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# Optimal Scheduling Thermal Systems Using A New Improved Lambda Iteration Method And Particle Swarm Optimization Technique

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***Abstract*—The product of Electricity Energy is one of the main problems for improvement of Country's economy. The main sources for the production of the electricity are water, coal, diesel and others various fuels. In this paper we will model the problem of the energy product in the Thermal Station, which is a non-linear optimization problem in short term thermal scheduling problem. We propose a new improve lambda iteration method (NLIM) to solve the Economic load dispatch problem (ELD). We compare the classic lambda iteration method (LIM) with propose lambda iteration method (NLIM) to solve the ELD problem. We take in consideration also basic PSO (particle swarm optimization) like an effective technique to solve large scale non linear optimization problems. The study take in consideration seven generators thermal of the Kosovo's Thermal Station (KOV).**

***Keywords—Economic load dispatch, new lambda iteration method (NLIM), lambda iteration method (LIM), Particle Swarm Optimization (PSO).***

## I. Introduction

Economic load dispatch (ELD) is a non-linear optimization problem which occupies an important place in the product system of the electricity.

To solve the ELD problems methods are used several methods as conventional methods of Lagrange Multiplier (LIM) method [1,2], Karush Kuhn Tucker Conditions (KKT) [3,4] ect. The Lagrange Multiplier method (LIM) is the most common methods used due to its easy implementation.

Also, evolutionary algorithms of the behavior and random research as Genetic algorithm (GA) [5], Particle swarm optimization (PSO) [6] are implemented in ELD problems. In PSO, each individual makes its decision based on its own experience together with other individual`s experiences. The individual particles are drawn stochastically towards the position of present velocity of each individual, their own previous best performance, and the best previous performance of their neighbors. PSO have been successfully applied to various fields of power system optimization in recent years such as reactive power and voltage control, power system stabilizer design and dynamic security border identification.

The individual particles are stochastically drawn towards the position of present Velocity of the each individual, on their best previous performance, and the best previous performance of their neighbors.

ELD problem is solved for a seven-unit generating using the conventional method (LIM), the propose method (NLIM) and PSO method.

In this paper we will solve the problem Economic Load Dispatch of Kosovo Energy Corporation JSC.

## II. Economic Load Dispatch Formulation

The main goal of an ELD problem is to find the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. ELD problem finds the optimal output $P_g$ to minimize the cost of power generation from all generators with different cost functions to supply specific load demand $P_D$. The fuel cost curve for any unit is assumed to be approximated by segments of quadratic functions of the active power output of the generator. For a given power system network, the problem may be described as optimization (minimization) of total fuel cost as defined by [1] under a set of operating constraints.

The objective function is minimizing the cost subjected to the following generator capacities and active power balance constraints [10]

$$F_T = \sum_{i=1}^{n} F(P_i) \quad (1)$$

Where $F_T$ is total fuel cost of generation in the system (\$/hr), *Pi* is the power generated by the *i-th* unit and *n* is the number of generators.

The fuel cost function of thermal generating unit *i* at time interval *t* can be expressed as a quadratic function as follows:

$$F(P_{i,t}) = c_i + b_i P_{i,t} + a P_{i,t}^2 \quad (2)$$

where $a_i, b_i, c_i$ are the fuel cost coefficients of the *i*-th thermal unit ( $a_i$ is a measure of losses in the system, $b_i$ is the fuel cost and $c_i$ is the salary and wages, interest and depreciation), $P_{i,t}$ is the real output power (MW) , $F_i(P_{i,t})$ is the operating fuel cost ( $/hr), *FT* is the total fuel cost of the system ($), T is the total number of time intervals for the scheduling horizon, G is the total number of thermal generating units

Generator capacities and active power balance constraints are:

$$P_i^{min} \le P_i \le P_i^{max} \quad for \ i = 1,2,\dots,n \quad (3)$$

where $P_i^{min}$ and $P_i^{max}$ are the minimum and maximum power output of the i-*th* unit.

$$P_D = \sum_{i=1}^{n} P_i - P_{loss} \quad (4)$$

where $P_D$ is the total power demand and $P_{loss}$ is total transmission loss. We consider $P_{loss}$ negligible.

With losses neglected, the fuel cost will be subjected to the power balance equation given as $P_D = \sum_{i=1}^{n} P_i$ which can be rewritten as

$$P_D - \sum_{i=1}^{n} P_i = 0 \quad (5)$$

## III. THE PROPOSE LAMBDA ITERATION METHOD (NLIM) AND LAGRANGE MULTIPLIER (LAMBDA ITERATION METHOD)

### A. *Lagrange multiplier, lambda iteration method (LIM)*

The ELD problem is a minimization problem with a single equality constraint. For an unconstrained minimization a necessary (but not sufficient) condition for a minimum is the gradient of the function must be zero. The gradient generalizes the first derivative for multi-variable problems:

Lets give the Lagrangian function

$$L: R^n \times R^m \times R^p \to R$$

$$L(P_i, \lambda) = F_T + \lambda( P_D - \sum_{i=1}^{7} P_i) \quad (6)$$

where $\lambda$ is the Lagrangian Multiplier.

The ELD problem is equivalent with Lagrangian minimizing giving by (6).

In order to $P^* = (P_{G1}^*, P_{G2}^*, \dots, P_{G7}^*)^T \in R^7$ minimize the Langrangian function $L(P_i, \lambda)$ its gradient must to be equal to zero.

$$\nabla L(P_i, \lambda) = 0 \quad (7)$$

Differentiating $L(P^*, \lambda^*)$ with respect to the generation *Pn* and equating to zero gives the condition for optimal operation of the system.

$$\frac{\partial L}{\partial P_n} = \frac{\partial F_T}{\partial P_n} + \lambda(0-1) = 0 \quad (8)$$

$$\frac{\partial F_T}{\partial P_n} - \lambda = 0 \quad (9)$$

Differentiating $F_T$ which is given by formula (1), we take

$$\frac{\partial F_T}{\partial P_n} = \frac{\partial F_n}{\partial P_n} = \lambda \quad (10)$$

Therefore the condition for optimum operation is

$$\frac{\partial F_1}{\partial P_n} = \frac{\partial F_2}{\partial P_n} = \cdots = \frac{\partial F_7}{\partial P_n} \quad (11)$$

This problem is solved with conventional LIM method [1, 2].

### B. *Proposed lambda iteration method (NLIM)*

Usually the conventional LIM method starts from an initial approximation of lambda. Doing several proves for solving the ELD problems we propose a better initial approximation value of lambda multiplier Lagrange. By using this better initial approximation value of lambda multiplier Lagrange we take the optimal result with less number of iteration.

Algorithm of the proposed method:

Step1. Initialize initial values, the number of generation units n, *Pd* the energy to be produced, limit values generating units (*Pmin, Pmax*), vectors that determine the cost of producing energy from each unit (a, b, c), the limit on the number of iterations *(n-max*), tolerance (*tol*).

Step 2. Computes

$$\lambda_0 = max(b_i) + \frac{P_d}{\sum_{i=1}^{n} Pmax(i)} \quad (12)$$

$$S = \sum_{i=1}^{n} \frac{1}{a_i} \quad (13)$$

Step 3. Compute the power product in units

$$Pg(i) = \frac{\lambda - b_i}{2a_i}, i = 1, n \quad (14)$$

Step 4. Compute the total energy

$$Pt = \sum_{i=1}^{n} Pg(i) \quad (15)$$

Step 5. Compute the difference

$$d = Pd - Pt \quad (16)$$

Step 6. Compute the coefficient changed by lambda in following iteration

$$\Delta P = \left|\frac{d}{s}\right| \quad (17)$$

Step 7. Compute $\lambda_{i+1}$ for the other iteration

$$\lambda_{i+1} = \begin{cases} \lambda_i + d, d > 0 \\ \lambda_i - d\ d < 0 \end{cases} \quad (18)$$

Step 8. Compute

$$eps = |Pd - Pt| \quad (19)$$

Step 9. If it is not passed the maximal number of iterations and is not obtained the eps desired go to step 4.
Step 10. Display the results and notify if it is overpass the maximal number of iterations.

## IV. Particle Swarm Optimization (PSO) for ELD Problems

Particle swarm optimization (PSO) is a population based stochastic optimization technique, inspired by social behaviour of bird flocking or fish schooling. It is one of the most modern heuristic algorithms, which can be used to solve non linear and non continuous optimization problems. PSO shares many similarities with evolutionary computation techniques such as genetic algorithm (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as mutation and crossover. The PSO algorithm searches in parallel using a group of random particles. Each particle in a swarm corresponds to a candidate solution to the problem. Particles in a swarm approach to the optimum solution through its present velocity, its previous experience and the experience of its neighbours. In every generation, each particle in a swarm is updated by two best values. The first one is the best solution (best fitness) it has achieved so far. This value is called *Pbest*. Another best value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called *Gbest*. Each particle moves its position in the search space and updates its velocity according to its own flying experience and neighbour's flying experience.[10, 11]
The basic concept of the PSO technique is given firstly by Kenedy and Eberhart 1995 [9].
PSO, as an optimization technique gives a research procedure in which the particles change their positions depending by time. The swarm flying in the multidimensional research space, with the goal to find the optimal solution. Each swarm *i* in d-dimensional space, have its vector of position and vector of velocity which are given respectively. $X_i = (x_{i1}, x_{i2}, \dots, x_{id})$ and $V_i = (v_{i1}, v_{i2}, \dots, v_{id})$.
The best position of the swarm *i* is given by $Pbest_i = (Pbedt_{i1}, Pbest_{i2}, \dots, Pbest_{id})$. The best position of all swarms $Gbest_d$. After finding the two best values, the particle updates its velocity and positions with following equation (8) and (9) as

$$V_{id}^{k+1} = w \times V_{id}^k + C_1 \times rand(\ \ ) \times \left(Pbest_{id} - V_{id}^k\right) + C_1 \times rand(\ \ ) \times \left(Gbest_{id} - V_{id}^k\right) \quad (20)$$
$$i = 1,2, \dots, N_p\ ; d = 1,2, \dots, N_g$$

Where $N_p$ and $N_g$ the number of swarm and the number of coordinates of a swarm. $V_{id}^k$ is the velocity of swarm *i* at *k-th* iteration, *w* is the inertia weight provides a balance between global and local explorations, $C_1$ and $C_2$ are constants which pulls each particle towards Pbest and *Gbest* positions, *rand* ( ) uniformly expand in [0,1].
The position of each swarm change by using the modified velocity in (20) as

$$X_{id}^{k+1} = X_{id}^k + V_{id}^{k+1} \quad (21)$$

The inertia weight is set according to the following equation

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \quad (22)$$

where $w_{max}$- maximum value of weighting factor
$w_{min}$ - minimum value of weighting factor
$iter_{max}$- maximum number of iterations
*iter*- current number of iteration

when any optimization process is applied to the ELD problem, some constraints are considered. In this work three different constraints are considered. Among them the equality constraint is summation of all the generating power must be equal to the load demand and the inequality constraint is the powers generated must be within the limit of maximum and minimum active power of each unit.

The sequential steps of the proposed PSO method are given below. [1, 2]

Step 1. The individuals of the population are randomly initialized according to the limit of each unit including individual dimensions. The velocities of the different particles are also randomly generated keeping the velocity within the maximum and minimum values.
Step 2. Each set of solution in the space should satisfy the equality constraints. So equality constraints are checked. If any combination doesn't satisfy the constraints then they are set according to the power balance equation.
Step 3. The evaluation function of each individual $P_i$ is calculated in the population using the evaluation function $F(P_i)$ . The present value is set as the value *Pbest.*
Step 4. Each *Pbest* values are compared with the other *Pbest* values in the population*.* The best evaluation value among the *Pbest* is denoted as *Gbest.*
Step5. The member velocity v of each individual *Pg* is modified according to the velocity update equation (20).

Step6. Check the velocity constraints of the members of each individual.
Step7. The position of each individual is modified according to the position update equation (21).
Step 8. If the evaluation value of each individual is better than previous *Pbest* , the current value is set to be *Pbest*. If the best *Pbest* is better than *Gbest* , the value is set to be *Gbest* .
Step 9. If the number of iterations reaches the maximum, then go to step 10. Otherwise, go to step 2.
Step 10. The individual that generates the latest *Gbest* is the optimal generation power of each unit with the minimum total generation cost.

## V. CASE STUDY

The case study taken in consideration is the Kosovo Thermal Station, which consists on to thermo-station 'Kosovo A" ( TEC Kov A), 'Kosovo B"( TEC Kov B). This generative station consists in five generator units in TEC Kov A and two generator units in TEC Kov B. The annual production of TEC Kov A is 1500GWh while The annual production of TEC Kov B is 3650GWh. Mainly the production of electricity in Kosovo is covered from the production of thermo-station (97%), which is the most potential sector. TEC Kov A and TEC Kov B works with coal. The scheduling time period is one day with 24 intervals study of one hour period. The Fuel cost coefficients and the minimum and maximum limits of seven thermal generating units are given in table 1. The load demand over the 24 hours is given in table 2.

TABLE I. THE FUEL COST COEFFICIENTS AND THE MINIMUM AND MAXIMUM LIMITS OF SEVEN THERMAL

| Unit | $P_g^{max}$ MW | $P_g^{min}$ MW | $a_i$ \$/MWh | $b_i$ \$/MWh | $c_i$ \$/h |
|---|---|---|---|---|---|
| $P_1$ | 55 | 34 | 0.0024 | 2.10 | 90 |
| $P_2$ | 99 | 72 | 0.0028 | 2.00 | 100 |
| $P_3$ | 153 | 115 | 0.0035 | 1.85 | 120 |
| $P_4$ | 153 | 115 | 0.0035 | 1.85 | 120 |
| $P_5$ | 157 | 118 | 0.0037 | 1.85 | 120 |
| $P_6$ | 309 | 170 | 0.0040 | 1.41 | 200 |
| $P_7$ | 309 | 170 | 0.0040 | 1.41 | 200 |

Where *g* are generator units, *Pmin* and *Pmax* are minimum and maximum power boundary of the generator, $a_i$ is a measure of losses in the system, $b_i$ is the fuel cost and $c_i$ is the salary and wages.

TABLE II. THE LOAD DEMAND OVER THE 24 HOURS

| *h* | $P_D$ *(MW)* | *h* | $P_D$ *(MW)* | *h* | $P_D$ *(MW)* | *h* | $P_D$ *(MW)* |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 7 | 775 | 13 | 1200 | 19 | 950 |
| 2 | 645 | 8 | 800 | 14 | 1150 | 20 | 925 |
| 3 | 675 | 9 | 825 | 15 | 1125 | 21 | 800 |
| 4 | 700 | 10 | 900 | 16 | 1040 | 22 | 875 |
| 5 | 750 | 11 | 925 | 17 | 975 | 23 | 720 |
| 6 | 775 | 12 | 1100 | 18 | 1000 | 24 | 650 |

## VI. RESULTS AND DISCUSSION

We have proved some manner to choice the initial lambda value for the LIM method. In table 3 is given the number of iteration that the LIM algorithm need for different choices of initial lambda value, to product the same energy Pd = 1000.

TABLE III. THE NUMBER OF ITERATION NEEDED FOR DIFFERENT CHOICES OF INITIAL LAMBDA VALUE, TO PRODUCT THE SAME ENERGY $P_D = 1000$.

| **Lambda** | **Nr. of iterations** |
|---|---|
| $\boldsymbol{min(b_i)}$ | 47 |
| $\boldsymbol{max(b_i)}$ | 40 |
| $\boldsymbol{mean(b_i)}$ | 43 |
| $\mathbf{max}(\boldsymbol{b_i}) + \boldsymbol{P_d} / \sum_{i=1}^{n} \boldsymbol{Pmax(i)}$ | 28 |

As we see from the table 3, if we start from an approximation initial lambda value $\lambda_0$ proposed by us in (12), the NLIM needs less iterations than LIM method which start from an whatever initial lambda $\lambda > 0$.
In the table 4 is given the *Pt* (power total) values, the total energy produced by generated units in each iteration by the proposed NLIM method. Starting from the Pd= 974.91 to the desired value Pd = 999.91 are needed 28 iterations.

TABLE IV. THE *PT* VALUES, THE TOTAL ENERGY PRODUCED BY GENERATED UNITS IN EACH ITERATION BY THE PROPOSED NLIM METHOD.

| $i$ | $Pt$ | $Fc$ | $i$ | $Pt$ | $Fc$ |
|---|---|---|---|---|---|
| 1 | 974.91 | 3169.4 | 14 | 998.45 | 3238.4 |
| 2 | 982.70 | 3192.1 | 15 | 998.73 | 3239.2 |
| 3 | 985.85 | 3201.3 | 16 | 998.96 | 3239.9 |
| 4 | 988.43 | 3208.9 | 17 | 999.15 | 3240.5 |
| 5 | 990.53 | 3215.0 | 18 | 999.31 | 3241.0 |
| 6 | 992.26 | 3220.1 | 19 | 999.43 | 3241.3 |
| 7 | 993.67 | 3224.3 | 20 | 999.54 | 3241.6 |
| 8 | 994.82 | 3227.7 | 21 | 999.62 | 3241.9 |
| 9 | 995.76 | 3230.5 | 22 | 999.69 | 3242.1 |
| 10 | 996.53 | 3232.7 | 23 | 999.75 | 3242.3 |
| 11 | 997.17 | 3234.6 | 24 | 999.79 | 3242.4 |
| 12 | 997.68 | 3236.1 | 25 | 999.83 | 3242.5 |
| 13 | 998.10 | 3237.4 | 26 | 999.86 | 3242.6 |
| 14 | 998.45 | 3238.4 | 27 | 999.89 | 3242.7 |

In the following table are given the results obtained from NLIM proposed algorithm for the ELD problem taken in consideration.

TABLE V. THE RESULTS OBTAINED FROM NLIM.

| Nr | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $P_d$ | 800 | 900 | 1000 | 1100 | 1200 |
| $P_1$ | 40.09 | 55.00 | 55.00 | 55.00 | 55.00 |
| $P_2$ | 72.00 | 99.00 | 99.00 | 99.00 | 99.00 |
| $P_4$ | 115.00 | 135.45 | 153.00 | 153.00 | 153.00 |
| $P_5$ | 118.00 | 128.13 | 150.91 | 157.00 | 157.00 |
| $P_6$ | 170.00 | 173.52 | 194.59 | 241.54 | 291.45 |
| $P_7$ | 170.00 | 173.52 | 194.59 | 241.54 | 291.45 |
| $FC$ | 2695.06 | 2955.82 | 3243.29 | 3557.73 | 3911.25 |
| $\lambda$ | 2.2923 | 2.7981 | 2.9666 | 3.3423 | 3.7441 |

The table 5 tells us how many does each unit produce in order that we take the value needed $P_d$ (MW), where $P_d$ is the required energy (MW), $P_i$ is the energy that which unit $i$ has to produce , $FC$ is fuel cost (Rs/h), $\lambda$ is the proposed lambda.

In the following figures are given respectively how the total energy ($P_T$) change depended from the number of iterations and the dependence of fuel cost (FC) from the number of iterations for the proposed method.

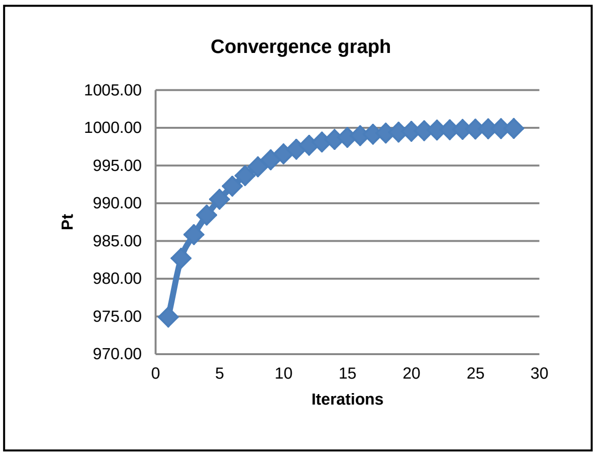


Fig. 1. The total energy change depended from the number of iterations.

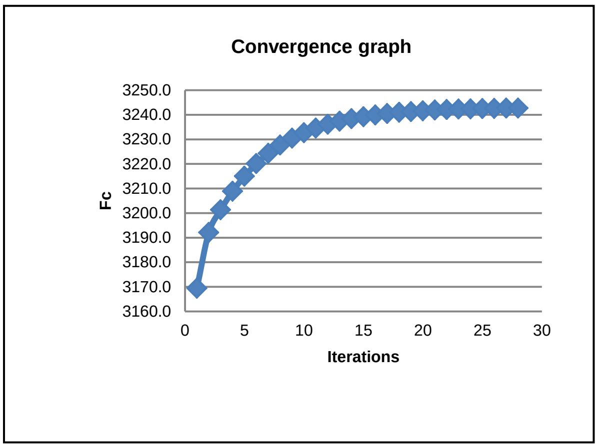


Fig. 2. The dependence of fuel cost (FC) from the number of iterations.

Solving the Economic Load Dispatch Problem Using Particle Swarm Optimization Technique. The results of PSO technique for each of seven generators unit production and the minimal cost are given in table 6.

TABLE VI. THE RESULTS OF PSO TECHNIQUE FOR ELD PROBLEM.

| Nr | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $P_d$ | 800 | 900 | 1000 | 1100 | 1200 |
| $P_1$ | 40.09 | 55.00 | 55.00 | 55.00 | 55.00 |
| $P_2$ | 72.00 | 99.00 | 99.00 | 99.00 | 99.00 |
| $P_4$ | 115.00 | 136.03 | 152.98 | 153.00 | 153.00 |
| $P_5$ | 118.00 | 128.03 | 150.42 | 157.00 | 157.00 |
| $P_6$ | 170.00 | 173.64 | 195.12 | 241.57 | 291.04 |
| $P_7$ | 170.00 | 173.75 | 194.46 | 241.42 | 291.95 |
| Costo | 2694.80 | 2955.60 | 3243.01 | 3557.40 | 3911.60 |

The following table presents data as *Gbest* varies depending on the number of iteration when $Pd = 1000$

TABLE VII. *GBEST* VALUE OF PSO TECHNIQUES.

| $i$ | 10000 | 20000 | 30000 | 40000 | 50000 |
|---|---|---|---|---|---|
| **Gbest** | 3334.37 | 3249.63 | 3244.09 | 3243.47 | 3243.11 |
| $i$ | 60000 | 70000 | 80000 | 90000 | 100000 |
| **Gbest** | 3243.04 | 3243.03 | 3243.02 | 3243.02 | 3243.01 |

The results above which are given in tables 6, 7 are illustrated with graphics as follow:

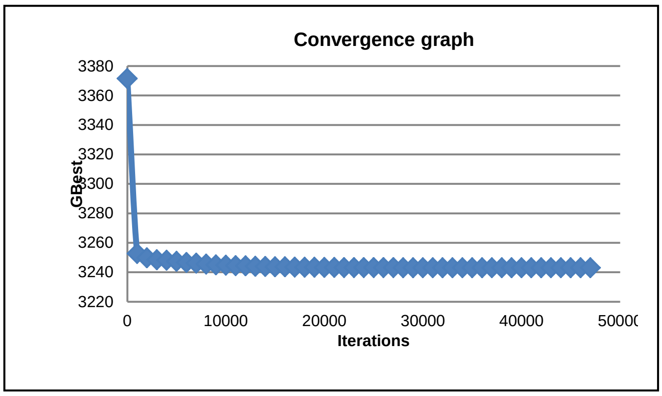


Fig. 2.The dependence of Gbest from the nr of iterations in case of $Pd = 1000$

From graphic we see that after 20000 iterations, we don't have any improvement of solution. The final value $Fc$ =3243.01 taken by the PSO technique is obtained in the moment when the algorithm does not have changes of the *Gbest* value in 5000 last iterations.
In the following table are given the fuel cost results taken by the proposed NLIM method and the PSO technique for various Pd values.

TABLE VIII. THE RESULTS OF NLIM AND PSO.

| $Nr$ | $P_d$ | $FC(LIM)$ | $FC(PSO)$ |
|---|---|---|---|
| **1** | 800 | 2695.06 | 2694.84 |
| **2** | 900 | 2955.82 | 2955.58 |
| **3** | 1000 | 3243.29 | 3243.01 |
| **4** | 1100 | 3557.73 | 3557.42 |
| **5** | 1200 | 3911.25 | 3911.62 |

Comparing the results of NLIM with PSO we see that PSO gives better solutions for Pd = 800, 900, 1000, 1100, while the NLIM method gives better solution for Pd=1200.

## VII. CONCLUSIONS

In this paper we proposed a new lambda iteration method (NLIM) for solving the economic load dispatch ELD problem. This paper demonstrates with clarity, chronological development and successful application of PSO technique to the solution of ELD. We have modeled the ELD problem for Thermal Station of KOSOVO, which is a seven generator system. We have tested the NLIM method compared with PSO technique in the ELD problem treated above. The proposed method is relatively simple, reliable and efficient and suitable for practical applications.

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