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Economic Load Dispatch of Renewable Energy Integrated System Using Jaya Algorithm

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Abstract- *With day by day increase in electrical energy demand and uneven distribution of sources in nature, there is a need of Integration of power plants. This integration needs a proper scheduling of all connected generating units in accordance with the variation in load demand. An optimum sharing of load is necessary to minimize the generation cost. Emission is also an important issue in a generation. An attempt is also made in this paper to analyze emission dispatch with the Economic Dispatch optimization. Environmental effects tend to involve renewable sources based power generation. Wind and Solar are most popular and highly abundant among all renewable sources. But, the fluctuations of these sources complicate the load dispatch optimization. Also, the conventional thermal generators itself affected by certain constraints and non linearity such as valve-point loading effect. A proper planning should involve consideration of all this issue, which requires advance soft computing technique. Previous approaches need proper tuning of their specific parameters, to remove this ambiguity, a new Jaya Algorithm technique is introduced in this paper.*

Keyword: Constrained optimization, Economic Dispatch, Non-smooth Optimization, Population based algorithm, Jaya algorithm, Valve-Point loading effect, Wind Energy..

1. INTRODUCTION

Electrical energy is the backbone of the modern technological world. It plays a vital role in satisfying various needs. From Indian Power system scenario, there is so much geographical variation in distribution of sources. Some areas have an abundance of power and some have deficiency of energy sources [1]. To overcome such difficulty, there is a need of an interconnected power system. The generated electrical power must be transmitted and distributed effectively over the demand area. The most crucial planning and operation in a generation system is the proper scheduling of all the connected generating to get the required power demand. As load demand is always variable, interconnected system becomes a better solution to exchange the peak loads [2]. The Economic Load Dispatch (ED) refers to an important optimization problem which deals with the optimum scheduling of all the connected generating units in a manner that overall generation cost is as least as possible. Also the various linear and nonlinear constraints should be obeyed. Certain complexities gets involved due to non-smooth phenomena like a valve- point loading effect [3], multi-fuel system and prohibited operating zones[4-5].

The clean air amendment of 1990 aims towards control of acid rain [6]. This made restrictions over the emission of sulphur dioxide (SO2) and Nitrogen oxides (NOx) from electrical Power generating plants. Acidic deposition mainly includes dry deposition of gaseous SO2 and Nox. This deposition through precipitation leads in follows the absorption by cloud moisture. The content of acidic deposition considered to be linearly related to the amount of emission of SO2 and NOx. Acid rains mainly cause a damage to aquatic ecosystem, health and forests. emissions of these particulates during generation must be reduced along with a reduction of fuel cost. So, a combined objective of economic and emission dispatch as a single optimization issue is necessary [7]. In this paper, a case study also included to consider the effect of emission of the generating unit.

Renewable energy power generation finds popularity as a result of clean energy policies in many countries. Climate change, global warming concerns and fossil fuel crisis tend to opt renewable sources instead of conventional fuels into power generation. These sources are also widely available over the entire geographical area. The renewable energy sources attain many

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advantages as energy saving, Emission reduction and sustainable development. And also having significant opportunities for energy efficiency [8]. Wind Power is fastest growing energy source and also the least expensive and highly abundant source. Solar Power, as the sun is a widely available energy source. Also the PV panel directly converts sunlight into electricity and modern technologies are much advanced in the solar power generation. It can be observed that wind and solar are more convenient to generate electricity and also not much dependent on location [9-11]. Hence they find better opportunities in modern integrated grid systems. Hence, an Integrated solar, wind and thermal unit system is chosen in this paper to study. Despite of extensive enhancement in renewable energy integration, The ED problem yet includes mainly the conventional thermal generators. Integration of renewable sources introduces further complexity in the ED problem as Nature of all such sources is highly unpredictable and this uncertainty leads to fluctuating power output from this sources [12-13]. For example, as Wind and Solar energy sources are considered in this study. In case of Wind, the Future Wind speed is a stochastic variable as its accurate value can't be predict by any measure. In turn, The output of Wind Power is entirely depends on its available wind speed hence, this uncertainty of wind power output will leads fluctuations in The ED Problem Formulation [14].

As the practical ED Problem is having a non-smooth cost function. The complexities involved in the cost function tend to find the optimal point quite more difficult. In previous researches, optimization is made to solve by other soft computing techniques as Particle Swarm Optimization [15-16], Mathematical approaches[17], evolutionary programming [18], a neural network approach [19], and artificial bee colony (ABC) algorithm [20-21]. These all methods have already been used to find to solve the ED optimization. But these techniques have need settings of their own specific parameters with every constraint include in optimization. Therefore, to consider various complexities and constraints, it is recommended that soft computing techniques are far better than conventional method to find an optimal point.

The Common Problem arises in these entire algorithm as discussed in the above Para, is that all are sensitive to an initial guess. Any kind of irregularity in selecting initial guess will leads to a local optimum point. Again Tuning of Algorithm Specific parameters separately for different program is again very crucial. A Proper tuning is necessary to get a real optimum solution. So, a proper investigation is required to tuning of such specific parameters. Convergence of solution is badly affected by improper tuning of these parameters hence improper tuning results in an unnecessary increase in computational time as well as can stick in a local optimum point. Although we are using soft computing methods, we have to get influenced by this ambiguity of specific parameters [22]. One of the specific parameter independent algorithm teaching Learning based Optimization (TLBO) was proposed by R. V. Rao in 2011 [23], like other nature inspired algorithm it also modifies as the behaviour of teaching and learning process. It is also population based technique and consist of two phases. And it depends on mean value of population to reforms the solution. This algorithm is a specific parameter free hence its operation is quite and smooth as compare to other previous approaches. One of the specific parameter independent algorithm teaching Learning based Optimization (TLBO) was proposed by R. V. Rao in 2011 [23], like other nature inspired algorithm it also modifies as the behaviour of teaching and learning process. It is also population based technique and consist of two phases. And it depends on mean value of population to reforms the solution. This algorithm is a specific parameter free hence its operation is quite and smooth as compare to other previous approaches. Reliability indices have been calculated for ELD problem as addressed by authors in Ref. [24]. A multi-objective ELD problem has been presented in Ref. [25] incorporating thermal generators and wind turbine in the developed model and Sequential Quadratic Programming (SQP) and PSO has been applied for optimization. A non-convex economic dispatch problem including valve point effect has been solved using artificial cooperative search algorithm (ACS) in Ref. [26]. For solving ELD problem conventional methods like lambda iterative method, gradient methods are not effectively solve the problem if complicated constraints like non-convex objective functions. To address multi-constraints optimization problem, a shrink Gaussian distribution quantum-behaved optimization (SG-QPSO) algorithm has been proposed in Ref. [27]. In the proposed SG-QPSO, a strong global solution can be obtained at the initial stage of the solution. The equilibrium optimizer (EO) is proposed to solve the combined economic emission dispatch problem (CEEDP) by M. A. El-Shorbagy et al. [28]. In this method, to minimize pareto border, a clustering has been performed. A nonconvex combined heat and power economic dispatch problem (CHPED) has been solved using combination of cuckoo optimization algorithm with penalty function [30]. In Ref. [31], a simple population based algorithm has been presented, which requires only two parameters, namely population size and maximum number of iteration, because of this, Jaya algorithm is free from specific parameters.

In the present work, a new simple and flexible yet powerful Jaya algorithm is introduced for solving the optimization problem and it is successfully implemented on different test case systems. Objective of this paper is to get a simple and flexible but accurate algorithm for the ED problem optimization. Which can withstand any kind of complexity arises due to valve-point loading and also due to integration of any kind of the Renewable Sources in the system. Main objectives of this paper are:

1. Combined study of Economic as well as Emission dispatch in the conventional thermal units to analyse the environmental effects of electrical power generation.
2. Consider the non-linearity arises because of multi-valve system in the ED optimization Problem to minimize the cost and losses.
3. Analyse the Fluctuations in Renewable sources and consider its effects in the Basic ED Problem.
4. An attempt is made to provide a simple and powerful optimization technique which is flexible for different test system and also reduce the ambiguity of tuning of Specific Parameter in every system.

2. ECONOMIC DISPATCH PROBLEM FORMULATION

ED optimization problem needs to be mathematically formulated according to its various linear and nonlinear constraints. Also, the effects of various complexities involves in generating unit analysis demands its mathematical analysis. The mathematical equations involve in ED problem will reflects various issues in soft computing method based analysis.

Basic ED Problem: Objective of ED optimization is optimum allocation of total demand among the various connected generating units, so as to get a minimum total generation cost. The linear and nonlinear constraints associated with each units must not be violated. The main objective function is Total cost of generation C which can be represented as a Summation of generation cost of all connected generating units in ($/hr) (1).

$$C = \sum_{i=1}^{m} G_i g_i \tag{1}$$

Here $G_i(g_i)$ is the Individual generation cost in ($/hr) corresponding to g_i Electrical power output in (MW) of

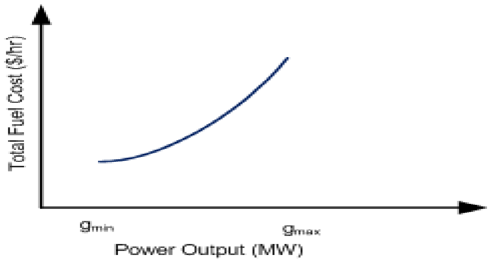

Fig. 1. Cost Curve of a thermal generator

i^{th} generating unit. Which can be formulated as a quadratic function (2).

$$G_i(g_i) = a_i g_i^2 + b_i g_i + c_i \tag{2}$$

Here, a_i, b_i, and ci are the cost coefficients of i_{th} generating unit. These coefficients represent various costs associated with the generation. Such as, a_i refers to cost associated with losses in ($/MW^{2}h), b_i refers to the variable costs like fuel cost, which changes proportionally as variation in generating output. And c_i refers to fixed costs in ($/hr) such as salaries or cost of land, which are fixed irrespective of power generation. Variation of cost with generating output can be represented by cost curve of generating unit. Fig. 1 shows the basic cost curve of a thermal generating unit. A more precise cubic cost function (3) is also analyzed in this paper with renewable energy integrated system[32]

$$G_i(g_i) = a_i g_i^3 + b_i g_i^2 + c_i g_i + d_i \tag{3}$$

Linear and Non-linear Constraints: Every generating unit restricted by some equality and inequality criteria. These boundaries must be considered during optimization operation. This limits can be mathematically formulated as follows :

Equality Constraint: The consumers must be satisfied; the overall demand must be fully supplied by generating units. Also, unnecessary production should be avoided. As extra production will leads to increase in generation cost and also waste of fuel. These equality constraints can be equated as (4)

$$\sum_{i=1}^{m} g_i + g_w + g_s = D \tag{4}$$

Here, g_w and gs are wind and solar unit generating output in (MW) if connected in system. And D is the Total consumer load demand in (MW).

Inequality Constraint: The graphical Lagrangian method [33] suggested that coordination equations define the optimal conditions for minimization problems. This classical approach has some disadvantages for obtaining constrained optimum. A suitable scheme for practical power system applications which rectified this problem has been discussed in Ref. [34]. The following strategy applied in order to set the limits on generation by Famideh-Vojdani [34]:

Let,

$$\Delta h = \sum_{i=1}^{R_1} h_i^{\max} - \sum_{i=1}^{R_2} h_i^{\min} \tag{5}$$

Where,

$h_i^{\max} = g_i - g_i^{\max}; (i = 1,2,.......R_1$: upper bound violations

$h_i^{\min} = g_i^{\min} - g_i; (i = 1,2,.......R_2$: lower bound violations

i. If Δh >0, set all R_1 upper bound violations to the upper limit, i.e. $g_i^{\max}$
ii. If Δh <0, set all R_2 lower bound violations to the upper limit, i.e. $g_i^{\min}$
iii. If Δh =0, set both R_1 upper bound and R_2 lower bound violations to their respective upper $g_i^{\max}$ and lower $g_i^{\min}$ limits.

Update new demand in a system which is the difference between previous demands minus the sum of fixed generation levels, mathematically;

$$P_D^{update-new} = P_D^{old} - \sum_{i=1}^{R_1+R_2} g_i \tag{6}$$

The update new demand is shared by other participated generators on an equal incremental cost basis. The operation of each generating unit is bounded by certain boundary limits. This inequality limits represents it's upper and lower boundary limits, under which it must be operated for stable operation. Beyond this, the unit may become unstable. Under such issue, generating unit will be isolated by protection system for safety purpose. So this generator inequality constraint must be considered in ED optimization. This constraint can be represented by Eq. (7).

$$g_{i\min} \leq g_i \leq g_{i\max} \tag{7}$$

Here g^i_{min} and g_{imax} are minimum and maximum allowable generating output of i^{th} thermal unit in (MW).

Multi Objective Economic/ Emission Dispatch: Electrical Power generation by conventional sources results in emission of hazardous pollutant gaseous material in the atmosphere. This is harmful for mankind and also violates our sustainable development policies. In 1990, clean air amendment for the pollution arises due to the emission from fossil fuel based electrical power generation is recognized. And a considerable attention is made to reduce the emission rate. So there is a necessity arises to study the effect of emission dispatch in combination with the economic dispatch. So that along with the cost the environmental emission reduction can also be taken into consideration. Like cost coefficients of thermal generator, emission coefficients depending on emission function can also be study and taken into consideration. Combined study of economic and emission dispatch power dispatch (CEED) is carried out to minimize the emission produced in generation. Sulphur dioxide and Nitrogen oxide emission is dependent on power consumption. Emission can be mathematically formulated as Eq. (8)

$$E = \sum_{i=1}^{m} x_i g_i^2 + y_i g_i + z_i \tag{8}$$

Here, E is Total generation emission in (Kg/hr). and x_i, y_i, z_i are the emission coefficients of i^{th} generating unit. these two objective function is converted into a single objective function by introducing a price penalty factor h.

Price Penalty Factor (PPF): It converts the multi objective CEED Problem into a single objective optimization problem. The CEED objective function can be represented as Eq. (9)

$$F = \sum_{i=1}^{m} \left[\left(a_i g_i^2 + b_i g_i + c_i \right) + h_i \left(x_i g_i^2 + y_i g_i + z_i \right) \right] \tag{9}$$

Here, F represent the total CEED cost in ($/hr). And hi is the price penalty factor in ($/kg). PPF tells about the physical measure of emission, it converts emission mass to the fuel cost for emission. It is ratio between maximum fuel cost and maximum emission of corresponding generator. It can be represented by:

$$h_i = \frac{G_i\left(g_{i\max}\right)}{E_i\left(g_{i\max}\right)} \tag{10}$$

For a particular load demand, following steps are followed to calculate the PPF. Calculate the ratio of fuel cost and emission cost for each generating unit corresponding to their maximum output power. Arrange the generating units according to ascending order of their penalty factor. Add the maximum capacity of each generating unit g_{imax} one by one according to ascending order of their h_i starting from smallest and add another just greater than it and so on. Repeat the step 3 until the summation of overall output exceeds the selected power demand. At the same time, add h_i for those units. And finally when the load demand is fulfilled, the corresponding sum of penalty factor associated with the last unit is penalty factor for that particular load demand.

Valve-Point Loading Effect: A turbine should load near valve point to get maximum efficiency. Because turbine operate away from valve point would affected from throttling of steam passing through the control valve [35]. The valve-point effect introduces ripple content as each valve begins to start. It can be analyzed by adding a sinusoidal term in basic generator quadratic cost function as in Eq. (11).

$$G_i(g_i) = a_i g_i^2 + b_i g_i + c_i + \left| e_i \times \sin\left(f_i \times \left(g_{i\min} - g_i \right) \right) \right| \quad (11)$$

Where, a_i, b_i and c_i are the fuel-cost coefficients of the i^{th} generating unit, and, e_i and f_i are the fuel-cost coefficients of the i^{th} generating unit with valve point effect. Cost curve with multi-valve system is shown in Fig. 3 below. Curve becomes a rippled efficiency curve.

3. MODELING OF WIND POWER UNIT

Wind is renewable, environmental friendly and potential source of energy. Utilization of wind in electricity production causes a significant reduction in overall cost. Besides starting land and capital cost, there is no other costs involved in wind energy conversion system (WECS). WECS are also considered as less polluting and widely available even at remote areas. Although, wind speed is a major uncertainty issue associated with WECS. So, integration becomes complex, however some researcher have made attempts to analyze wind speed profile. Here, a wind a probability density function is introduced to consider the wind speed at a particular instant. The available output power corresponding to wind speed intervals is also formulated for analysis of WECS into conventional ED optimization.

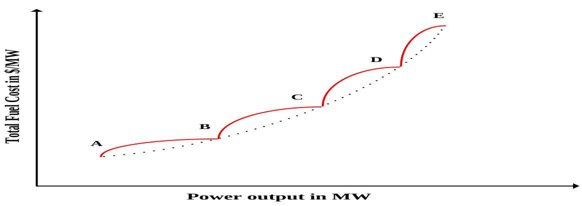

Fig.2. Cost Curve with 5 valve system

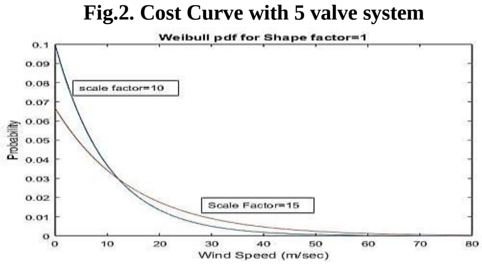

Fig. 3. Weibull pdf for shape factor 1 and scale factor 10 and 15

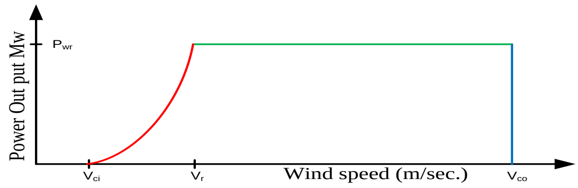

Fig. 4. Variation of Total wind power output with wind speed[37]

Wind Speed Probability Density Function: The future wind speed is unpredictable. A perfect forecast is quite impossible. However, certain attempt by using fuzzy logic [36], neural network [37], and time series [38] were made. In 2008, John Hetzer proposed a probability density function (pdf) based analysis for stochastic nature of wind speed and utilize the corresponding wind power output for consideration wind power output for consideration in ED problem formulation. It is observed that wind speed profile closely follows the weibull pdf and based on this, wind speed can be analysed as a stochastic random variable. And its pdf can be define as in Eq. (12) [37].

$$pdf(\upsilon) = \left(\frac{\mu}{\lambda}\right)\left(\frac{\nu}{\lambda}\right)^{(\mu-1)} \times e^{\left[-\left(\frac{\nu}{\lambda}\right)^{\mu}\right]} \quad (12)$$

Here, υ is wind speed in (m/s); ν is the wind speed random variable, μ is shape factor for given location (dimensionless) and λ is the scale factor in (m/s) [38]. fig. 4 shows weibull pdf of wind speed. Here, shape factor is 1 and scale factor 10 and 15 is taken. random speed is selected based on this wind speed probability and consider it for ED optimization problem. Fig. 3 above shows a rough idea about the probability of certain wind speed to be available at a particular instant. Although this assumption is not accurate but a very close wind profile can be obtained for analysis. corresponding output power can be calculated based on the selected wind speed by weibull pdf [38].

WECS Output Function: As the Irregular wind speed is characterized as in the form of weibull pdf profile [38]. Now, its wind power output (g_w) can be transformed based on different speed intervals. Fig. 4 depicts about the variation of available wind power with different wind speed intervals. It can be observed that the wind power output curve is comprises of different regions. So, its mathematical formulation would require separate equation for each region.

$$g_w = 0 \quad \text{for } (\upsilon < \upsilon_{ci}) \text{ or } (\upsilon > \upsilon_{co}) \quad (13)$$

$$g_w = \frac{(\upsilon - \upsilon_{ci})}{(\upsilon_r - \upsilon_{co})} \times g_{wr} \quad \text{for } (\upsilon_{ci} \le \upsilon \le \upsilon)_r \quad (14)$$

$$g_w = g_{wr} \quad \text{for } (\upsilon_r \le \upsilon \le \upsilon_{co}) \quad (15)$$

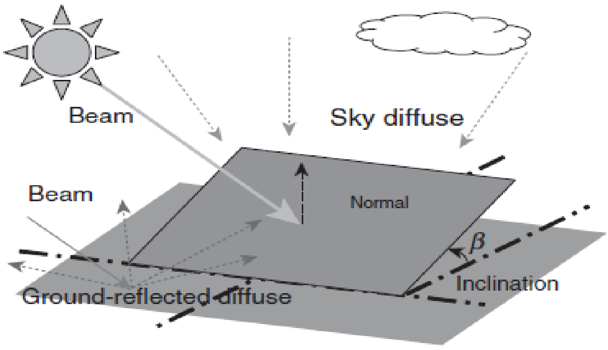

Fig.5. Components of solar radiation on PV panel [36]

Here, g_{wr} is rated wind power output (in MW); υ_{ci} is the cut-in speed below which the torque is not enough to rotate the turbine blades. And υ_{co} is the cut-out speed above which rotor operation is insecure. So below υ_{ci} and above υ_{co} wind output is not available (11). υ_r is the rated wind speed. From υ_{ci} to υ_r, a linear variation with wind speed is observed (12); but than the turbine design is adjusted to maintain power at its rated maximum level. So there is no further rise in wind power. Hence, a constant rated power available in this region (13).

4. MODELING OF SOLAR POWER UNIT

The sun is a universal source of energy available worldwide irrespective of place. At highly warmed remote desert areas, it finds a better alternative of conventional sources. Also the reduction is cost is quite significant and there is very less maintenance and operation effort needed. The solar output available depends on solar radiation available at that site. Although solar radiation and temperature is also very unpredictable in nature also influenced by weather conditions so integration with conventional sources is required to sustain the reliability.

Solar Power radiations: Solar power inputs are solar radiation and temperature. Solar radiation refers to the sunlight available at the Photovoltaic (PV) panel surface [9]. The radiated sunlight falls in different way on PV panel. The portion directly fall is called as normal inclined radiation. Although major portion which falls on ground get reflected on PV panel which is also usable part termed as reflected radiation. And some part of got scattered in atmosphere which partially diffused and reached to the PV panel, which is called as diffused radiation. This all 3 kind of radiation will be clear from the fig. 5 below. Total solar radiation I_T is the sum of all these three radiation (16). It can be calculated using solar radiation data of that particular site [39]

$$I_T = I_{normal} + I_{reflected} + I_{diffused} \tag{16}$$

This is the general equation of total solar radiation available at a particular location at a specific time. Estimation influenced by location of sun in the sky which is abruptly changing every month.

Solar Power Output: The solar power output g_s available is entirely depends upon input solar radiations and temperature [36]. It can be calculated on hourly basis from Eq. (17).

$$g_s = I_T \eta A_{PV} \tag{17}$$

Here, A_{PV} is area of PV Panel in (m^2); and η is the system efficiency and depends on temperature is given by Eq. (18)

$$\eta = \eta_m \eta_{pc} P_f \tag{18}$$

Here, η_m is module efficiency, which is measure of percentage of solar light converted into electrical energy. η_{pc} is power conditioning efficiency tells about the power quality that obtained after conversion, and P_f the packing factor; it is the ratio of area of PV panel to the area of total system. Module efficiency is given by Eq. (19)

$$\eta_m = \eta_{re}\left[1 - \beta\left(T_c - T_r\right)\right] \tag{19}$$

Here, β is array efficiency temperature coefficient, η_{re} is module reference efficiency, T_r is reference temperature for cell efficiency and T_c is monthly average cell temperature. Hence it can be analyzed that efficiency is measure of temperature of solar radiation. The above equations clearly represent the formulation for available solar power output of PV panel under given parameters [40]. This formulation is desirable to consider solar power unit in ED optimization problem.

5. PROPOSED ALGORITHM

Jaya Algorithm optimization won't require tuning of any specific algorithm parameter or any kind of probability. All the design variables are modified themselves in such a manner so as to get close towards the "**Best Candidate"** and at the same time away from the "**Worst Candidate"** [31]. There are some simple steps involved in operation of Jaya Algorithm.

Step 1: Randomize the design variables under their boundary limits and initialize each candidate under constraints.

Step 2: Evaluate objective function for each candidate corresponding to initialized values and identify best and worst candidate among them.

Step 3: Modify each design variable according to the best and worst solutions.

Step 4: Evaluate the objective function for modified values of designed variables; and compare the modified solution with the previous solution; update the candidate with the better solution.

Step 5: Now again identify best and worst candidate according to the updated solution.

Step 6: Go to step 3 ; and repeat steps 3 to 5 until the stopping criteria is reached;

The detailed operation of Jaya Algorithm for ED optimization problem is as following:

Framework and Initialization of all candidates: The initialization process involves only to set the common population based parameters. Set no. of candidates 'r', stopping criteria i.e. no. of iteration 'n' and no. of design variables i.e. thermal generating unit 'm'. Although the variables are set to keep in mind as they must follow the boundary limits as well as follow the equality and inequality criteria and other limitations. Evaluate the equality criteria i.e. Power demand 'D' (D-g_w-g_s).A matrix *x* is initialized which consist of all the candidates with their randomize design variables and objective function i.e. 'Total Cost' in the last column. Following are the steps involved in the initialization of design variables under equality and inequality criteria :

Step 1: Calculate the wind and solar power output if available and subtract it from total load demand.

Step 2: select first candidate j=1; and initialize values of all the m generating units (from i=1 to m), satisfying their boundary limits by the formula (20).

$$g_i = g_{i\min} + u(g_{i\max} - g_{i\min}) \quad (20)$$

Here, *u* is a random number between [0,1]; hence the whole span between lower and upper boundary limit is available to a generating unit. similarly all the m generating units are randomized.

Step 3: Now to satisfy the equality criteria, randomly select a generating unit (i.e. '*h*') and reset its value (g_h) by subtracting summation of all the remaining generator output (21).

$$g_h = \left(D - \sum_{i=1}^{m} g_i - g_h \right) \quad (21)$$

And check whether these assign value lies under that particular '*h*' generating unit boundary limits. If not again repeat the step 2 and 3.

Step 4: Increase J=2,3,4…..upto r and randomize the generating units for all candidates in the same manner by repeating step 2 and 3.

Step 5: Calculate "Total Cost" for each candidate by using the cost function.

Step 6: Identify the **"Best"** and **"Worst"** candidate among all candidate by comparing their Fitness value i.e. 'Total Cost' candidate with the lowest cost is the Best and with highest cost is the worst candidate.

Modification Process: Modification is the way of movement of generating units to another value to acquire another possible solution in the span. Every candidate is varied to analyze different random combination, so that solution won't converges to a local optimum solution. Direction of movement of design variables is guided by the **'Best'** and **'worst'** candidate [31]. Various steps involved in modification process are as follows:

Step 1: set s=1,i.e. no. of iteration.

Step 2: Now select each candidate from j=1, 2, 3….r and modify value of each generating unit for the same by using the Jaya Algorithm Modification Eq. (22):

$$g'_{s,j,i} = g_{s,j,i} + u \times \left[\left(g_{s,best,i} - \left|g_{s,j,i}\right|\right) - v \times \left[g_{s,worst,i} - \left|g_{s,j,i}\right|\right]\right] \quad (22)$$

Here $g'_{s,j,i}$ is the modified value of generating unit *i* for j^{th} candidate during s^{th} iteration. And $g_{s,best,i}$ is the value of corresponding unit for the best candidate and $g_{s,worst,i}$ is the value of corresponding unit for the worst candidate. *u* and *v* are two different random number which can get any value from [0,1].

Step 3: After modify all the generating value for an candidate select an random generating unit and reset its value to satisfy the Equality Criteria for every candidate as we already done in the Initialization Process.

Step 4: Increase no. of candidate j=2 and so on and perform same process for each candidate.

Update Process: The New Modification may or may not favour to a better change from the previous set of values for candidates. So a cross check is necessary before going to the next iteration. Update process provides a better convergence towards the solution. It prevents candidates from acquiring a modification which is not better than its own previous solution.

Step 1: Calculate Modified fitness values i.e. cost of each candidate based on their new modified values of generating units.

Step 2: Compare this modified cost for each candidate with their previous cost calculated based on previous generating units value.

Step 3: If the modified cost is Less, Replace the values of generating units for that candidate with new modified value.

Step 4: If the Modified Cost is high, retain the previous set of values for that candidate.

Step 5: After updating all the candidates with their updated cost. Now again compare cost of each of the candidate. And identify **New 'Best'** and **'worst'** candidate among them.

Step 6: Again continue the Modification Process by using the updated '**best'** and '**worst'** candidates.

Stopping Criteria: The Algorithm will modify and update the candidates again and again until the maximum no. of iteration **'s'** won't reached. Here the value of s is already set during initialization process. Stopping criteria is a crucial factor in the absence of which algorithm will trap into infinite loop.

6. SIMULATION RESULTS AND DISCUSSION

To analyze the performance and flexibility of the proposed method, it is applied to four test systems. The population size is selected as 50 for all cases. The convergence of curve between Total cost in ($/hr) to the no. of Iterations is plotted for each test system.

Test System 1: Here standard IEEE 30 bus system with 6 generating units, 43 branches and 21 load buses is used [41]. The load demand of the given system is 450 MW [19]. The results are taken with and without consideration of transmission losses. The results obtained by Jaya algorithm optimization technique is shown in table 1.

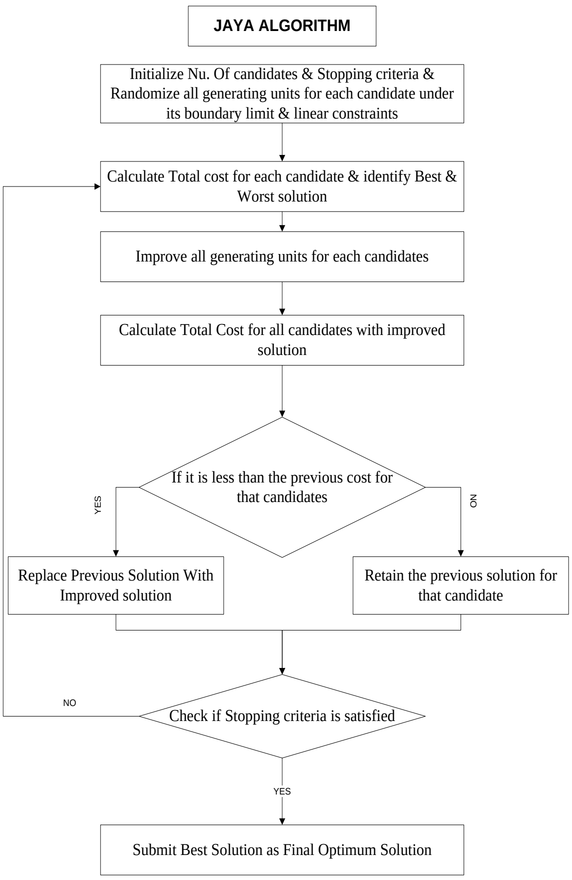

Fig. 6. Flow Chart of Jaya Algorithm

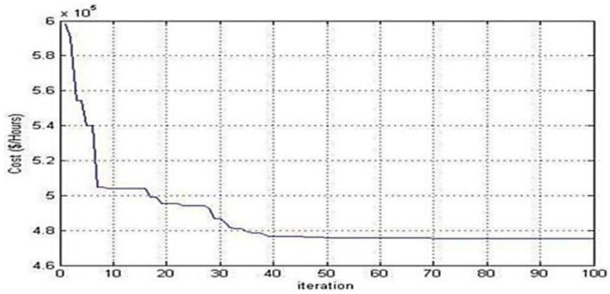

Fig 7. Convergence of Min. Cost with Iterations without losses

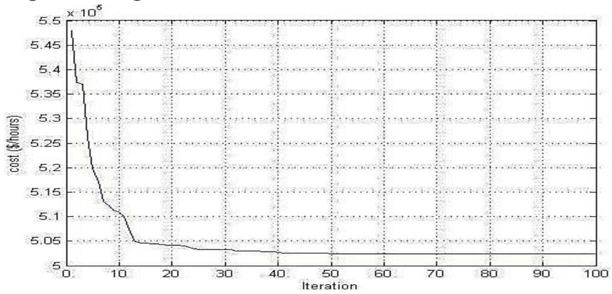

Fig 8. Convergence of Min. Cost with losses each Iteration considering

Table 1 Results of Test system 1 for Jaya Algorithm

Generator Unit	Without losses (MW)	With Losses (MW)
G1	87.8435	79.5476
G2	90.2941	94.0585
G3	44.5801	49.4885
G4	92.8025	98.6445
G5	44.201	47.9760
G6	90.2786	93.0345
Total Power	450	462.75
Losses	0	12.75
Minimum Cost ($/hr)	475518.6237	502468.6357
Computation Time	3.4568 sec	4.2015 sec

Table 2 Results of Test Case 2 for Jaya Algorithm

Unit	Power Output	Max. Power Output (MW)	Max. Unit Cost (ELD)	Max. Cost (Emission)	Penalty Factor h_i
G1	110.6655	300	2765	1101.3	2.51
G2	286.6217	450	2943.75	5584.523	.5271
G3	211.3904	450	2958.75	5584.523	.5298
G4	117.0396	100	120	28.07	4.275
G5	93.1075	300	1940	1101.35	1.76
G6	165.8865	450	3003.75	5584.523	.5378
G7	119.054	200	1242	255.04	4.86
G8	180.1773	500	4421	7529.03	.5871
G9	35.4465	600	6115	12507.05	.4889
G10	117.0396	100	129	28.07	4.56
G11	167.0396	150	406.25	148.26	2.74
G12	67.0369	50	126.75	-12.16	-
G13	283.1210	300	1065	1101.3	.9670
G14	167.0396	150	426.25	158.06	2.69
G15	53.9347	500	4055	7529	.5385
G16	167.0396	150	401.25	148.26	2.70
G17	117.0396	100	120	-106.57	-
G18	317.0396	300	910	1101.3	.8262
G19	136.2782	600	6270	12627.01	.49655
output	2910	-	-	-	-
cost	12791.21	-	-	-	-

Test System 2: Indian utility Sixty Two bus system with 19 generating units and 33 load buses is considered here [42]. The load demand of the given system is 2910 MW [43]. And study of combined Economic and

Emission Dispatch is carried out and penalty Factor is calculated for each unit [42].

Table 2 depicts the results obtained from the Jaya Algorithm and it is successfully implemented on this test system. Number of iteration is taken 500. The total generation cost is comes out to be 12791.21 $/hr. column 2 consist of corresponding maximum power output of each unit. Based on this, maximum ED cost and emission cost has been calculated. And penalty factor is calculated by taking ratio of maximum ED cost and emission cost for each unit. Now, the penalty factor is to be calculated by above data for the load demand of 2910 MW. Generating units is to be arranged in increasing order of their corresponding penalty factor in Table 3. Here the Maximum Power of each generating unit and their corresponding penalty factors are added which are chosen based on ascending sequence of penalty factor. After selection of 6 units the total generation exceeds the given load demand 2910 MW. Hence, the corresponding penalty factor 3.11865 is the penalty factor for selected load demand.

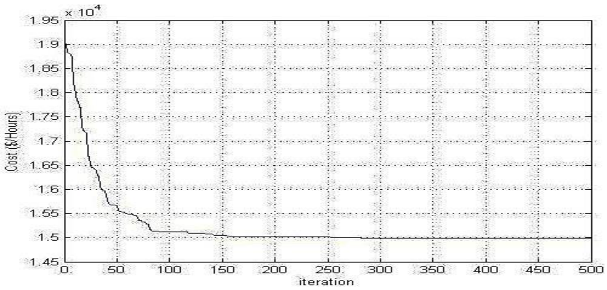

Fig. 9. Convergence of Min. Cost with each Iteration for test case 2

Table 3 Price Penalty factors in ascending order

G_i(max)	Penalty Factor
600	0.4889
1200	0.98545
1650	1.51255
2100	2.04235
2550	2.58015
3150	3.11865

Table 4 Results of test system3 for Jaya Algorithm

Unit No.	Power Dispatch (MW)	Unit no.	Power Dispatch (MW)
1	675.680	8	154.961
2	360.000	9	139.246
3	319.874	10	76.570
4	109.875	11	109.464
5	113.320	12	99.464
6	141.206	13	99.389
7	121.788	MIN COST	24122.97 ($/hr)

Table 5 Comparison of result for test case 3

Methods	GA	CRO	BSA	JAYA
Min cost ($/hr)	24398.23	24165.1664	24164.0524	24122.97
Max cost ($/hr)	NA	24169.3642	24166.5831	24213.60
Avg cost ($/hr)	NA	24166.9355	24164.2942	24166.88
CPU time (sec)	NA	5.56	5.12	0.956915

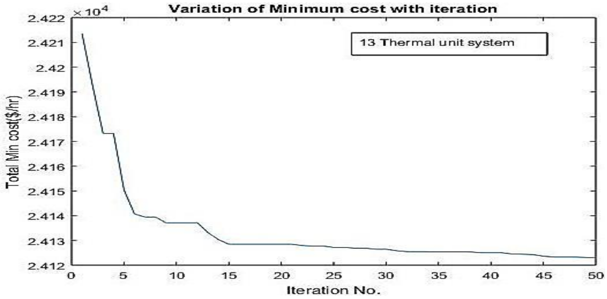

Fig 10. Convergence Characteristic for test system 3

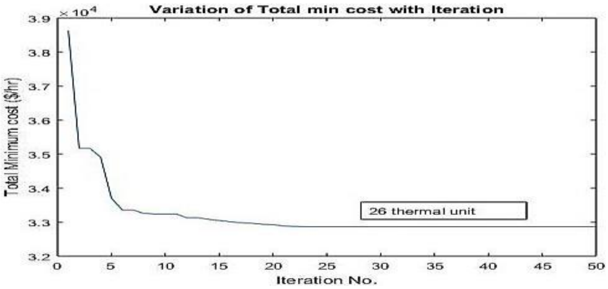

Fig. 11. Convergence Characteristic for test system 4

Test System 3: 13 generating unit case is considered with valve point loading effect [44]. The Total Load Demand is taken as 2520 MW. And losses are neglected in this case. The results obtained are shown in Table 7.4 and the results are compared with other previous techniques in table 7.5 to show the effectiveness of Jaya Algorithm.

Comparison with other Techniques: The results obtained for Test System 3 by Jaya algorithm are compared with some other techniques in Table 5 as Generic Algorithm (GA) [45], Chemical Reaction Optimization [46], and Backtracking Search Algorithm (BSA) [40].

Comparison of results with other techniques shows that Jaya Algorithm has lowest total cost of generation. And also the computational time taken is much less as compared to other methods. This results shows the superiority of Jaya Algorithm over other techniques. Fig. 4 shows convergence characteristics of total minimum cost with each iteration for test system 3.

Test System 4: 26 generating unit systems is considered with Cubic Cost characteristic [47]. The Power demand is set as 2900 MW. Transmission losses are not considered here. This case is considered for analysing the effects of renewable energy sources with thermal units. Next test system 5 and 6 are just continuation of test system 4.

Test System 5: Similar to test system, 4 and a solar power plant with maximum rating 50 MW. Data for radiation and average ambient temperature is taken from "*Solar Radiation Handbook*, 2008" [39] for Bhopal location. P_f =0.9, A_{pv} =90163.04 m^2 , β =-0.0047, η_{re} =0.105, η_{pc} =0.9,and T_{re} =25°C.

Test System 6: Similar to test system 5 and a wind power plant. Constants set as υ_{ci} =5, υ_{co} =45, υ_r =15, μ =1, λ =15, g_{wr} =155MW.

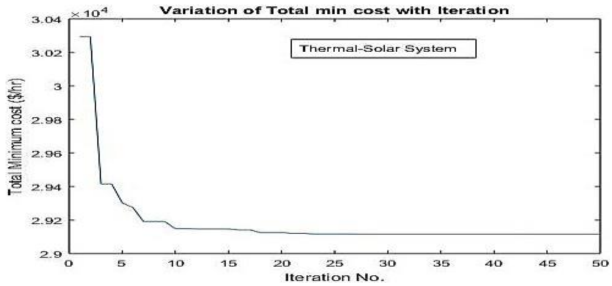

Fig 12. Convergence Characteristic for test case 5

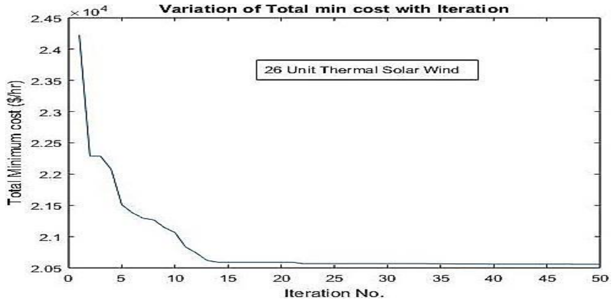

Fig 13. Convergence Characteristic for test case 6

Table 6 combined results for test case 4, 5 and 6

Unit No.	Test System 4	Test System 5	Test System 6
1	12	12	12
2	12	12	11.9938
3	12	12	12
4	12	12	12
5	12	12	11.9936
6	20	20	20
7	20	20	20
8	20	20	20
9	20	20	20
10	76	76	76
11	76	76	76
12	76	76	76
13	76	76	76
14	100	100	100
15	100	100	100
16	100	100	99.957
17	155	155	155
18	155	155	155
19	155	155	155
20	155	155	155
21	197	197	197
22	197	197	197
23	197	197	197
24	350	350	298.250
25	298.041	273.2394	222.226
26	296.958	272.3724	225.183
Solar power	0	49.3881	49.3881
Wind Power	0	0	155
Min cost ($/hr)	32864.4212	29115.637	20557.883
Max Cost ($/hr)	38629.8609	30651.788	24224.528
Avg Cost ($/hr)	33209.9962	29214.434	20836.227
CPU (sec)	3.890722	4.126117	3.970857

Table 6 shows combined results for test system 4, 5 and 6. Output of each generating unit and total generation cost for each test system is shown for comparison of integrated system with conventional thermal unit system. Minimum cost for convention thermal unit system in test system 4 is 32864.4212 and after integration of only solar unit in test system 5 the cost is reduced to 29115.637 and after again integration of wind unit reduces the total cost to 20557.883 this results shows a great economic saving by the integration of renewable energy sources. Also the computational time is very less in each case. Hence, this result proves successful implementation of Jaya Algorithm for renewable energy integrated system. Fig. 11, Fig. 12 and Fig 13 shows convergence characteristics for test case 4, 5 and 6 respectively. A smooth characteristic is obtained in each case hence; it shows flexibility of Jaya Algorithm for every test case system.

7. CONCLUSION

ED is a major issue to overcome require load demand. The main aim is the optimum allocation of all the connected generating units to get the minimum total generation cost. As, ED problem is subjected to various constraints and nonlinearities and complication due to integration of renewable energy source, Environmental effects of a generator should also analyse during generation, A proper technique is required which can flexibly handle all the issues. Study made in this work shows the superiority of Jaya Algorithm over other existing techniques for optimization.

Jaya algorithm is successfully implemented on different test system without any need of tuning of any specific parameter. It shows simplicity and flexibility of this algorithm. IEEE 30 bus system, Indian utility 62 bus system, standard 13 bus system with valve point loading effect and standard 26 bus system taken in this study are successfully optimized in this thesis work. The MATLAB simulation results of all test system demonstrate that different kind of issues of ED optimization problem can be easily analyse using Jaya Algorithm without any need of any setting of a specific parameter. Very less computational time in Jaya algorithm find it as a great advantageous for study of Dynamic systems considering continuous varying load profile. In present paper, the established algorithm is applied for considering losses, Valve Point loading effect, combined economic and emission dispatch problem, and integration of wind and solar power units for an optimal solution. However, there is a need to investigate more issues related to ED optimization problem Such as

- Other Kind of non-linearities such as multi-fuel system, generator ramp rate limits and prohibited operating zone can also be included.
- This Technique can be implemented on other test system and also with integration of other kind of renewable energy sources unit.
- As Jaya Algorithm takes very less computational time, so, it can be implemented for dynamic economic load dispatch optimization.
- A continuous wind speed profile and continuous solar radiation profile can be analysed with corresponding energy storage system.
- Certain modification can be made in Jaya Algorithm to find a more convergent and better optimal point.

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