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Approaches for smart linear regression in a difficult quasi economic dispatch problem

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ABSTRACT

Traditional methods indispensably necessitate monotonically increasing characteristic for fuel cost of generators in a thermal power plant. However, in medium and large thermal power plants, this condition is a dream to accomplish. So, to meet out these exigencies heuristic methods like swarm optimization technique, genetic algorithm technique and bee colony based hybrid solar thermal technology (BHSTT) are used to realize the practical nonlinearities associated with valve point loading emanated out of multi-valving effect, associated with power station. However, the heuristic methods too face challenges arising out of bulky thermal power plants adopting cubic cost functions and possessing stringent non-convex economic dispatch problem following multi-valving and erratic behavior of nonlinear loads at the load center. So, at its favor function evaluation method dealing with cubic cost function is attempted in this dissertation to yield a satisfactory optimal solution for economic dispatch problem. This method deals with the real power generation of producing units as well as the complex power of units, as well as dealing with severe nonlinear stringent fuel cost characteristics that are prevalent in today’s bulky thermal power plants. In comparison to previous approaches, the findings achieved are highly encouraging.

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1. INTRODUCTION

Higher degree polynomials, which are common in science and engineering are the subject of this research. Normally, a linear function of degree ‘n’ has n distinct solutions [1]. The process of solving the polynomial equation involving symbolic manipulation was tried by Pacioli in 1494 involving quadratic equations. He experienced different ways to solve cubic problems and appealed the Italians intellectual group to support him. Del Ferro was the one to discover the remedy towards the cubic equations, but despite releasing it he gave it to his students. Caradano published the information in 1540, praising Del Ferro for his assistance. Cardano also published Ferrari’s quartic equation solution (QE). The general cubic form was reduced to a depressed form involving a new variable with proper substitution [2]. This work done was highly appreciated [3]. Euler reduced the quartic polynomial equation in 1733 wherein the cubic term was suppressed to zero.

While higher order cost functions replace obsolete quadratic cost functions, the predictable economic power dispatch problem becomes more complicated. Hence, it is vital to manifest higher order cost functions as they are more exact and authentic than other cost functions. With higher order cost functions, inefficient power dispatch is possible. Many numerical optimization techniques have been explored, according to a bibliographical survey outlined above. For improved outcomes in these vibrant and sophisticated cubic cost functions, new innovative exploratory strategies are currently required. As part of this study approaches smart linear regression in a difficult quasi economic dispatch (SLRDQED) analysis has been done for obtaining optimal fuel cost function with and without conduction loss. In this dissertation on solving the resolvent QE [4]–[8], we ascertained that each root of the deflated equation is a solution of a resolvent cubic equation composed of sum of three square roots. In analogy with resolvent cubic equation [9] we analyzed the cubic cost function for thermal power plant pertaining to economic load dispatch problem (ELD). We determined three roots of cost equation of thermal power plant and obtained the minimum of them and determined cost function ε_i for this optimal P_{gi}. We ascertained the optimal real generation for 12 such units in the very similar process and obtained the corresponding values of ε_i for i =1, 2, 3, … 12. These optimal values obtained through function evaluation technique are found to satisfy equality and inequality constraints as well that are described through (10) to (11). The result obtained for ε_i is as accurate as reasonably approximate.

2. METHOD

The smart linear regression technique forms the basic guideline for optimizing the stern non convex fuel cost function [10], [11] designed with cubic polynomial attributes for realizing the heat rate input output characteristic of a power station. The fuel cost ε_i is expressed as (1)-(5).

$$\varepsilon_i = \begin{bmatrix} \Gamma_{1i} + \Gamma_{2i}P_{gi} + \Gamma_{3i}P_{gi}^2 + \Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}Cos\Gamma_{5i}P_{gi} \\ -\Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}sin\Gamma_{5i}P_{gi} + \Gamma_{6i}P_{gi}^3 \end{bmatrix} \tag{1}$$

$$\varepsilon_i = \begin{bmatrix} \Gamma_{1i} + \Gamma_{2i}P_{gi} + \Gamma_{3i}P_{gi}^2 + \Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}\left[\Gamma_{5i}P_{gi} + \frac{{\Gamma_{5i}}^2{P_{gi}}^2}{2}\right] - \\ \Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}\left[\Gamma_{5i}P_{gi} + \frac{{\Gamma_{5i}}^3{P_{gi}}^3}{6}\right] + \Gamma_{6i}P_{gi}^3 \end{bmatrix} \tag{2}$$

$$\varepsilon_i = \begin{bmatrix} \Gamma_{1i} + P_{gi}\left[\Gamma_{2i} + \Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}\Gamma_{5i} - \Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}\Gamma_{5i}\right] + \\ P_{gi}^2\left[\Gamma_{3i} + \frac{\Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}{\Gamma_{5i}}^2}{2}\right] + P_{gi}^3\left[\Gamma_{6i} + \frac{\Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}{\Gamma_{5i}}^3}{6}\right] \end{bmatrix} \tag{3}$$

$$Þ{\varepsilon_i}' = \begin{bmatrix} \Gamma_{2i} - \Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}\Gamma_{5i} + \Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}\Gamma_{5i} \\ +\left[2\Gamma_{3i} + \Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}\Gamma_{5i}\right]P_{gi} \\ +\left[3\Gamma_{6i} + 0.5\Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}{\Gamma_{5i}}^3\right]P_{gi}^2 \end{bmatrix} \tag{4}$$

$${\varepsilon_i}^{"} = 2\Gamma_{3i} + \Gamma_{4i}sin\Gamma_{5i}P_{gi}^{min}{\Gamma_{5i}}^2 + 6P_{gi}\Gamma_{6i} + \Gamma_{4i}cos\Gamma_{5i}P_{gi}^{min}{\Gamma_{5i}}^3 \tag{5}$$

The values of cost coefficients $\Gamma_{1i} - - - \Gamma_{6i}$ and minimum and maximum bounds of real power [12]–[15] are described in Table 1. On suitable substitution in cubic cost function using function evaluation technique the coefficients a and b are computed which are further used to compute the values of parameters θ in (8). The cubic equation's three different roots, namely, $P'_{gi}, {P_{gi}}''$ and ${P_{gi}}'''$ are computed involving parameters a, b, θ and variable P_{gi} using (14), (15) and (16) which was computed by equating ε''_i to zero. Of these values of ${P_{g_1}}', {P_{g_1}}''$ and ${P_{g_1}}'''$ the bare minimum is kept, while the rest is ignored. Similarly, for other units real powers three each for P_{g2}, P_{g3} ... up to P_{g12} are computed and minimum of P_{g2}, P_{g3} ... P_{g12} are retained and rest are neglected. As a result of these 12 optimum values so obtained for 12 thermal units, are found to satisfy (10) and (11) to yield both inequality and equality limits, respectively. These optimum real powers are too utilized to ascertain the transmission loss using (12) making use of loss coefficients B_{mn} computed for the power plant and expressed in (13).

$$a = \frac{\varepsilon'_i}{3} \tag{6}$$

$$b = -\frac{\varepsilon_i}{2} \tag{7}$$

$$\theta = cos^{-1}\left(\frac{b}{\sqrt{(-a)^3}}\right) \tag{8}$$

$$\varepsilon_i = \begin{bmatrix} \Gamma_{1i} + P_{gi,new1}\left[\Gamma_{2i} + \Gamma_{4i} sin\Gamma_{5i} P_{gi}^{min} \Gamma_{5i}\right] \\ -\Gamma_{4i} cos\Gamma_{5i} P_{gi}^{min}\Gamma_{5i} + P_{gi,new1}^2\left[\Gamma_{3i} + \frac{\Gamma_{4i} sin\Gamma_{5i} P_{gi}^{min} {\Gamma_{5i}}^2}{2}\right] + \\ P_{gi,new1}^3\left[\Gamma_{6i} - \frac{\Gamma_{4i} cos\Gamma_{5i} P_{gi}^{min} {\Gamma_{5i}}^3}{6}\right] \end{bmatrix} \tag{9}$$

$$P_{gi}^{min} < P_{gi} < P_{gi}^{max} \tag{10}$$

$$P_{gi} = P_D + P_{loss} \tag{11}$$

$$P_{loss} = \sum P_{gm} B_{mn} P_{gn} \tag{12}$$

$$\mathrm{B_{mn}} = \begin{pmatrix} 129 & 15.9 & 13.9 & 17.9 & 24.9 & 20.9 & 129 & 15.9 & 13.9 & 17.9 & 24.9 & 20.9 \\ 15.9 & 58.9 & 11.9 & 14.9 & 13.9 & 18.9 & 15.9 & 58.9 & 11.9 & 14.9 & 13.9 & 18.9 \\ 13.9 & 11.9 & 63.9 & 15.9 & 22.9 & 17.9 & 13.9 & 11.9 & 63.9 & 15.9 & 22.9 & 17.9 \\ 17.9 & 14.9 & 15.9 & 69 & 28.9 & 23.9 & 17.9 & 14.9 & 15.9 & 69 & 28.9 & 23.9 \\ 24.9 & 13.9 & 22.9 & 28.9 & 67.9 & 30.9 & 24.9 & 13.9 & 22.9 & 28.9 & 67.9 & 30.9 \\ 20 & 18.9 & 17.9 & 230 & 83.9 & 30.9 & 20 & 18.9 & 17.9 & 230 & 83.9 & 30.9 \\ 129 & 15.9 & 13.9 & 17.9 & 24.9 & 20.9 & 129 & 15.9 & 13.9 & 17.9 & 24.9 & 20.9 \\ 15.9 & 58.9 & 11.9 & 14.9 & 13.9 & 18.9 & 15.9 & 58.9 & 11.9 & 14.9 & 13.9 & 18.9 \\ 13.9 & 11.9 & 63.9 & 15.9 & 22.9 & 17.9 & 13.9 & 11.9 & 63.9 & 15.9 & 22.9 & 17.9 \\ 17.9 & 14.9 & 15.9 & 69 & 28.9 & 23.9 & 17.9 & 14.9 & 15.9 & 69 & 28.9 & 23.9 \\ 24.9 & 13.9 & 22.9 & 28.9 & 67.9 & 30.9 & 24.9 & 13.9 & 22.9 & 28.9 & 67.9 & 30.9 \\ 20 & 18.9 & 17.9 & 230 & 83.9 & 30.9 & 20 & 18.9 & 17.9 & 230 & 83.9 & 30.9 \end{pmatrix} \times 10^{-6} \tag{13}$$

$$P_{gi}^{'} = 2\sqrt{(-a)} cos\left(\frac{\theta}{3}\right) + P_{gi} \tag{14}$$

$$P_{gi}'' = 2\sqrt{(-a)} cos\left(\frac{\theta + 2\pi}{3}\right) + P_{gi} \tag{15}$$

$$P_{gi}''' = 2\sqrt{(-a)} cos\left(\frac{\theta + 4\pi}{3}\right) + P_{gi} \tag{16}$$

The proposed smart linear regression in a difficult quasi economic dispatch technique is described vividly step by step in algorithm 1.

Algorithm 1. SLRDQED algorithm
Step-1: Set real power generating units P_{gi}, i =1, 2, 3…12.
Step-2: Determine the functions $\varepsilon_i, \varepsilon_i^{'}$ and $\varepsilon_i^{''}$ at P_{gi}=0.
Step-3: Find the parameters a, b and θ using (6), (7), and (8).
Step-4: Find D using the mapping $D = a^3 + b^2$.
Step-5: When D=0, the roots are real and unequal; alternatively, one root is real while another two are complicated.
Step-6: Find P_{gi}', P_{gi}'' and P_{gi}''' using (14), (15), and (16).
Step-7: Choose the smallest value among the P_{gis} in step 6 and find ε_i for the P_{gi}.
Step -8: Increase P_{gi} by incremental change of 5 units.
Step-9: If the new P_{gi} satisfies both equal and in equal criteria then find ε_i.
Step-10: If $\Delta P_{gi} = 125$ then find ε_i else go to step 8.
Step-11: Plot the graph between ε_i vs P_{gi} with and without transmissionloss.

Table 1. Cost coefficients and real power generation bounds with transmission loss

P_{gi}	P_{gi}^{min}	P_{gi}^{max}	Γ_{1i}	Γ_{2i}	Γ_{3i}	Γ_{4i}	Γ_{5i}	Γ_{6i}
226.57	56.84	283.21	1000.4	40.54	0.11	33	0.01	0.001
215.35	53.84	269.18	949.69	38.76	0.104	323	0.009	0.0009
291.35	72.84	364.18	1284.85	52.44	0.142	43.70	0.012	0.0012
242.24	60.56	302.8	1068.27	43.60	0.12	36.34	0.01	0.001
293.02	73.26	366.27	1292.22	52.74	0.142	43.70	0.012	0.0012
242.04	60.56	302.8	1068.28	43.60	0.12	36.34	0.01	0.001
302.57	75.64	378.21	1334.34	54.46	0.15	45.39	0.013	0.001
242.24	60.56	302.8	1068.28	43.60	0.12	36.34	0.01	0.001
355.50	88.88	444.37	1567.76	63.99	0.17	53.33	0.015	0.0016
288.91	72.3	361.13	1274.09	52.00	0.14	43.34	0.013	0.0013
355.50	88.88	444.37	1567.76	63.99	0.17	53.33	0.015	0.0016
288.91	72.23	361.13	1274.09	52.00	0.14	43.34	0.013	0.0013

3. PERFORMANCE CHARACTERISTICS

IEEE 30 bus 12-unit systems has been attempted to ascertain the cost of fuel with and without transmission loss for a thermal power plant supplying a power demand of 2,676 MW to the load center. To evaluate higher-level functions, involving non-convex constraint [16]–[20], ELD uses a complex function evaluation mechanism for polynomial cost function to cubic cost function involving synthetic division by estimating one root by various iteration methods. The roots of the cubic cost [21]–[25] function are determined by using (14), (15) and (16). The cost coefficients and minimum and maximum bounds of real power indispensable for computing the cost of fuel are tabulated in Tables 1 and 2 for a 12-unit 30 bus IEEE system with and without transmission loss respectively. The proven SLRDQED method on the system with and without transmission loss comprising 12 units is simulated in MATLAB programming language and run in core i5 machine with 4 GB RAM. Following 50 iterations, the convergence characteristics for cost of fuel are depicted in Figures 1 and 2.

Table 2. Cost coefficients and real power generation bounds without transmission loss

P_{gi}	P_{gi}^{min}	P_{gi}^{max}	Γ_{1i}	Γ_{2i}	Γ_{3i}	Γ_{4i}	Γ_{5i}	Γ_{6i}
181.26	56.84	283.21	1000.4	40.54	0.11	33	0.01	0.001
172.28	53.84	269.18	949.69	38.76	0.104	32.3	0.009	0.0009
233.08	72.84	364.18	1284.85	52.44	0.142	43.70	0.012	0.0012
193.79	60.56	302.8	1068.27	43.60	0.12	36.34	0.01	0.001
234.41	73.26	366.27	1292.22	52.74	0.142	43.70	0.012	0.0012
193.79	60.56	302.8	1068.28	43.60	0.12	36.34	0.01	0.001
242.05	75.64	378.21	1334.34	54.46	0.15	45.39	0.013	0.001
193.79	60.56	302.8	1068.28	43.60	0.12	36.34	0.01	0.001
284.8	75.644	444.37	1567.76	63.99	0.17	53.33	0.015	0.0016
231.13	60.56	361.13	1274.09	5200	0.14	43.34	0.013	0.0013
284.8	88.88	444.37	1567.76	63.99	0.17	53.33	0.015	0.0016
233.13	72.23	361.13	1274.09	52.00	0.14	43.34	0.013	0.0013

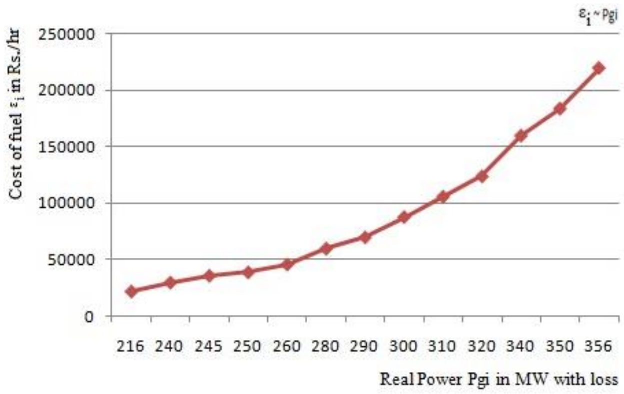

Figure 1. Variation of cost of fuel with real power incorporating transmission loss for test case-1

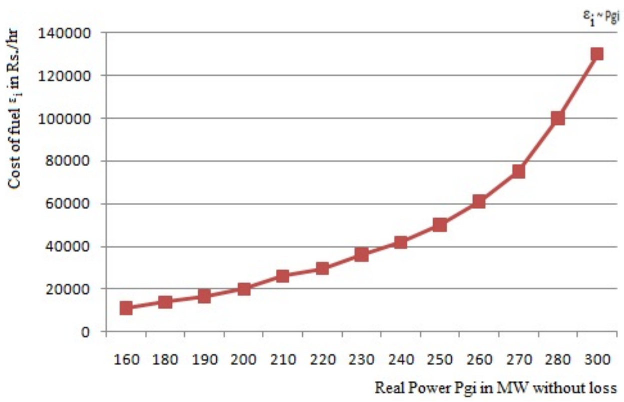

Figure 2. Cost of fuel vs. unit power ignoring transmission loss for test case-1

The SLRDQED approach incorporates 20 seconds to perform. Figures 3, 4, and 5 show the Simulink model and simulation output data for proposed method with signal attenuation. Figure 6 describes the step-by-step procedure involved in the proposed SLRDQED method for obtaining the optimal fuel criteria for thermal power plant using IEEE, 30 bus 12-unit system supplying 2,676 MW to load center without transmission loss.

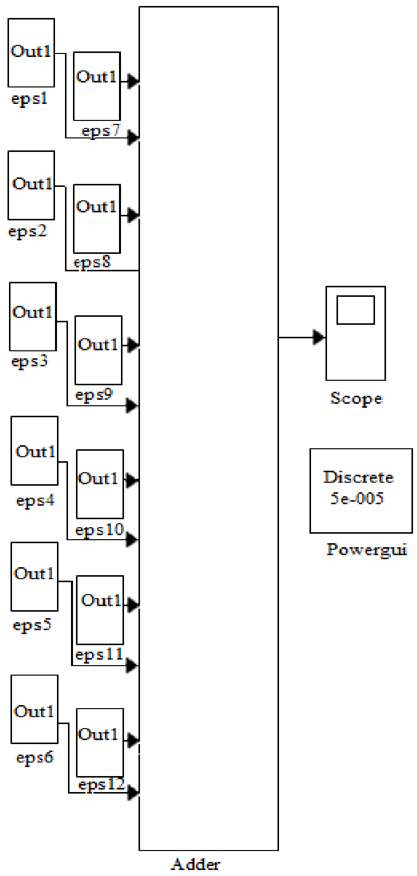

Figure 3. Simulink model for fuel price with and without transmission loss

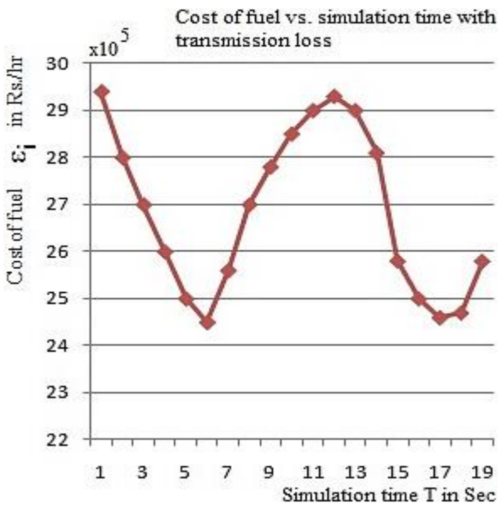

Figure 4. Variation of cost of fuel ε_i vs simulation time T for test case 2

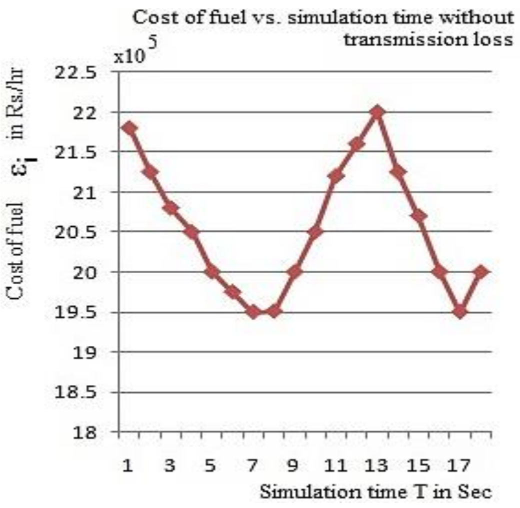

Figure 5. Variation of cost of fuel ε_i vs simulation time T for test case 2

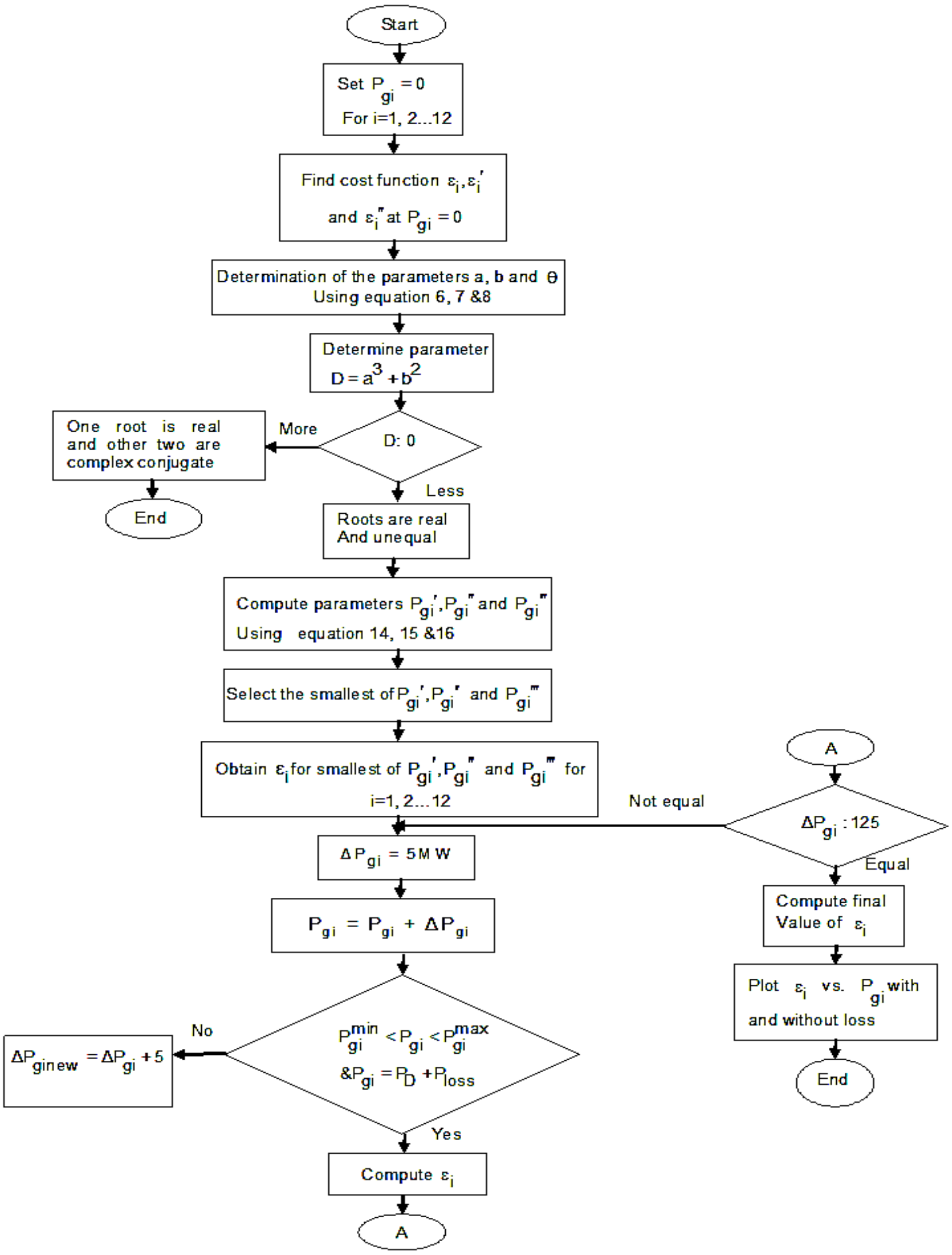

Figure 6. Flow chart for SLRDQED technique

4. RESULT DISCUSSION

The new SLRDQED methodology has been used to two test case systems, each one with 12 units, which include and exclude the transmission loss. Tables 3 and 4 show the numerical results and correlations with established and other heuristic approaches for optimal dispatch [25]-[27] The results obtained in Table 3 using proposed SLRDQED approach indicate a promising performance in terms of fuel costs which are reduced to 968843 Rs./hr and 533121Rs./hr with and without transmission loss respectively. The proposed test case system when tried by sine cosine (SC) algorithm, particle swarm optimization (PSO) technique [27]-[29], genetic algorithm (GA) and traditional lambda iteration method. it is found that sine cosine algorithm method proved costlier over the proposed SLRDQED method followed by genetic algorithm technique, based hybrid solar thermal technology (BHSTT), PSO technique and lambda iteration technique respectively. In the electric power market the supplier should be able to deal with generating units [29] to meet out load requests as quick as possible failing which there will be bottle necks in transmission line or in system constraints. Results proved that proposed SLRDQED method outsmarts other heuristic and traditional approaches in treating the cost of fuel of thermal power plants.

Table 3. Comparison of cost of fuel for various soft computing methods for a PD=3,344 MW with loss

Method		λ Iteration	GA	PSO	SCA	SLRDQED
Load Demand in MW		3344	3344	3344	3344	3344
Generation Scheduling	U1	225	220	230	230	226.57
	U2	220	300	304	304	291.35
	U3	299	300	304	304	304
	U4	240	240	245	245	242.24
	U5	290	290	285	285	293.02
	U6	240	240	235	235	242.24
	U7	300	300	295	295	302.57
	U8	240	240	242	242	242.24
	U9	360	360	360	360	355.5
	U10	285	285	283	283	288.91
	U11	360	360	345	345	355.5
	U12	285	284	300	300	288.91
Cost in Rs./hr		968880	968876	968872	968865	968843

Table 4. Comparison of cost of fuel for various soft computing methods for a PD=2,676 MW without loss

Method		λ Iteration	GA	PSO	SCA	SLRDQED
Load Demand in MW		2676	2676	2676	2676	2676
Generation Scheduling	U1	180	180	185	185	181
	U2	170	170	168	168	172
	U3	230	232	232	230	233
	U4	190	192	192	185	194
	U5	230	228	228	234	234
	U6	195	192	190	190	194
	U7	240	242	242	242	242
	U8	195	195	193	193	194
	U9	280	306	300	300	285
	U10	216	230	240	240	231
	U11	280	280	281	284	285
	U12	230	230	225	225	231
Cost in Rs./hr		533170	533164	533161	533131	533121

5. CONCLUSION

This paper studies the optimization of fuel cost using the SLRDQED algorithm along with equality and inequality constraints for four different cases involving cubic cost functions to determine the optimum fuel cost. The results are compared for each case involving different heuristic methods. To obtain the optimum fuel cost, four different test cases are solved and compared with SLRDQED method including equality and inequality constraints. A complete assessment of the composition and optimization of the economic load dispatch problem was part of the proposed effort. It is validated that cubic cost functions are not only more précised ones but also characterized by pragmatic results. When the order of the system is going to be increased function results are enhanced than the previous order of the system. The SLRDQED approach will be more realistic in modeling the areas and the tie lines. Renewable sources can be put into service as alternative to static reactive power for better voltage profile. From the results it is concluded that this method is quite simple as compared to other algorithms used for economic dispatch problem. Because the remedy is defined in terms of mainly two values, the procedure for solving it is simplified. The proposed method is also applicable to higher level polynomials such as third-degree polynomials, quintic polynomials, and nth degree polynomials. The SLRDQED method solved not just two roots but also complicated roots with ease. Iteration takes much less time than other numerical as well as vibrant programming techniques. The formulae for assessing cubic equations are somewhat difficult to use in order to analyze the collected data. However, this paper showed that it was possible to ease the expression for cubic equation solutions using a method that required only estimation of the utilitarian utility and the parody at this value, which makes the cubic equation’s second derivative zero.

6. FUTURE WORK

SLRDQED algorithm can be combined with other simple optimization techniques to improve their performance when applied to ELD problems and obtain better results. Bus data and line data of the system can be taken as input along with the load demand to obtain the minimization function with constraints on voltage and reactive power at various points of the system.

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