Economic Operation of Libyan Western Electric Network Based on OPF and ED Algorithms

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Abstract

The optimal power flow becoming more important because of its capabilities to deal with various situations of power system operation, this problem involves the optimization of objective functions for power generation operation and control.

This paper investigating the optimal power flow (OPF) and Economic Dispatch (ED) of the western area of Libyan national network of (220 &400kv) system for optimizing power system losses and reducing fuel costs, by using different scenarios to keep the network operating in good condition, OPF and (ED) are formulated as an optimization problem for minimizing the total fuel cost and power loss of all committed plants while meeting the network operation constraints. Applying the OPF and ED as base for system analysis with a unified power flow controller (UPFC) solved most power system problems and maintains system stability even during difficult operation condition.

Keywords OPF, ED, UPFC, PF, optimization, MBTU, Heat rate curve, Cost rate curve

I- Introduction

Power system generally has several power plants, in which each has several generating units. The total load in the power system should be met by power generated of all power units in different power plants. Economic dispatch control determines the optimal power output of each power plant, and optimal power output of each generating unit within a power plant, that will minimize the overall cost of power production that includes the fuel cost, operation and maintenance (O&M).In economic dispatch practices there are many choices for determining the economic operating points of generators, the main aim of the economic dispatch is to analyze the system variables that affect the generator performance such as operational cost, the generator location, type of fuel, load capacity, and transmission line losses. By including these variables one can be able to perform an economic dispatch problem for minimizing the operating cost functions. The generation cost is typically represented by many curves, namely: Input/output curve (I&O), heat rate curve, fuel cost carves and incremental cost curve.(OPF) and (ED) are used for allocating loads to generator plants for minimum cost while meeting the network constraints [1].

II- Heat and Cost Rate Curves Construction.

The relation between fuel input and heat input with generated power output for the power generation units can be constructed and formulated by the initial tests of such units, those tests usually done by the manufacturers and given as a data sheet information to the users, and known as a standard heat rate curves for the units, So each thermal unit has its own thermal curves that will be used during its operation by the product engineers [2].

Also after years of operation the thermal units are deteriorated and the input-output relations are changed, as its efficiency is reduced, In such case a new data should be taken for each thermal unit, which will be possible only during maintenance periods or through events when the unit stops operation, and restarted, When starting the thermal units the data is collected per hour for fuel quantities and power output in MW.

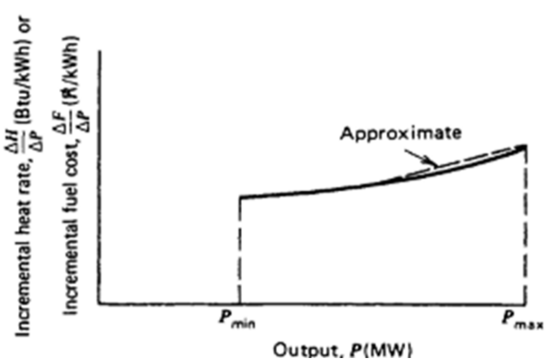

Fig (1) General heat rate and output power relationship [2].

In the heat rate curves data, the quantity of fuel in cubic meter or tons are transferred to British thermal unit (Btu) or (MBtu), against power output in MW, in the cost rate curves data, the cost of MBtu/h is calculated considering fuel cost including transportation, storage, and operation maintenance O&M cost of the unit operation, against output MW's, figure (1) shows the general heat in (MBtu/Mwh) and power output in MWH of thermal units [3].

III-Power System Of Western Libyan (220,400kv) Description.

The Western Libyan (220kv, 400kv) electric system consists of:

1- (9) Power plants and the total generation units are (40), and still there are some generation units under installation.

2- (115) 220kvbuses and (8) 400kvbuses connected with loads (3720MW)

3- Typical of a network clarified in figure (2).

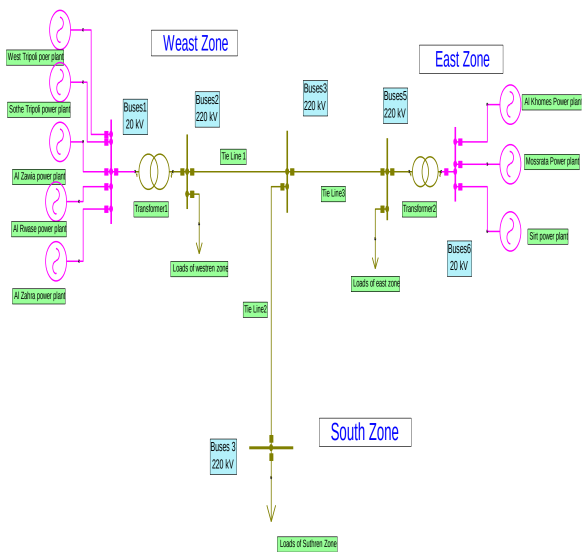

Fig (2) Typical of western Libyan power system.

IV- Heat Rate Equations Of Western Libyan (220KV-400KV) Network.

Each thermal unit operating data for fuel inputs and power output is considered. And by using the transformable procedure for the heat rate and cost relation with power outputs a curve fitting algorithms will be used to perform equation, relating such data.The heat rate and cost rate equations can be performed, considering only the second order for quadratic form, since the higher order power can be neglected, to simplify calculation and iteration procedure of solution, the equation are performed on the quadratic form as follows:-

Heat rate equation $(H) = AP_{gi}^2 + BP_{gi} + C$ (1)

Or

Cost rate equation $F(P_{gi}) = A'P_{gi}^2 + B'P_{gi} + C'$ (2)

Where:-

A, B, C, A', B', C' are generator constants

P_{gi} is the output power of the ith generator in MW

V- Economic Dispatch Model Of Power System.

Model can be performed through two deplanes:

a- Economic Dispatch Neglecting power system Losses.

A cost functions are assumed to be a known parameter for each plant. The variation of the dispatch functions with respect to active power generation is shown in Figure (1) ideally; they are monotonically increasing quadratic functions that given by the equations (1) or (2) above.

Now, the problem is to allocate the real power generation P_{gi} for each generator, in which the operating cost minimized & the generating limits are satisfied $P_{gi.min}$ & $P_{gi.max}$ which are the minimum and the maximum limits for each generator.

Suppose a generating station with NG generators committed to feed an active load demand of PD MW, The real power generated P_{gi} for each generator has to be allocated so as to minimize the total cost. Economic Dispatch attains its simplest form when the transmission losses are neglected. So, the total load demand PD is equal to the sum of power generated by t units, the optimization objective function can be written as:

$$Min\{F_i(P_{gi})\} = \sum_{i=1}^{N_g} F_i(P_{gi}) \qquad (3)$$

Equation (3) is subjected to

1-The equality constraints equation of the energy balance equation.

$$\sum_{i=1}^{N_g} P_{gi} = P_D \qquad (4)$$

2-The inequality constraints equation which are the generating limits, of each unit.

$$P_{gi_{min}} \leq P_{gi} \leq P_{gi_{min}} \qquad (5)$$

b- Economic Dispatch Considering power System Losses

Transmission losses are neglected when they are small in magnitude but when the length of transmission is large.

In case of large network; transmission losses become accountable and cannot be neglected. They affect the process of economic load dispatch [3]. The economic load dispatch [3]. The economic load dispatch problem, considering the transmission power loss Pl, for the objective function, is same as, equation (2) & equation (3). But what changes equality constraints which adding the term of Pl is added to the equations and defined in the terms of B-coefficients and changed as follows:-

1-The equality constraint, Energy Balance Equation gets modified to, be:

$$\sum_{i=1}^{N_G} P_{gi} = P_D + P_L \quad (6)$$

Where:

PL is the transmission power losses, in MW.

2-The system power losses PL should be formulated in terms of generated power and system parameters, in a quadratic form.

The general loss formula using B-coefficients is given by decoupling solution method, or extended Newton-Raphson method as [4].

$$P_L = \sum_{i=1}^{N_G} \sum_{i=1}^{N_G} P_{gi} B_{ij} P_{gi} + \sum_{i=1}^{N_G} B_{0i} P_{gi} + B_{00} \quad (7)$$

VI- Western Libyan Power Generators Heat Rate Curves.

The thermal heat rate (THR) test was originally designed as a diagnostic type of test. This test provides a broad range of data on the thermal efficiency and operating costs of the turbine steam cycle, and consequently of the entire unit. Moreover, it is standard practice to run a THR test in order to determine the overall efficiency of the system (since efficiency is the reciprocal of heat rate). And used load curve fitting to get quadratic function from real data as shown below, the graph in each plant uses a quadratic cost function such as the Fuel Cost Curve.

The western Libyan network heat-power data is collected through tests and those tests were implemented practically in the system power plants [5], the data are collected for:-

1. Misrata CCGT Generation Units HRC.

Figure (3) and Figure (4) shows the real test data for the generators starts from 85.5-to 285 MW output for GT generators. And from 40 -to 110 MW output for ST generators respectively.

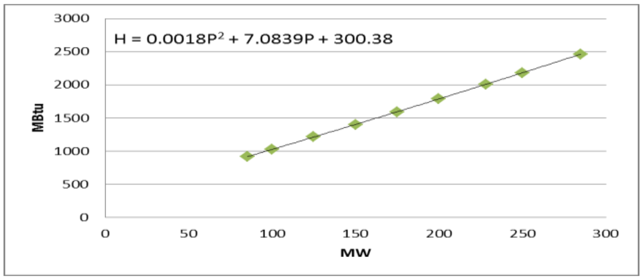

Fig (3) Heat rate curve for Misrata GT power plant with heat rat equation.

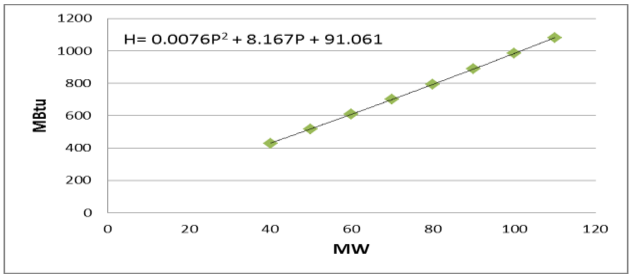

Fig (4) Heat rate curve for Misrata ST power plant with heat rat equation .

1. **Khoums GT&ST Generation Units HRC.**

Figure (5) shows the real tests data for GT generators starts from 26.7 to 136 MW, and Figure (6) shows the real test data for ST generators 40 to 110 MW outputs respectively.

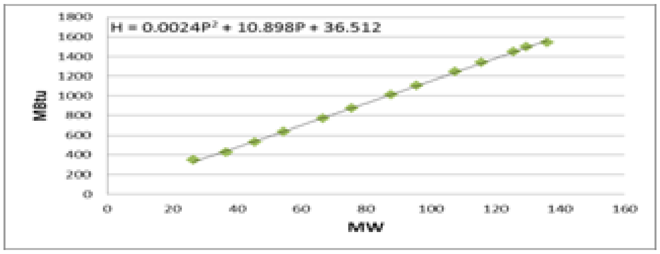

Fig (5) Heat rate curve for Khoums GT power plant with heat rate equation

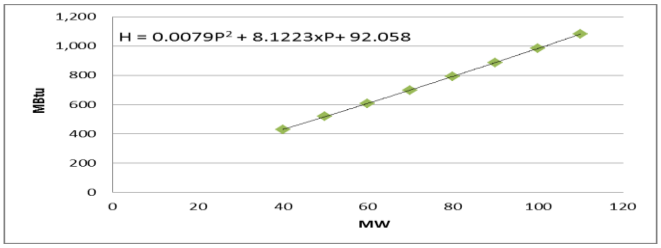

Fig (6) Heat rate curve for Khoums ST power plant with heat rat equation.

2. West Mountain GT Generation Units HRC.

Figure (7) shows the real test data for the generators start from 15 to 150 MW output the last column is calculated.

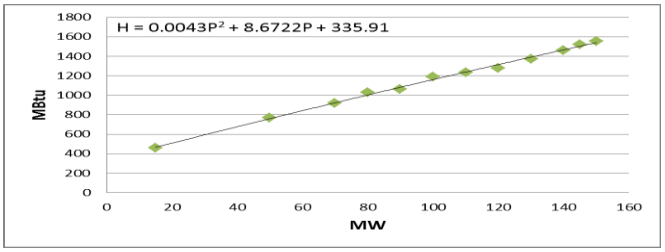

Fig (7) Heat rate curve for West Mountain GT power plant with heat rat equation

3. Tripoli South GT Generation Units HRC.

Figure (8) shows the real test data for the GT generators starts from (20.6) MW output up to (96.1) MW output the last column is calculated.

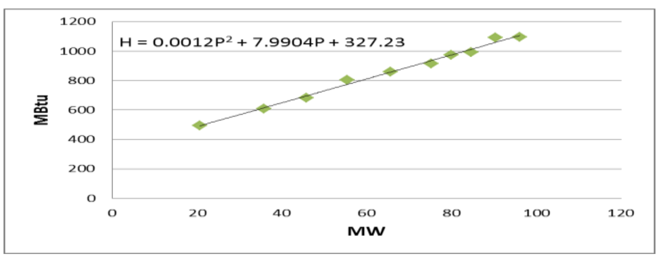

Fig (8) Heat rate curve for Tripoli South GT power plant with heat rate equation.

4. Tripoli West GT&ST Generation Units HRC.

Figure (9) shows the real tests data for the GT generators starts from (12.5 to 40) MW output and Figure (10) shows the test data for ST generators from 50 to 105 MW output respectively.

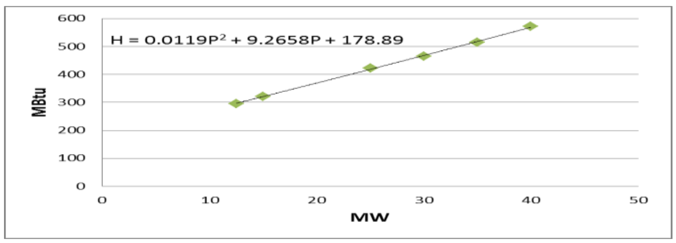

Fig (9) Heat rate curve for Tripoli West GT power plant with heat rat equation.

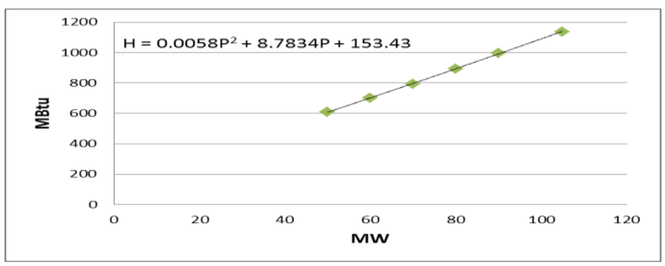

Fig (10) Heat rate curve for Tripoli West ST power plant with heat rat equation.

5. Zawia GT&ST Generation Units HRC.

Figure (11) shows the real tests data for the GT generators starts from 12.5to 140 MW output and Figure (12) shows the real data for ST generators from 50 to 140 MW output respectively and the last column is calculated.

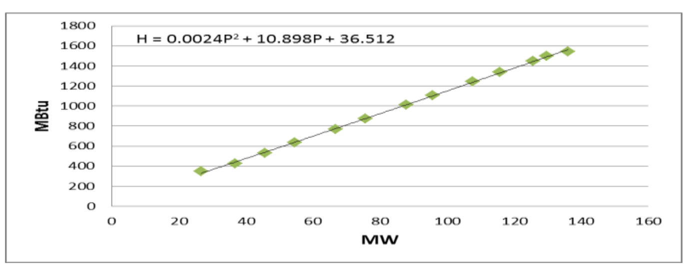

Fig (11) Heat rate curve for Zawia GT power plant with heat rat equation .

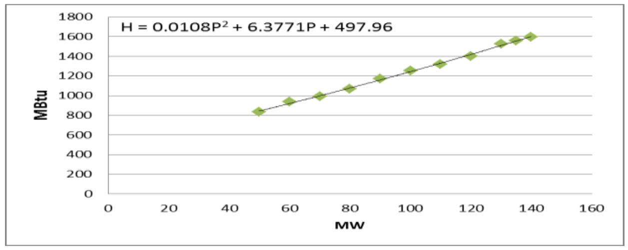

Fig (12) Heat rate curve for Zawia ST power plant with heat rat equation.

6. AL Zahra GT Generation Units HRC.

Figure (13) shows the real test data for the generators starts from 20.6 to 96.1 MW output the last column is calculated.

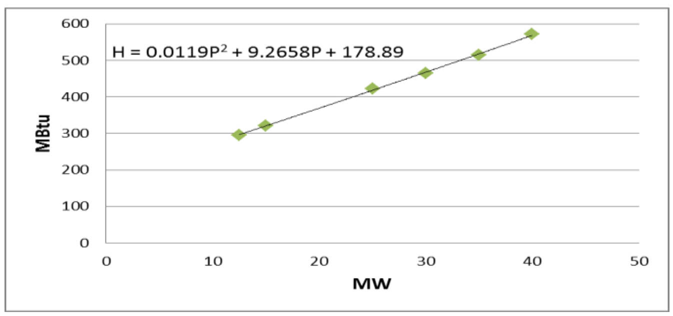

Fig (13) Het rate curve for AL Zahra GT power plant with heat rate equation.

VII- First Case Study For Western Libyan Network.

Applying power flow analysis for the western Libyan grid system considering ED and OPF operation of the system and comparing the result with normal power flow NFL for many different loading percentage to specify optimal operating point as shown in figure (14), the optimal power flow analysis results at peak loading only are summarized and shown in table (1).

Table (2) shows the results of OPF and ED load flow at peak loads also.

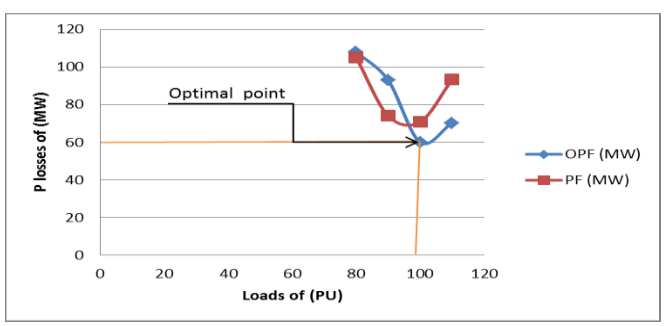

Fig (14) Comparing result between power flow and OPF.

Table (1) summarizes the load flow results of normal case study.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
70.803	-1920.063	287.011	28.985	3791.153	976.03	3720.35	1795.456	39332.784

Table (1) shows the result in normal load flow of Libyan electric power system, where the cost is found to be 39332.78 MMBtu/hr.

Table (2) results of first case study for ED, OPF case.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
59.977	-2000.027	262.347	28.582	3780.327	895.849	3720.35	1795.456	36867.838

Table (2) clarifies the improving result with optimal power flow for western electrical grid and reducing the generator cost as mentioned above where the cost was found to be 36867.838 MMBtu/hr. That means a 2464.942MMBtu/hr. are saved plus the reduction of power loss of 10.891 MW/hr.

VIII- Second Case Study Is Injecting SIRT Power Plant With Western Libyan Power System.

In this case applying Normal Load Flow analysis for the western power system with SIRT power plant is connected. Also considering ED and OPF operation of the system, tables (3) & (4) summarize the normal power flow and optimal power flow results respectively.

Table (3) summarizes the load flow results of normal case study.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
69.029	-1938.022	30.237	-37.232	3789.379	888.433	3720.35	1795.456	42000.62

Power flow studies of this case shows not too much change from the first case, only the power supplied by SIRET power plant is added to the main network; it cause reducing in imported power from east area, and increasing in generator cost and power loss is still in the same ranges the generation cost is 42000.62 MMBtu/hr. and power loss of 69.029 MW .

Tables (4) result of first case study for ED, OPF case.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
58.119	-2016.042	187.911	-43.53	3778.469	806.431	3720.35	1795.456	37674.927

Table (4) clarifies the improving result with SIRT power plant in optimal power flow to reduce losses to 58.119 MW and fuel cost of 37674.927 MMBtu/hr. that the power loss reduced by 10.91 MW/hr. and 4325.693 MMBtu/hr. for western electrical grid.

IX -Third Case Study Adding OBARY And SIRT Power Plants to Western Libyan Power System.

In this case connecting OBARY and SIRT power plant in southern zone so that increasing generation production, and disconnecting the compensation of UBFC that has been already connected with network for enhancement and Applying normal load flow analysis for the western grid system at different loading conditions in order to specify optimal point, and then considering ED and OPF operation of the system.

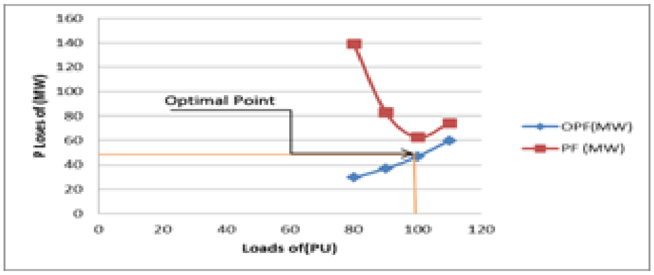

Fig (15) Comparing result between power flow and OPF.

Table (5) NPF result for western Libyan network with OBARY and SIRT power plants.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	MBtu/h
62.481	-1894.93	-61.311	-10.513	3844.142	1025.162	3781.661	1805.969	42840.79

The result in table (5) shows the participating OBARY power plant with western Libyan electric power system and solved the problem in the voltage profile of buses in the southern zone, which are keeping the voltage within the requiring limits.

Table (6) OPF result of western Libyan network with OBARY power plant.

P Loss	Q Loss	P Imp	Q Imp	P Gen	Q Gen	P Load	Q Load	Gen. Cost
MW	MVar	MW	MVar	MW	MVar	MW	MVar	Mbtu/h
46.741	-2043.216	162.146	-35.39	3767.091	872.173	3720.35	1795.456	38033.663

Table (6) clarifies the improving result with OBARY power plant with optimal power flow for western electrical grid, and the results are more improved in the benefits of OPF

analysis such as power loss reduction of about 16MW/hr., and fuel cost reduction that equivalent of about 4800 MMBtu/hr., and since 1MMBtu/hr. equals 0.293297222 MW which means about 1408 MW are Saved that about 12% of total is saved, plus the 16 MW of power loss that saved besides the enhancement of the voltage profile and system stability

X -Conclusions.

This research studied and solves the economic dispatch operation problems based on Optimal Power Flow OPF for western Libyan Electric power system.

Two objective function were considered for optimization procedure; the first for heat rate changes that represent heat rate parameters in MBtu/h or cost rat parameter of $/h at different load changes, and the second objective function represents the power system losses in terms of power flow of (P&Q) and system constants of line and transformers parameters. Many scenarios are considered for analysis of western Libyan electric network of (220,400) KV. Studies were performed on the network with and without ED operation. The NEPLAN software is used for system simulation and analysis checking the impacts of the ED and OPF on system performance.

The results, shows the grate impacts of using ED based on OPF that can be summarized as follows:

1- Decreasing power system losses and maintaining system stability.

2- High reduction of fuel cost that including operation, maintenance and power system losses that reached 12% at peak load.

3- The interconnecting of new power plants is considered such as OBARY Power plant that adds a better performance of the system

4- This research adding a good information to GECOLE about the Economic operation of Libyan Electric Grid

5- Results of this Study can be implemented directly by GECOLE that will reduce Millions of Dinars to the Company.

XI-Acknowledgment

We would like to express our sincere gratitude to general electrical company of Libya, and the Support of Libyan Authority for Scientific, Technology & research (LASTAK).

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