Electrical, Control and Communication Engineering
ISSN 2255-9159 (online)
ISSN 2255-9140 (print)
2021, vol. 17, no. 1, pp. 39–46
https://doi.org/10.2478/ecce-2021-0005
https://content.sciendo.com

Economic Dispatch with Transmission Losses in a Distributed Generation Network of Bahawalpur

Ahmad Khan (*M. Sc. Student, The Islamia University of Bahawalpur, Bahawalpur, Pakistan*),
Zeeshan Rashid* (*Assistant Professor, The Islamia University of Bahawalpur, Bahawalpur, Pakistan*),
Farhana Umer (*Assistant Professor, The Islamia University of Bahawalpur, Bahawalpur, Pakistan*),
Abdur Rehman Yousaf (*Lecturer, The Islamia University of Bahawalpur, Bahawalpur, Pakistan*),
Arif Saeed (*Lecturer, Institute of Southern Punjab, Multan, Pakistan*)

Abstract **– In an electrical power system, the ultimate aim is to generate and deliver electrical energy to consumer side with minimum cost involved. Thus, least fuel cost, effective unit commitment and minimum transmission losses are desirous to achieve economic dispatch in a distributed generation network. In this research, economic dispatch considering transmission losses in a distributed generation network of Bahawalpur is reported. A MATLAB algorithm is designed which gives optimum division of power between two power plants and their transmission losses. Power plants considered here are thermal power plant Muzafargarh and Kot Addu Power Company (KAPCO), the former being located at smaller distance from Bahawalpur district. Finally, load trend of Bahawalpur district, optimum generation verses power demand, associated transmission losses, penalty factor and fuel cost economy are shown in the Results Section through graphs and tables. It is concluded that thermal power plant shares higher contribution of load power due to smaller distance from load and, thus, smaller transmission losses ensuring minimum cost operation.**

Keywords **– Cost benefit analysis; Cost function; Iterative algorithms; Optimization methods; Power generation dispatch; Power system economics.**

I. Introduction

With increasing power demands, the sizes of electric power systems are increasing rapidly. To meet this rapidly increasing power demand, many power plants are connected simultaneously to supply loads in the power system. Therefore, the economic operation of these power plants in the grid is of paramount importance. Online load dispatch and unit commitment are two basic steps in the problem of economic load dispatch [1]. The unit commitment selects the units from the available options, which satisfy the system load for a specified period of time at the optimum cost [2]. Then total load is divided into the already committed units through an online load dispatch technique to reduce the total supply cost.

Economic dispatch is actually the determination of the optimal output of the number of power generating units to meet system power demand at the lowest cost, considering other operational and transmission constraints and distribution required for generation among power generating units economically. Optimization goals include reduction of production cost, total power loss in the system, lower voltage deviation and increased reliability of the power system [3]. While designing optimization techniques, one or more of these objectives are considered.

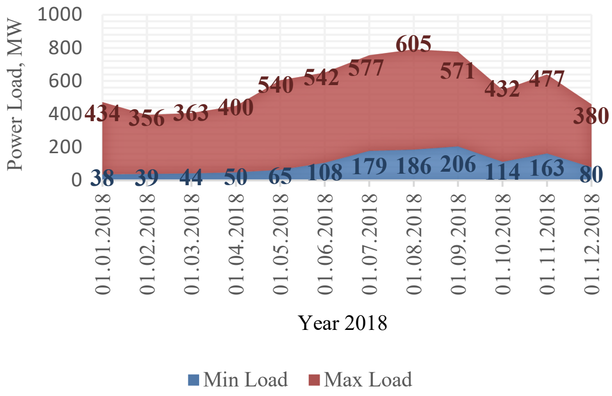

Fig. 1. Load demand trend of Bahawalpur.

Figure 1 shows the trend of power demand in the city of Bahawalpur across one calendar year (2018). The peak demand takes place during summer [4], and the maximum load is 605 MW in August. To overcome shortage of electricity and meet the load requirement, which is increasing sporadically in Bahawalpur, integration of multiple power generating units is essential. Most manufacturing units are of the following three types: hydro, nuclear and thermal (using fossil fuels such as gas, oil and coal). Nuclear plants operate at specified production energy levels. While the operating cost of hydroelectric units does not vary greatly with production, the operating cost of thermal energy varies considerably with production power [5].

There are two distinct phases of economic load dispatch: unit commitment and unit dispatch. Unit commitment gives a set of manufacturing units that are best in considering economy and

* Corresponding author.
Email: zeeshan.rashid@iub.edu.pk

executed before real-time operations. Unit dispatch gives the required output from each available product unit and this happens when the system is in operation [6].

In this paper, economic load dispatch algorithm is designed to get an optimum generation level from multiple thermal power plants, which are feeding electrical load connected to a single bus as shown in Fig. 2. The block diagram framework shows *N* thermal units composed of unique fuel cost functions, turbines and generators, and these thermal units are treated as analogous to the practical units providing electricity to Bahawalpur. While assigning a generation level to ensure optimum operation for a particular load, transmission losses and the resulted penalty factors are also taken into account. Fuel cost equations, incremental fuel cost equations and loss coefficients matrix of transmission lines are determined and utilized in the algorithm to find out an optimum solution. At the end, a cost comparison is made to describe benefit in Rs/h, which can be achieved by utilising this algorithm for economic dispatch compared to the regular operation when equal sharing is considered. Practically, there are two power plants supplying electricity to Bahawalpur: 1) thermal power plant Muzaffargarh and 2) Kot Addu Power Company (KAPCO).

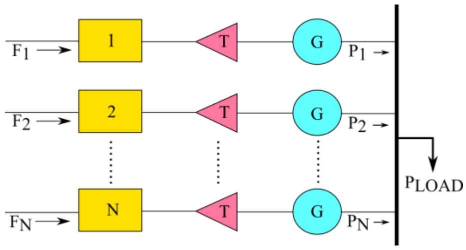

Fig. 2. Single bus-bar connected to *N* thermal units.

The paper is organised as follows. In Section 2, the economic load dispatch with and without transmission loss consideration is discussed. In Section 3, problem formulation is addressed and Section 4 deals with the classical dispatch technique in detail. In Section 5, the economic load dispatch in Bahawalpur is formulated. Finally, results and conclusions are presented in Sections 7 and 8, respectively.

II. Economic Load Dispatch with and without Transmission Losses

Economic load dispatch (ELD) means that the active and reactive power of the generator can be varied to meet the load demand with minimal fuel costs and without violating the specified limits. The optimization is carried out on cost functions, so only active power components are included since the cost of electricity is determined from kWh consumed. When some generating units are physically located close to each other and participate in the same bus bar, then we may neglect transmission losses while solving an economic dispatch problem.

$$\sum_{i=1}^{N} P_i = P_d . \quad (1)$$

Fuel cost Rs/h is a quadratic function of output power as represented below:

$$f_i = \frac{a_i}{2} P_{gi}^2 + b_i P_{gi} + c_i . \quad (2)$$

Incremental fuel cost of units Rs/MWh can be denoted by λ_i which is defined by

$$\lambda_i = \frac{\partial f_i}{\partial P_{gi}} = a_i P_{gi} + b_i . \quad (3)$$

where a_i, b_i and c_i are the constants. The appropriate incremental fuel cost is actually the additional fuel cost we have to bear if we increase output of a selective plant or unit by 1 MW. Incremental fuel cost can be obtained by measuring the slope of the input-output curve and then multiplying with cost per Btu in proper units.

If we consider transmission losses while looking for ELD solution, then the power balance equation or constraining equation may be shaped as follows:

$$P_L + P_{\text{load}} - \sum_{i=1}^{N} P_{gi} = 0 , \quad (4)$$

where P_{load} is the total power received at the load end, P_L is the transmission loss and $\sum_{i=1}^{N} P_{gi}$ is the total generation. It is worthwhile mentioning that the solution of this method yields an exact solution since the power balance constraints are verified after each iteration step. A system with *N* generating units with different costs associated with them, the total cost can be represented as follows:

$$f = f_1 + f_2 + f_3 + \ldots f_N = \sum_{i=1}^{N} f_i . \quad (5)$$

III. Problem Formulation

Bahawalpur is a district of Punjab, Pakistan located in the south of the province. The overall load demand of Bahawalpur district varies depending on different seasons and ranging between an average of 400 MW to 600 MW according to the load demand data of 2018. To meet this load demand effectively, we have to arrange an appropriate generation level through generating units keeping in view the losses occurred during transmission as well. The selection of generating units among available generating units to meet a specific demand level is done through the unit commitment process. After the units are selected through unit commitment called committed units, the generation among these committed units is distributed through ELD algorithms, which consider economy and transmission losses at the same time to find out an optimum solution of the given generation level [7].

Mathematically, the problem can be defined as to minimise fuel cost associated with generation by Eq. (2) subject to power balance equation given in Eq. (4) and inequality constraint given below:

$$P_{i(\min)} \le P_i \le P_{i(\max)} . \quad (6)$$

After combining total fuel cost and constraint equation, a new cost function is obtained as given below:

$$F = \left(f_1 + f_2 + f_3 + \ldots f_N\right) + \lambda\left(P_L + P_{\text{load}} - \sum_{i=1}^{N} P_{gi}\right), \quad (7)$$

where the parameter λ is known as Lagrange multiplier and F is the Lagrangian function. To obtain minimum cost, derivative of F with respect to each P_{gi} is calculated and put equal to zero.

$$\frac{\partial F}{\partial P_{gi}} = \frac{\partial}{\partial P_{gi}}\begin{bmatrix} \left(f_1 + f_2 + f_3 + \ldots f_N\right) + \\ \lambda\left(P_L + P_{\text{load}} - \sum_{i=1}^{N} P_{gi}\right) \end{bmatrix} = 0. \quad (8)$$

As P_D is a fixed and it varies only if output of any unit varies, so the above equation is reduced to the form below:

$$\frac{\partial F}{\partial P_{gi}} = \frac{\partial f_i}{\partial P_{gi}} + \lambda\left(\frac{\partial P_L}{\partial P_{gi}} - 1\right) = 0. \quad (9)$$

As f_i depends only on P_{gi}, the partial derivatives become full derivative and the parameter λ can be found as follows:

$$\lambda = \left(\frac{1}{1 - \frac{\partial P_L}{\partial P_{gi}}}\right)\frac{\mathrm{d}f_i}{\mathrm{d}P_{gi}}. \quad (10)$$

$$\lambda = L_i \frac{\mathrm{d}f_i}{\mathrm{d}P_{gi}}. \quad (11)$$

$$L_i = \left(\frac{1}{1 - \frac{\partial P_L}{\partial P_{gi}}}\right). \quad (12)$$

L_i in the expression above is a penalty factor for any plant, i. The penalty factor in simple words is the ratio of cost experienced when transmission losses are taken in consideration to the cost experienced without taking transmission losses. Genetic algorithm [8], Cuckoo search algorithm [9], linear programming [10], particle swarm optimization [11], interior point method [12], Tabu search [13], Artificial Bee Colony algorithm (ABC) [14], Mine blast [15], gradient projection algorithm [16], Grey wolf [17] and dynamic programming [18] are the commonly used algorithms for ELD problems.

IV. Lambda Iteration Method: The Classical Economic Load Dispatch

It is an optimization method based on the principle of equal incremental fuel cost λ. As shown in Fig. 3, the algorithm starts with an estimate of λ to calculate the difference between the total generation and total load added to the transmission losses. The error ϵ is calculated after each iteration and compared with the tolerance to narrow the search scope and to find out the most feasible solution. After number of iterations, when total cost, λ, is equal among all the generating units, the fuel cost at that time will be the lowest [9]. There are two possible arrangements used to optimize the problems of ELD. One is for generating units situated locally or supplying power to the same bus bar. Here, we may ignore transmission losses and find out an optimum solution. Other possible scenario is for generating units situated far away from each other and also feeding different bus bars. In this case, we have to consider transmission losses as well while looking for an optimal solution to ELD problems [19], [20]. The applied method is a universal algorithm valid for any number (say n) of distributed generation plants with their unique incremental cost functions. In that case, the required impedance or admittance matrices, B matrix and incremental cost matrix [shown in Eq. (18)] will be n^{th} order. The cost of computations will be different which may not be straight forward to predict since the underlying system is nonlinear and the number of iterations for each value of power may vary depending on the state variable behaviour.

While determining ELD solution, the penalty factor is unity if we neglect transmission losses. When we include transmission losses in ELD strategy, it can be solved through the iterative process by solving nonlinear coordination equations illustrated below:

$$\frac{\mathrm{d}f_i}{\mathrm{d}Pg_i} - \lambda + \lambda\frac{\partial P_L}{\partial Pg_i} = 0. \quad (13)$$

The partial derivative term in Eq. (13) is incremental loss which is a measure of the sensitivity of losses occurred in the system to an additional amendment in output of power plant i, while keeping all the outputs of other plants constant. As we are discussing system for two plants, so for unit 1, the incremental loss expressions can be given as follows:

$$\frac{\partial P_L}{\partial Pg_1} = 2B_{11}P_{g1} + 2B_{12}P_{g2} + B_{10}. \quad (14)$$

Putting values of incremental fuel cost and incremental loss expression into Eq. (13), we find

$$\left(a_1 P_{g1} + b_1\right) - \lambda + \lambda\left(2B_{11}P_{g1} + 2B_{12}P_{g2} + B_{10}\right) = 0. \quad (15)$$

After solving and dividing equation by λ, we get

$$\left(\frac{a_1}{\lambda} + 2B_{11}\right)P_{g1} + 2B_{12}P_{g1} = \left(1 - B_{10}\right) - \frac{b_1}{\lambda}. \quad (16)$$

In the same fashion, we can find an analogous expression for unit 2 as given below:

$$2B_{21}P_{g1} + \left(\frac{a_2}{\lambda} + 2B_{22}\right)P_{g2} = \left(1 - B_{20}\right) - \frac{b_2}{\lambda}. \quad (17)$$

For plants 1 and 2, we can rearrange Eqs. (15)–(17) into vector matrix form as follows:

$$\begin{bmatrix} \left(\dfrac{a_1}{\lambda}+2B_{11}\right) & 2B_{12} \\ 2B_{21} & \left(\dfrac{a_2}{\lambda}+2B_{22}\right) \end{bmatrix} \begin{bmatrix} P_{g1} \\ P_{g2} \end{bmatrix} = \begin{bmatrix} \left(1-B_{10}\right)-\dfrac{b_1}{\lambda} \\ \left(1-B_{20}\right)-\dfrac{b_2}{\lambda} \end{bmatrix}. \quad (18)$$

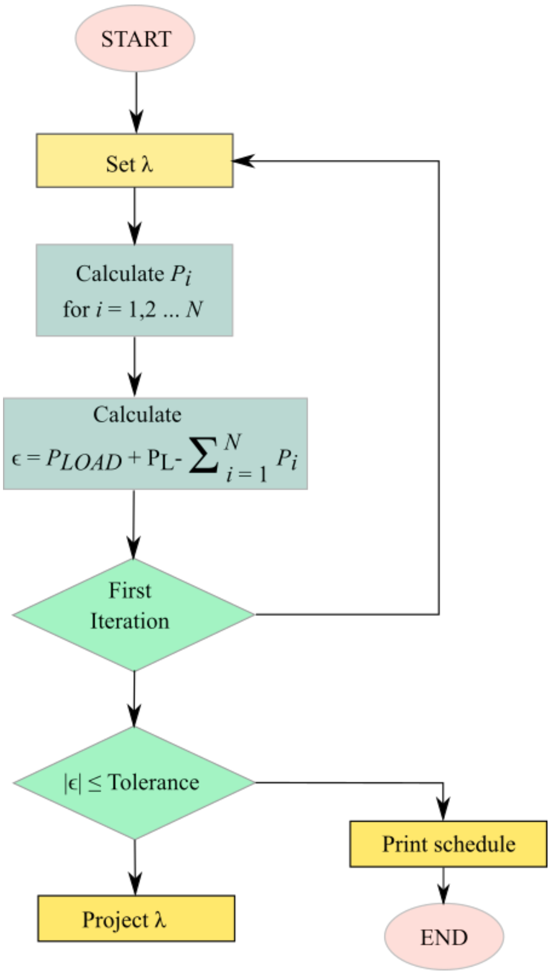

Fig. 3. Flowchart of Lambda iteration method.

The power balance equation of the whole system in terms of plant loading, loss coefficients and the total load in a generalized form can be given as below:

$$\left(\sum_{i=1}^{K}\sum_{j=1}^{K} P_{g1} B_{ij} P_{gj} + \sum_{i=1}^{K} B_{i0} P_{gi} + B_{00}\right) + P_D - \sum_{i=1}^{K} P_{gi} = 0. \quad (19)$$

ELD technique is actually based on solving Eq. (18) in such a way that the output of Eq. (19) also remains satisfied. The transmission line loss equation of power network can be given as follows:

$$P_{\text{loss}} = P^{\mathrm{T}}\mathrm{B}\mathrm{P} + B_0^{\mathrm{T}}\mathrm{P} + B_{00}. \quad (20)$$

In Eq. (20), P is a vector of net outputs of all generator buses, B is a square matrix, B_{00} is a constant and B_0 is also a vector of length equal to P. The B terms in the expression above are called B coefficients or loss coefficients and K×K matrix B is commonly known as a B matrix. The B matrix for two power plants as we discussed above can be given as follows:

$$\mathrm{B} = \begin{bmatrix} B_{11} & B_{12} & B_{10}/2 \\ B_{21} & B_{22} & B_{20}/2 \\ B_{10}/2 & B_{20}/2 & B_{00} \end{bmatrix}. \quad (21)$$

To achieve ELD of some specific area, we have to go through the following six steps.

Step 1: Set the system load or power demand level.
Step 2: Set some initial values for system lambda to start the iterative process.
Step 3: Put the value of lambda into Eq. (18) and solve itto find out the value of P_{gi} through some effective means.
Step 4: Calculate transmission losses by Eq. (20) using P_{gi} values obtained in the previous step.
Step 5: Compare the power generation with power demand using power balance Eq. (19) and if the power balance is not achieved, then update the system lambda as given below:

$$\lambda^{(k+1)} = \lambda^{(k)} + \Delta\lambda^{(k)}, \quad (22)$$

where

$$\lambda^{(k)} = \frac{\lambda^{(k)} - \lambda^{(k-1)}}{\sum_{i=1}^{K} P_{gi}^{(k)} - \sum_{i=1}^{K} P_{gi}^{(k-1)}} \left[P_D + P_L^{(k)} - \sum_{i=1}^{K} P_{gi}^{(k)} \right]. \quad (23)$$

In the equations above, the superscript $(k + 1)$ shows the iteration level being started, the superscript k shows the iteration level completed and the superscript $k - 1$ shows the previous iteration.
Step 6: Go back to Step 3 and compute results for Steps 3–5 until final convergence is achieved within specified limits.

V. Economic Load Dispatch in Bahawalpur

The power load requirements of Bahawalpur district vary between 38 MW and 605 MW as per data of 2018 [3]. We will do ELD by using two thermal power plants, which are feeding Bahawalpur district in this research.

The first power plant we will consider is thermal power station Muzafargarh, which is comprised of two units with 727 MW capacity in overall and located about 107 km away from Bahawalpur. The second power plant is Kot Addu Power Company (KAPCO), which is comprised of fifteen units with overall power capacity of 1600 MW and located 150 km away from Bahawalpur. Thermal power station Muzafargarh uses furnace oil as its fuel while KAPCO power units are multi-fuel fired type.

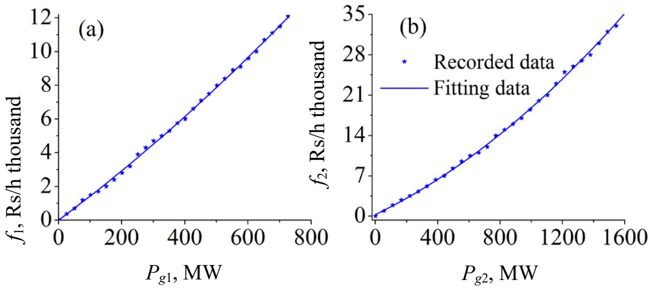

Fig. 4. Quadratic regression model for fitting on-site recorded data for (a) plant 1 and (b) plant 2.

The fuel cost equations [Eq. (2)] of these two thermal power plants considered in this paper are constructed by recording on field data which are shown by dotted curve in Fig. 2. The data contains cost of electricity (COE), which is a sum of capital, fuel, operations and maintenance cost of the plant. The corresponding coefficients (a_i, b_i, c_i) in the fuel cost function are evaluated by performing quadratic regression to best fit the recorded data. The evaluated coefficients are plugged into the fuel cost equations for both the plants and plotted on top of the recorded data as shown in Figs. 4(a) and 4(b) for plants 1 and 2, respectively. Clearly, the evaluated coefficients are absolutely satisfying the recorded data. These evaluated coefficients are given in Table I. The final incremental fuel cost equations of the two plants are given in Eqs. (24) and (25).

TABLE I
EVALUATED VALUES OF COEFFICIENTS AFTER QUADRATIC REGRESSION

Coeff.	**Value**	**Coeff.**	**Value**
a_1	0.0072	a_2	0.0110
b_1	13.9216	b_2	13.0487
c_1	0.2118	c_2	281.7390

$$\frac{\partial f_1}{\partial P_{g1}} = 0.0072 P_{g1} + 13.9216. \tag{24}$$

$$\frac{\partial f_2}{\partial P_{g2}} = 0.0110 P_{g2} + 13.0487. \tag{25}$$

Equation (24) is the incremental fuel cost equation of thermal power plant Muzafargarh, while Eq. (25) is the incremental fuel cost equation of thermal power station Kot Addu (KAPCO).

The transmission loss matrix B is evaluated in two steps. The first step involves power invariant transformation on Z_{bus} matrix to express the loss in terms of generator currents. In the second step, generator currents are transformed into power outputs of the plants. Each transmission line is represented by its π equivalent circuit with half of the line charging susceptance. For a 4-bus system with buses 1 and 2 being the generator buses, the resistance and reactance matrices and power flow data are used to compute the load currents and transformation matrix C. The values of α_1 and α_2 are calculated using the expression $\alpha_i = (1 - js_i)/V_i^*$. Here $s_i = Q_{gi}/P_{gi}$. The following operation is carried out to obtain Hermition matrix T_α:

$$T_\alpha = \text{diag}\left[\alpha_1, \alpha_2, I_{n0}\right] C^{T} R_{bus} C \,\text{diag}\left[\alpha_1, \alpha_2, I_{n0}\right]^*, \tag{26}$$

where, I_{n0} is the no load current and diag represents a diagonal matrix. The on-site data consisted of P_{gi}, Q_{gi}, V_i, I_{n0}, length of the transmission line and bus connectivity to construct impedance matrix. The final B matrix of transmission lines is evaluated by taking the real part of the Hermition matrix in Eq. (26) [$B = (T_\alpha + T_\alpha^*)/2$] as given below:

$$B = \begin{bmatrix} 7.385783 & -0.050448 & 0.375102 \\ -0.049518 & 5.983568 & 0.198971 \\ 0.395082 & 0.204971 & 0.089121 \end{bmatrix}. \tag{27}$$

VI. RESULTS AND DISCUSSION

The algorithm of ELD problem will give optimum generation levels for power plants considering transmission losses as well. Through this algorithm, most optimum combination of power from the generating units considering economy can be determined as a function of total demand. Furthermore, the transmission losses associated with that power demand and optimum value of λ are also obtained. It is notable from Fig. 1 that the demand changes drastically throughout the year and throughout the day as well. Therefore, optimum generation levels are required essentially at every instant for the most economic operation. For the sake of brief, different values of power demand with regular intervals within a power demand range of Bahawalpur district are taken and the results of the algorithm are shown in Fig. 5. The sum of P_{g1} optimum and P_{g2} optimum is slightly greater than power demand with the surplus power representing the transmission losses.

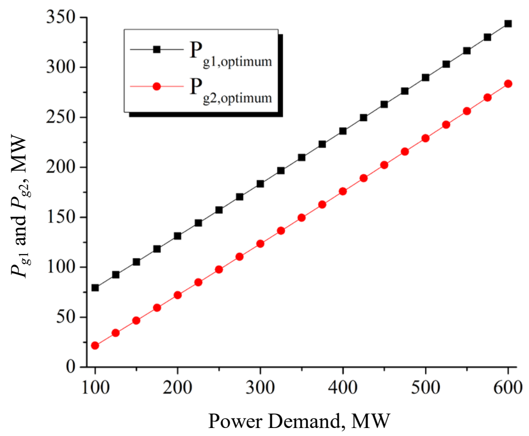

Fig. 5. Power division vs power demand between generating stations.

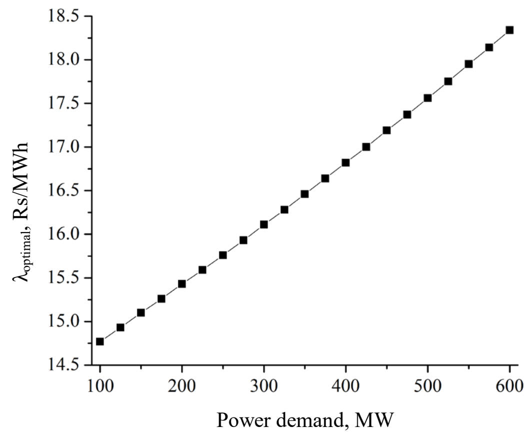

Fig. 6. Power demand vs lambda optimal.

Figure 6 shows $\lambda_{optimal}$ achieved while looking for an optimal solution to ELD problem against different power load requirements. The $\lambda_{optimal}$ value changes from 14.75 Rs/MWh for demand power of 100 MW and increases almost linearly as the demand increases. For demand power of 600 MW, $\lambda_{optimal}$ value is found to be 18.27 Rs/MWh.

Figure 7 shows the transmission losses incurred as the power load demand varies from minimum to maximum requirements. For demand power of 100 MW, 1.44 MW is the total transmission loss, which increases almost quadratically with the increase of load. For a 600 MW load, transmission loss of 27.12 MW is evaluated as shown in Fig. 5. Transmission losses and efficiency are major factors involved in the selection of power plant for economic operation of the power system if they are located at different locations from the load centre.

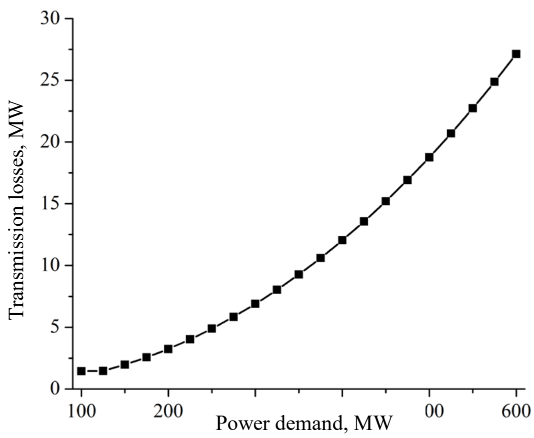

Fig. 7. Power demand vs transmission losses.

Figure 8 shows the penalty factor, L_1, of power plant 1 faced in shape of penalized extra generation because of transmission losses associated with it against different power generation level of P_{g1}. The value of L_1 increases linearly with the increase of load since the generation of the plant has to compensate the increased transmission losses. The value of L_1 is 1.034 for output power of 344 MW.

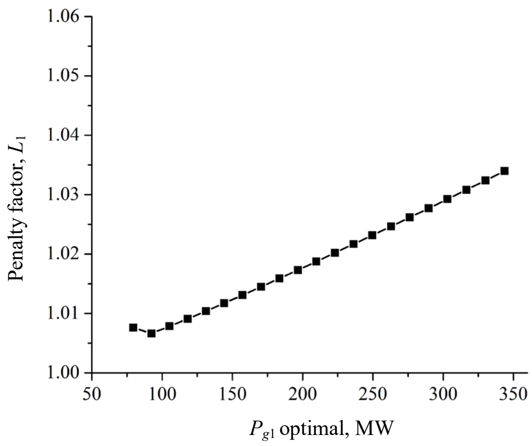

Fig. 8. Penalty factor L_1 vs $P_{g1,}$ optimal.

Penalty factor, L_2, for the second plant is shown in Fig. 9 whose maximum value is 1.06 at the output power of 283.5 MW. Clearly, this value is greater than L_1 shown in Fig. 6 due to the fact that plant is located at a smaller distance as compared to plant 2 from the load centre offering higher transmission losses. This implies that plant 2 will bear higher penalty and will contribute smaller as compared to plant 1. This contrast can be observed in Fig. 5, where P_{g1} can be seen bigger than P_{g2} to fulfill the demand power.

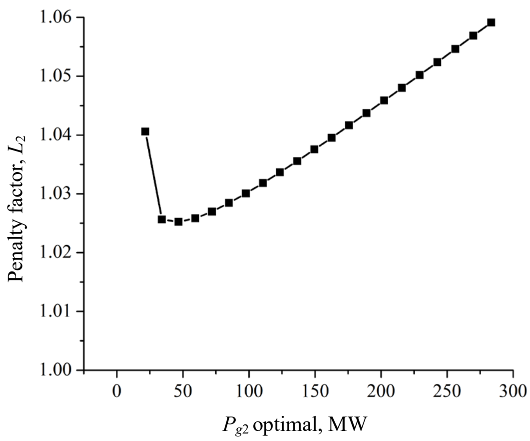

Fig. 9. Penalty factor L_2 vs P_{g2} optimal.

Finally, an analysis is carried out considering equal sharing of generation from plant 1 and plant 2 to fulfill the demand power and to compute the cost. The cost with equal operation and optimum operation at each generation level is compared and their difference is computed to evaluate the savings in Rs/h, which is plotted in Fig. 10. The savings in Rs/h vary from 15.20 for demand of 100 MW and increase up to 26.58 for power demand of 600 MW.

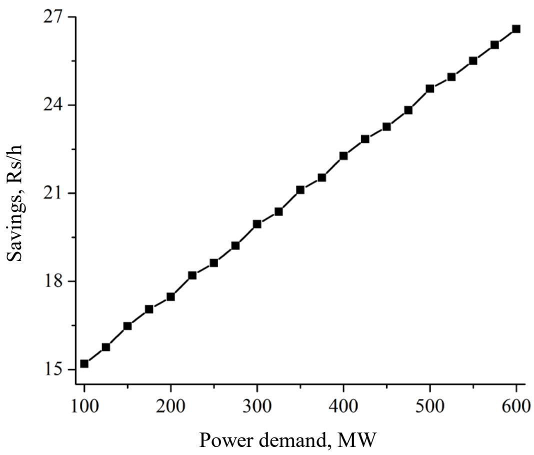

Fig. 10. Power demand vs savings.

VII. Conclusion

The presented research has primarily focused on achieving economic load dispatch in Bahawalpur district by evaluating the most optimum operation of two power plants. In this work, a numerical algorithm has been developed and executed for two thermal power plants, which are feeding Bahawalpur, while considering transmission losses as well using the classical economic dispatch algorithm. The success of convergence at each iteration raises questions when modelling multimachine systems owing to the complexity associated with high dimensional loss, admittance and cost matrices. The fuel cost functions are found by recording the real-time data from both sites and performing quadratic regression to approximate the mathematical fuel cost functions. These functions are differentiated to obtain incremental fuel cost functions for both the plants and calculating the penalty factor and λ parameter. The loss or B matrix of transmission lines is evaluated by building a bus impedance matrix based on the power system network of the region and then doing some fundamental calculations. This procedure is utilized in the developed algorithm to find out optimum levels for two thermal power plants used and to find out transmission losses for different supposed values of power demand within a range of power load trend of Bahawalpur district.

The research results imply that power plant 1 located in Muzaffargarh at smaller distance bears less penalty as compared to power plant 2 located in Kot Addu. This smaller distance causes smaller transmission losses and more contribution for feeding the load. Graphs exhibit the optimum generation levels and load sharing trend of two thermal power plants considered against power demand, the value of $\lambda_{optimal}$ and transmission losses associated with that power demand in achieving economic load dispatch of Bahawalpur district. To benefit from the economic load dispatch algorithm, fuel cost in Rs/h is calculated and plotted, which we can save using the economic load dispatch algorithm verses equal sharing of power demand among power generating units. This saving will greatly benefit the consumers and power companies over a span of several months and even more over a period of years in a developing country.

References

[1] M. Afzal and M. K. Madhav, "Economic load dispatch and unit commitment solution using advanced optimization approach", *IJSRD - International Journal for Scientific Research & Development*, vol. 6, no. 04, 2018.

[2] A. Bhardwaj, N. S. Tung and V. K. Kamboj, "Unit commitment in power system: A review", *International Journal of Electrical and Power Engineering*, vol. 6, no. 1, pp. 51–57, 2012. https://doi.org/10.3923/ijepe.2012.51.57

[3] A. Ahmed Faraj, S. A. Baiyat and T. C. Cheng, "Economic load dispatch multiobjective optimization procedures using linear programming techniques", *IEEE Transactions on Power Systems*, vol. 10, no. 2, pp. 731–738, 1995. https://doi.org/10.1109/59.387910

[4] MEPCO electricity demand forecast based on power market survey, Twenty Fourth Issue. Prepared by MEPCO and Planning Power NTDC, May 2015.

[5] H. Saadat, *Power system analysis*. WCB/McGraw-Hill, 1999.

[6] F. N. A. Farsi, M. H. Albadi, N. Hosseinzadeh and A. H. A. Badi, "Economic dispatch in power systems", *Proceedings 2015 IEEE 8th GCC Conference & Exhibition*, Oman, 2015. https://doi.org/10.1109/IEEEGCC.2015.7060068

[7] U. Qazi and M. Jahanzaib, "An integrated sectoral framework for the development of sustainable power sector in Pakistan", *Energy Reports*, vol. 4, pp. 376–392, 2018. https://doi.org/10.1016/j.egyr.2018.06.001

[8] L. M. Le et al., "Hybrid artificial intelligence approaches for predicting buckling damage of steel columns under axial compression", *Materials*, vol. 12, no. 10, 2019. https://doi.org/10.3390/ma12101670

[9] V. K. Dutta, J. K. Dhami and L. Singh, "Weighting sum method to solve combined economic emission dispatch problem", *International Journal of Engineering Research and Technology*, vol. 4, no. 15, 2016.

[10] M. Shahidehpour, "Linear programming applications to power system economics, planning and operations", *IEEE Transactions on Power Systems*, vol. 7, no. 3. pp. 1155–1163, 1992. https://doi.org/10.1109/59.207329

[11] X. Yu and X. Zhang, "Unit commitment using Lagrangian relaxation and particle swarm optimization", *International Journal of Electrical Power and Energy Systems*, vol. 61, pp. 510–522, 2014. https://doi.org/10.1016/j.ijepes.2014.03.061

[12] L. Wehenkel, "Interior point methods: a survey, short survey of applications to power systems, and research opportunities", Technical Report, 2004.

[13] Tabu search: A tutorial, Center for applied artifial intelligence, university of Colorado, 80309-0419.

[14] S. Kumar, V. Sharma and R. Kumari, "Randomized memetic artificial bee colony algorithm", *International Journal of Emerging Trends and Technology in Computer Science*, vol. 3, no. 1, pp. 52–62, 2014.

[15] A. Sadollah, A. Bahreininejad, H. Eskandar and M. Hamdi, "Mine blast algorithm for optimization of truss structures with discrete variables", *Computers and Structures*, vol. 102–103, pp. 49–63, 2012. https://doi.org/10.1016/j.compstruc.2012.03.013

[16] M. Su and H. K. Xu, "Remarks on the gradient-projection algorithm", *Journal of Nonlinear Analysis and Optimization*, vol. 1, no. 1, pp. 35–43, 2010.

[17] S. Mirjalili, S. M. Mirjalili and A. Lewis, "Grey wolf optimizer", *Advances in Engineering Software*, vol. 69, pp. 46–61, 2014. https://doi.org/10.1016/j.advengsoft.2013.12.007

[18] A. H. Zhou, L. P. Zhu, B. Hu, S. Deng, Y. Song, H. Qiu and S. Pan, "Traveling-salesman-problem algorithm based on simulated annealing and gene-expression programming", *Information*, vol. 10, no. 1, 2018. https://doi.org/10.3390/info10010007

[19] I. Musirin and T. K. A. Rahman, "Evolutionary programming optimization technique for solving reactive power planning in power system", *Proceedings of the 6th WSEAS International Conference on Evolutionary Computing*, pp. 239–244, May 2005.

[20] K. S. Hindi and M. R. Ab Ghani, "Multi-period economic dispatch for large scale power systems", *IEE Proceedings C(Generation, Transmission and Distribution)*, vol. 136, no. 3, pp. 130–136, 1989. https://doi.org/10.1049/ip-c.1989.0019

Ahmad Khan received his B. Sc. and M. Sc. degrees in Electrical Engineering from The Islamia University of Bahawalpur, Pakistan in 2015 and 2020, respectively. Currently, he is working as an Intelligence Officer at Special Branch, Punjab Police in Bahawalnagar. His area of interests includes renewable energy, power electronics, power system economics, advanced optimization techniques and state estimation in power networks.
Address: Special Branch, Punjab Police, Bahawalnagar, Pakistan.
E-mail: engrak125@gmail.com

Zeeshan Rashid received his PhD degree from Koc¸ University, Istanbul, Turkey in 2018. Currently, he is working as an Assistant Professor at the Department of Electrical Engineering, The Islamia University of Bahawalpur, Pakistan. His research interests include modelling of fibre lasers, harmonic wave propagation in smart grids, high frequency distortion in underground cables, model predictive control and modelling of low voltage power circuits at harmonic frequencies in a smart network.
Address: Department of Electrical Engineering, The Islamia University of Bahawalpur, Pakistan.
E-mail: zeeshan.rashid@iub.edu.pk
ORCID iD: https://orcid.org/0000-0002-5592-412

Farhana Umer received her PhD degree from the school of Electrical-Electronics Engineering, Selcuk University, Turkey in 2017. She completed her M. E. degree in Electrical Power Engineering from Mehran University of Engineering & Technology, Pakistan, in 2013. She worked as a Lecturer at the department of Electrical Engineering, the IUB from 2009 to 2016. Now she is working as an Assistant Professor at the Department of Electrical Engineering, The Islamia University of Bahawlpur, Pakistan. Her research interests include transient analysis of power systems, distributed energy generation and power system analysis.
Address: Department of Electrical Engineering, The Islamia University of Bahawalpur, Pakistan.
E-mail: farhana.umer@iub.edu.pk
ORCID iD: https://orcid.org/0000-0002-5392-7964

Abdur Rehman Yousaf received B. Sc. degree in Electronics Engineering, the Islamia University of Bahawalpur, Pakistan in 2006. He obtained M. Sc. degree in Electrical Engineering from the National University of Science & Technology Rawalpindi, Pakistan in 2009. He has been working as a Lecturer at Department of Information and Communication Engineering, The Islamia University of Bahawalpur, Pakistan for past 10 years. He has made some publications in various conferences and journals all over the world. Currently, he is pursuing PhD in Electrical Engineering at his host university. His research interests include power flow solutions, economic dispatch problems, modeling of complex power networks, renewable energy integration and advanced optimization techniques.
Address: Department of Information and Communication Engineering, The Islamia University of Bahawalpur, Pakistan.
E-mail: engr.rehman@iub.edu.pk

Arif Saeed received B. Sc. degree in Electronic Engineering from The Islamia University of Bhawalpur, Pakistan and M. Sc. degree in Electrical Engineering from the University of Management and Technology Lahore, Pakistan in 2010 and 2013, respectively. He has been working as a Lecturer at the Department of Electrical Engineering, Institute of Southern Punjab Multan, Pakistan for past 4 years. Currently, he is pursuing PhD in Electrical Engineering at the Islamia University of Bahawalpur. His research interests include advanced power electronics, fuzzy logic control, particle swarm optimization and power flow solutions.
Address: Department of Electrical Engineering, Institute of Southern Punjab, Multan, Pakistan.
E-mail: arifsaeed.06es05@gmail.com