11	0.2573	9-10	0.2919	9-11
14	8	28	0.3368	9-11	0.2485	9-10	0.2919	9-11
15	5	7	0.3361	9-11	0.2509	2-5	0.2916	9-11
16	6	8	0.3358	9-11	0.2490	9-10	0.2914	9-11
17	25	27	0.3347	9-11	0.2597	9-10	0.2909	9-11
18	15	18	0.3343	9-11	0.2527	9-10	0.2907	9-11
19	12	14	0.3341	9-11	0.2510	9-10	0.2906	9-11
20	24	25	0.3340	9-11	0.2480	9-10	0.2906	9-11

Figure-2 compares ASI with and without TCSC. The deployment of TCSC lowered the ASI of severe lines. Figures 3 and 4 compare LUF and FVSI values at each transmission line in the 30-bus system.

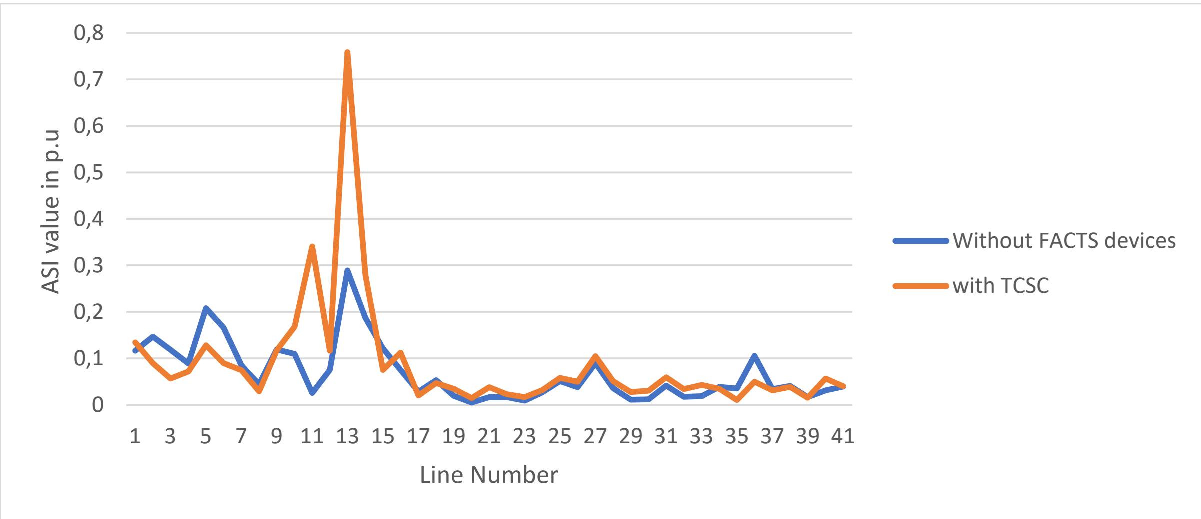

Figure-2. Comparison of ASI with and without TCSC.

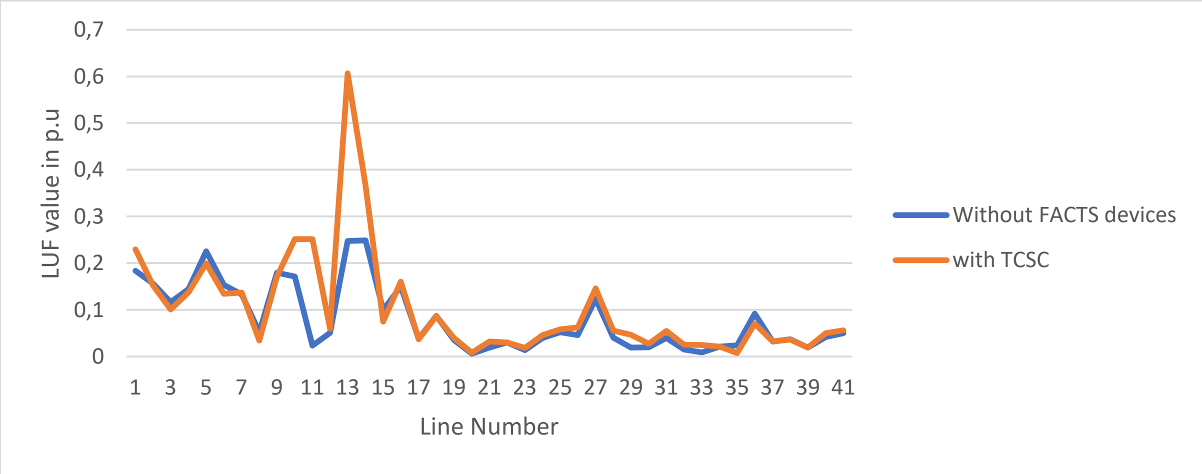

Figure-3. Comparison of LUF with and without TCSC.

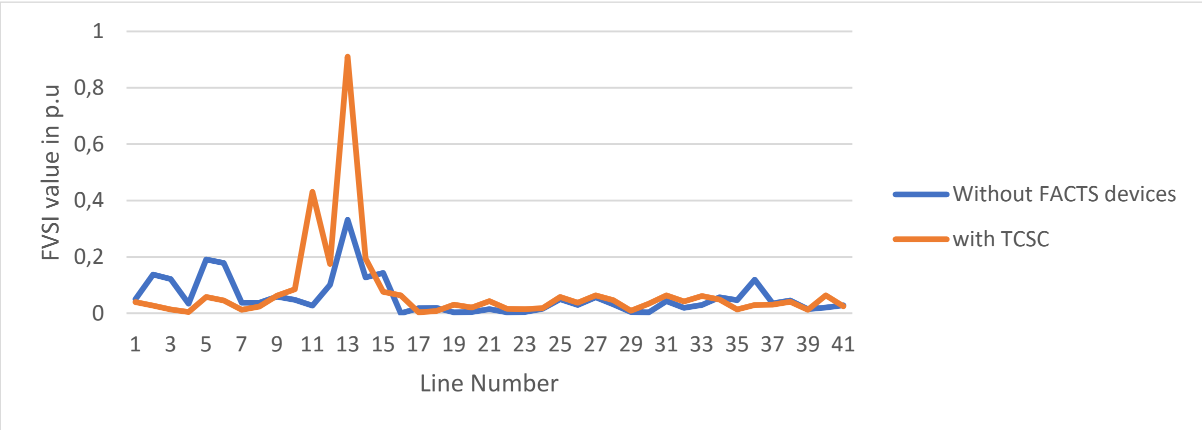

Figure-4. Comparison of FVSI with and without TCSC.

After the TCSC is positioned and tuned optimally, the 30-bus system's power distribution is optimized. For the line 6-7 scenario, it is shown that power loss decreases to 5.4 MW (Table-3). For line 2-5, the system power loss is reduced to 6.19 MW (Table-4).

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Table-4. Optimal power flows for various objective functions with contingency at line 6-7 and renewable energy sources with TCSC using MFO Algorithm

S. No	Parameters		OF_1	OF_2	OF_3	OF_4
1	Real power generation (MW)	P_{G1}	154.0362	159.1948	58.6486	71.6089
		P_{G2}	43.7470	20.0000	80.0000	67.2097
		P_{G5}	20.7713	15.0000	50.0000	50.0000
		P_{G8}	10.0000	35.0000	35.0000	35.0000
		P_{Gs}	35.0000	35.0000	35.0000	35.0000
		P_{Gw}	30.0000	30.0000	30.0000	30.0000
2	Total Active power generation (MW)		293.5545	294.1948	288.6486	288.8186
3	Total real power generation cost (Rs/hr)		588.1648	608.4057	712.3633	689.2817
4	Active power Loss (MW)		10.1545	10.7948	5.2486	5.4186
5	Valve point effect(Rs/hr)		615.5886	636.8653	757.9184	745.5423
6	Voltage deviation (p.u.)		1.3782	1.3750	1.3828	1.3819
7	CE(ton/hr)		0.1287	0.1358	0.0528	0.0534
8	Ptcsc(p.u)		0.4949	0.4949	0.4949	0.4949
9	Qtcsc(p.u)		2.0140	2.0140	2.0151	2.0151
10	Xtcsc (p.u)		0.1015	0.1079	0.0525	0.0542
11	FPL		49.4666	49.4666	49.4666	49.4666
12	FPG		588.1648	608.4057	712.3633	689.2817
13	NSW		538.6982	558.9391	662.8967	639.8151
14	Objective function		538.6981	1.3750	5.2486	1.3199e+03

Table-5. Optimal power flows for various objective functions with contingency at line 2-5 and renewable energy sources with TCSC using MFO Algorithm

S. No	Parameters		OF_1	OF_2	OF_3	OF_4
1	Real power generation (MW)	P_{G1}	154.0540	204.7910	59.4112	77.4515
		P_{G2}	43.4202	23.3391	80.0000	62.1442
		P_{G5}	22.9481	15.0000	50.0000	50.0000
		P_{G8}	10.7088	10.0000	35.0000	35.0000
		P_{Gs}	35.0000	35.0000	35.0000	35.0000
		P_{Gw}	30.0000	12.0000	30.0000	30.0000
2	Total Active power generation (MW)		296.1311	300.1301	289.4112	289.5957
3	Total real power generation cost (Rs/hr)		597.7004	679.6232	714.2263	683.9014
4	Active power Loss (MW)		12.7310	16.7302	6.0112	6.1957
5	Valve point effect(Rs/hr)		626.6383	691.1469	760.2613	742.9421
6	Voltage deviation (p.u.)		1.2795	1.2678	1.2997	1.2988
7	Carbon Emission(ton/hr)		0.1289	0.2202	0.0533	0.0551
8	Ptcsc(p.u)		0.4949	0.4949	0.4949	0.4949
9	Qtcsc(p.u)		2.0139	2.0102	2.0198	2.0199
10	Xtcsc (p.u)		0.1273	0.1673	0.0601	0.0620
11	FPL		49.4666	49.4666	49.4666	49.4666
12	FPG		597.7004	679.6232	714.2263	683.9014
13	NSW		548.2338	630.1566	664.7597	634.4348
14	Objective function		548.2338	1.2678	6.0112	1.3839e+03

The system voltage curve with and without FACTS devices is shown in Figure-5. Figure-6 compares multi-objective function convergence without and with TCSC. Figure-7 shows negative social welfare with and without TCSC in various system setups.

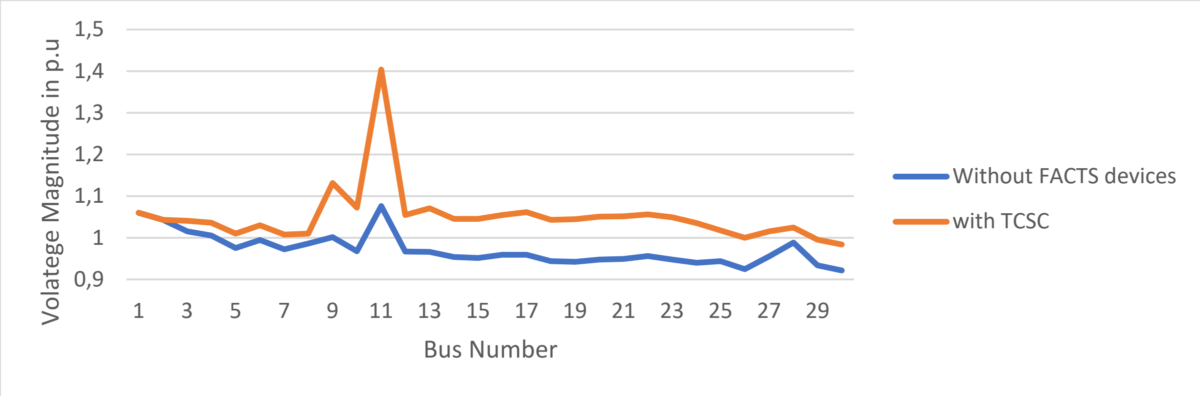

Figure-5. Voltage profile of the multi-objective function.

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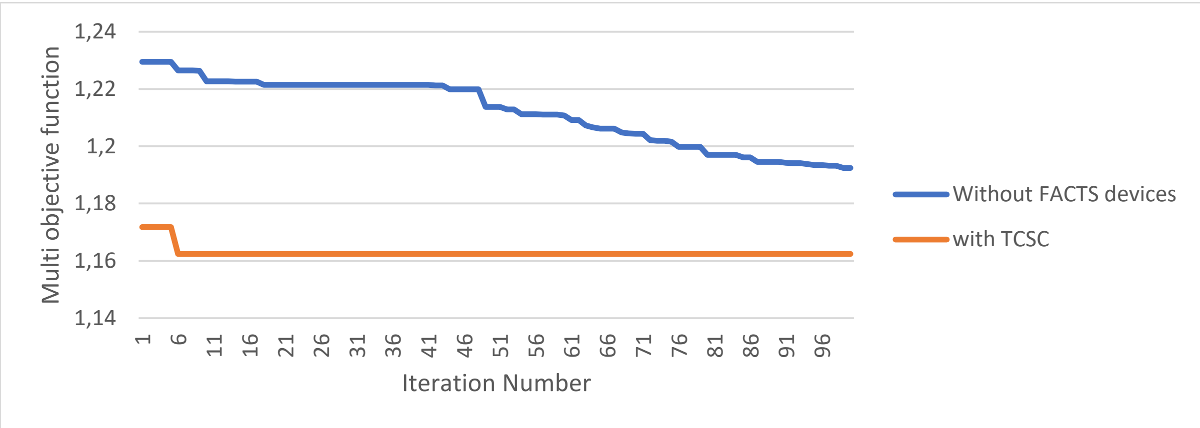

Figure- 6. Convergence of the Multi-objective function.

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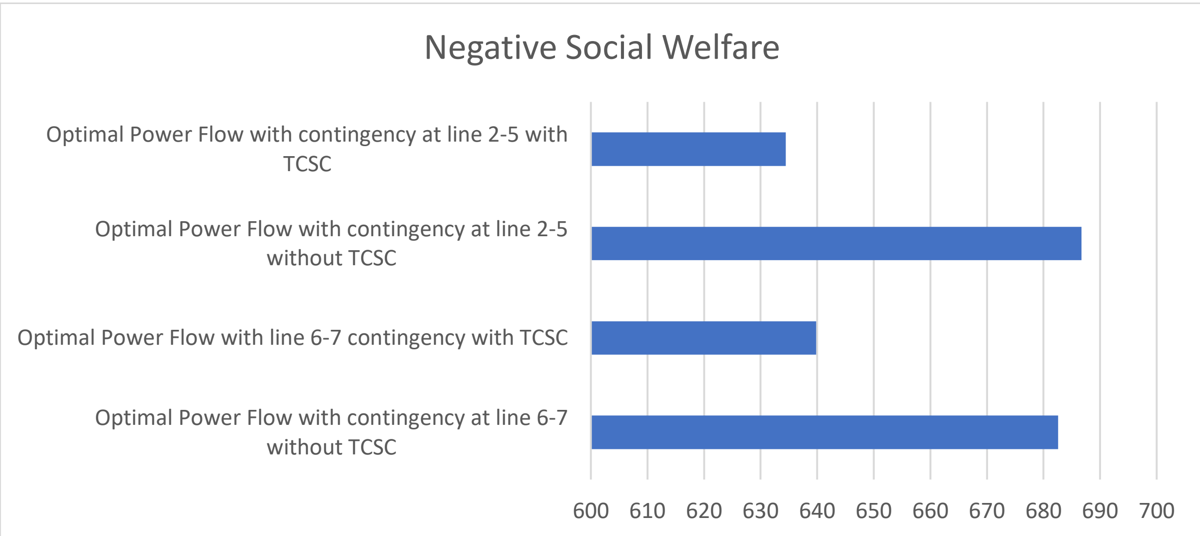

Figure-7. Comparison of Negative Social Welfare with and without TCSC.

5. CONCLUSIONS

Attracting industrial and foreign investment requires a reliable electricity grid. FACTS devices may be used in combination with renewable energy sources, which are already a potential alternative to conventional power systems, to boost the stability and dependability of the present power systems.

- The OPF enhances power flow capacity when renewable production is present.
- Optimal TCSC tuning and placement enhance system efficiency.
- TCSC deployment in the intended area leads to an 18% increase in social welfare.
- Moth Flame optimization is an effective approach for multi-objective problems.
- TCSC is a cost-effective alternative to conventional FACTS devices.

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