

# **Educational Software for Economic Load Dispatch for Power Network of Thermal Units Considering Transmission Losses and Spinning Reserve Power**

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## **Abstract:**

Power dispatching for generating units of a power network is one of the important considerations of economically optimized power system. The provision of total consumption load under various specified constraints requires determining the share of each generating unit in the best possible way. Minimization of the total fuel cost of all units is one of the basic objectives in large integrated networks. This is because a small percentage of saving in fuel consumption would yield considerable reduction in total costs and environmental degradation due to burning fuels..

This article introduces a highly capable software system that can be used in training of the generating units and network operators.

To this end, the existing methods and algorithms of optimal dispatch are briefly discussed . This paper considers transmission losses and the spinning reserve power that actually exists in the network. Also examined are refinements of the regular calculations for Economic Load Dispatch(ELD). By further refinement of ELD calculations, fuel costs of the generating plants and losses of the transmission systems are minimized, thereby improving the optimization of generating and transmission costs.

## **1 - Introduction**

The monotonically increasing global price of fuels and the inflation trend necessitate the frequent, if not continuous, monitoring and re-evaluation of the optimized dispatch in utilization of the power networks. Some constraints add to, and amplify the complexities of ELD calculations including the

diversity of power plant types (steam turbine, gas turbine, hydro-electric, solar, wind, nuclear...).[6]

Optimal dispatch requires:

- 1) minimization of fuel costs
- 2) transmission losses and environmental degradation,
- 3) due consideration of the specific constraints for each power plant.

In fact, from a mathematical point of view, the problem of ELD boils down to a large-scale, non-linear optimization problem with several constraints. Various methods are being used both individually and in combination to for optimize power dispatch. These methods include Lagrange Method, Lambda( $\lambda$ ) Iteration Method, 1<sup>st</sup> and 2<sup>nd</sup> -order Gradient Method, Coefficients of Sharing, Linear Programming, Neural Networks, Fuzzy Algorithms, ...<sup>[1]</sup>

In the arid and dry countries of the middle-east region, hydroelectric power plants have a negligible share in production of power. About 98% of the power originates from thermal units like steam turbines, gas turbines and combined-cycle units. Therefore, this article deals primarily with the thermal units.

The overall costs of the power networks can be classified in two categories of fixed costs (for construction of the power plants) and variable costs (for maintenance and operation of the units). In networks that mainly consist of thermal plants, the cost of fuel is more important and has a great impact on the problem of ELD and operation.<sup>[4]</sup>

## 2 Selection of the Method and Formulation of the Problem

This software system is based on the Lagrange Method, because it offers a precise, reliable and conclusive solution. Compared to other methods, the speed of convergence for this software is acceptable. These make it a suitable choice for the ELD problems.

## 3 Objective Function and Constraints

The objective function is introduced to minimize the total production costs of the generating units:

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

Where

$F_T$  : Total generating costs of all units

$F_i$  : Cost of the  $i^{\text{th}}$  unit

$P_i$  : Generating power of the  $i^{\text{th}}$  unit

$n$  : Number of units

As shown in the following two formulas,  $F$  is the product of heat function  $H$  by Cost.  $H$  quantifies the generating cost in terms of output MW, and it is a 2<sup>nd</sup> - or 3<sup>rd</sup> -degree function of the generating power of the unit that is also called "input-output curve". In the following formulas, "Rial" is the currency of Iran and 10000 Rials buy one USD(\$).

$$H_i(\text{Mbtu}/h) = A_i + B_i P_i + C_i P_i^2$$
$$F_i(\text{Rial}/h) = H_i(\text{Mbtu}/h) * \text{Cost}(\text{Rial}/\text{Mbtu})$$

For minimization of (1) the following constraints should be observed:

$$\phi = P_R - \sum_{i=1}^n P_i + P_{loss} = 0 \quad (2)$$
$$P_{min_i} \leq P_i \leq P_{max_i}$$

These constraints ensure that the total generating power equals the sum of power demands and transmission losses. Besides, each unit should operate within its own limits:

$\phi$  : Constraint Function

$P_R$  : Total consumed load

$P_{loss}$  : Total system losses

$P_{min_i}$  : Minimum generating power of the  $i^{\text{th}}$  unit

$P_{max_i}$  : Maximum generating power of the  $i^{\text{th}}$  unit

#### 4 Solution by Lagrange Method

The cost-minimization Lagrange function selected in this article is defined as follows:

$$L = F_T + \lambda \phi \quad (3)$$

In other words, the Lagrange function is defined by cost function  $F$  plus the constraint function  $\phi$  multiplied by a penalty coefficient  $\lambda$ . Then to minimize  $L$ , its derivative needs to be set to zero. Thereby, a system of simultaneous equations will be obtained that we may call "Coordination Equations", and their solution minimizes the costs.

$$\frac{\partial L}{\partial P_i} = \frac{dF_i}{dP_i} - \lambda \left( 1 - \frac{\partial P_L}{\partial P_i} \right) = 0 \quad (4)$$

The inequality conditions specified in (2) expand to the following set of equations:

$$\frac{dF_i}{dP_i} = \lambda \quad \text{for} \quad P_{min_i} < P_i < P_{max_i}$$

$$\frac{dF_i}{dP_i} < \lambda \quad \text{for} \quad P_i = P_{max_i}$$

$$\frac{dF_i}{dP_i} > \lambda \quad \text{for} \quad P_i = P_{min_i}$$

These inequalities signify the fact that any unit with incremental cost higher than  $\lambda$  is "expensive" and should be set to operate at lowest level of production.

In this way all equations are solved until all conditions are satisfied. The main point of consideration is analysing and limiting the level of production for each unit.

## 5 Modelling of Transmission Losses

The relation for the losses is based on the matrix B defined as follows:

$$P_L = P^T [B] P + P^T B_0 + B_{00} \quad (5)$$

Where

$P$  : A vector showing the net MW of all generating units

$[B]$  : A square matrix with dimensions equal to that of the vector  $P$

$B_0$  : A vector with length equal to that of  $P$

$B_{00}$  : A constant value

The equation (5) can be rewritten as follows:

$$P_L = \sum_{i=1}^n \sum_{j=1}^n P_i B_{ij} P_j + \sum_{i=1}^n B_{i0} P_i + B_{00} \quad (6)$$

Various methods are proposed for solving the matrix of losses, but they are cumbersome and presume solution conditions that never realize in a actual network. Therefore, the matrix of losses offers an approximate answer.

Here, the losses are assumed to be located at the main diagonal cells of the matrix  $[B]$ , as shown in the following formula:

$$P_L = a_1 P_1^2 + a_2 P_2^2 + \dots + a_n P_n^2 \quad (7)$$

This relation gives an acceptably good result that is close to real situation.<sup>[6]</sup>

## 6 Modelling of Spinning Reserve Power

The implemented algorithm of the software includes "spinning reserve power", i.e., generating capacity available from units that is not being used but is connected and synchronized with the grid to serve additional demand. The spinning reserve must be under automatic governor control to instantly respond to system requirements. The spinning power reserve is necessary for controlling the frequency within set limits in case one or more units get out of service.

The spinning power reserve does not add to the total demand for power.<sup>[2]</sup>

Modelling of the spinning power reserve should cover two cases:

Case 1: Reserve Power is less than the unused capacity of the active units, in which case the total cost remains unchanged.

$$\sum_{i=1}^n (Cost)_i = Cost_{Load} + Cost_{Reserve} \quad (8)$$

$$Cost_{Reserve} = 0$$

Case 2: Reserve Power exceeds the unused capacity of the active units. This necessitates an optimal activation of one or more inactive units. This adds to the running costs of the network.

$$\sum_{i=1}^n (Cost)_i = Cost_{Load} + Cost_{Reserve} \quad (9)$$

In both cases, the sum of generating power of thermal units is the same but in Case 1, fewer units with higher generating power energize the network, while in Case 2, more units operate at a lower generating power. Consequently, the total unused capacity is increased.

## 7 The Software Program

The program accepts all input data via interactive windows for user interface. For clarity and ease of use, the visual environment of the familiar GUI of the MATLAB is utilized. The program consists of three main windows for inputting the various categories of related data, as shown in Fig. 1, Fig. 2, and Fig. 3 and described in the following:

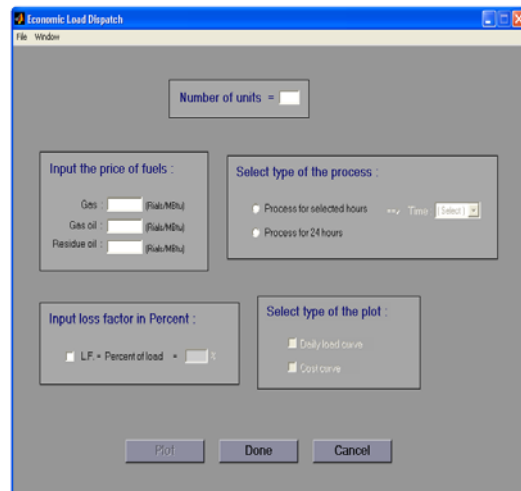


Fig. 1 – Economic Load Dispatch

**Economic Load Dispatch Window:** As can be seen in Fig.1, this window has five parts:

- 1- Number of Units: Up to 40 units can be introduced.
- 2- Price of Fuels: Allows inputting the cost of fuel for Gas, Gasoil, and Mazotte in terms of Rials per MBTU.
- 3- Loss Factor: For inputting the loss factor as a percentage of the load at that time. Inputting 0 prevents consideration of losses. If left blank, the losses are taken into account on the basis of afore-mentioned formuli.
- 4- Type of Process: Allows processing for 24 hours or less.
- 5- Type of Plot: Allows selection of daily load and cost curves.

**Unit Structure Window:** is shown in Fig. 2 below and is used to specify the structure of input data for units. Each part has the ON / OFF options to signify the status of the variables of the generating units. Also, space is provided for specifying the maximum/minimum levels of each variable. The "A", "B", and "C" coefficients of each unit correspond to the formulas for the objective function and the constraints. The coefficient "a" of each unit that refer to the formula (7) are also entered here. Since many units use various kinds of fuels, the type of fuel can be entered in this window.

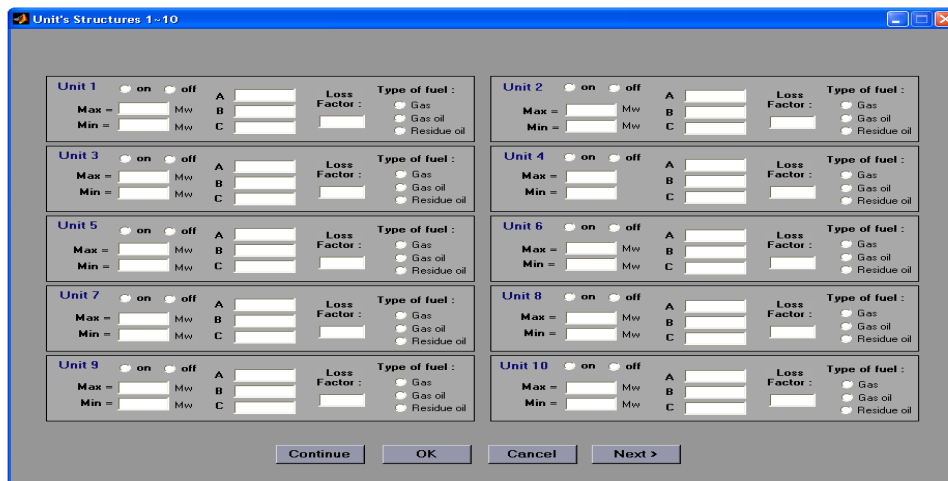


Fig 2. Unit's Structure Window (for upto 40 units)

The third window, namely, Daily Load and Reserve Load accepts the daily load and power reserve load. The reserve load can be specified as percentage of the hourly load or MW. Besides, a constant hourly reserve can also be specified.

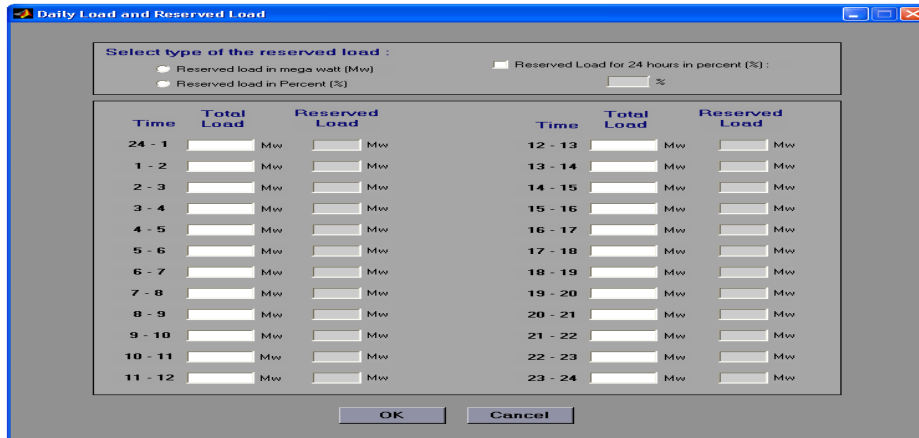


Fig. 3 – Daily Load and Spinning Reserve Power

Fig. 4 shows the "File" and "Window" menus.

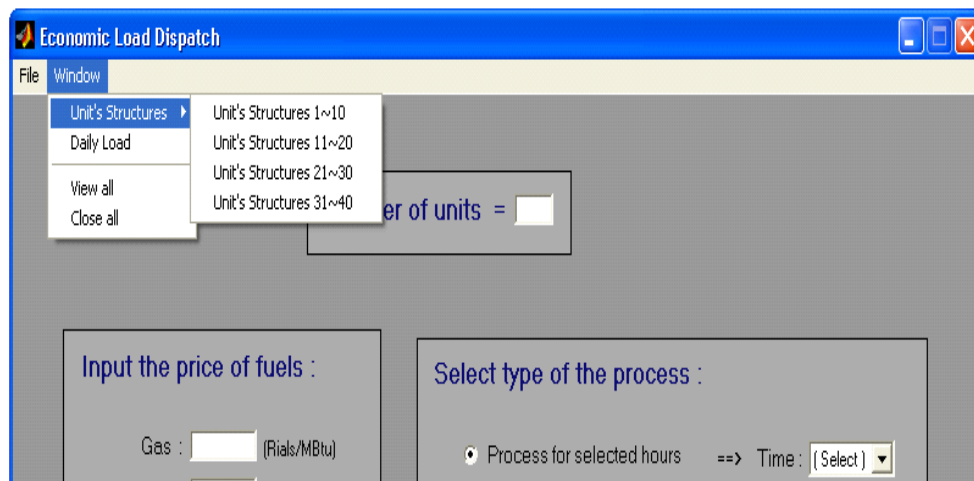


Fig. 4 – File and Window menus

The "File" menu allows saving of the data and calculations, for subsequent comparison with further calculations. The comparison of results from successive calculations is useful for studying the role and effect of each parameter on final results, thereby increasing the knowledge and insight of the operators of the units and the network.

The "Window" menu is designed to open, access and close various windows for inputting and editing data. When an incorrect or incomplete data is entered, an appropriate message will be displayed. In each window, the "OK" and "Cancel" buttons are used saving or discarding the input data.

When all data is input, pressing the "Done" button starts the calculations and the following results will be shown in the "Command" window.

- Date and Time of calculations
- Computed power produced in each unit
- The total figures for units' hourly production, load, and the costs.

```

MATLAB
File Edit View Web Window Help
-----
* 21-Jul-2003 12:36:19 *
-----
Time : 2-3

P1 = 21.1667 (Mw)
P2 = 21.1667 (Mw)
P3 = 21.1667 (Mw)
P4 = 21.1667 (Mw)
P5 = 21.1667 (Mw)
P6 = 21.1667 (Mw)
P7 = 0 (Mw)
P8 = 18 (Mw)
P9 = 18 (Mw)

-----
Sum of the units above is : 163 (Mw)
Total Load (in this time) is : 163 (Mw)

*****

* Total price is : 1.70138e+006 (Rials) *
-----
>> |
Ready

```

Fig. 5 shows a sample of output.

## 8 - Solving a Typical Example and Comparison of Results

To study and test the program, the following problem is solved:

For purposes of this research, the daily operation of a power station with 40 units is considered. The nominal installed power is 1270 MW, using the natural gas and gasoil fuels. Since this problem is limited to a single power station, no transmission losses are entered. The daily load is obtained from one day's operation of this power station. After inputting the data and calculations, the output results indicate that the economical dispatch calculations of this program reduce the cost of fuel consumption by 970,219 Rials per day or 400,000,000 Rials per year.

## 9- Conclusion

This article studied the subject of economic load dispatch for power stations and thermal units of a network, with the objective of minimizing the fuel costs. The fast, reliable method of Lagrange method was used that converges to a conclusive result.



The software program under consideration can be effectively used for educational purposes and operator training. This is done along with the various methods and algorithms of Economic Load Dispatch, and optional inclusion of the transmission losses and spinning reserve power that impose modifications on calculation formulas.

A comprehensive and complete programme for operator training empowers them to:

- objectively and precisely calculate the problem of Economic Load Dispatch,
- minimize fuel costs,
- minimize transmission losses
- consider spinning reserve power
- obtain a clear vision and insight of the problem

and is a step toward improvement and optimization of the power system monitoring and management.

Some factors complicate the problem including coordination of various generating units and power stations, environmental issues, upkeeping the system reliability. However, a proper operator training and educational programme with scientific and theoretical substantiation can greatly help the management of operations and dramatically reduce the non-recoverable costs.

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