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AN ADAPTIVE HYBRID OPTIMIZATION ALGORITHM FOR MULTI-OBJECTIVE SECURITY CONSTRAINED OPF WITH FACTS DEVICE

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ABSTRACT

This paper presents a Hybrid Particle Swarm Optimization with Differential Perturbed Velocity with adaptive acceleration coefficient (APSO-DV) to examine the security constrained Multi-objective Optimal Power Flow (OPF) control with a powerful Flexible Alternating Current Transmission Systems (FACTS) device such as Unified Power Flow Controller (UPFC) under normal and network contingencies. Firstly, contingency analysis and ranking is done by taking voltage magnitudes, voltage stability index (L-Index) and Fast Voltage Stability Index(FVSI) along with Line Loadings as input parameters to the fuzzy system where L-Index and FVSI are real numbers which gives fair and consistent results for stability analysis among different methods of voltage stability analysis. Secondly, the strategic location of UPFC and the optimal control settings of UPFC are found using APSO-DV under severe contingencies along with OPF constraints. The fuzzy based System Overall Severity Index (SOSI) and the combination of fuzzy based SOSI along with fuel cost were used as an objective to be minimized to improve the security of the power system. The feasibility of the proposed method has been tested on IEEE-30 bus system with two different objective functions. The test results show the effectiveness of robustness of the proposed approach and provides superior results compared with the existing results in the literature.

Keywords: SC-OPF, differential perturbed velocity, adaptive acceleration, **c**ontingency, fuzzy, UPFC, L-Index and MSV.

1. INTRODUCTION

In recent days the power system network is encountering very serious stressed conditions due to the ever increasing load demand, making its operation even more complex and less secure. Probably the better solution to meet the growing demand being either the effective utilization of the existing lines or the construction of new transmission lines. However the former is always the better solution when the economic and environmental feasibility is considered rationally [1-3]. FACTS controllers are the very effective means in improving the utilization of the existing transmission system.

The reduction in power flows of heavily loaded lines can be significantly achieved through the insertion of FACTS devices at optimal locations in the power system. Besides maintaining bus voltage magnitudes at their desired level apparently the improvisation of the overall stability and security of power network under normal/network contingencies can be accomplished. UPFC is a versatile FACTS device that can control the active, Reactive powers and the bus voltage magnitudes independently [4]. However it is very important to identify the optimal location of UPFC with appropriate control settings for the best utilization of its functionality. Researchers have tried to improve power system security and load ability by proper placement of FACTS controllers [5-6]. Different algorithms have been proposed for OPF with UPFC as well as optimal placement of UPFC. For the best instance: UPFC has been placed based on sensitivity based approach [7], An evolutionary programming based load flow algorithm for system containing UPFC [8], Arbkhaburi D, *et al.* [9] has been used genetic algorithm for Optimal placement of UPFC in Power system and Saravanan M, *et al.* [10] has been proposed an application of PSO technique for optimal location of FACTS devices considering system load ability and cost of installation.

Contingency screening and ranking is one of the important components of on-line system security assessment. It comprises of the quick and accurate short listing of critical contingencies from a large list of potential contingencies and rank them according to their severity. Several contingency selection methods can be found in [11-12]. Sudersan A [13] *et al.* developed a heuristic based genetic algorithms approach for the placement of FACTS devices to enhance the static security in power systems under contingency condition. Price KV [14-15] *et al.* has proposed a novel easy, simple, yet fast and robust evolutionary algorithm popularly known as Differential Evolution (DE). The application of PSO-DV and APSO-DV for optimal location of FACTS devices in general and UPFC in particular haven't been found recently in the open literature.

This paper proposes a PSO with differentially perturbed velocity equipped with adaptive acceleration co-efficient to resolve multi-objective OPF issues with UPFC under severe contingencies to improve the system security. The location of UPFC is identified by considering the voltage stability Index and Minimum Singular Value (MSV) of the system along with the objective function to be minimized. IEEE-30 bus system is considered to examine the effectiveness of the proposed method and the results obtained are remarkable.

A. L- Index

Consider a transmission network containing 'n' buses that include 'g' generator buses, 'n-g' load buses.

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For a given network operating condition, by using load-flow results, the Voltage-Stability Index is determined as:

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ji} \frac{v_i}{v_j} \right| \quad (1)$$

Where j = g +1... n. The F_{ji} values are determined from the system Y-bus matrix and are complex in nature.

$$\text{i.e. } F_{LG} = \left[Y_{LL}\right]^{-1}\left[Y_{LG}\right]^{-1} \quad (2)$$

Where, $[Y_{LG}]$ and $[Y_{LL}]$ are the sectionalized parts of Y-bus system matrix. For voltage stability analysis, at any load bus j the L_j value should not exceed the maximum limit of 1 [16].

B. Fast Voltage Stability Index (FVSI)

The development of a novel Fast Voltage Stability Index (FVSI) referred to a line which is capable in determining the point of voltage collapse, maximum permissible load and weak bus in the system and the most critical line in an inter-connected system. The FVSI was derived by considering a 2-bus power system model and is given by [17]:

$$FVSI_{ij} = \frac{4Z^2 Q_j}{V_i^2 X} \quad (3)$$

Where Z = line impedance, X = line reactance, Q_j = reactive power at the receiving end and V_i = sending end voltage

Any line in the system that exhibits FVSI closed to unity indicates that the line is approaching its stability limit hence may lead to system violation. Therefore, FVSI has to be maintained less than unity in order to maintain a stable system.

C. Power flow model of UPFC

UPFC, an advanced FACTS device, can provide instantaneous control of real and reactive power flows along with voltage magnitudes. Figure-1 depicts the UPFC equivalent circuit with power injection model equipped with a pair of coordinated voltage sources for the specific purpose of fundamental steady-state analysis [18]. The voltage sources of UPFC are:

$$V_{sh} = V_{sh}(cos\delta_{sh} + jsin\delta_{sh}) \quad (4)$$

$$V_{se} = V_{se}(cos\delta_{se} + jsin\delta_{se}) \quad (5)$$

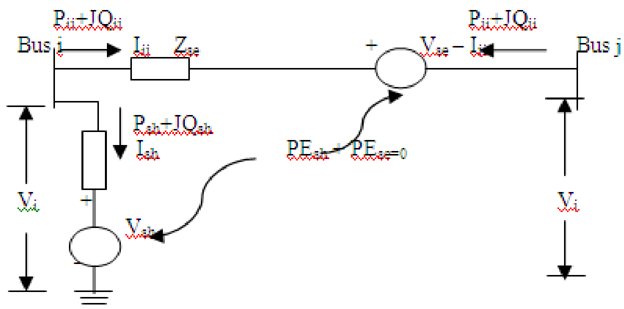

Figure-1. UPFC equivalent circuit.

Where,

V_{sh} = Voltage magnitude of shunt converter
δ_{sh} = Voltage angle of shunt converter
V_{se} = Voltage magnitude of series converter and
δ_{se} = Voltage angle of series converter.

Using the equivalent circuit and equations (4) and (5), the real and reactive power flow expressions are formulated as:

$$P_{sh} = V_i^2 g_{sh} - V_i V_{sh} \begin{pmatrix} g_{sh}\cos(\theta_i - \theta_{sh}) \\ +b_{sh}\sin(\theta_i - \theta_{sh}) \end{pmatrix} \quad (6)$$

$$Q_{sh} = -V_i^2 b_{sh} - V_i V_{sh} \begin{pmatrix} g_{sh}\sin(\theta_i - \theta_{sh}) \\ +b_{sh}\cos(\theta_i - \theta_{sh}) \end{pmatrix} \quad (7)$$

$$\begin{aligned} P_{ij} &= V_i^2 g_{ij} - V_i V_j \left(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij} \right) \\ &- V_i V_{se}\left(g_{ij}\cos(\theta_i - \theta_{se}) + b_{ij}\sin(\theta_i - \theta_{se}) \right) \end{aligned} \quad (8)$$

$$\begin{aligned} Q_{ij} &= -V_i^2 b_{ij} - V_i V_j \left(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij} \right) \\ &- V_i V_{se}\left(g_{ij}\sin(\theta_i - \theta_{se}) + b_{ij}\cos(\theta_i - \theta_{se}) \right) \end{aligned} \quad (9)$$

$$\begin{aligned} P_{ji} &= V_j^2 g_{ij} - V_i V_j \left(g_{ij}\cos\theta_{ji} + b_{ij}\sin\theta_{ji} \right) \\ &+ V_j V_{se}\left(g_{ij}\cos(\theta_j - \theta_{se}) + b_{ij}\sin(\theta_j - \theta_{se}) \right) \end{aligned} \quad (10)$$

$$\begin{aligned} Q_{ji} &= -V_j^2 b_{ij} - V_i V_j \left(g_{ij}\sin\theta_{ji} - b_{ij}\cos\theta_{ji} \right) \\ &+ V_j V_{se}\left(g_{ij}\sin(\theta_j - \theta_{se}) + b_{ij}\cos(\theta_j - \theta_{se}) \right) \end{aligned} \quad (11)$$

Where

$$g_{sh} + jb_{sh} = \frac{1}{z_{sh}},\ g_{ij} + jb_{ij} = \frac{1}{z_{se}} \text{ and}$$

$$\theta_{ij} = \theta_i - \theta_j,\ \theta_{ji} = \theta_j - \theta_i$$

2. CONTINGENCY RANKING

In this proposed Fuzzy approach L-indices of buses and FVSI of all lines are used as post contingent

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quantities in addition to line loadings and bus voltage magnitudes to evaluate contingency ranking. The Fuzzy rules are used to evaluate the severity of each post contingent quantity after getting the fuzzy sets of input and output parameters of Fuzzy Logic Controller (FLC) and they can be expressed as:

A. Bus voltages

The post contingent bus voltage magnitudes are divided into three categories using fuzzy-set notations: Low Voltage (LV), below 0.95 p.u.; Normal Voltage (NV), 0.95-1.05 p.u.; and Over Voltage (OV), above 1.05 p.u.

B. L-Index

The post contingent L-indices are divided into five categories using fuzzy set notation; Very Less Index (VLI),0-0.2; Less Index (LI), 0.2-0.4; Medium Index (MI), 0.4-0.6; High Index (HI), 0.6-0.8; and Very High Index (VHI) 0.8-1.0.

C. Line loadings

The post contingent line loading are divided into four divisions such as Lightly Loaded (LL), 0–50 %, Normally Loaded (NL), 50–85 %, Fully Loaded (FL), 85–100 %, and Over Loaded (OL), above 100 %.

D. FVSI

The post contingent FVSI values are divided into five categories using fuzzy set notation; Very Less Index (VLI), 0-0.2; Less Index (LI), 0.2-0.4; Medium Index (MI), 0.4-0.6; High Index (HI), 0.6-0.8; and Very High Index (VHI) 0.8-1.0. The fuzzy rules are used to evaluate severity index of post contingent quantities and are given in the following Table-1.

Table-1. Fuzzy rules.

Post contingent quantity	Severity index
Voltage: LV,NV,OV	MS,BS,MS
L-Index: VLI,LI,MI,HI,VHI	VLS,LS,BS,AS,MS
Line Loadings:LL,NL,FL,OL	LS,BS,AS,MS
FVSI: VLI,LI,MI,HI,VHI	VLS,LS,BS,AS,MS

VLS- Very Less Severe, LS- Less Severe, BS- Below Severe, AS - Above Severe and MS - Most Severe of the output variable.

After obtaining the Severity Indexes (SI) of Bus-Voltage magnitudes, L-Index, Line loadings and FVSI, the Overall-Siverity Indices (OSI) for a particular line outage are obtained as:

$$OSIVP = \sum W_{VP}\, SIVP \quad (12)$$

$$OSIVSI = \sum W_{VSI}\, SIVSI \quad (13)$$

$$OSILL = \sum W_{LL} SILL \quad (14)$$

$$OSIFVSI = \sum W_{FVSI}\, SIFVSI \quad (15)$$

Where, W_{VP}, W_{VSI}, W_{LL} and W_{FVSI} are weighting coefficients of severity indexes of voltage magnitudes, L-indices, Line loadings and FVSI respectively. SIVP, SIVSI, SILL and SIFVSI are the severity indices of post-contingent Voltages, L-indices, Line loadings and FVSI respectively. The SOSI can be obtained by adding all the four Overall severity indices as Shown in Figure-2 and it is given by:

$$SOSI = OSIVP + OSIVSI + OSILL + OSIFVSI \quad (16)$$

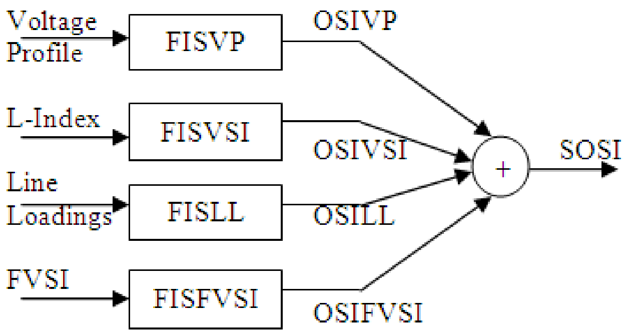

Figure-2. Parallel operated Fuzzy system.

3. PROBLEM FORMULATION

The OPF solution aims at optimizing a chosen objective function with the best possible tuning of system control variables satisfying the numerous specified inequality and equality constraints [19]. The OPF problem is formulated as:

$\min J(x, u)$
Subject to: $g(x, u) = 0$
$h_{min} \leq h(x, u) \leq h_{max}$

Where
J = Objective function to be minimized.
x = vector of depe ndent variables.
g = Equality constraints and
h = operating constraints
u = vector of control variables such as:

a) Voltage magnitude of generators V_G at PV buses.

b) Real power output of generator P_G at PV buses excluding at the slack bus P_{G1}.

c) Tap settings of Transformer T.

d) Shunt VAR compensators.

The UPFC is located to minimize the selected objective function and enhance the system stability and security while satisfying thermal limits and voltage constraints with the following two objective function:

VOL. 11, NO. 23, DECEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

F_1 =System Overall Severity Index (SOSI)
F_2 = w_1*SOSI+w_2*Total Fuel cost.
Where,
w_1 $=0.8$ and $w_2=0.2$ are the weighting factors

SOSI = OSIVP + OSIVSI + OSILL + OSIQ

$$\text{Fuel cost} = \left[\sum_{i=1}^{NG} \left(a_i P_{Gi}^2 + b_i P_{Gi} + c_i \right) \right] \tag{17}$$

Where,

NG = Number of generating units,
P_{Gi} = Generation of active power of i[th] generator, a_i,b_i and c_i are the i[th] generator cost coefficients.

The objective function '*f*' by imposing the constraints can be written as:

$$f = F + K_p \left(P_{G1} - P_{G1}^{lim}\right)^2 + K_v \left(\sum_{i=1}^{NL} (V_i - V_{lim})^2\right) + K_q \left(\sum_{i=1}^{N} \left(Q_{G,i} - Q_{G,i}^{lim}\right)^2\right)$$
$$+ K_s \left(\sum_{i=1}^{nl} abs\left(S_i - S_i^{lim}\right)^2\right) + K_l \left(\sum_{j=1}^{NL} \left(L_j - L_j^{lim}\right)^2\right) \tag{18}$$

K_p, K_v, K_q, K_s and K_l are the penalty factors.
NL = No. of PQ buses,
Nl = No. of transmission lines and
Y^{lim} = limiting values dependent variable given as:

$$Y^{lim} = \begin{cases} Y^{max}; & Y > Y^{max} \\ Y^{min}; & Y < Y^{min} \end{cases} \tag{19}$$

A. Equality constraints

These are the set of nonlinear load flow expressions that regulate the power systems, i.e.

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) = 0 \tag{20}$$

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin\left(\theta_{ij} - \delta_i + \delta_j\right) = 0 \tag{21}$$

Where, P_{Gi}, P_{Di} and Q_{Gi}, Q_{Di} are the real and reactive power generation and demands at bus-i respectively and the $|Y_{ij}|$ are the elements of bus admittance matrix.

B. Inequality constraints

The power network operational and security limits are represented as the set of inequality constraints, i.e.

a) Generators real and reactive power outputs.

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}, \text{ i=1, 2, 3,......,}N_G \tag{22}$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}, \text{ i=1, 2, 3,......,}N_G \tag{23}$$

b) Voltage magnitudes of each bus

$$V_i^{min} \le V_i \le V_i^{max}, \text{ i=1, 2, 3,........,}N \tag{24}$$

c) Tap settings of Transformer

$$T_i^{min} \le T_i \le T_i^{max}, \text{ i=1, 2, 3,........,}N_T \tag{25}$$

d) VAR injections by capacitor banks

$$Q_{Ci}^{min} \le Q_C \le Q_{Ci}^{max}, \quad \text{i=1,2,3,........,}C_S \tag{26}$$

e) Loading on Transmission lines

$$S_i \le S_i^{max}, \quad \text{i=1,2,..........,}N_L \tag{27}$$

f) Voltage stability index

$$L_{ji} \le L_{ji}^{max}, \text{i=1,2,.........,}N_{LD} \tag{28}$$

C. UPFC constraints

UPFC Series injected voltage limits:

$$V_{se\ min} \le V_{se} \le V_{se\ max} \tag{29}$$

$$\theta_{se\ min} \le \theta se \le \theta_{se\ max} \tag{30}$$

UPFC Shunt injected voltage limits:

$$V_{sh\ min} \le V_{sh} \le V_{sh\ max} \tag{31}$$

$$\theta_{shmin} \le \theta sh \le \theta_{sh\ max} \tag{32}$$

The above constraints are controlled using APSO-DV technique which is discussed in subsequent section.

4. HYBRID APSO-DV ALGORITHM

The chief objective of APSO-DV is to make use of the adaptive acceleration coefficient to update the position of the particle for PSO-DV in order to hasten the global solution search [20].The APSO-DV is discussed as follows:

Step I: Initialization:

The initial population generation is done randomly as given by:

$$Y_i^0 = Y_{i,\min} + rand().(Y_{i,\max} - Y_{i,\min}), i=1,...N_p \tag{33}$$

Where, rand () represents a random number distributed uniformly within the range of 0 to 1.This produces Np of individualsY_i^0, at random. The initialization involves the random generation of the control variables, generator voltages, real power generations, shunt reactive power injections, transformer taps, and the

VOL. 11, NO. 23, DECEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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velocity of control variables, each within its respective permissible limits.

Step II: Run the load flow and determine the degree of fitness of each individual.

Step III: Mutation Operation:

The mutation operator is introduced in the velocity updation scheme of PSO, wherein the selection of two particles is done at random, and then, the construction of mutation operator is undertaken as follows:

$$\overrightarrow{\delta_d} = \beta\left(\overrightarrow{Y_k} - \overrightarrow{Y_j}\right) \qquad i \neq j \neq k \tag{34}$$

Step IV: Crossover Operation:

It is a complimentary process. The perturbed individual of $\hat{Y}_i^{G+1}$ is produced from the present individual Y_i^G by combining differentially perturbed velocity to V_i^G to expand the diversity of additional individuals at subsequent generation. The velocity j of the i[th] individual of each parameter is regenerated from the perturbed individual velocity V_i^{G+1} and the current individual velocity V_i^G is given by:

$$V_{ij}^{G+1} = \begin{cases} \omega V_{ij}^G + \delta_d + C_2\varphi_2\left(P_{gj} - Y_{ij}^G\right), if rand(0,1) < CR \\ V_{ij}^G, \qquad Otherwise \end{cases} \tag{35}$$

Where J=1,…n; i=1,…Np and n=total no. of parameters.

The adaptive acceleration coefficient C_2 is given below:

$$C_2 = \left(C_{2f} - C_{2i}\right)\frac{gen}{gen\max} + C_{2i} \tag{36}$$

Where C_{2i} and C_{2f} are constants and the weighing factor is calculated as $\varpi = 1 - \frac{gen}{gen\max}$ (37)

Step V: Estimation and selection:

The fitness of the offspring is in competition with its parent. The replacement of parent by its offspring results when the latter is fitter than the former. On the other hand, the retention of the parent in the next generation is witnessed when the offspring is less fit than that of its parent. These two forms are presented as follows:

$$Y_i^{G+1} = \arg\max\left\{f\left(Y_i^G\right), f\left(Y_i^{G+1}\right)\right\} \tag{38}$$

$$Y_b^{G+1} = \arg\max\left\{f\left(Y_i^{G+1}\right)\right\} \tag{39}$$

Where, arg max refers to the argument of the maximum. The usage of arg max is justified because of the fitness function, f=1/OF, where OF is the objective function to be minimized.

Step VI: Repeat steps 2-5 till the maximum generation quantity is attained.

5. SIMULATION RESULTS AND DISCUSSIONS

The proposed method is tested on IEEE-30 bus system in MATLAB programming environment. The bus data and line data has taken from [21]. It has six generators interconnected with 41 transmission branches with a total load of 283.4 MWand126.2 MVAR. The shunt VAR compensators are provided at buses 10, 12, 15, 17, 20, 21, 23, 24 and 29. The contingency ranking is obtained using fuzzy approach and is given in Table-2.

Table-2. Fuzzy severity based contingency ranking.

Contingency	OSI VP	OSI VSI	OSI FVSI	OSI LL	SOSI	Rank
2-5	941.87	179.48	501.33	931.02	2553.71	1
10-20	911.04	159.92	446.12	946.89	2463.97	2
10-17	911.03	159.56	445.62	852.11	2368.33	3
27-30	911.04	158.91	531.33	729.54	2330.83	4
22-24	911.03	159.87	446.39	810.51	2327.81	5
23-24	911.03	158.99	444.93	810.52	2325.49	6
13-7	976.46	166.26	517.88	662.45	2323.06	7
9-10	911.04	157.91	446.15	806.19	2321.30	8
5-7	976.46	182.30	506.54	650.39	2315.71	9
10-22	911.038	159.86	445.92	752.43	2269.27	10

From the Table-2, contingency 2-5 has gained highest severity considered as rank-1 followed by 10-20, 10-17 and 27-30 etc according to the severity. The line between 10-21 is selected as most favorable location of UPFC after checking all possible locations in the vicinity of top-10 contingencies. The OPF results of the system with APSO-DVUPFC for 150 iterations with two objective functions are shown in Table-3 and Table-4 respectively.

Table-3. Comparison of results for objective function-1(F_1).

Parame Ter	LIMITS MIN	LIMITS MAX	APSO-DV Normal	APSO-DV Outage: 2-5	APSO-DV UPFC 10-21
P_{G1}	0.5	2.0	1.5106	1.3829	1.3707
P_{G2}	0.2	0.8	0.2393	0.3663	0.4123
P_{G5}	0.1	0.35	0.2827	0.2735	0.2021
P_{G8}	0.1	0.3	0.2009	0.2118	0.2507
P_{G11}	0.1	0.5	0.3693	0.4387	0.5000
P_{G13}	0.12	0.4	0.3088	0.2795	0.2001
V_{G1}	0.9	1.1	1.0021	0.9836	1.0503
V_{G2}	0.9	1.1	0.9809	0.9754	1.0336
V_{G5}	0.9	1.1	0.9736	0.963	0.9989
V_{G8}	0.9	1.1	0.9561	0.9498	1.0005
V_{G11}	0.9	1.1	0.9791	0.9593	1.0074
V_{G13}	0.9	1.1	1.0061	0.9862	1.0536
T_{11}	0.9	1.1	0.9975	1.0128	0.9496
T_{12}	0.9	1.1	1.0598	1.0501	1.0025
T_{15}	0.9	1.1	0.9369	0.9854	1.0214
T_{36}	0.9	1.1	0.9902	1.0344	1.0600
Q_{C10}	0.0	0.2	0.0591	0.1436	0.0694
Q_{C12}	0.0	0.2	0.0686	0.0000	0.0818
Q_{C15}	0.0	0.2	0.1443	0.1770	0.1459
Q_{C17}	0.0	0.2	0.0000	0.0000	0.0665
Q_{C20}	0.0	0.2	0.1091	0.1024	0.1178
Q_{C21}	0.0	0.2	0.0287	0.0740	0.0789
Q_{C23}	0.0	0.2	0.0676	0.0550	0.0977
Q_{C24}	0.0	0.2	0.0163	0.0803	0.1122
Q_{C29}	0.0	0.2	0.1393	0.1748	0.0838
F_1			1217.5	1469.5	1349.5
$P_{loss}\,(P.u)$			0.0776	0.1187	0.1019
L_j^{max}	0.0	0.5	0.1427	0.1582	0.1449
MSV			0.2180	0.1960	0.2158
V_{se}	0.0	0.2			0.0507
V_{sh}	0.9	1.1			0.9424

From the above Table-3, it is noticed that, SOSI in the proposed method is reduced from 1469.5 to 1349.5 with APSO-DVUPFC under contingency where as in normal condition 1217.5 with APSO-DV and the corresponding graphical representations are shown in Figure-3. It is also observed that, the L-Index value is reduced from 0.15825 to 0.1449 and the value of MSV is increased from 0.1960 to 0.2158 with APSO-DVUPFC which indicates enhanced voltage stability and security respectively and the corresponding power loss also reduced from 11.87MW to 10.19MW.

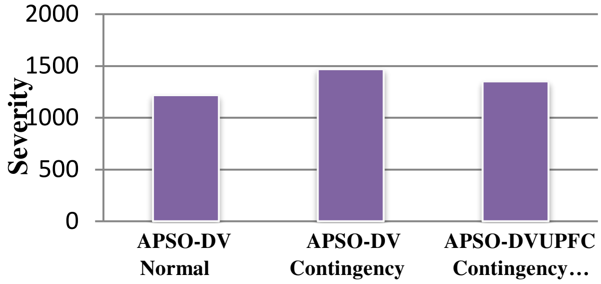

Figure-3. Comparison of fuel cost for different OPF methods.

Table-4. Comparison of results for objective function-2(f_2).

Parameter	LIMITS MIN	MAX	APSO-DV Normal	APSO-DV Outage: 2-5	APSO-DV UPFC 10-21
P_{G1}	0.5	2.0	1.5643	1.4806	1.5025
P_{G2}	0.2	0.8	0.5345	0.4924	0.4533
P_{G5}	0.1	0.35	0.3019	0.2907	0.2689
P_{G8}	0.1	0.3	0.1475	0.1517	0.167
P_{G11}	0.1	0.5	0.2272	0.3647	0.3652
P_{G13}	0.12	0.4	0.1394	0.1746	0.1947
V_{G1}	0.9	1.1	1.0500	1.05	1.073
V_{G2}	0.9	1.1	1.0388	1.0429	1.0627
V_{G5}	0.9	1.1	1.0209	1.0161	1.0284
V_{G8}	0.9	1.1	1.0141	0.9829	1.0041
V_{G11}	0.9	1.1	1.0116	0.957	0.9705
V_{G13}	0.9	1.1	1.0500	1.0183	1.0055
T_{11}	0.9	1.1	1.0166	1.0077	1.0021
T_{12}	0.9	1.1	0.9972	1.0652	1.0277
T_{15}	0.9	1.1	0.9796	0.9938	1.0362
T_{36}	0.9	1.1	0.9599	0.9869	1.042
Q_{C10}	0.0	0.2	0.1043	0.131	0.1668
Q_{C12}	0.0	0.2	0.0000	0	0.0863
Q_{C15}	0.0	0.2	0.2000	0.1616	0.129
Q_{C17}	0.0	0.2	0.0000	0	0.0662
Q_{C20}	0.0	0.2	0.0208	0.0484	0.0753
Q_{C21}	0.0	0.2	0.1161	0.0475	0.0748
Q_{C23}	0.0	0.2	0.0000	0	0.0729
Q_{C24}	0.0	0.2	0.0197	0.0861	0.0694
Q_{C29}	0.0	0.2	0.0255	0.053	0.0694
F_2			952.2310	983.475	974.9931
$P_{loss}\,(P.u)$			0.0809	0.1206	0.1176
L_j^{max}	0.0	0.5	0.1262	0.1312	0.1291
MSV			0.2395	0.2169	0.2279
V_{se}	0.0	0.2			0.0418
V_{sh}	0.9	1.1			0.9584

From the above Table-4, it is identified that, the multi-objective F_2 in the proposed method is reduced from 983.475 to 974.99 with APSO-DVUPFC under contingency where as in normal condition it is 952.23 with APSO-DV. It is also observed that, the L-Index value is reduced from 0.1312 to 0.1291 and the value of MSV is increased from 0.2169 to 0.2279 with APSO-DVUPFC which indicates enhanced voltage stability and security respectively and the power loss also reduced from 12.06MW to 11.76MW.

The severity status of all the buses and transmission lines for objective function-1 under top contingency 2-5 are given in Table-5. From the results it is evident that the proposed APSO-DVUPFC is very effective in improving the security of the system and the UPFC is very effective in maintaining all the buses, lines and reactive power generations under less and below severe conditions shown in Table-5.

Table-5. Comparison of fuel cost for IEEE-30 bus system.

Parameter	**Method/Condition of the system**	**Severity status**				
		LS	**BS**	**AS**	**MS**	
Line loadings	APSO-DV(Normal)	38	3	0	0	
	APSO-DV (Contingency)	30	9	1	0	
	APSO-DVUPFC (Contingency)	31	9	0	0	
Voltage magnitude	APSO-DV (Normal)	BS	AS	MS		
		24	0	0		
	APSO-DV (Contingency)	24	0	0		
	APSO-DVUPFC (Contingency)	24	0	0		
L-Index	APSO-DV (Normal)	VLS	LS	BS	AS	MS
		24	0	0	0	0
	APSO-DV (Contingency)	24	0	0	0	0
	APSO-DVUPFC (Contingency)	24	0	0	0	0
Reactive power	APSO-DV (Normal)	BS	AS	MS		
		6	0	0		
	APSO-DV (Contingency)	6	0	0		
	APSO-DVUPFC (Contingency)	6	0	0		

6. CONCLUSIONS

In this paper, enhancement of security has been formulated as multi-objective optimization problem and solved by using APSO-DV with UPFC equipped with two objective functions viz., Severity of the system and the combination of total fuel cost and severity of system under contingency condition. Fuzzy approach is used to find the contingency ranking which effectively eliminates the masking effect. L-index and FVSI are used to find the contingency ranking to have more effectiveness in finding the severity whereas, while minimizing the SOSI as an objective, instead of FVSI, reactive power generations are used which has more influence on generating cost. The MSV is used to assess the security of the power system. Simulation results show that APSO-DV with UPFC outperforms the original PSO-DV and APSO-DV algorithms under normal and network contingencies. The comparison of the results shows that the UPFC is very effective in increasing the security and stability limits of the network and reducing the power loss of the system and also kept the system under less stressed condition.

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