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Performance Study of the System with optimal location of SVC device using AHP method under different operating conditions

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ABSTRACT:FACTS devices can enable a line to carry its flow close to rating capacity and consequently can improve the power system security even in contingency and over loaded network. An opposition-based modified differential evolution algorithm is proposed to solve the OPF problem under different operating conditions for enhancement of power system performance with a SVC device. The best location of SVC device is determined based on AHP method. The effectiveness of the proposed method is demonstrated on IEEE 30-bus test system.
KEYWORDS:AHP method,Optimal power flow, OMDE algorithm, SVC

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I. INTRODUCTION

In recent years, there are emerging technologies available which can help to deal with problems of power system. One of such technologies is Static Var compensator (SVC) [1] device. To a large extent, proper allocation of SVC can make great enhancement to power system performance/voltage stability. Thus, the proper allocation of SVC device is based on AHP method which differentiates the optimal solution obtained by optimal method.

The analytic hierarchy process [2] is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. It has particular application in group decision making and is used around the world in a wide variety of decision situations in many fields.

Several population-based methods have been proposed for solving the OPF problem successfully in [3-14]. However, these algorithms present certain drawbacks like techniques rely on the initial condition and convexity to find the global optimum, complex operation, prematurity convergence or slow convergence speed in some problems. Therefore, an attempt to speed up DE is considered necessary. A novel algorithm to accelerate the modified differential evolution, influence of dimensionality, population size, jumping rate and various mutation strategies is opposition based MDE presented by ShahryarRahnamayan et al [15]. This paper introduces an opposition-based modified differential evolution (OMDE), a modification to DE that enhances the convergence rate without compromising with the solution quality and also proposes an approach based on AHP method for locating SVC device for solving OPF problem without and with SVC device under different operating conditions. The proposed approaches are illustrated through the IEEE 30-bus test system in presence of best location of SVC device.

II. SVC DEVICE

The SVC device consists of a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching. From the operational point of view, the SVC can be seen as a variable shunt reactance in which the shunt reactance is automatically adjusted in response to changing system operative conditions. In this way, the voltage of the bus in a transmission system, which the SVC is connected with, can be controlled [1].

III. FLCC SEVERITY INDEX OF POWER SYSTEMS

A set of multiple-antecedent fuzzy rules are established for determining the overall severity indices for line flow (OSILL), voltage profile (OSIVP), voltage stability index (OSIVSI) and reactive power outputs (OSIQG) the input to the rules (LL), (VP), (VSI),(QG) and the output consequent are (OSILL), (OSIVP), (OSIVSI) and (OSIQG) respectively. Having related the input variables to the output variable, the fuzzy results are defuzzified through what is called a defuzzification process, to achieve a crisp numerical value. The overall fuzzy logic composite criteria [16] based severity index for the pre/post contingency operating conditions is obtained using the parallel operated fuzzy inference systems [16].

IV. ANALYTIC HIERARCHY PROCESS METHOD

AHP [2] is a decision-making tool, which helps in finding goals or objectives among alternative. It is a systematic method for comparing a list of objectives and the alternative solutions satisfying respective objectives [2]. Some mathematical steps involved in AHP method are as

Step1: Selection and evaluation of attributes
Step2: Selection of alternatives
Step3: Formation of decision matrix
Step4: Construction of pairwise comparison matrix
Step5: Find the relative normalized weight
Step6: Calculate matrices A_3 and A_4
Step7: Determine the maximum Eigen value λ_{max}
Step8: Calculate the consistency index
Step9: Obtain the random index
Step10: Calculate the consistency ratio
Step11:Find overall performance score of the alternatives.

V. PROBLEM FORMULATION

The main goal of the OPF is to optimize a certain objective subject to several equality and inequality constraints. The problem can be mathematically modeled as follows:

OPF objective functions:

$$\mathrm{Minf}_1 = F(P_G) = \sum_{i=1}^{n_g}(a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad (1)$$

$$\mathrm{Minf}_2 = P_L = \sum_{i=1}^{N_i} g_k[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \quad (2)$$

$$\mathrm{Minf}_3 = \sum_{j=1}^{n_b} L_j^2 \quad (3)$$

$$\mathrm{Minf}_4 = VD = \sum_{i=1}^{n_b}(|V_i - 1|)^2 \quad (4)$$

Equality Constraints:

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n}|V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (5)$$

$$Q_{Gi} - Q_{Di} - \sum_{j=1}^{n}|V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (6)$$

Inequality Constraints**:**

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}, i = 1, \dots\dots, n_g \quad (7)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q^{max}, i = 1, \dots\dots, n_g \quad (8)$$

$$V_i^{min} \le V_i \le V_i^{max}, i = 1, \dots\dots, NL \quad (9)$$

$$T_i^{min} \le T_i \le T_i^{max}, i = 1, \dots\dots, nt \quad (10)$$

$$Q_{ci}^{min} \le Q_{ci} \le Q_{ci}^{max}, i = 1, \dots\dots, cs \quad (11)$$

$$S_i \le S_i^{max}, i = 1, \dots\dots, nl \quad (12)$$

$$L_j \le L_j^{max}, i = 1, \dots\dots, NL \quad (13)$$

$V_{VR}^{min} \le V_{VR} \le V_{VR}^{max}$ SVC voltage magnitude (14)

$\theta_{VR}^{min} \le \theta_{VR} \le \theta_{VR}^{max}$ SVC voltage angle (15)

VI. OVERVIEW OF OPPOSITION- BASED MODIFIED DIFFERENTIAL EVOLUTION

Opposition-based Modified Differential Evolution **(**ODE) [15] uses opposite numbers during population initialization and also for generating new populations during the evolutionary process. The original DE is chosen as a parent algorithm and the proposed opposition-based ideas are embedded in DE to accelerate its convergence speed.

Opposition-based population initialization:

- Initialize the population $P(Np)$randomly.
- Calculate opposite population by

$$OP_{i,j} = a_j + b_j - P_{i,j}, i = 1,2, \dots Np, j = 1,2, \dots D \quad (16)$$

where$P_{i,j}$and $OP_{i,j}$denote j[th] variable of the i[th] vector of the population and the opposite-population, respectively.

- Select the Np fittest individuals from $\{P \cup OP\}$as initial population.

Opposition-Based Generation Jumping:

Unlike opposition-based initialization, generation jumping calculates the opposite population dynamically.

$$OP_{i,j} = MIN_j^{\,p} + MAX_j^{\,p} - P_{i,j}, i = 1,2, \dots Np \quad (17)$$

Modified differential evolution algorithm

Best of random mutation:

Best of random mutation is applied here using:

$$V_{i,G} = X_{b,G} + F(X_{R1,G} - X_{R2,G}) \quad (18)$$

where $X_{b,,G}$, $X_{R1,G}$ and $X_{R2,G}$ are theindividualswhicharerandomlychosenfromthepop ulationat generation $G, 1 \le i \ne b \ne R1 \ne R2 \le NP$.

Randomized local search:

The proposed randomized local search is defined as follows:

$$x^*_{j,best,G} = 0.1.\left(x_{j,best,G}^{max} - x_{j,best,G}^{min}\right) \mathrm{Gauss}(0,1) + x_{j,best,G}, j \in [1, D] \quad (19)$$

$$x^*_{j,best,G} = 0.1.\left(x_j^{up} - x_j^{low}\right)\mathrm{Gauss}(0,1) + x_{j,best,G}, j \in [1, D] \quad (20)$$

Where $X_{best,G}$ is the best individual ingeneration G; $x_{j,best,G}$ is the j[th] variables of $X_{best,G}$.

VII. IMPLEMENTATION STEPS OF OMDE TO OPF

Step1:Parameter setup and declaration of constants
Step 2:Declaration of data
Step3:Initialize a set of random values of population NP as parent vector within permissible range using the equation

$$X_{G0} = \mathrm{rand}(0,1).\left(X_{Gi}^{max} - X_{Gi}^{min}\right) + X_{Gi}^{min} \quad (21)$$

$$X_{G0} = [P_{G0}, V_{G0}, T_{G0}, Q_{G0}]OX_0$$
$$= X_{min+}X_{max} - \quad X_{G0.}$$

Step 4: Run the NR load flow with parent vector
Step 5: The obtained initial individuals are used to determine each objective function individually.
Step6: Determine the fitness function
Step 7: Mutation
Step 8: Crossover
Step 9: Selection
Step 10: Update the vector limits of the variables.
Step11: Determine best and worst of each individuals.
Step12: Randomized local search

$$x^{*}_{j,best,G}{=}x_{j,best,G} + .1(x^{max}_{j,G-1}\text{-}x^{min}_{j,G-1}) \qquad (22)$$

Step 13: Apply Opposition-based generation jumping to X

$$OX_{i,j} \leftarrow MIN^{p}_{j} + MAX^{p}_{j} - X_{ij} \qquad (23)$$

and select NP fittest individuals from set the {X, OX} as current population X
Step 14: Run NR load flow method with this mutant vector.
Step 15:The obtained initial individuals are used to determine each objective function
Step16:Evaluate fitness function and select for parent vector the next generation.
Step 17:Otherwise worst individual act as a parent vector for the next generation.
Step 18:This process continues until best vectors are formed.
Step 19:The program terminates if the G value is greater than the Gmax value, else the program continues from step 5.

VIII. SIMULATION RESULTS

The proposed OMDE and AHP algorithms are applied on IEEE 30 bus System without and with SVC device under normal load operation, rank-1 network contingency and 10% overloaded conditions. The details of the system and optimal parameters used in OMDE algorithm for the simulation studies are summarized in Table 1.

TABLE 1

DESCRIPTION OF TEST SYSTEMS

Parameter	IEEE 30- Bus System	Optimal Parameter Setting For OMDE	IEEE 30- Bus System
No.of buses No.of Gene. No.of T/Fs No.of shunts No.of Br.	30 6 4 2 37	Population size No of iterations Cross over Prob. Mutation Prob. Zumping rate	50 250 0.8 0.2 0.3

IEEE 30- Bus System results

The adapted IEEE 30 bus System consists of six generating units interconnected with 41 branches of a transmission network with a total load of 283.4 MW and 126.2 MVAR. The objective functions taken into consideration are quadratic fuel cost of generation, total real power loss, sum of squared voltage stability index and voltage deviation. The considered three case studies for simulation are as follows:

Case I: Single-objective optimization without SVC device under different operating conditions

In this simulation study, minimization of different objectives under different operating conditions to obtain the best OPF solutions without SVC is carried out. Before solving the OPF problem, the line outage 8-11 has been ranked as rank-1 network contingency using FLCC severity index. The convergence characteristic of each objective for the best run under different conditions converges smoothly to the optimum value without any abrupt oscillations and is shown in Figures 1(A)-1(D) and values are in Table 2. These values are not negligible because of the continuous operations of power dispatch throughout the years. This shows the convergence reliability of the proposed algorithm compare to other literature methods which is shown in Table 3.

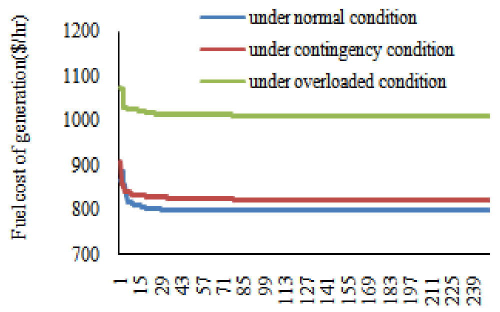

Figure 1(A). Convergence of fuel cost of generation without SVC under different operating condition

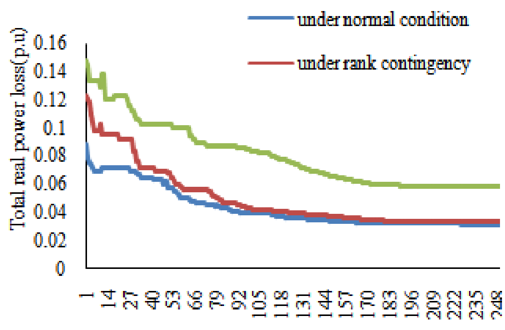

Figure 1(B). Convergence of total real power loss without SVC under different operating condition

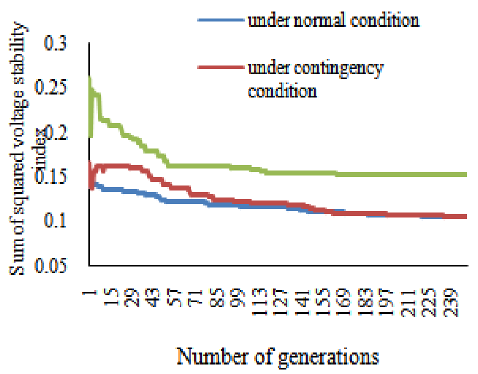

Figure 1(C). Convergence of voltage stability index without SVC under different operating condition

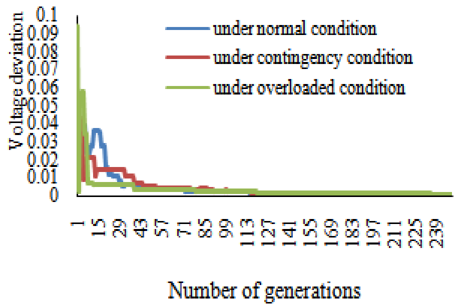

Figure 1(D). Convergence of voltage deviation without SVC under different operating condition

Case II: Single-objective optimization with SVC device at the selected locations under different operating conditions

The proposed OMDE algorithm is applied for solving the OPF problems subjected to different equality and inequality constraints with SVC device in the selected locations under three different operating conditions. The selected locations are the lines connected between buses 9, 10, 12, 14 and 16. Figures 2(A)-2(D) shows the convergence characteristics of different objectives with SVC located at different locations of optimal values under three operating conditions. Table 2 shows the OPF results with device location at selected buses with respect to different objective functions. This table also gives that maximum SVC candidate buses gives better values compare to optimization without device but SVC candidate bus 12 gives best minimum fuel cost 798.9362$/hr, SVC at bus 10gives best minimum power loss 0.0314p.u, SVC candidate bus 9 gives best minimum sum of squared voltage stability index 0.1019 and best minimum voltage deviation 0.0008 at buses 10, 12 and 14 under normal condition. From this it can be observed that at different operating conditions one or two alternatives gives best minimum value compared to SVC located in other alternatives. So in order to differentiate the optimal location for SVC device AHP method is applied.

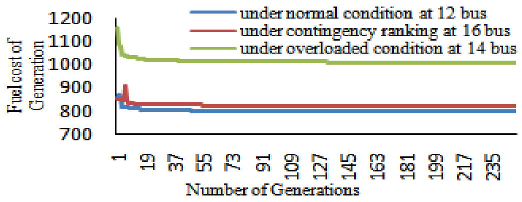

Figure 2(A) Convergence of fuel cost of generation of IEEE 30 bus system under different conditions

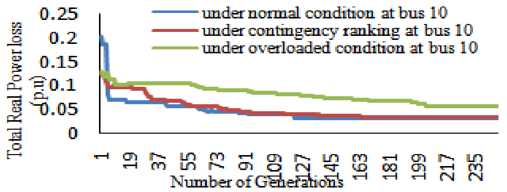

Figure 2(B) Convergence of total power loss of IEEE 30 bus system under different conditions

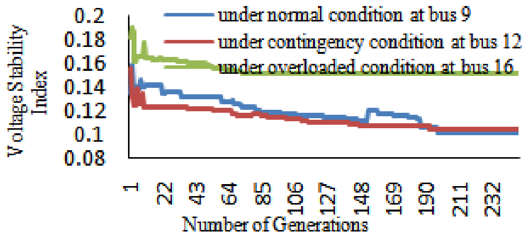

Figure 2(C) Convergence of voltage stability index of IEEE 30 bus system under different conditions

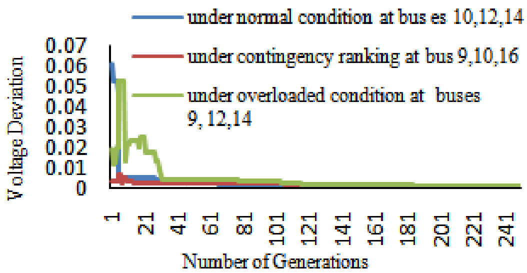

Figure 2(D) Convergence of voltage deviation of IEEE 30 bus system under different conditions

Case III:Application of AHP method for determination of optimal location of SVC under different operating conditions

In this case, AHP method is applied in order to differentiate the best alternative out of five considered alternatives. The OPF results with SVC device which is shown in Table 2 is used as decision matrix for the system and also given as an input to AHP method. This pairwise comparisons matrix given in Table 4 determines the preference of each attribute over another and the number of pairwise comparisons is 6 which are done according to scale introduced by Saaty. Table 5 is weight matrix of the attributes. Since it is normalized, the sum of all attributes in priority vector is 1 and Priority vector shows relative weights among the things that we compare. This shows that considered preference

matrix or pairwise comparisons is acceptable because the degree of consistency or Consistency ratio is 0.0580 which is smaller to 10% (given by saaty), where the consistency is acceptable. Random Consistency index (RCI) is 0.89 taken from Saaty.
Table 6 shows that relative ranking of alternatives under different operations by AHP method. From the Table 5 it is observed that under all operating conditions AHP method gives rank one for alternative 10. So it is considered as a best choice for the location of SVC device among the buses considered for the system and this gives highest benefits to the power system operation in terms of performance parameters. Figure 3(A)-3(D) shows the convergence characteristics of different objective function with SVC located at optimal bus 10 under three operating conditions.

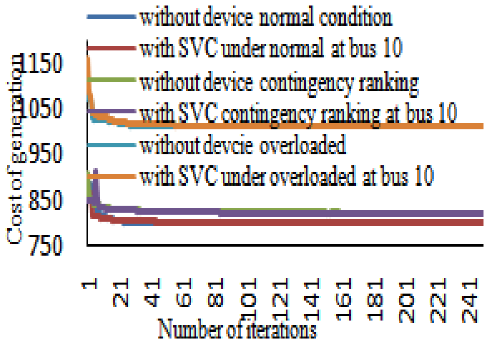

Figure 3(A) Convergence of fuel cost of generation of IEEE 30 bus system under different conditions

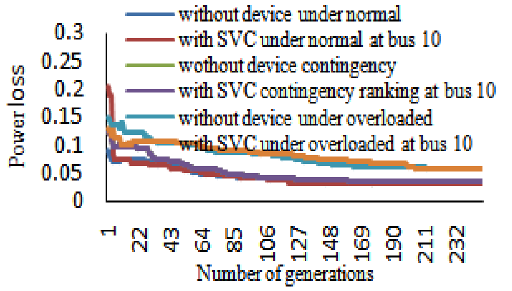

Figure 3(B) Convergence of total power loss of Indian Standard 82-bus system under different conditions

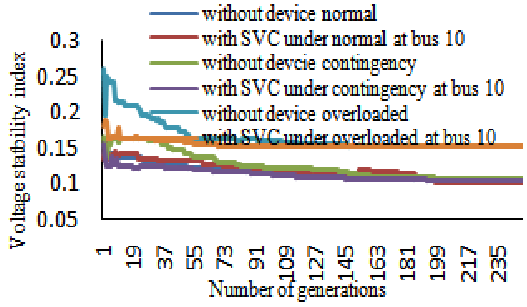

Figure 3(C) Convergence of voltage stability index of IEEE 30 bus system under different conditions

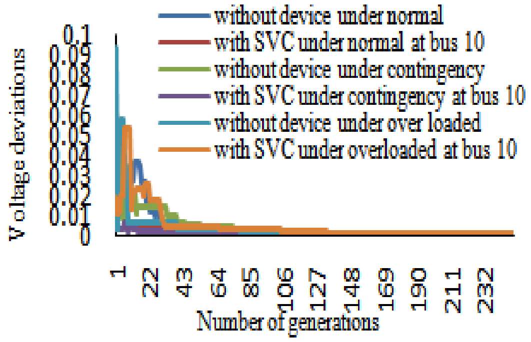

Figure 3(D) Convergence of voltage deviation of IEEE 30 bus system under different conditions

TABLE 2 OPF RESULTS AND DECISION TABLE FOR AHP METHOD

Alternatives	**Attributes**											
	Cost (\$/hr)			**Power Loss(p.u)**			**Voltage Stability Index**			**Voltage Deviation**		
	I	II	III	I	II	III	I	II	III	I	II	III
without	798.8986	822.6679	1,012.4	0.0316	0.0333	0.0588	0.1057	0.1059	0.1532	0.0008	0.0008	0.0010
9	799.5141	822.2569	1,011.21	0.0327	0.0375	0.0595	0.1019	0.1054	0.1546	0.0009	0.0008	0.0010
10	798.8775	822.3071	1,011.14	0.0314		0.0578	0.1035	0.1053	0.1531	0.0008	0.0008	0.0011
12	798.8362	822.7438	1,011.38	0.0354	0.0330	0.0686	0.1048	0.1048	0.1523	0.0008	0.0009	0.0010
14	798.6983	822.2931	1,011.10	0.0351	0.0354	0.0594		0.1060	0.1562	0.0008	0.0009	0.0010
16	798.7812	822.2409	1,011.29	0.0317		0.0581	0.1060	0.1053	0.1520	0.0009	0.0008	0.0011
					0.0384		0.1053					
					0.0392							

TABLE 3 BEST GENERATION COST/ POWER LOSS/ VSI/VD WITH DIFFERENT ALGORITHMS

Method	Cost($/h)	Method	Loss(MW)	Method	VSI	Method	VD
MATPOWER[3]	804.06	EGADQLF	3.2008	EGADQLF	0.10402	BBO [9]	0.15499
HS [5]	802.620	[4]	2.9678	[4]	0.10	FFA[11]	0.0918
IPSO [6]	799.035	HS [5]	5.0732	HS [5]	060	**OMDE**	0.0008
ACSA[7]	799.012	IPSO [6]	3.2250	IPSO [6]	0.10370		
VSC-OPF[8]	802.20	ACSA[7]	9.453	ACSA[7]	0.10950		
BBO[12]	799.1116	VSC-	5.6320	VSC-	0.2905		
PPSO[13]	800.64	OPF[8]	7.0733	OPF[8]	00.1246		
DE[14]	799.2891	BBO [9]	4.7106	DE[10]	0.10570		
OMDE	798.899	DE[10]	3.1600	**OMDE**			
		FFA[11]					
		OMDE					

TABLE 4
PAIR WISE COMPARISON MATRIX FOR ATTRIBUTES

Attributes	Attributes			
	Fuel Cost	**Power Loss**	**Voltage Stability Index**	**Voltage Deviation**
Fuel Cost	1	2	3	3
Power Loss	1/2	1	3	5
VSI	1/3	1/3	1	2
VD	1/3	1/5	1/2	1

TABLE 5
WEIGHT MATRIX AND VALUE OF ATTRIBUTES

Attributes	Weight-Age	Subjective Measure Of Attribute	Assigned Value
Fuel Cost	0.4266	Eigen value	4.1548
Power loss	0.3427	Consistency index	0.0516
VSI	0.1422	Consistency ratio	0.0580
VD	0.0885		

TABLE 6
RELATIVE RANKING OF ALTERNATIVES BY AHP METHOD

Alternatives	AHP Ranking		
	I	II	III
9	3	3	3
10	1	1	1
12	5	2	5
14	4	5	4
16	2	4	2

IX. CONCLUSIONS

This paper presented an OMDE algorithm and AHP method for optimal power flow solution without and with SVC device under different operating conditions for system performance enhancement. These proposed approaches have been successfully and effectively implemented to find the optimal settings of the control variables on the IEEE 30-bus test system. Thus, proposed algorithms give encouraging results for improving the operational conditions of the system.

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