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Multi-Objective Optimal Power Flow Including FACTS Devices using Moth Flame Optimizer

Sundaram B. Pandya[1] and Hitesh R. Jariwala[2]
[1]Research Scholar, Department of Electrical Engineering,
S.V. National Institute of Technology, Surat-395007 (Gujarat), India.
[2]Associate Professor, Department of Electrical Engineering,
S.V. National Institute of Technology, Sura-395007 (Gujarat), India.

(Corresponding author: Sundaram B. Pandya)
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ABSTRACT: This paper delivers an impact of FACTS devices on multi-objective optimal power flow problem. The FACTS devices can play vital role in the power system. The study shows the solution of optimal power flow issue before and after allocation of FACTS devices. Typical FACTS devices like Static VAR Compensator and Thyristor Controlled Series Capacitor could be easily and quickly vary its injected power and apparent reactance separately as per the network necessity. For optimization issues, moth flame optimizer is projected and the fuzzy decision technique is projected to determine the finest optimum solution. The adequacy of the recommended approach may try on IEEE-30 bus test network and compared with latest techniques.

Keywords: Meta-heuristics; Multi-objective Optimal Power Flow, Moth Flame Algorithm.

I. INTRODUCTION

Now a days, in the restructured power network, FACTS frameworks are widely utilized as a part of the current time to expand the power transmission capability of the long-distance line and also for enrichment of the network dependability. These apparatus are proficient to control voltage level, phase angle, impedance and current of the transmission framework for expanding the network security, cos ϕ improvement, optimization of losses, managing reactive and real power loading and voltage abnormality. The important focal point of the optimal power system is to discover the operational state of the electrical network through optimizing specific objective functions where as satisfying the inequality and equality bounds. It was first to present via Carpentier [1].

Through extending power transmission frameworks operation and control turns out to be bitten by a bit more confounded use of FACTS devices turns into a suitable option for tackling these issues. The FACTS devices increase the constancy of electrical network both through their quick regulating qualities and constant compensation ability. As per the attributes of the FACTS devices, various objective problems were contemplated in literature to decide optimum factors of these devices. Few of these stated objectives are enlightening voltage solidity [2], diminish connection price of FACTS strategies [3], grid safety improvement [4], enrichment power scheme load ability [5], upsurge power schemes constancy [6–8] and energy price saving [9–11]. The optimal power flow can fulfill condition through the goal that's the reason it is taken as an essential matter in the electrical network [12, 13]. Likewise, in order to operate a power network safely, particular steadiness level is necessary. In this way, the voltage steadiness improvement index identified through bus voltage magnitude is taken as the problem function and optimized to build the safe task of the electrical network.

In this work, dual device policies are displayed as inserting power devices which infuses a specific quantity of power in the unique spot. These prototypes are the straightforward and appropriate option for FACTS devices. As specified previously, altering factors of FACTS devices is not a linear and complicated issue due to the non-linearity condition of FACTS devices which need to tackle through the robust and precise algorithm. In this proposed work, another technique recognized as the moth flame optimization approach invented by Mirjalili (2015) [14] is a nature-roused strategy for directing the process of moths in nature named transverse orientation. Thus, the principal objective of the present article is to apply MFO approach to illuminate the single objectives, multi-objective optimal power flow issue and after that to apply the FACTS devices. In this proposed work non-dominating procedures connected to discover the best optimal arrangement of the multi-objective optimization issue. The finest compromise outcomes are accomplished through the assistance of fuzzy decision-making practice. The multi-objective kind of the presently introduced multi-objective moth flame optimization (MOMFO) method. Afterward, the article is organized as follows;

The steady-state modeling of dual device are shown in section II. In section III, the optimal power flow problem is enclosed. Also, briefly introduction of the single-objective version and multi-objective version of MFO algorithm is proposed in section IV. Afterwards, section V contains the simulation output results through detail discussions and investigation through and deprived of FACTS devices. Finally, section VI gives the conclusion of the paper and delivers future research trends.

II. MODELLING OF FACTS STRATEGIES

The TCSC is associated in sequence manner while the SVC is linked in parallel manner through the bus.

The steady state modelling of dual device are as follows:

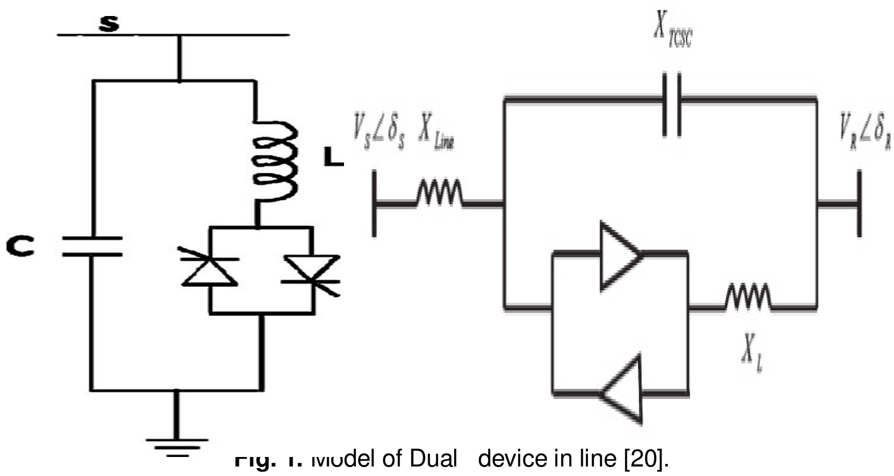

Fig. 1. Model of Dual device in line [20].

A. Stable state modelling of dual device

SVC includes a gathering of shunt coupled capacitive and reactive banks having quick controller of thyristor switching stroke. From the functioning perspective, SVC may be viewed as a changeable parallel reactance which is attuned automatically with respect to change in an operating environment of the network system. According to the idea of the corresponding SVC's reactance, the SVC fetches an inductive or capacitive current from the system. One-phase outline of SVC is delineated in Fig. 1. The VAR infused or consumed by the SVC is utilized as the flexible of this model (Q_{SVC}). The operative practical boundary for this variable is $Q_{minSVCi} \leq Q_{SVCi} \leq Q_{maxSVCi}$. In TCSC, two probable operations are conceivable which are inductive and capacitive, to reduce or raises the line reactance. Fig. 1 displays transmission line model showing TCSC coupled between bus r and bus s. In the stable condition, TCSC may be used as a static reactance (–jX_{TCSC}). This regulating reactance X_{TCSC} can be limited between $X_{minTCSCi} \leq X_{TCSCi} \leq X_{maxTCSCi.}$ The power inserted calculations of TCSC can be derivative as follow;

$$P_{sr} = V_S^2 \Delta G_{sr} - V_S V_R \begin{bmatrix} \Delta G_{sr} & \cos(\delta_s - \delta_r) \\ +\Delta B_{sr} & \sin(\delta_s - \delta_r) \end{bmatrix} \quad (1)$$

$$Q_{sr} = -V_S^2 \Delta B_{sr} - V_S V_R \begin{bmatrix} \Delta G_{sr} & \sin(\delta_s - \delta_r) \\ +\Delta B_{sr} & \cos(\delta_s - \delta_r) \end{bmatrix} \quad (2)$$

$$P_{sr} = V_R^2 \Delta G_{sr} - V_S V_R \begin{bmatrix} \Delta G_{sr} & \cos(\delta_s - \delta_r) \\ -\Delta B_{sr} & \sin(\delta_s - \delta_r) \end{bmatrix} \quad (3)$$

$$Q_{sr} = -V_R^2 \Delta B_{sr} + V_S V_R \begin{bmatrix} \Delta G_{sr} & \sin(\delta_s - \delta_r) \\ +\Delta B_{sr} & \cos(\delta_s - \delta_r) \end{bmatrix} \quad (4)$$

where, $\Delta G_{sr} = \frac{X_{TCSC} R_{sr} (X_{TCSC} - 2X_{sr})}{(R_{sr}^2 + X_{sr}^2)(R_{sr}^2 + (X_{sr} - X_{TSCS})^2)}$

$$\Delta B_{sr} = -\frac{X_{TCSC} R_{sr} (X_{TCSC} - 2X_{sr})}{(R_{sr}^2 + X_{sr}^2)(R_{sr}^2 + (X_{sr} - X_{TCSC})^2)}$$

X_{sr} and R_{sr} are the admittance and resistance of the line between the bus s and bus r respectively.

III. OPTIMIZATION ISSUES

A. Optimal Power Flow Problem

The OPF contains the objectives of optimal active-reactive power dispatch. In this section, the objectives of optimal power flow through FACTS device are incorporated as follows;

1. Minimization of entire price: The major objective is minimization of total entire price.

Objective 1: Minimize –

$$F1 = C(P) = \sum_{i=1}^{NG} (A_i P_{gi}^2 + B_i P_{gi} + C_i) \quad (5)$$

where A_i,B_i and C_i are the fuel price coefficients of the i^{th} unit.

2. Minimization of emission: The goal in this objective is to limit the outflow amount of contaminations that is hazardous gases. The objective function can be written as;

$$F2 = \sum_{i=1}^{NG} (\alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2 + \xi_i \exp(\lambda_i P_{gi})) \quad (6)$$

where, γ_i, β_i, α_i, ξ_i, and λ_i are the emission coefficients of i^{th} unit

3. Minimization of voltage deviance: Bus voltage is a standout amongst the premier vigorous safety and management superiority lists. The improving voltage outline will be learned by preventive the deviances in voltage of PQ bus from 1.0 for each unit. The objective function will be given by:

Objective 2: Minimize –

$$F3 = \sum_{i=1}^{N_{pq}} |v_i - 1.0| \quad (7)$$

where N_{pq} shows the number of load (PQ) buses, v_i shows the p.u voltage of ith bus.

4. Minimization of active power losses: The optimization of real power losses P_{LOSS} (MW) may be computed by:

Objective 3: Minimize –

$$F4 = P_{LOSS} = \sum_{i=1}^{NB} P_{Gi} - \sum_{i=1}^{NB} P_{Di} \quad (8)$$

where P_{Gi} and P_{Di} represent the output and dispatch at i^{th} bus; NB shows the number of buses.

5. Enhancement of voltage steadiness index: The most significant measure, which designates the voltage constancy margin of each bus, is the L_{max} index to reserve the continuous voltage inside appropriate margin under ordinary working environments. $L_{\max}$ index delivers a scalar quantity for each PQ bus. $L_{\max}$ index lies in a span of '0' (no load) to '1' (voltage failure). The amount of voltage downfall pointer for j^{th} bus is acquired as

$$L_j = \left|1 - \sum_{i=1}^{N_g} F_{ji} \frac{V_i}{V_j}\right| \quad \forall j = 1,2, \dots \dots, NL \quad (9)$$

$$F_{ji} = -[Y_1]^{-1}[Y_2] \quad (10)$$

where Y_1 and Y_2 were the sub-matrices of Y_{BUS}. The objective function of voltage immovability improvement is written by;

$$F5 = L = \max(L_j) \quad \forall j = 1,2, \dots \dots, NL \quad (11)$$

B. Equality constraints

The equality constraints are nothing but basically the load flow equations and are written as;

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{N} v_j \left(G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij})\right) = 0 \;\; i = 1,2,3, \dots \dots N \quad (12)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{N} v_j \left(G_{ij} \sin(\delta_{ij}) + B_{ij} \cos(\delta_{ij})\right) = 0 \;\; i = 1,2,3, \dots \dots N \quad (13)$$

Where N is the total number of buses in the power system networks, V_i and v_j are the magnitudes of voltages at i^{th} bus and j^{th} bus, respectively; δ_{ij} is the voltage phase angle at i^{th} bus and j^{th} bus, respectively. P_{Gi} and Q_{Gi} demonstrates the real and reactive power outputs at i^{th} bus, P_{Di} and Q_{Di} are associated real and reactive power demands at i^{th} bus, G_{ij} and B_{ij} are the conductance and susceptance of the ij^{th} component of the bus admittance matrix, respectively

C. Inequality constraints

Generator constraints: It contains generator real power P_{Gi}, generator imaginary power Q_{Gi}, and generator voltage magnitude V_{Gi} which are controlled by its higher and lower restrictions:

$$P_{Gimin} \le P_{Gi} \le P_{Gimax} \quad i = 1, \dots \dots Ng \quad (14)$$

$$Q_{Gimin} \le Q_{Gi} \le Q_{Gimax} \quad i = 1, \dots \dots N \quad (15)$$

$$V_{Gimin} \le V_{Gi} \le V_{Gimax} \quad i = 1, \dots \dots N \quad (16)$$

Transformer constraints: Transformer tapings are also inequality constraints, having their higher and lower setting limits:

$$T_{imin} \le T_i \le T_{imax} \quad i = 1, \dots \dots Nt \quad (17)$$

Switching VAR constraints: The switch in greactive sources have limitations as follows:

$$Q_{cimin} \le Q_{ci} \le Q_{cimax} \quad i = 1, \dots \dots Nc \quad (18)$$

d. Security constraints: These comprise of the limitations on voltage magnitudes of PQ bus and load flow bounds of a line:

$$V_{Limin} \le V_{Li} \le V_{Limax} \quad i = 1, \dots \dots Np \quad (19)$$

$$|S_{Li}| \le S_{Limax} \quad i = 1, \dots \dots \dots . N_l \quad (20)$$

d. FACTS devices constraints: These includes the operation of dual device limits:

$$Q_{minSVCi} \le Q_{SVCi} \le Q_{maxSVCi} \; i = 1, N_{SVC} \quad (21)$$

$$X_{minTCSCi} \le X_{TCSCi} \le X_{maxTCSCi} \; i = 1, N_{TCSC} \quad (22)$$

IV. MULTI-OBJECTIVE MOTH FLAME OPTIMIZER

A. Formulation of multi-objective function through the non-sorting MFO algorithm

Here, the Moth Flame Optimization (MFO) algorithm is implemented to solve the multi-objective optimal power flow problem. It is fundamentally stimulated from the moths in environment. The transverse orientation of mechanism is utilized by the moths for navigation as shown in Fig. 2. The multi-objective optimization issues comprising the amount of clashing objective functions are optimized simultaneously while at same time fulfilling all the constraints. There are number of optimization methods that are utilized prior to the article to explain the multi-objective OPF problem. Starting through those works of literature, it is seen that numerous researchers have changed over that multi-objective issue under a single objective issue utilizing the straight mixture of the two clashing objective works toward applying the weighting components approach. Furthermore, finer route for finding the result of the multi-objective issue may be to estimate the set of ideal tradeoffs what's more discovering the best compromising solutions around every last one of Pareto fronts. The multi-objective optimization problem needs to be figured as;

$$Min\, f_i(u), \quad i = 1,2,3 \dots \dots \dots \dots, N \quad (23)$$

$$Subjected\ to\ g_j(u) = 0, \;\; j = 1,2,3 \dots \dots \dots . . M \quad (24)$$

$$h_k(u) \le 0, \quad k = 1,2,3 \dots \dots \dots \dots . K \quad (25)$$

where f_i shows the i^{th} objective function; u represents the decision vectors; N stands for total objective function; M stands for the total power flow bounds and K stands for total physical bounds on devices. In the multi-objective optimization, the non-dominated sorting technique can have two probabilities, one dominating the other objectives or no one dominated the other. In other words, deprived of losing generality; u_1 dominates the u_2 only if the given two criteria are fulfilled;

$$\forall i \in \{1,2,3 \dots \dots N\} \quad : \; f_i(u_1) \le f_i(u_2) \quad (26)$$

$$\exists j \in \{1,2,3 \dots \dots N\} \quad : \; f_j(u_1) \le f_j(u_2) \quad (27)$$

In the event that any of the above conditions is disregarded, at that point, arrangement u_1 does not rule u_2. The arrangement u_1 is known as the non-commanded arrangement, if u_1 overwhelms the u_2 arrangements. The method of the suggested non-sorting MFO approach has appeared in algorithm-2. Initially, introduce parameters, for example, population size N_{pop}, and stopping value, here it is the most extreme no. of generation to proceeds the method. Besides, a random parent population P_o in possible space S is produced and every objective function of the objective vector F for P_o is assessed. Afterward, non-dominated sorting along through crowding distance calculation is implemented on P_o. Subsequently, MFO approach is utilized to make the fresh population P_j, and then it is converged through P_o to shape the blended population P_i. This P_i is arranged in view of elitism non-domination, and in light of the figured estimations of crowding distance (CD) and non-domination rank (NDR), the best N_{pop} arrangements are refreshed to frame another parent population. This procedure is repeated until the highest no. of generations (cycles) are come to. It must be noticed that a similar approach can be utilized along through end criteria set according to the total evaluations of the function.For more details in moth flame algorithm [14-15].

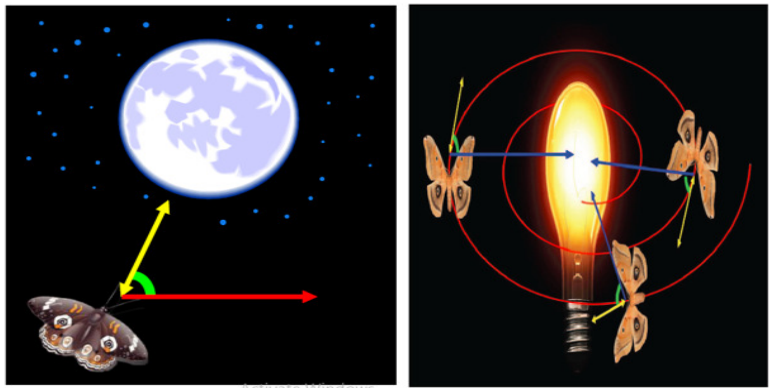

Fig. 2. Transverse Orientation [14].

B. Fuzzy model for the multi-objective problem

For finding the best compromising solution among all the non-inferior results, the fuzzy membership approach can be applied in multi-objective functions. The fuzzy membership function μ_{f_i} is looking after minimum f_i^{min} and maximum f_i^{max} values for every objective goal through the help of fuzzy membership function. Now, the membership function of i^{th} objective is expressed as

$$\mu_{f_i} = \begin{cases} 1 & f_i \leq f_i^{min} \\ \frac{f_i^{max} - f_i}{f_i^{max} - f_i^{min}} & f_i^{min} < f_i < f_i^{max} \\ 0 & f_i \geq f_i^{max} \end{cases} \quad (28)$$

The values of membership functions lie in the scale of (0-1) and shows that how much it satisfies the function f_i. Afterward, the decision-making function μ^k should be computed as follows;

$$\mu^k = \frac{\sum_{i=1}^{N} \mu_{f_i}^k}{\sum_{k=1}^{M} \sum_{i=1}^{N} \mu_{f_i}^k} \quad (29)$$

The decision-making function can also be considered as the normalized membership function for non-inferior results and shows the ranking of the non-dominated results. The final result is treated as the best compromising solution among all the Pareto front having the value maximum $\{\mu^k: k = 1,2,3 \ldots \ldots . M\}$

V. SIMULATION RESULTS AND ANALYSIS

In the present paper, the effect of dual devices on OPF issue has been examined. The single and multi-objective OPF issue using the tool of Moth Flame Optimization algorithm (MFO) is tried upon the IEEE-30 bus test framework. In proposed work, computer programs are written through MATLAB programming language and runs on PC comprising 3.4 Gigahertz, Intel i5 processing system of 8 GB RAM. The population size of 40 and highest iterations of 100 are taken for the calculation.The IEEE-30 bus network is utilized to identify the strength of the recommended approach.

The parameters, price constants and emission constants of IEEE-30 bus system are taken from [16]. There are three distinct cases taken to see the result of FACTS devices in OPF issue.

— *IEEE-30 bus test system through TCSC only.*
— *IEEE-30 bus test system through SVC only.*
— *IEEE-30 bus test system through dual device both.*

Case-1: IEEE-30 bus test system through TCSC only. Initially, the IEEE-30 bus framework deprived of TCSC is considered. The diverse solitary and multi-objective functions are optimized through the moth flame optimization method. Afterward, the arrangement FACTS device, TCSC is incorporated. Here, the TCSC is situated at line 36 which is associated through the bus 27-28. In this study, the highest and lowest reactance bounds of TCSC is selected as 0 and 0.20. p.u [20]. Table 1 indicates results after optimization of the single like fuel price, active loss, voltage deviance and voltage steadiness index through and deprived of TCSC. The multi-objective optimization through non-dominated arrangement technique applied through moth flame algorithm and after the fuzzy decision-making practice, the finest compromise solutions are also cited in Table 2. The convergence characteristic of fuel price through TCSC is shown in Fig. 3 and 4 demonstrates the examination chart of the single objectives through and deprived of TCSC. It is seen that the voltage deviance is decreased to 3.50% in the wake of utilizing the TCSC device. Likewise, the voltage steadiness index is diminished to 2.06% in the wake of distributing the FACTS device. The Pareto front of fuel price and voltage deviance through TCSC is displayed in Fig. 5 while optimum solution of fuel price, voltage deviance, and voltage steadiness index through TCSC has appeared in Fig. 6. It is seen that subsequent to apply the TCSC device the outcomes are improved.

Table 1: Single objectives results of through and deprived of TCSC.

Objectives	Case-1 Through and deprived of TCSC only									
	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC
	Obj.-1		Obj.-2		Obj.-3		Obj.-4		Obj.-5	
FC	799.1191	**799.1135**	-	-	-	-	-	-	-	-
Emmi.	-	-	0.2056	**0.2056**	-	-	-	-	-	-
Ploss	-	-	-	-	2.8596	**2.8594**	-	-	-	-
VD	-	-	-	-	-	-	0.1057	**0.1020**	-	-
Lmax	-	-	-	-	-	-	-	-	0.1114	**0.1091**

Table 2: Multi-objectives results of through and deprived of TCSC.

Objectives	Case-1 Through and deprived of TCSC only									
	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC	Deprived of TCSC	Through TCSC
Multi-Objective Manner	FC+VD Combine Optimized		FC+LmaxCombine Optimized		VD+LmaxCombine Optimized		FC+VD+LmaxCombine Optimized		FC+VD+Lmax+PlossCombine Optimized	
FC	804.1379	803.6933	809.2576	801.2812	-	-	847.6139	837.9152	858.6073	852.4998
VD	0.2798	0.1602	-	-	1.1913	0.8221	1.1126	0.8556	1.1841	0.6477
Lmax	-	-	0.1116	0.1128	0.1221	0.1219	0.1234	0.1223	0.1272	0.1301
Ploss	-	-	-	-	-	-	-	-	8.4692	8.7157

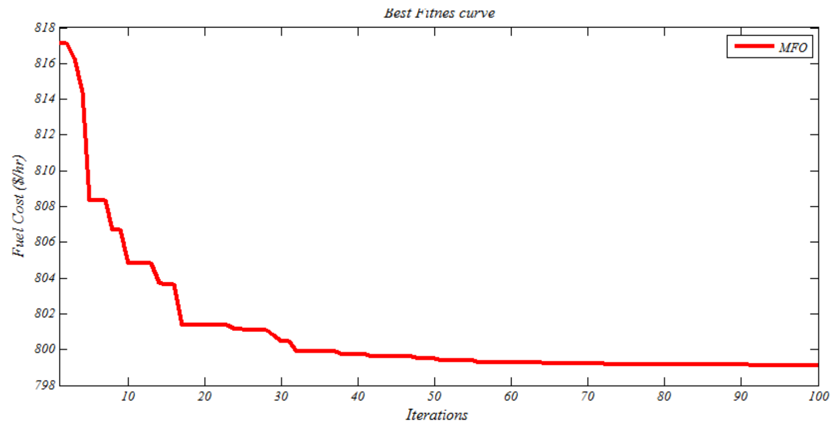

Fig. 3. Convergence characteristic of fuel price minimization through TCSC.

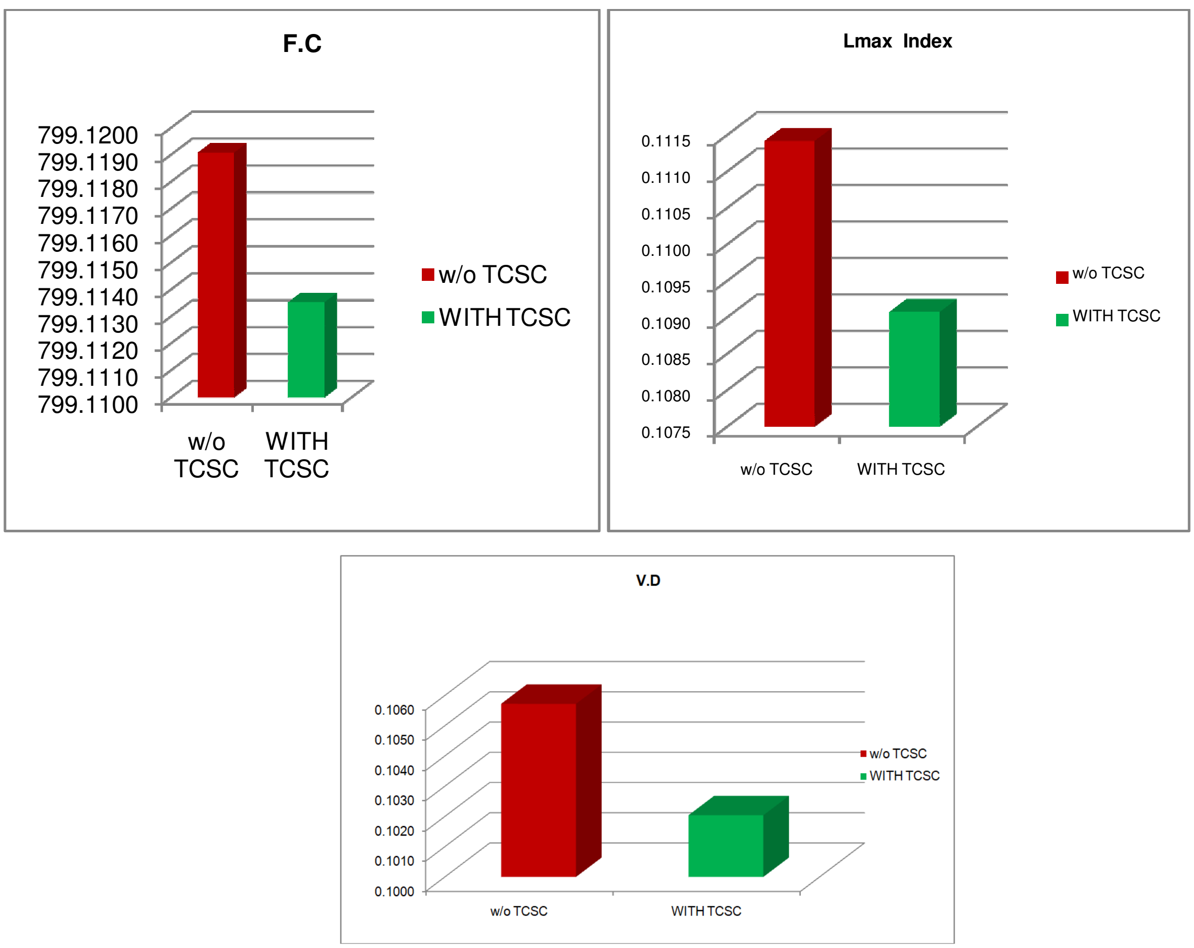

Fig. 4. Evaluation of Fuel price, Voltage steadiness index and Voltage deviance through and deprived of TCSC.

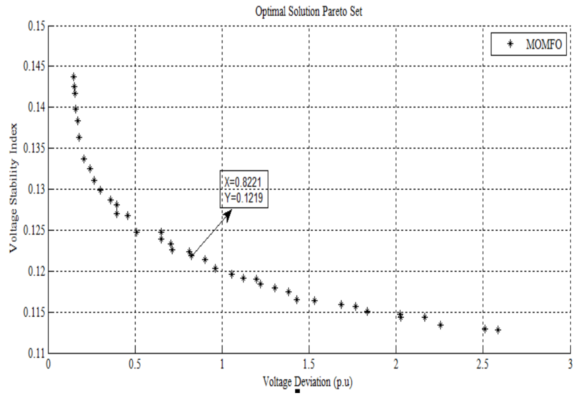

Fig. 5. Pareto front of Fuel price and voltage deviance minimization through TCSC.

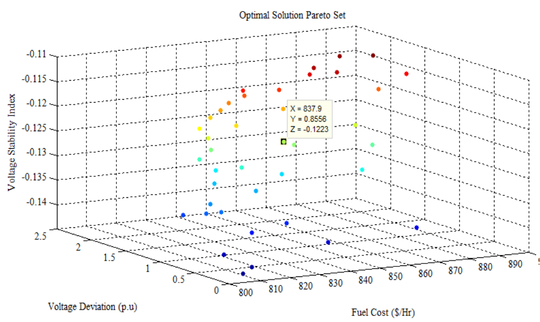

Fig. 6. Best compromise solution of fuel price, voltage deviance and voltage steadiness index minimization through TCSC.

Case-2 IEEE-30 bus test system through SVC only. Static VAR Compensator (SVC) includes shunt coupled reactors and capacitor banks through quick control method of thyristor switching. From the functional perspective, SVC may be viewed as a changeable shunt reactance which can be adjusted automatically through respect to changes in the operational situation of the system. According to the nature of the equivalent SVC's reactance, it fetch an inductive or capacitive current from the system. Here the SVC is situated at the bus-27 of IEEE-30 bus framework. The base and most extreme limit of SVC is 0-15 MVAr. The single objective optimization before and after incorporating of SVC through the moth flame algorithm is appeared in Table 3. The estimation of the fuel price and voltage deviance through and deprived of the SVC device are depicted in Fig. 7. The use of the SVC gives the 2.78% decrease in voltage deviance as shown in Fig. 7. The multi-objective optimization through non-dominated solution technique applying through moth flame algorithm is shown in Table 4. From Table 4, it is seen that in the wake of applying the SVC device, the outcomes are improved. The Pareto front of the two objectives and three objectives functions have appeared in Fig. 8 and 9.

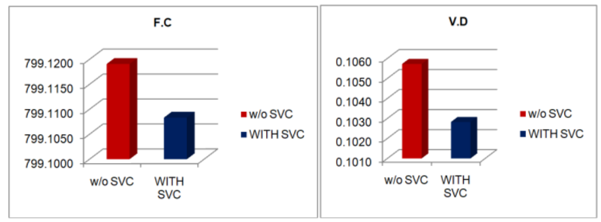

Fig. 7. Comparison of Fuel price and voltage deviance through and deprived of SVC**.**

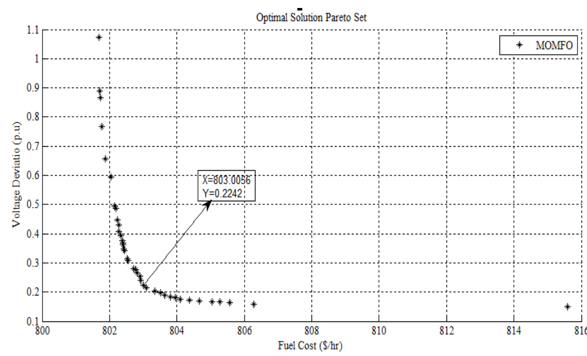

Fig. 8. Pareto front of Fuel price and voltage deviance minimization through SVC.

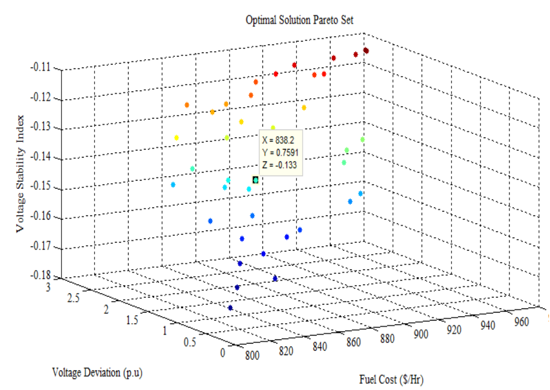

Fig. 9. Best compromise solution of fuel price, voltage deviance and voltage steadiness index minimization through SVC.

Table 3: Single objectives results of through and deprived of SVC.

Objectives	Case-2 Through and deprived of SVC only									
	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC
	Obj.-1		Obj.-2		Obj.-3		Obj.-4		Obj.-5	
FC	799.1191	799.1083	-	-	-	-	-		-	-
Emmi.	-	-	0.2056	0.2056	-	-	-	-	-	-
Ploss	-	-	-	-	2.8596	2.8594	-	-	-	-
VD	-	-	-	-	-	-	0.1057	0.1028	-	-
Lmax	-	-	-	-	-	-	-	-	0.1114	0.1116

Case-3 IEEE-30 Bus test system through dual device both [20]. For enhancing the performance, two FACTS devices TSCS and SVC are located in IEEE-30 bus test framework. Here the TCSC is situated at line-34 (between the bus 25 and 26) and the SVC is situated at the bus-27. The limits of SVC are 0-15MVAr and the TCSC limits are 0-0.2 p.u. The change of voltage profile after allotment of dual device has appeared in Fig. 10. The optimized parameters of single objectives functions have appeared in Table 5. From the Table 7, it is seen that the MFO gives the better performance compared to cited techniques. The voltage deviance is diminished to 2.93% and the voltage steadiness index is enhanced up to 12.47% which is appeared in Fig. 11. Similarly, the consequences of multi-objective optimization through FACTS devices are specified in Table 6. It is observed that the best tradeoff arrangement accomplished after provision of dual device is grander than deprived of these both devices. From Table 7-9, it is seen that after applying the both dual device devices, the results of single and multi-objectives OPF is improved.

Table 4: Multi-objective results of through and deprived of SVC.

Objectives	Case-2 Through and deprived of SVC only									
	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC	Deprived of SVC	Through SVC
Multi-Objective Manner	FC+VD Combine Optimized		FC+LmaxCombine Optimized		VD+LmaxCombine Optimized		FC+VD+LmaxCombine Optimized		FC+VD+Lmax+PlossCombine Optimized	
FC	804.1379	803.0056	809.2576	824.6483	-	-	847.6139	838.2007	858.6073	832.5689
VD	0.2798	0.2243	-	-	1.1913	1.1235	1.1126	0.7591	1.1841	1.1091
Lmax	-	-	0.1116	0.1133	0.1221	0.1252	0.1234	0.1330	0.1272	0.1350
Ploss	-	-	-	-	-	-	-	-	8.4692	5.8201

Table 5: Single objectives results of through and deprived ofboth device.

Objectives	Case-3 Through and deprived ofboth device									
	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC
	Obj.-1		Obj.-2		Obj.-3		Obj.-4		Obj.-5	
FC	799.1191	799.1034	-		-	-	-	-	-	-
Emmi.	-	-	0.2056	0.2056	-	-	-	-	-	-
Ploss	-	-	-	-	2.8596	2.8595	-	-	-	-
VD	-	-	-	-	-	-	0.1057	0.1026	-	-
Lmax	-	-	-	-	-	-	-	-	0.1114	0.0975

Table 6: Multi-objective results of through and deprived of both device.

Objectives	Case-3 Through and deprived ofboth device									
	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC	Deprived of TCSC & SVC	Through TCSC & SVC
Multi-Objective Manner	FC+VD Combine Optimized		FC+LmaxCombine Optimized		VD+LmaxCombine Optimized		FC+VD+LmaxCombine Optimized		FC+VD+Lmax+PlossCombine Optimized	
FC	804.1379	803.1806	809.2576	802.1537	-	-	847.6139	809.1337	858.6073	850.3360
VD	0.2798	0.1972	-	-	1.1913	0.4988	1.1126	0.7925	1.1841	0.2885
Lmax	-	-	0.1116	0.1020	0.1221	0.1137	0.1234	0.1148	0.1272	0.1234
Ploss	-	-	-	-	-	-	-	-	8.4692	8.5885

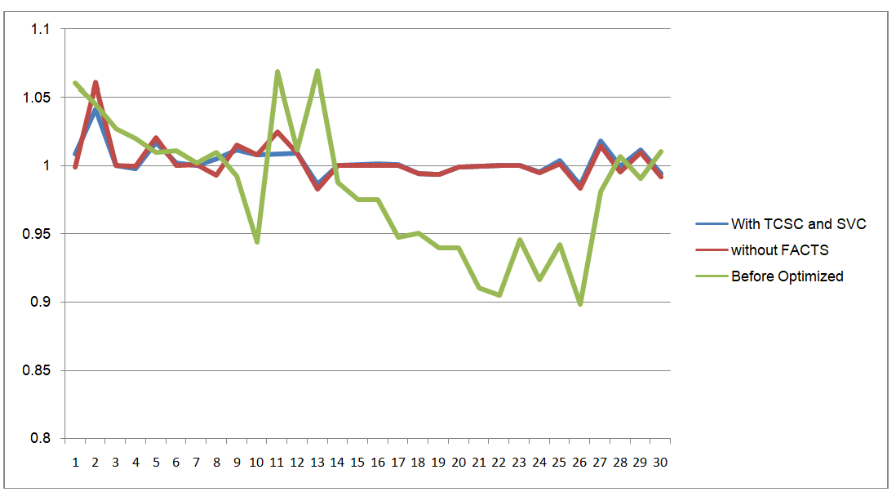

Fig. 10. Voltage profile improvement after allocating the dual device.

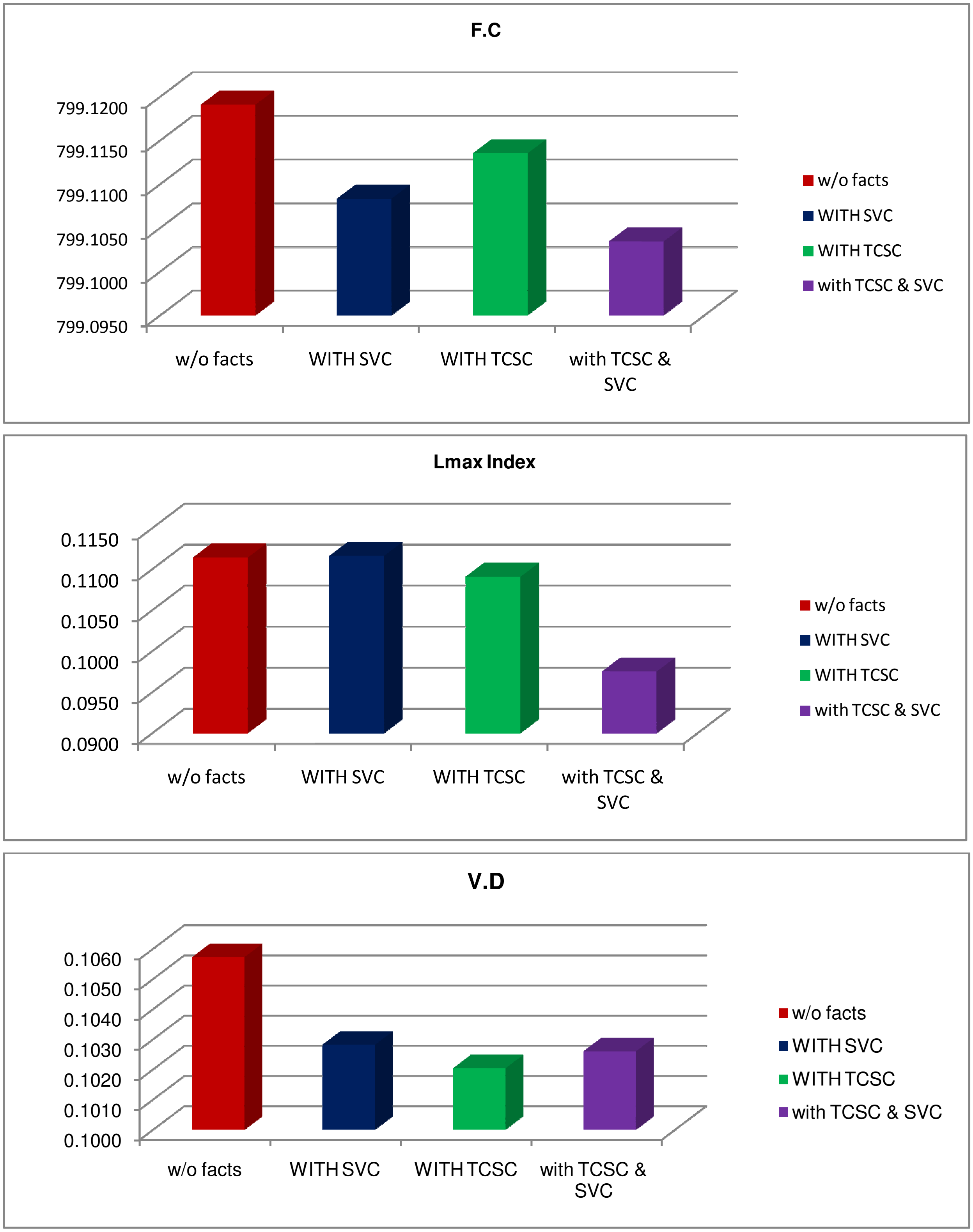

Fig. 11. Comparison of Fuel price, Voltage steadiness index and Voltage deviance through and deprived of FACTS Devices.

Table 7: Comparison of Fuel price through and deprived of FACTS.

Method	Fuel price	Method Description
MFO (Deprived of FACTS)	**799.1191**	**"Moth Flame Optimization (Deprived Of FACTS)"**
DE[21]	799.2891	"Differential Evaluation"
SA[21]	799.45	"Simulated Annealing"
AGAPOP[21]	799.8441	"Adaptive Genetic Algorithm With Adjusting Population Size"
BHBO[21]	799.9217	"Black Hole Based Optimization"
EM[21]	800.078	"Electromagnetic Like Mechanism"
EADHDE[21]	800.1579	"Genetic Evolving Ant Direction Hde"
EADDE[21]	800.2041	"Evolving Ant Direction Differential Evaluation"
PSO[21]	800.41	"Particle Swarm Optimization"
FPSO[21]	800.72	"Fuzzy Particle Swarm Optimization"
IGA[21]	800.805	'Improved Genetic Algorithm"
FGA[21]	801.21	"Fuzzy Genetic Algorithm"
ICA[21]	801.843	"Imperialistic Competitive Algorithm"
EGA[21]	802.06	"Enhanced Genetic Algorithm"
TS[21]	802.2900	"Tabu Search"
MDE[21]	802.376	"Modified Differential Evaluation"
IEP[21]	802.465	"Improved Evolutionary Programming"
EP[21]	802.62	"Evolutionary Programming"
RGA[21]	804.02	"Refined Genetic Algorithm"
GM[21]	804.853	"Gradient Method"
MFO(Through TCSC)	**799.1135**	**"Moth Flame Optimization (Through Tcsc)"**
MFO(Through SVC)	**799.10834**	**"Moth Flame Optimization (Through Svc)"**
MFO(Through TCSC&SVC)	**799.0994**	**"Moth Flame Optimization (Through Both Device)"**

Table 8: Comparison of Voltage deviance through and deprived of FACTS.

METHOD	Voltage deviance	METHOD DESCRIPTION
MFO (Deprived of FACTS)	**0.1057**	**"Moth Flame Optimization (Deprived of FACTS)"**
ABC[18]	0.1351	"Artificial Bee Colony"
MABC[18]	0.1292	"Modified Artificial Bee Colony"
SFLA[18]	0.1445	"Shuffle Frog Leaping Algorithm"
CPSO[18]	0.1469	"Chaotic Particle Swarm Optimization"
MFO(Through TCSC)	**0.1020**	**"Moth Flame Optimization (Through TCSC)"**
MFO(Through SVC)	**0.1028**	**"Moth Flame Optimization (Through SVC)"**
MFO(Through TCSC&SVC)	**0.1019**	**"Moth Flame Optimization (Through both device)"**

Table 9: Comparison of L-index through and deprived of FACTS.

METHOD	L index	METHOD DESCRIPTION
MFO (Deprived of FACTS)	**0.1114**	**"Moth Flame Optimization (Deprived of FACTS)"**
DSA[19]	0.1244	"Differential Search Algorithm"
MODE[19]	0.1246	"Modified Differential Evaluation"
ABC[17]	0.1379	"Artificial Bee Colony"
GSA[17]	0.116247[a]	"Gravitational Search Algorithm"
HS[17]	0.1075[a]	"Harmony Search"
DE[17]	0.1219[a]	"Differential Evaluation"
PSO[17]	0.1246[a]	"Particle Swarm Optimization"
MFO(Through TCSC)	**0.1019**	**"Moth Flame Optimization (Through TCSC)"**
MFO(Through SVC)	**0.1116**	**"Moth Flame Optimization (Through SVC)"**
MFO(Through TCSC&SVC)	**0.0973**	**"Moth Flame Optimization (Through both device)"**

a-Infeasible solution

VI. CONCLUSION

This work assesses the adequacy of dual FACTS device in diminishing the generation cost, limiting the voltage deviance and refining the voltage steadiness index in power systems. Additionally, this work shows another strategy to optimize objective functions separately and simultaneously called as multi-objective version of moth flame optimization (MOMFO) technique. At last, a fuzzy involvement technique is utilized to recognize the optimum solution. According to the simulated outputs, obviously suggested MFO technique can give better optimal results for single and multi-objective OPF issue. So at last, it can be inferred that all Pareto answers when dual device are in the grid, ruled arrangements which FACTS devices are not in grid, it demonstrates the FACTS devices impact on price, voltage deviance, and voltage steadiness index.

VII. FUTURE SCOPE

In future, the multi-objective optimal power flow problem will also deal through the hybrid energy resources.

Conflict of Interest. The authors declare that there is no conflict of interest of any sort on this research.

REFERENCES

[1]. Carpentier (1985). Optimal power flows uses, methods, and developments. *Proceeding. IFAC Conference, 18*(7),11-21.

[2]. Amaris, H., & Alonso, M. (2011). Coordinated reactive power management in power networks with wind turbines and FACTS devices. *Energy Conversion and Management*, *52,*2575–2586.
[3]. Saravanan, M., Slochanal, S. M. R., Venkatesh, P., & Abraham, J. P. S. (2007). Application of particle swarm optimization technique for optimal location of FACTS devices considering cost of installation and system loadability. *Electric power systems research*, *77*(3-4), 276-283.
[4]. Sharma, N. K., Ghosh, A., & Varma, R. K. (2003). A novel placement strategy for FACTS controllers. *IEEE Transactions on Power Delivery,* 982–987.
[5]. Sharma, A., Chanana, S., & Parida, S. (2005). Combined optimal location of FACTS controllers and loadability enhancement in competitive electricity markets using MILP. In *IEEE Power Engineering Society General Meeting,* pp. 670-677.
[6]. Noroozian, M., Angquist, L., Ghandhari, M., & Andersson, G. (1997). Improving power system dynamics by series-connected FACTS devices. *IEEE Transactions on Power Delivery*, *12*(4), 1635-1641.
[7]. Phorang, K., Leelajindakraireak, M., & Mizutani, Y. (2002). Damping improvement of oscillation in power system by fuzzy logic based SVC stabilizer. In *IEEE/PES Transmission and Distribution Conference and Exhibition 3*,1542-1547.
[8]. Du, W., Wu, X., Wang, H. F., & Dunn, R. (2010). Feasibility study to damp power system multi-mode oscillations by using a single FACTS device. *International Journal of Electrical Power & Energy Systems*, *32*(6), 645-655.
[9]. Mahdad, B., Bouktir, T., Srairi, K., & Benbouzid, M. E. (2010). Dynamic strategy based fast decomposed GA coordinated with FACTS devices to enhance the optimal power flow. *Energy Conversion and Management*, *51*(7), 1370-1380.
[10]. Ara, A. L., Kazemi, A., & Niaki, S. N. (2011). Modelling of Optimal Unified Power Flow Controller (OUPFC) for optimal steady-state performance of power systems. *Energy conversion and Management*, *52*(2), 1325-1333.
[11]. Rahimzadeh, S., & Bina, M. T. (2011). Looking for optimal number and placement of FACTS devices to manage the transmission congestion. *Energy conversion and management*, *52*(1), 437-446.
[12]. Niknam, T., Azizipanah-Abarghooee, R., & Narimani, M. R. (2012). Reserve constrained dynamic optimal power flow subject to valve-point effects, prohibited zones and multi-fuel constraints. *Energy*, *47*(1), 451-464.
[13]. Narimani, M. R., Azizipanah-Abarghooee, R., Zoghdar-Moghadam-Shahrekohne, B., & Gholami, K. (2013). A novel approach to multi-objective optimal power flow by a new hybrid optimization algorithm considering generator constraints and multi-fuel type. *Energy*, *49*, 119-136.
[14]. Mirjalili, S. (2015). Moth-flame optimization algorithm: A novel nature-inspired heuristic paradigm. *Knowledge-based systems*, *89*, 228-249.
[15]. Savsani, V., & Tawhid, M. A. (2017). Non-dominated sorting moth flame optimization (NS-MFO) for multi-objective problems. *Engineering Applications of Artificial Intelligence*, *63*, 20-32.
[16]. Washington, U. (1999). Power systems test case archive. *2014G11G01]. http://www. ee. washington. edu/research/pstca*.
[17]. Adaryani, M. R., & Karami, A. (2013). Artificial bee colony algorithm for solving multi-objective optimal power flow problem. *International Journal of Electrical Power & Energy Systems*, *53*, 219-230.
[18]. Bhowmik, A. R., & Chakraborty, A. K. (2014). Solution of optimal power flow using nondominated sorting multi objective gravitational search algorithm. *International Journal of Electrical Power & Energy Systems*, *62*, 323-334.
[19]. Abaci, K., & Yamacli, V. (2016). Differential search algorithm for solving multi-objective optimal power flow problem. *International Journal of Electrical Power & Energy Systems*, *79*, 1-10.
[20]. Dutta, S., Paul, S., & Roy, P. K. (2018). Optimal allocation of SVC and TCSC using quasi-oppositional chemical reaction optimization for solving multi-objective ORPD problem. *Journal of Electrical Systems and Information Technology*, *5*(1), 83-98.
[21].Bouchekara, H. R. E. H. (2014). Optimal power flow using black-hole-based optimization approach. *Applied Soft Computing*, *24*, 879-888.

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