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TRADEOFF CURVE OF AN ECONOMIC EMISSION LOAD DISPATCH USING NSGA-II and PVDE

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ABSTRACT

In this paper a new hybrid method is proposed for nonlinear constrained environmental economic load dispatch problem which is the combination of Non-dominated Sorting Genetic Algorithm (NSGA-II) and Population Variant Differential Evolution (PVDE) algorithm methods. The hybrid method is employed to evaluate the optimal solution for optimization problem which is incorporated with two contradictory objectives of minimizing cost and emission. To overcome the premature convergence in an optimization problem diversity preserving mechanism is employed with concept of elitism. Fuzzy set theory is employed to achieve the optimal solution from the tradeoff curve and tested for different systems. The hybrid method is applied for different cases and results are compared with the existing methods like MODE, MOPSO, FCPSO, SPEA-II, and NSGA-II.

Keywords: multiobjective function, cost function, economic load dispatch, trade off curve.

1. INTRODUCTION

Reaching the goal of load demand with the scheduling of committed generating units with minimum fuel cost satisfying equality and inequality constraints is the objective of economic load dispatch. With the incorporation of emission objective according to the clean air act amendments in 1990[1] many of the researchers concentrated on single objective economic load dispatch as a multiobjective function represents environmental economic load dispatch (EED). Emission objective enhanced the complexity of the optimization problem with many equality and inequality constraints. To achieve optimal solution for the nonlinear multiobjective optimization problem many methods such as classical methods, heuristic method, metaheuristic methods and hybrid methods are applied. Some of the conventional methods such as Linear Programming technique [2] considered as single objective optimization problem with lot of assumptions and doesn't provide the easy approach. With another approach [3] conversion of multiobjective function to mono objective function is implemented by using suitable weights and drawback associated with this method, it requires multiple runs to get the tradeoff curve. To overcome this difficulty ε constraint method was developed [4], considering other objective as a constraint with its limitation of ε levels, but this is a time consuming process with the production of weak nondominated solutions. Later a novel method fuzzy optimization technique [5] was applied but due to lack of composition in direct search towards the tradeoff curve and hence it was not preferred. A fuzzy satisfaction maximizing decision making [6] implemented satisfactorily but the extension of objectives has become a tedious process. A novel approach is introduced [7] which is a formidable and exhibiting untimely convergence characteristic.

Recent methods employing Evolutionary Algorithms (EA) for solving EELD problems eliminating the downside of the classical methods to obtain pareto set. These algorithms are based on the population which generates optimal solution on single run and has its own merits. Non-dominated Sorting Genetic Algorithm [8] is applied which exhibited the suboptimal solution of result and consuming more time for the evaluation. NSGA-II [9] exhibits elitism, ranking but fails in its uniformity of the tradeoff, and this can be overcome using dynamic crowding distance method and more MOEAs such as Strength Pareto Evolutionary Algorithm [10], Niched Pareto Genetic Algorithm [11], Multiobjective Particle Swarm Optimization [12], Multiobjective Differential Evolution [13]. In a MOEA a set of solutions are obtained, which utilizes the fuzzy set theory to achieve best solution.

Combining two or more algorithms is referred as hybridization which is a successful approach in solving environmental economic load dispatch. The main objective of hybrid method is to provide diversified pareto front. In this paper a hybrid method which uses with the combination of PVDE and NSGA-II is presented and in the initial stage half of the population is carried by NSGA-II where non-dominated sorting is implemented, dynamic crowding distance is evaluated for the generation of offspring's and remaining half of the population is refreshed based on the concept of interquartile range to eliminate immovable local optima using PVDE and corresponding offspring's is generated. This hybrid method is tested on IEEE 30 bus system with six generators with and without losses and IEEE 118 bus system with fourteen generators with and without valve point loading effect and standard forty generators system, with less number of iterations. The remaining paper is organised as follows: section 2 related to mathematical formulation of EELD, section 3 explains on multiobjective optimization, section 4 presents brief discussion on PVDE and hybrid method and section 5 results are presented for three test cases which shows better performance and compared to existing methods reported in the literature and section 6 presents the conclusion on hybrid method.

2. PROBLEM FORMULATION

The combined environmental and economic emission dispatch is formulated with two contradictory objectives of minimization of cost and emission with constraints. The cost function of every individual power generation plant is represented as quadratic function as given in Eqn. (1)

$$C = \sum_{k=1}^{n} F_k(P_{Gk}) \quad (1)$$

where

$$F_k(P_{Gk}) = (a_k + b_k P_{Gk} + c_k P_{Gk}^2) \quad (2)$$

$F_k(P_{Gk})$ is cost function of k^{th} generator cost function.
a_k, b_k, and c_k are referred the fuel cost coefficient of k^{th} generator.
'n'is the number of generating units.
P_{Gk} is generated power of k^{th} generator.

The emission level of all harmful toxic gases is represented as quadratic and exponential function as mentioned in Eqn. (3).

$$E(P_{Gk}) = \sum_{k=1}^{n}(\alpha_k + \beta_k P_{Gk} + \gamma_k P_{Gk}^2 + \exp(\lambda_k P_{Gk})) \quad (3)$$

where $E(P_{Gk})$ represents emission level of k^{th} unit.
α_k, β_k, γ_k, λ_k are the emission coefficient of k^{th} unit. The constraints of the problem are presented in the following subsections.

2.1 Power balance equations

The power balance equation is represented in Eqn. (4).

$$\sum_{k=1}^{n} P_{Gk} = P_D + P_{LOSS} \quad (4)$$

where the power losses are approximately calculated by using Eqn. (5).

$$P_{LOSS} = \sum_{k=1}^{n}\sum_{l=1}^{n} P_{Gk} B_{kl} P_{Gl} + \sum_{k=1}^{n} P_{Gk} B_{ok} + B_{oo} \quad (5)$$

where B_{kl}, B_{ok}, B_{00} are powerloss coefficients or B coefficients.

2.2 Power capacity limits

$$P_{Gkmin} \le P_{Gk} \le P_{Gkmax} \quad (6)$$

where P_{Gkmax} and P_{Gkmin} are the maximum and minimum values of power at the generator of k^{th} unit.

2.3 Valve point effect on cost function

With the incorporation of valve point loading effect in the problem of optimization is transformed into a non-convex problem with cost function including the ripple curve. The modified quadratic equation with this effect is written as follows:

$$F_k(P_{Gk}) = a_k + b_k P_{Gk} + c_k P_{Gk}^2 + |e_k(\sin(f_k(P_{Gkmin} - P_{Gk})))| \quad (7)$$

2.4 Mathematical Formulation

Mathematical formulation of multiobjective optimization problem with its objectives and constraints are represented as follows:

Minimize $[F(P_G), E(P_G)]$ (8)

Subjected to equality constraints: $g(P_G) = 0$ (9)

inequality constraints: $h(P_G) \le 0$ (10)

where F and E sets refers to the fuel cost and emission functions of generators, g represents the equality constraints of a power balance and h represents inequality constraints of a power capacity limits.

3. MULTIOBJECTIVE OPTIMIZATION

Optimization problems are many in the real time with several objectives which are contradictory in nature. An objective function with single objective function gets one optimal solution and in a multiobjective function, multiple solutions are obtained which is termed as Pareto optimal solutions. Multiobjective problem with objectives having equality and inequality constraints is formulated as follows:

$$\text{Minimize} \quad f_i(x); \quad i = 1,2,\ldots\ldots N_{obj} \quad (11)$$

$$\text{Subjected to} \begin{cases} g_j(x) = 0; & j = 1,2,\ldots\ldots..M \\ h_k(x) \le 0; & k = 1,2,\ldots\ldots K \end{cases} \quad (12)$$

where f_i states i^{th} objective function, x represents decision vector, N_{obj} presents number of objectives.
where g_j represents j^{th} equality constraint and h_k represents k^{th} inequality constraint and M & K are the number of equality and inequality constraints.

The multiobjective problems having any two solutions x_1 and x_2 can have two possibilities that are non-dominates conditions that have to be satisfied one by other or none if x_1 dominates x_2 then following:

$$\forall_i \in \{1,2,,\ldots\ldots.N_{obj}\}; \quad f_i(x_1) \le f_i(x_2) \quad (13)$$

$$\exists_j \in \{1,2,\ldots\ldots..N_{obj}\}; \quad f_j(x_1) < f_j(x_2) \quad (14)$$

if violation of any of the above condition exists, x_1 is the not dominated one of x_2 solution else if x_1 dominates it is termed as non-dominated solution with in the set $\{x_1, x_2\}$. In the entire exploration space, the number of non-dominated solutions forms a pareto optimal set. Evolutionary Algorithm is employed using MATLAB for obtaining the optimal solution.

4. EVOLUTIONARY ALGORITHMS

Evolutionary algorithms overcome the drawbacks associated with the classical methods. In the present work the hybrid method implemented so as to achieve efficient, good diversity and better convergence rate.

4.1 Population Variant Differential Evolutionary Algorithm

In PVDE [14] the initial population is refreshed using interquartile concept at the initial stage to make it an efficient algorithm. Scaling factor and crossover probability variation plays a vital role in production of offspring's.

Step1: The initial random population is generated using the equation as

$$\mathrm{Pop_{ij}} = \mathrm{P_{Gmin_j}} + \mathrm{rand} * \left(\mathrm{P_{Gmax_j}} - \mathrm{P_{Gmin_j}}\right) \tag{15}$$

$$i = 1,2, \ldots . N_{pop}; \quad j = 1,2, \ldots \ldots n$$

where

P_{Gmin_j}, P_{Gmax_j} are the minimum and maximum limits of the power generations and $rand$ is the random value ranges from [0,1]. N_{pop}, represents population size and n size of decision vector.

Step 2: A two row vector is initialized for crossover probability and scaling factor parameters in the range [0,1] and its minimum size is [1x3] vectors. Evaluation of maximum, minimum and median values for each parameter is

$$\mathrm{cp^{min}} = \min\left(\mathrm{t_{cp}}\right); \mathrm{cp^{max}} = \max(\mathrm{cp}); \mathrm{cp^{median}} = \mathrm{median(cp)} \tag{16}$$

$$\mathrm{sf^{min}} = \min(\mathrm{sf}); \mathrm{sf^{max}} = \max(\mathrm{sf}); \mathrm{sf^{median}} = \mathrm{median(sf)} \tag{17}$$

Step 3:

a) Initially vector difference $\mathrm{Var_{min}}$ is evaluated with generation limits and its difference is multiplied with 0.01.

b) Var is calculated using the concept of interquartile with each column of parent population.

c) if Var is less than $\mathrm{Var_{min}}$

$$\begin{aligned} \mathrm{Lower} &= \mathrm{parent_{median}} - \beta * \mathrm{Var} \\ \mathrm{Higher} &= \mathrm{parent_{meian}} + \beta * \mathrm{Var} \end{aligned} \tag{18}$$

Lower and Higher are the minimum and maximum generators limits after refreshment of population and population refreshment parameter is β.

d) With new limits Lower and Higher a new refreshment population is evaluated using step1.

Step 4:

a) Evaluate the fitness of the refreshed parent population to find the best one that gives the minimum fitness value, upgradation of scaling factor (sf) and crossover probability(cp) is done.

$$\mathrm{sf_j} = \begin{cases} \mathrm{sf_j^{max}} + \sqrt{\mathrm{rand} * \left(\mathrm{sf_j^{max}} - \mathrm{sf_j^{min}}\right) * \left(\mathrm{sf_j^{median}} - \mathrm{sf_j^{min}}\right)}, & \text{if } \dfrac{\left(\mathrm{sf_j^{median}} - \mathrm{sf_j^{min}}\right)}{\left(\mathrm{sf_j^{max}} - \mathrm{sf_j^{min}}\right)} > rand \\ \mathrm{sf_j^{max}} - \sqrt{(1 - \mathrm{rand}) * \left(\mathrm{sf_j^{max}} - \mathrm{sf_j^{min}}\right) * \left(\mathrm{sf_j^{median}} - \mathrm{sf_j^{min}}\right)}, & \text{otherwise} \end{cases} \tag{19}$$

$$\mathrm{cp_j} = \begin{cases} \mathrm{cp_j^{max}} + \sqrt{\mathrm{rand} * \left(\mathrm{cp_j^{max}} - \mathrm{cp_j^{min}}\right) * \left(\mathrm{cp_j^{median}} - \mathrm{cp_j^{min}}\right)}; & \text{if } \dfrac{\mathrm{cp_j^{median}} - \mathrm{cp_j^{min}}}{\mathrm{cp_j^{max}} - \mathrm{cp_j^{min}}} > rand \\ \mathrm{cp_j^{max}} - \sqrt{\mathrm{rand} * \left(\mathrm{cp_j^{max}} - \mathrm{cp_j^{min}}\right) * \left(\mathrm{cp_j^{median}} - \mathrm{cp_j^{min}}\right)}; & \end{cases} \tag{20}$$

b) Find the mutation with the corresponding equation

$$\mathrm{P^{mut}} = \mathrm{P^{best}} + \mathrm{sf_i} * (\mathrm{P^p} - \mathrm{P^q}); \begin{cases} \mathrm{i} = 1,2, \ldots \ldots \mathrm{N_{pop}} \\ \mathrm{p} \neq \mathrm{q} \neq \mathrm{best} \neq \mathrm{i} \end{cases} \tag{21}$$

c) crossover

$$\mathrm{child(k,l)} = \begin{cases} \mathrm{P^{best}(k,l)} + \mathrm{r} * (\mathrm{p^{mut}(k,l)} - \mathrm{P^{parent_{ref}}(k,l)}; & \mathrm{cp(k)} \geq 0.01 \\ \mathrm{p^{parent_{ref}}(k,l)}; & \mathrm{cp(k)} < \mathrm{rand(0,1)} \\ \mathrm{p_t^{mut}(k,l)}; & \mathrm{else} \end{cases} \tag{22}$$

$\mathrm{k}=1,2,3.....\mathrm{N_{pop}}$; $\mathrm{l}=1,2,3..\,.\mathrm{n}$

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d) Selection is made from the merge population of offspring and parent selection and upgradation of parameter is done.

4.2 Hybrid method

In the present work the combination of Non dominant Sorting Genetic Algorithm-II and Population Variant Differential Evolution algorithms are used as a hybrid method for the solving environmental economic load dispatch problem having two objectives of minimizing cost and emission. In PVDE [14] two objectives are converted into mono objective function using weighted sum method, but in this paper cost function and emission function is considered as two different objectives. In this paper the entire population is splited into two halves, the first half of the population is applied using NSGA-II method and second half of the population is applied using PVDE method, to achieve best optimal solution [15] which is applied on three test cases. The application of PVDE and NSGA-II for combined environmental economic load dispatch is as follows:

a) Initialize the number of objectives, decision variables, load demand, maximum number of iterations, cost coefficients, emission coefficients and power loss coefficients are to be specified.

b) Let $k=[k_1,k_2,k_3,k_4,k_5,.....]$ where k is the decision vector and each element corresponds to the output power of each generator.

c) Generate the random population using the Eqn. (15) such that it has to satisfy equality constraint in the Eqn. (4).

d) Using the Eqns. (2 & 3) evaluate the objective function of both F and E of cost and emission functions.

e) NSGA-II is applied for first part of initial population from the existing population initially identify the nondominated individuals of population. Predict the nondominated sorting [16] such that ranking selection method is implemented to highlight the ranking fronts.

f) For the application of crowding distance method, the sorted population of each objective function value is arranged in the increasing order.

g) Generation of half of the initial population of the offspring's done by performing the mutation and crossover [17].

h) Evaluate the objective functions E and F from the equation 2 and 3 for the next half of the population using PVDE. For this population refreshment is done by using the concept of interquartile.

i) Predicting the best population which gives minimum cost value and perform the crossover and mutation for the generation of offspring's.

j) Merge both the offspring's that will equalise to the population in number. Combine parent population and the offspring population that leads to twice the population.

k) Select the best individuals of population which exhibits the best nondominant one and place in repository. The next iteration is taken as new parent population and the process repeats until it reaches maximum generation.

Generally, the multiobjective combined environmental economic load dispatch solution leads to multiple optimal points in which best optimal is obtained by using fuzzy set theory.

4.3 Best optimal value

Fuzzy set theory is employed in achieving best solution from the pareto optimal set for the decision maker, decision maker decision is inaccurate in nature, k^{th} objective function of solution in pareto set F_k is indicated by a membership function μ_k is defined as

$$\mu_k = \begin{cases} 1, & F_k \le F_k^{min} \\ \frac{F_k^{max}-F_k}{F_k^{max}-F_k^{min}}, & F_k^{min} < F_k < F_k^{max} \\ 0, & F_k \ge F_k^{max} \end{cases} \tag{23}$$

F_k^{min} and F_k^{max} are the minimum and maximum values of the k^{th} objective function, nondominated solution i the normalized membership function μ^i is

$$\mu^i = \frac{\sum_{k=1}^{N_{obj}} \mu_k^i}{\sum_{j=1}^{M} \sum_{k=1}^{N_{obj}} \mu_k^j} \tag{24}$$

the nondominant solutions obtained in number is represented as M among this the best solution is having maximum value of μ^i, and according to the membership function the solution obtained is placed in reducing manner for the availability of decision maker and guide present operating conditions. The flow chart for implementing the above algorithm is given in fig. 7.

5. RESULTS AND DISCUSSIONS

This hybrid method is tested for the following three test cases. Case 1 IEEE 30 bus system with 6 generators with and without losses and Case 2 IEEE 118 bus system with 14 generators with and without valve point loading effect and Case 3 standard 40 generators system without losses. In all the cases cost and emission

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objective functions are considered as multiple objective in the optimization problem. MATLAB programe was developed on Intel i3 processor with 4GB RAM, operating system is WINDOWS 10.

Case 1: The solutions obtained using the proposed hybrid method and the other methods reported in the literature like SPEA-II, MODE, NSGA-II, MOPSO, FCPSO are presented. The cost and emission coefficients as well as maximum and minimum values of power generation is shown in Table-1[18]. The data is taken as follows for obtaining the results. The load demand is 2.834 p.u. (on 100 MVA base), population size 40, the maximum number of iterations is 100. The tradeoff curve for the environmental economic load dispatch without losses is shown in Figure-1 and with losses is shown in Figure-2. With this proposed method 600.127 ($/hr) minimum fuel cost is acheived for the emission of 0.2222(ton/hr) and the maximum fuel cost of 638.170($/hr) with the emission of 0.1942(ton/hr) shown in Table-2. The execution time taken without losses is 8.901sec and with the losses lowest cost value is 603.146($/hr) for the emission value of 0.2216(ton/hr) is shown in Table-3. The results obtained by other methods such as SPEA-II, MODE, NSGA-II, MOPSO, FCPSO are also presented for comparision. The losses are low compared with other methods and the time taken for the computation with losses is 9.389sec. This method exhibits robustness in achieving tradeoff curve and posses the high diveristy and convergence rate.

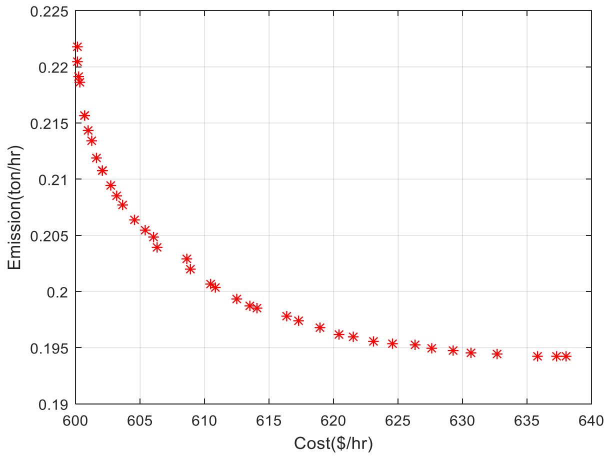

Figure-1. IEEE 30 bus system without losses.

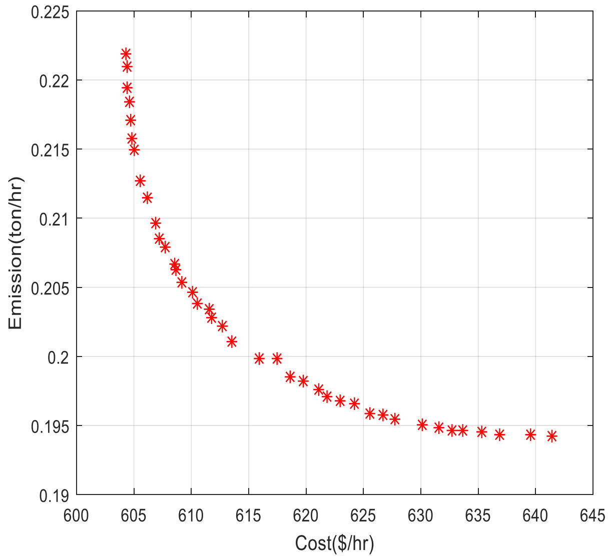

Figure-2. IEEE 30 bus system with losses.

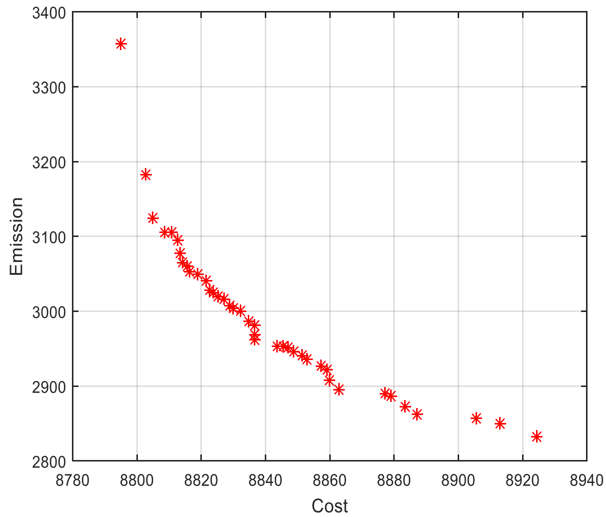

Figure-3. IEEE 118 bus system without valve point loading effect.

Table-1. IEEE 30 bus 6 generators system data.

Gen No	Fuel cost coefficients			Emission Coefficients					Generation Limits	
	a_i	b_i	c_i	α_i	β_i	γ_i	τ_i	ξ_i	Pmin	Pmax
1	10	200	100	4.091	-5.554	6.490	2.0e-4	2.857	0.05	0.5
2	10	150	120	2.543	-6.047	5.638	5.0e-4	3.333	0.05	0.6
3	20	180	40	4.258	-5.094	4.586	1.0e-6	8.000	0.05	1.0
4	10	100	60	5.326	-3.550	3.380	2.0e-3	2.000	0.05	1.2
5	20	180	40	4.258	-5.094	4.586	1.0e-6	8.000	0.05	1.0
6	10	150	100	6.131	-5.555	5.151	10e-5	6.667	0.05	0.6

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Table-2. IEEE 30 bus system without losses.

Method	PVDE+NSGA-II		SPEA2[21]		NSGA-II [21]		MODE		MOPSO		FCPSO [21]	
	cost	emission	cost	emission	cost	emission	cost	emission	cost	emission	cost	emission
PG1	0.1072	0.4134	0.1097	0.4060	0.1059	0.4074	0.1162	0.4151	0.1194	0.3979	0.1070	0.4097
PG2	0.3040	0.4488	0.2993	0.4589	0.3177	0.4577	0.2865	0.4604	0.3072	0.4258	0.2897	0.4550
PG3	0.5366	0.5353	0.5243	0.5378	0.5216	0.5389	0.5605	0.5409	0.4907	0.5268	0.5250	0.5363
PG4	1.0168	0.3877	1.0162	0.3834	1.0146	0.3837	1.0098	0.3808	1.0041	0.3984	1.0150	0.3842
PG5	0.5164	0.5334	0.5245	0.5378	0.5159	0.5352	0.5060	0.5298	0.5212	0.5336	0.5300	0.5348
PG6	0.3530	0.5154	0.3598	0.5101	0.3583	0.5111	0.3550	0.5070	0.3914	0.5515	0.3673	0.5140
Cost	600.127	638.170	600.109	638.264	600.155	638.249	600.2071	638.9388	600.2823	636.9045	600.132	638.358
Emission	0.2222	0.1942	0.2221	0.1942	0.22188	0.1942	0.2219	0.1942	0.2205	0.1944	0.2222	0.1942

Table-3. IEEE 30 bus system with losses.

Method	PVDE+NSGA-II		SPEA2[21]		NSGA-II [21]		MODE		MOPSO		FCPSO [21]	
	cost	emission	cost	emission	cost	emission	cost	emission	cost	emission	cost	emission
PG1	0.1172	0.4100	0.1189	0.4107	0.1132	0.4004	0.1318	0.4169	0.1145	0.3872	0.1130	0.4063
PG2	0.3023	0.4437	0.3085	0.4635	0.3130	0.4593	0.2925	0.4478	0.3240	0.4209	0.3145	0.4586
PG3	0.5253	0.5569	0.5200	0.5447	0.5370	0.5371	0.5287	0.5488	0.5086	0.5271	0.5826	0.5510
PG4	1.0167	0.3915	1.0081	0.3903	0.9904	0.4230	0.9934	0.3847	1.0525	0.4545	0.9860	0.4084
PG5	0.5194	0.5158	0.5286	0.5444	0.5404	0.5494	0.5362	0.5635	0.5488	0.5950	0.5264	0.5432
PG6	0.3667	0.5297	0.3742	0.5155	0.3788	0.5036	0.3786	0.4995	0.3191	0.4828	0.350	0.4974
Cost	603.146	641.006	605.548	646.190	608.837	643.447	606.276	644.1750	607.8919	637.6409	607.786	642.896
Emission	0.2216	0.1942	0.2208	0.1942	0.2198	0.1942	0.2197	0.1942	0.2247	0.1947	0.2201	0.1942
Losses		0.0136		0.0351		0.0388		0.0272		0.0335		0.0309

Case 2: This hybrid method is also implemented on IEEE 118 bus system with 14 generators with and without valve point loading effect. With the incorporation of valve point, the nonlinearity of the test system will be enhanced and hybrid method is a trust worthy in performance and convergence rate. The results with and without valve point loading effect are presented and compared with the results obtained from the other methods. Total Demand was 2000MW [19] with population of 40 and the crossover probability and mutation values are 0.85 and 0.166. The results without valve point effect is shown in Table 4 and with valve point loading effect is shown in Table 5. The corresponding pareto optimal solutions are shown in Figure-3 and Figure-4. The two cases are implemented without considering the losses. For a minimum emission of 2832.7952(ton/hr) the cost value is 8924.4355($/hr) is obtained having the execution time of 9.594sec in case of without valve point and with valve loading point minimum emission 2826.2027(ton/hr) and related cost value is 8971.8996($/hr) with execution time of 9.719sec. The comparison of the results obtained by this method and other methods are presented in Table 4 and Table 5.

Case 3: The proposed method is applied on the standard 40 generators system and the results are shown in the Table 6. The corresponding pareto graph is shown in Figure-5 indicating the best compromise solution. The total demand was 10500MW[20] with the population of 40 exhibited with 100 iterations and the tradeoff curve is obtained for the trails of 30 times and for the minimum emission value 127474.1855 (ton/hr) the achieved cost value 125258.6087($/hr) and the time taken for the execution of the matlab program is 16.269sec. Transmission losses are not considered in the analyzation process of achieving the tradeoff curve. As the load enhances and with increase in the number of buses the execution time is increased which is observed from the above test cases. In all the three test cases the population parameter is considered as a constant because variation in the population affects the optimal solution [14]. The robustness and efficiency of this hybrid method is accomplished over trails of 30.

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Table-4. IEEE 118 bus system without valve point loading effect.

Method	PVDE+NSGA-II		SPEA2		MODE		MOPSO		FCPSO	
	cost	emission	cost	emission	cost	emission	cost	emission	cost	emission
PG1	246.202330	218.833070	296.3509	246.8471	153.5750	168.8941	324.7054	239.6029	216.4557	286.376
PG2	224.980685	160.073592	241.7726	150.4743	265.0155	172.3666	276.4297	163.9795	150.0000	190.3236
PG3	128	130	129.9890	129.8961	130	130	130	130	128.0957	129.8318
PG4	128	130	129.9089	129.8309	130	130	128.8885	130	128.6252	130
PG5	191.059073	180.172667	185.9583	185.5165	207.6958	189.1446	150	150	167.1691	214.5001
PG6	183.911788	195.470035	153.1214	209.2804	183.2105	227.9459	135	233.1789	246.1363	184.9357
PG7	156.138115	189.274275	135.5672	165.1871	168.3606	175.3394	135	175.0504	192.4926	136.8049
PG8	129.213014	174.176361	105.7464	163.6128	140.1426	184.3094	136.3490	156.1880	169.1117	127.7989
PG9	161	162	161.9681	161.6514	162	162	162	162	161.7869	162
PG10	159	160	159.9998	159.9815	160	160	160	160	159.9508	159.9885
PG11	79	80	79.9868	79.9412	80	80	80	80	80.0000	80
PG12	79	80	79.9989	79.9355	80	80	80	80	79.5883	79.9255
PG13	80.494995	85	84.9480	84.9999	85	85	46.6272	85	84.0850	83.0693
PG14	54	55	54.6837	52.8453	55	55	55	55	36.5027	34.4457
Cost	8795.022698	8924.435504	8743.1324	8893.0161	8889.1259	8986.5415	8780.4490	8912.0763	8797.1	8997.1
emission	3357.146571	2832.795231	3709.5100	2859.0759	3638.3866	2864.2789	4272.1903	2855.2959	3349.9	2840.6

Table-5. IEEE 118 bus system with valve point loading effect.

Method	PVDE+NSGA-II		SPEA2		NSGA-II		MOPSO	
	cost	emission	cost	emission	cost	emission	cost	emission
PG1	260.068245	226.690350	329.7295	236.8771	240.0744627	219.0736953	325.8810125	241.12950
PG2	201.475105	159.410190	150.0293	150.0267	302.1989162	150.6923233	150	150
PG3	130	130	95.3337	129.1020	95.45584417	124.9328568	130	130
PG4	130	130	121.6660	127.7472	69.40934829	128.162376	130	130
PG5	190.786468	165.101551	250.0010	150.6224	247.4409679	153.9634802	202.8506499	178.9299
PG6	192.638942	240.843922	182.3107	283.9287	236.9518621	284.5399178	194.7000195	222.3214
PG7	147.727093	193.172257	184.7832	184.8378	185.3721777	187.2257978	135	179.9619
PG8	144.193736	155.083590	158.0345	153.9764	160.0652935	160.9197992	109.6862982	145.6571
PG9	151.276372	139.698137	123.2748	126.1220	76.80905607	156.0239136	162	162
PG10	153.132855	160	155.5005	159.6728	137.061836	155.842515	160	160
PG11	78.701174	80	60.4520	79.7902	60.57466401	68.81129742	79.9998252	80
PG12	80	80	71.0185	79.6400	63.67633379	77.84660684	80	80
PG13	85	85	62.9139	82.6571	71.51900455	79.1796138	84.8821944	85
PG14	55	55	54.9524	54.9995	53.39023292	52.78580703	55	55
Cost	8816.924643	8971.899603	9342.9384	9853.5973	9415.714478	10133.17467	9701.492335	8908.9372
Emission	3191.561593	2826.202762	3605.6451	2850.1017	4799.83267	2850.457813	3255.166772	2827.1320

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Table-6. Forty generators system without losses.

Generators	Max emission Mini cost	Mini Emission Max Cost	Generators	Max emission Mini cost	Mini Emission Max Cost
PG1	106.898624279498	107.175376568093	PG22	451.603002587995	438.277524044442
PG2	109.373879812466	110.873207558968	PG23	539.538529205645	540.538529205645
PG3	110.688463679995	110.688463679995	PG24	444.973486778514	445.973486778514
PG4	180.210735156562	184.039672896009	PG25	455.88597314243	456.88597314243
PG5	96.2554528228673	96.292395881109	PG26	428.494652007507	421.115517500101
PG6	137.709937654407	136.745312725745	PG27	20.8982282906621	21.8982282906621
PG7	267.468905230082	263.119075951983	PG28	37.8993813500852	38.8993813500852
PG8	266.771374594599	266.796031921588	PG29	53.50153925784	39.1240487338631
PG9	291.804393063947	284.152948003546	PG30	89.3705908395719	90.3705908395719
PG10	279.153832313169	252.703060933193	PG31	159.109486087611	160.109486087611
PG11	266.101928672759	278.830547266526	PG32	187.710894317563	178.057070901572
PG12	303.018930757191	294.372002950698	PG33	160.276934148609	161.276934148609
PG13	351.357731134222	390.207525672491	PG34	174.784525630281	175.784525630281
PG14	411.660404657108	421.174479588935	PG35	197.265317225968	198.265317225968
PG15	349.547762352275	350.547762352275	PG36	191.014532030534	194.383827773909
PG16	423.38730770749	435.08053456119	PG37	96.8461843919123	97.8461843919123
PG17	442.887727338665	441.476082232614	PG38	97.2259601253875	99.0044090417807
PG18	457.683464315996	450.39739561124	PG39	93.7884132708423	95.2802442935096
PG19	423.87312266183	424.87312266183	PG40	431.742161436149	432.074850167281
PG20	461.661809401457	462.661809401457	Cost	125600.92753237	125258.608795979
PG21	450.554420268307	452.627062032763	emission	129237.858409632	127474.185577607

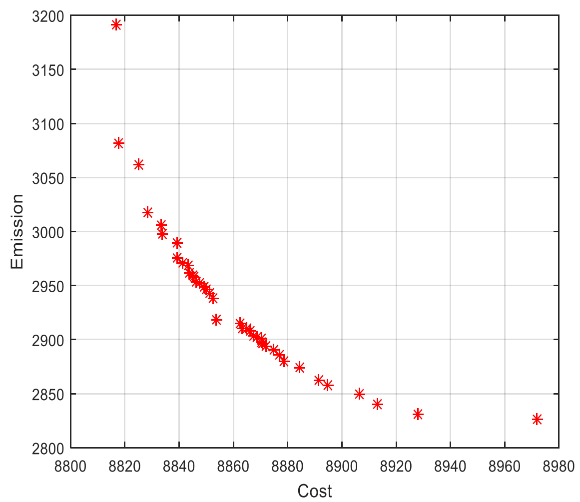

Figure-4. IEEE 118 bus system with valve point loading effect

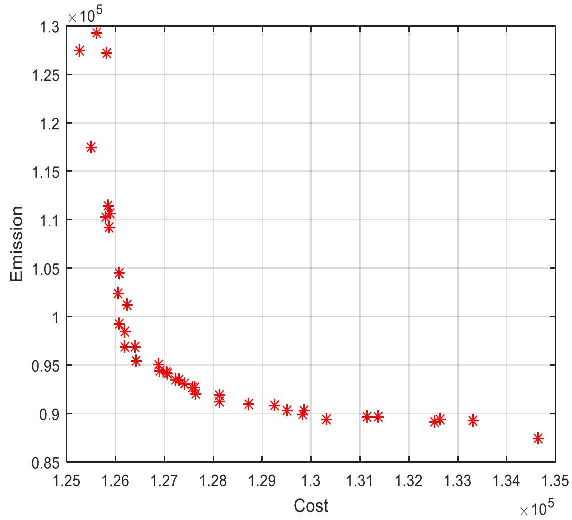

Figure-5. 40 generators system without losses.

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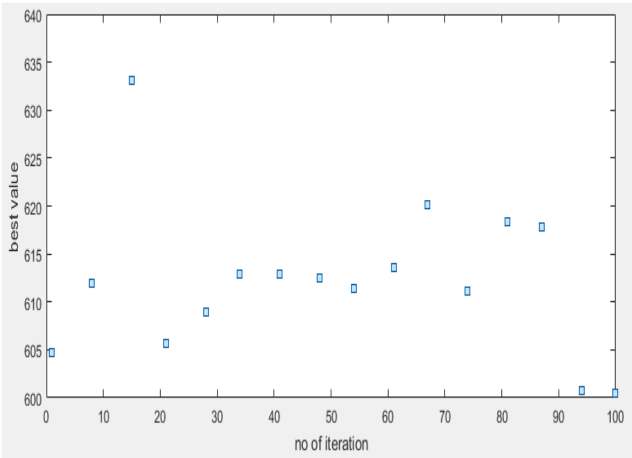

Figure-6. Best value with number of iterations.

From figure-6 it is predicted that the best value of the cost function over iteration 100 reaches the minimum cost value which is used for mutation and crossover evaluation in PVDE.

The flow chart shown in Figure-7 represents the steps in implementing the hybrid method. Initially non-dominant sorting genetic algorithm -II is applied followed by Population Variant Differential Evolution algorithm in both the methods non-dominant sorting is applied for the generation of offspring's and in this stream elitism concept is employed to make the best one in the repository which enhances the convergence rate. The selection process is ordered by the crowding distance operator for improving the uniform spread over trade off curve.

In NSGA-II simulated binary crossover and polynomial mutation is carried over for the generation of corresponding offspring's and in the later method PVDE best value which produces a minimum fitness is predicted from the refreshed population which is used in the calculations of mutation and crossover to obtain the trust worthy results.

6. CONCLUSIONS

The multiple objective environmental economic load dispatch optimization problem has been solved with many heuristic and novel methods. In this paper two conflicting objectives are simultaneously considered and the combination of NSGA-II and PVDE is highlighted as a hybrid approach is employed for the solution. PVDE plays better enrolment in enforcing of part of the parent population and NSGA-II with its dynamic crowding distance generates the good offspring's. It is tested on IEEE 30 bus system with 6 generators, IEEE 118 bus system with 14 generators and with standard 40 generators system. The results obtained by this method are compared with existing methods. In all the three test cases population parameter and maximum number of iterations remain same in achieving the pareto optimal set. Many number of trials of about 30 were implemented for all compared methods like SPEA-II, MOPSO, MODE achieving the optimal solutions. The proposed hybrid method achieves a best optimal solution with good convergence in comparison with other methods.

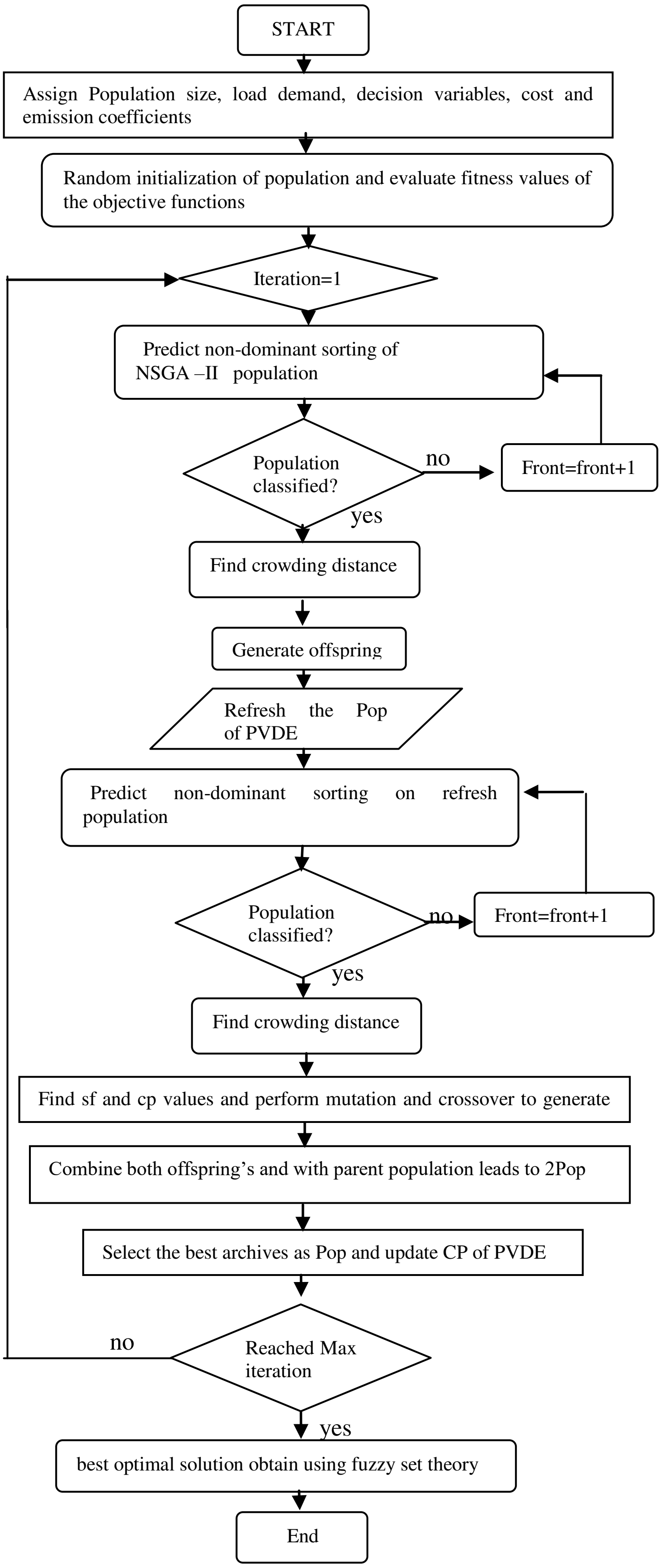

Figure-7. Flow chart of PVDE+NSGA-II

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