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Economic Dispatch and Interruptible Load Management with Renewable Energy using Particle Swarm Optimization

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***Abstract* - Electrical Power systems are designed to meet the continuous variation of power demand. The objective of modern electric power utility system is to deliver reliable power to the customer at low cost without violating the operational constraints. This formulates the Economic Load Dispatch (ELD) problem. So Economic dispatch & Interruptible Load Management is formulated by using Particle Swarm Optimization (PSO). Integrating wind energy into bulk power system will leads to operational challenges like non-dispatch ability and variability. By considering the wind power along with Economic Load Dispatch and Interruptible Load Management is investigated by PSO. In this paper, six unit systems are considered and the conventional method like Lambda-Iteration is compared with PSO method with cost. IEEE 30 bus system is used for checking the effectiveness. At the end, the costs of both methods are compared to examine the best one among them.**

Keywords: Economic Dispatch, Integrating wind Energy, Interruptible Load Management, Lambda-Iteration, Particle Swarm Optimization.

I. INTRODUCTION

In spite of rely only on conventional energies like fossil fuel & Nuclear energy generation; make use of Renewable or Natural energy sources like solar, wind, bio-mass & geo-thermal. In order to meet the Renewable Portfolio Standard (RPS) increased production of energy from renewable sources, particularly integrating wind into bulk power system [1]. The difficulties in integrating the wind energy into bulk power system poses challenges to power system operators & planners arise from its limited predictability and high inter-temporal variation [2]. Need for non-conventional source of power generation increases. Because of increasing demand of electricity, integrating wind energy into power system also reduces the environmental impacts. 3 methods are considered to integrate into generation technology mix optimal model [3].The method to identify the suitable level of spinning & non-spinning reserves and their cost in a power system with high level of wind power [4]. The stochastic approach with wind generation has manyadvantages over deterministic approach [5].PSO method can be used to solve valve point loading using secant method [6]. The amount of fossil fuels available in this world is decreasing day-by-day.. Increasing the demand of electricity would improve the operation of markets. The consumers of electricity can also take part in provision of power system security [7]. The generation of synthetic wind speed and wind power in Markov-chain model used to develop a stochastic forecasting method that provides a approximate values of future wind power generation during short period [8]. In [9] Markov chain Monte-Carlo method for the direct generation of synthetic time series of wind power output. The impacts of the interruptible load to the peak demand reduction and change of daily load curve for industrial customers were analysed [10].

In this paper, I proposed PSO technique for solving Economic Dispatch problem during different types of interruptible load management with renewable energy source like Wind Energy. Two cases are considered namely six unit systems with wind energy and six unit systems without wind energy. Finally, these results are compared with Lambda-Iteration method. On the whole, it is found that PSO is superior & can be used for various constraints in economic load dispatch problems.

II. ECONOMIC DISPATCH

In this section, Economic dispatch problem is investigated by using both interruptible load and forecasting the distribution of wind generation. Particularly using the forecast model of Markov chain, the economic dispatch issue is considered as a optimization problem (p_1).

Economic dispatch (p_1) reduces the operation cost of system including the generation cost ($(C_g^G(P_g^t))$), interruptible load cost ($(C_b^I(P_b^t))$) & Interruptible wind generation cost ($(E(C_w^W(P_w^t)))$) that are taken for consideration, so that anticipated expanses of utilizing reserves to compromise for errors of prediction, when the prediction is more than real wind power production.

$$P_1 : \text{Min} \sum_{g\in G} (C_g^G(P_g^t)) + \sum_{b\in B} (C_b^I(P_b^t)) + \sum_{w\in W} (E(C_w^W(P_w^t))) \quad (1)$$

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$$\sum_{g\in G_b} P_g^t + \sum_{w\in W_b} P_w^t - D_b^t + P_b^t = \sum_{b'\in B} P_{bb'} \quad (2)$$

$$P_g^{min} \leq P_g^t \leq P_g^{max} \quad (3)$$

$$P_w^{min} \leq P_w^t \leq P_w^{max} \quad (4)$$

Where,

$C_g^G(.)$	Generation cost function of generator g
$C_w^W(.)$	Cost function of integrating the wind generation of wind farm w
P_b^t	Scheduled interruptible load at bus b at time t
P_g^t	Scheduled output power of generator g at time t
P_w^t	Power generation from wind farm w at time t
C_b^I	Cost of interruptible load at bus b
D_b^t	Load at bus b at time t
P_g^{max}	Maximum output power of generator g
P_g^{min}	Minimum output power of generator g
$P_{bb'}$	Branch power flow
P_w^{max}	Wind farm maximum power generation
P_w^{min}	Wind farm minimum power generation

III. PARTICAL SWARM OPTIMIZATION

The PSO algorithm was developed by Kennedy and Eberthart in 1995. It is based on the behaviour of a colony or swarm of insects, a flock of birds or a school of fish. This applies to the concept of behaviour of social organism to problem solving. The word particle denotes, a bee in a colony. Each particle behaves in a distributed way using its own intelligence & group of intelligence of swarm. If one particle finds good path to food, the remaining swarm will also be able to follow that path, even if their location is far from the distance.

In Multivariable Optimization, the swarm is assumed to be fixed size. Initially each particle is located at random locations in the designed space. Each particle will have two characteristics: a position and a velocity. Each particle moves in a leisurely way in the designed space and remembers the best position i.e maximum of objective function, it has discovered. The particle communicates information or good position to each other and relocates their individual positions & velocities based on the information received from good position.

The PSO is developed based on the following model:

1. When one bird discovers a target or food i.e, maximum of objective function, it automatically transmits the information to other birds also.
2. All other birds tends to migrate to the target or food i.e maximum of objective function.
3. Each bird's will have their own independent thinking as well as past memory.

A. Steps involved in Particle Swarm Optimization

1. Initialize original position and velocity of particles.
2. Find the fitness value of each particle.
3. For each particle, compare the fitness value with fitness value of P_{best}, if current value is better, then renew the position with current position and fitness value is to be updated.
4. Determine the best particle of group with the best fitness value, if the fitness value is better than the fitness value of gbest and gbest is to be updated.
5. Check the final criteria, if it has been satisfied, stop the iteration otherwise go to step 2. The flow chart of PSO is as shown in figure 1.

The Velocity and position of each particle is to be updated according to the best position of any particleby using the formula

$$\mathbf{V}_j(i) = \theta\, \mathbf{V}_{(j)}(i-1) + c_1 r_1[\mathbf{P}_{best},(j) - \mathbf{X}_j(i-1)] + {}_2r_2[\mathbf{G}_{best} - \mathbf{X}_j(i-1)] \quad (5)$$

$$\theta_{(i)} = \theta(max) - \{(\theta(max) - \theta(min)) / i(max))\} i \quad (6)$$

Where, c_1 is individual learning rates,c_2 group learning rate. Rating of c_1& $c_2$are normally taken as 2. r_1 and r_2 value lies between 0 to 1. θ is the inertia term &the value ranges from 0.9 to 0.4.

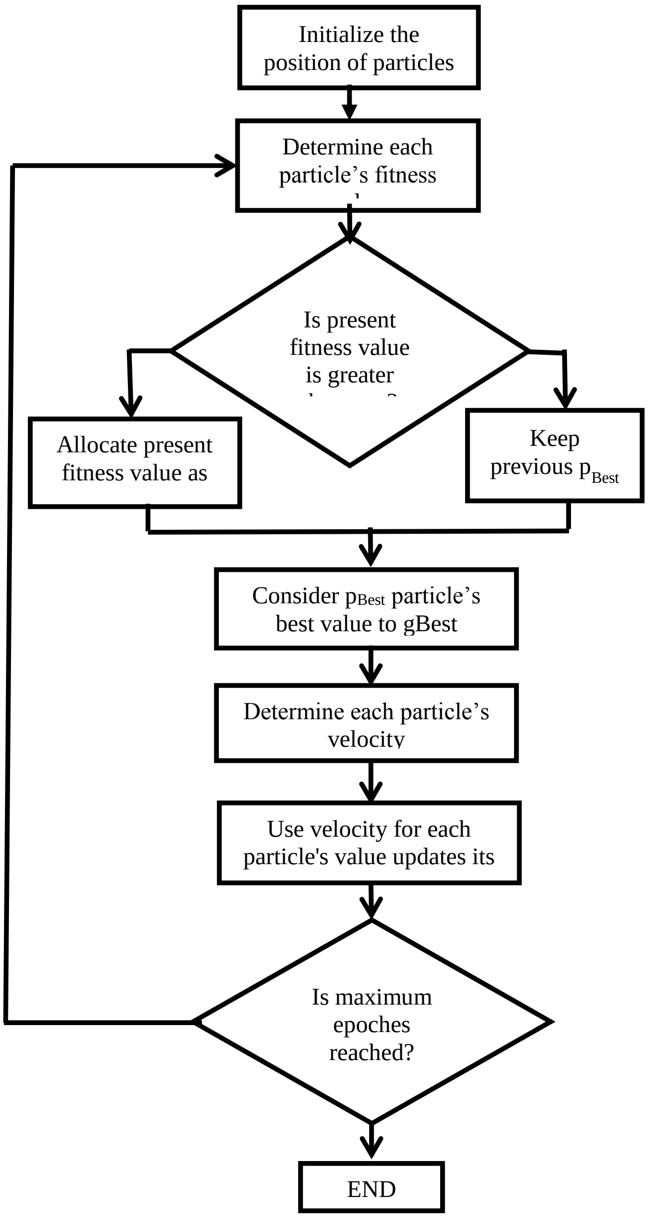

Fig. 1 Flow chart of PSO

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IV. RESULTS AND DISCUSSION

In this section, to evaluate the cost of Lambda-Iteration & PSO, I have considered 30 Bus systems as shown in the fig. 2. The results of different methods are explained and tabulated as follows,

1. Six unit system with wind energy using PSO.
2. Six unit system using PSO.
3. Six unit system using Lambda Iteration Method.
4. Cost Comparison of six unit system using PSO and Lambda Iteration Method.

The graphs of above mentioned methods are shown below. Fig. 3 to fig. 6 represents six unit systems with wind energy. Fig. 7 to fig. 10 represents six unit systems without wind energy for different interruptible loads.

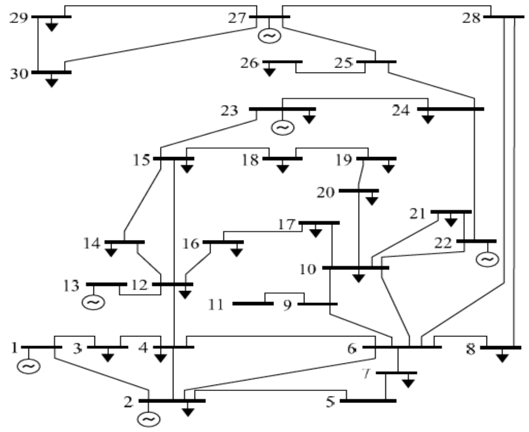

Fig. 2 Single line diagram of IEEE 30 Bus system

A. PSO method using six unit systems with wind energy

Table1 Six unit systems with wind energy using PSO

Sl. No.	Load Demand (MW)	Power Generation P_{g1} (MW)	Power Generation P_{g2} (MW)	Power Generation P_{g3} (MW)	Power Generation P_{g4}(MW)	Power Generation P_{g5}(MW)	Power Generation P_{g6}(MW)	Wind Power Generation P_{W1}(MW)	Power Loss (MW)	Fuel Cost ($/hr.)
1	283.4	173.67	48.10	21.26	19.97	11.54	10.16	8.57	9.87	928.6
2	212.55	141.33	40.14	18.44	1.91	5.40	4.33	7.84	6.84	684.6
3	141.7	94.76	28.94	15.0	0.0	0.0	0.0	0.0	3.80	466.8
4	70.85	32.27	20.0	15.0	0.0	0.0	0.0	0.0	1.89	285.4

The different Interruptible loads and their corresponding Power Generation, Power losses & Fuel Cost values has been tabulated for six unit system including wind energy by using PSO method as mentioned in above table.

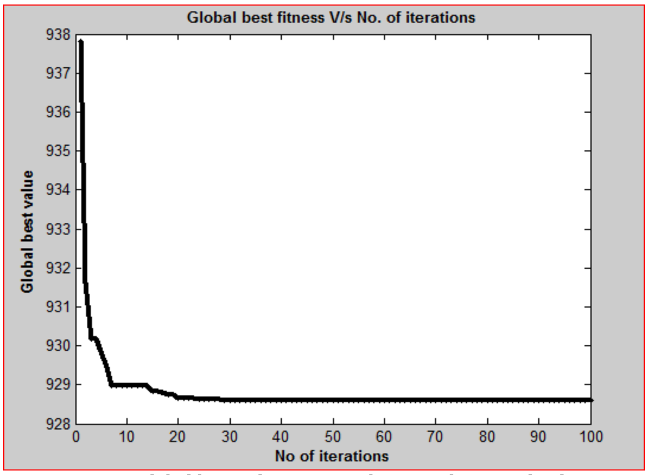

Fig. 3 Global best value curve with 100% change in load

For 100 iterations, thefuel cost is converged at a cost of 928.54$/hr.with the transmission losses of 9.87MW as shown in the above diagram.

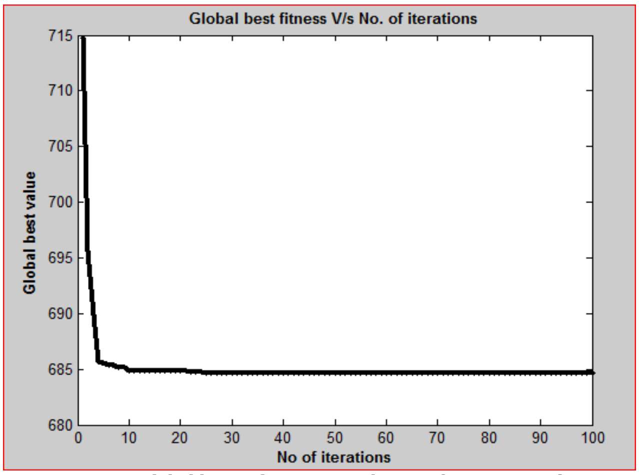

Fig. 4 Global best value curve with 75% change in Load

For 100 iterations, the fuel cost is converged at a cost of 684.6$/hr. with the transmission losses of 6.84 MW as shown in the above diagram.

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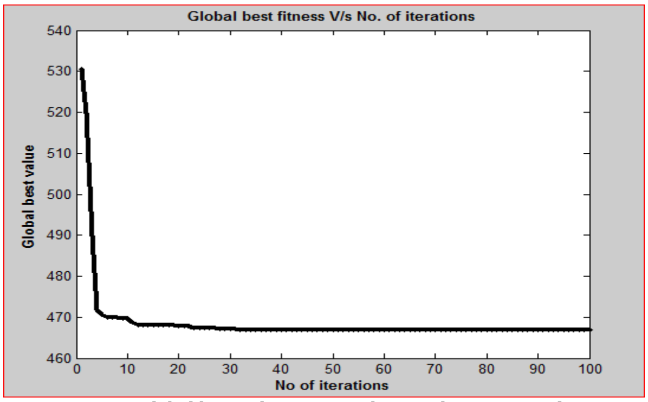

Fig. 5 Global best value curve with 50% change in Load

For 100 iterations, the fuel cost is converged at a cost of 466.81$/hr. with the transmission losses of 3.80 MW as shown in the above diagram.

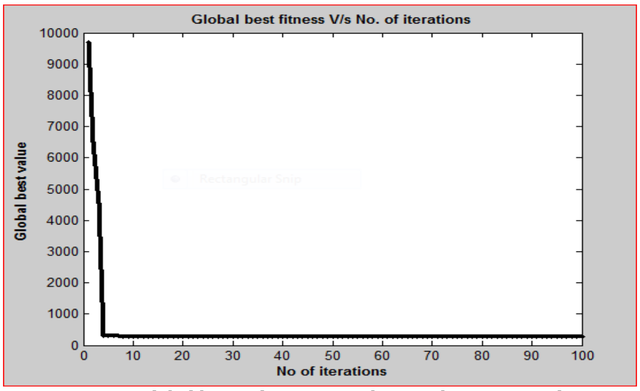

Fig. 6 Global best value curve with 25% change in Load

For 100 iterations, the fuel cost is converged at a cost of 285.48$/hr. with the transmission losses of 1.89 MW as shown in the above diagram.

B. PSO method using six unit systems without wind energy

Table 2 Six unit systems without wind energy using PSO

Sl.No.	Load Demand (MW)	Power Generation P_{g1}(MW)	Power Generation P_{g2}(MW)	Power Generation P_{g3}(MW)	Power Generation P_{g4}(MW)	Power Generation P_{g5} (MW)	Power Generation P_{g6}(MW)	Power Loss (MW)	Fuel Cost ($/hr.)
1	283.4	177.10	48.92	21.50	21.86	12.16	11.26	9.40	941.83
2	212.55	144.43	40.87	18.66	3.57	5.95	5.31	6.24	695.33
3	141.7	99.79	30.11	15.0	0.0	0.0	0.0	3.20	474.54
4	70.85	36.92	20.0	15.0	0.0	0.0	0.0	1.07	290.02

The different Interruptible loads and their corresponding Power Generation, Power losses and Fuel cost values has been tabulated for six unit system by using PSO method as mentioned in the above table.

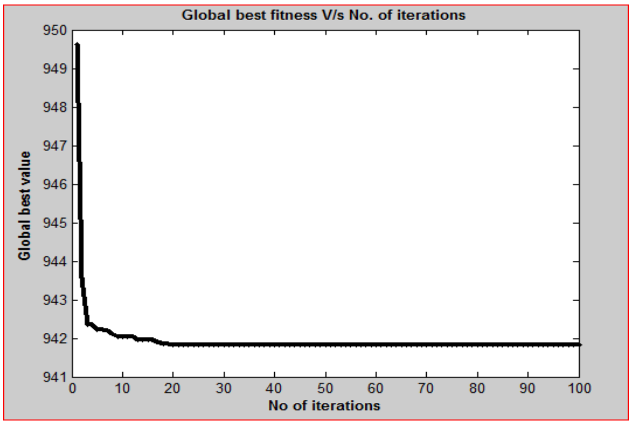

Fig. 7 Global best value curve with 100% change in load

For 100 iterations, the fuel cost is converged at a cost of 941.83$/hr. with the transmission losses of 9.40 MW as shown in the above diagram.

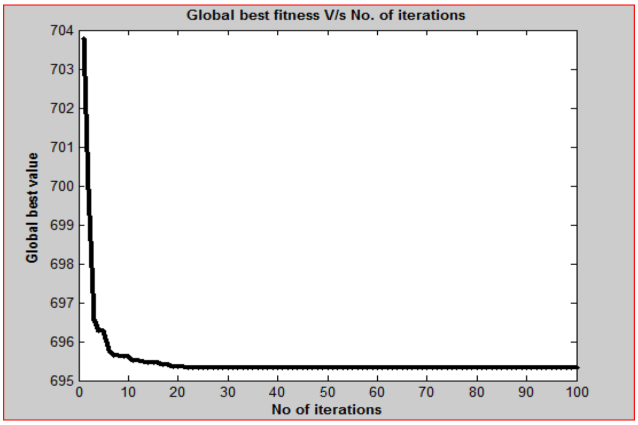

Fig. 8 Global best value curve with 75% change in load

For 100 iterations, the fuel cost is converged at a cost of 695.33$/hr. with the transmission losses of 6.24 MW as shown in the above diagram.

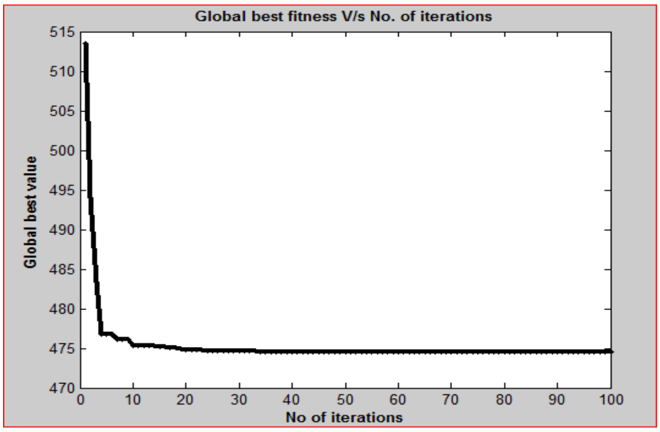

Fig. 9 Global best value curve with 50% change in load

For 100 iterations, the fuel cost is converged at a cost of 474.54$/hr. with the transmission losses of 3.20 MW as shown in the above diagram.

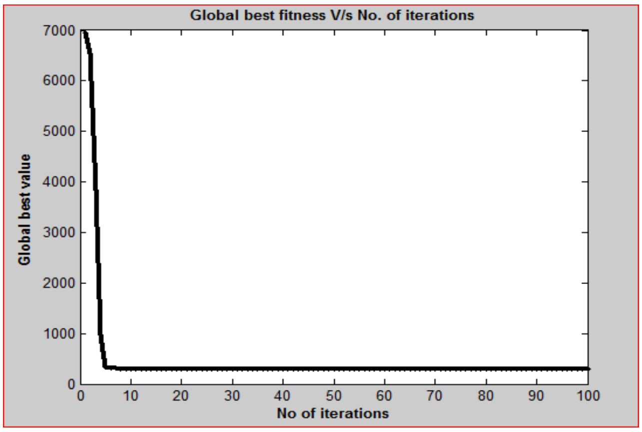

Fig. 10 Global best value curve with 25% change in load

For 100 iterations, the fuel cost is converged at a cost of 290.02 \$/hr. with the transmission losses of 1.07 MW as shown in the above diagram.

C. Six unit systems of Lambda-Iteration method

Table 3 Six unit systems through Lambda-Iteration method

Sl.No.	Load Demand (MW)	Power Generation P_{g1}(MW)	Power Generation P_{g2}(MW)	Power Generation P_{g3}(MW)	Power Generation P_{g4}(MW)	Power Generation P_{g5}(MW)	Power Generation P_{g6}(MW)	Power Loss (MW)	Fuel Cost (\$/hr.)
1	283.4	50	28.451	49.686	15.378	16.607	16.658	0.3805	21919.1
2	212.55	50	28.45	49.686	15.378	16.607	16.658	0.3805	14834.1
3	141.7	50	20.641	36.07	11.152	12.056	12.034	0.2472	8224.1
4	70.85	50	20	15	10	12	12	0.1681	11481.3

The different Interruptible loads and their corresponding Power Generation, Power losses and Fuel cost values has been tabulated for six unit system by using Lambda-Iteration method as mentioned in the above table.

D. Cost Comparison

Table 4 Cost comparison between PSO method & Lambda-Iteration

Sl.No.	Load Demand (MW)	Lambda-Iteration method in (\$/hr.)	PSO method in (\$/hr.)
1	283.4	21919.1	941.83
2	212.55	14834.1	695.33
3	141.7	8224.81	474.54
4	70.85	11481.3	290.02

The cost for different interruptible loads of both methods has been tabulated and compared in the above table. It shows that PSO method is twenty to thirty times better than Lambda-Iteration method. It also indicates PSO method has lower fuel cost.

V. CONCLUSION

The conventional method of Lambda Iteration and proposed method of PSO are executed to verify the best one among them. PSO will display high quality solution with quick convergence characteristics and also efficient in global search. The six unit system along with wind energy and interruptible load management are performed and graphs are plotted, showed the behaviour of convergence characteristics of PSO method. Cost difference of Lambda Iteration and PSO method were compared. This shows that PSO method has less fuel cost compared to lambda Iteration method. So PSO method holds good for Economic Dispatch problem.

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