International Journal of Engineering Inventions
ISSN: 2278-7461, www.ijeijournal.com
Volume 1, Issue 6(October2012) PP: 49-54

Optimum Power Dispatch Problems: An Overview

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Abstract—An efficient operating policy for committed units (CU) in order to meet the load demand is very important for power system operators. Optimum Power Dispatch (OPD) problems help to find such suitable operating policies for CUs without violating system and unit constraints. Minimization of fuel cost or reduction of amount of pollutants emission or optimization of both fuel cost and emission are the objectives of OPD problems. Based on the objectives, OPD problems are classifieds and are briefly discussed in this paper. The OPD problem of hybrid power system with and without solar and wind energies is considered and this paper illustrates the OPD with MATLAB simulations.

Keywords—economic dispatch, environmental friendly dispatch, multi-objective, optimization, renewable energy.

I. INTRODUCTION

Optimum power dispatch problem is to find the optimum scheduling for committed units in order to meet the load demand while satisfying all unit and system constraints [1-4]. World consumption of energy was about 84 million barrels per day (MBD) in 2008. According to International Energy Agency it will reach 113 MBD by year 2030. According to Executive Director for Exploration & Production for Royal Dutch, the world energy demand could double by 2050 [5]. The energy consumption of developing countries has increased more than four times over the past three decades. The annual demand growth of developing countries is 2.7 % while that of industrialized countries is 1.2 % [6]

The existing energy production is not clean. About 63% of world electricity is obtained by burning fossil fuels; 40% of which is from coal-fired electric power stations. Most of the coal-fired power stations were built two decades before and emit 80-85% of NO_x generated by utilities. Some older power plants operate with pollution rates of up to 70 to 100 times greater than the new plants [7-10]. Due to the increased cost and dwindling supplies of fossil fuels, awareness on carbon footprint and effect of global warming, the utilities have been forced to use renewable energy sources in hybrid power systems and to modify their operation strategies in order to reduce fuel cost, fuel demand, and atmospheric emission pollutions by power plants. OPD is the suitable tool for the same. Economic Dispatch (ED), Environmental Friendly Dispatch (EFD) and Economical and Environmental Dispatch (EED) are some of the important OPD problems that are discussed in this paper.

Minimizing the fuel cost is the objective of ED problems while the minimization of pollutants emission is the objective of EFD [11, 12]. The EED problem minimize both fuels cost and amount of emissions. EED distributes active and renewable production among the available power stations to meet the minimization of both fuel cost and pollutant emissions simultaneously [13, 14]. However, this distribution in case of ED is only for minimizing fuel cost while in EFD; it is only for reducing the amount of emissions. ED and EFD are treated as single objective problems while EED is treated as a multi-objective problem [1, 12].

Renewable energy resources depend on the climate data such as the wind speed, solar radiation, and temperature. The uncertainty and the variation of the renewable resources create issues in OPD problems. Different methodologies were illustrated in several articles to overcome these issues [11-17]. One of the methods is to treat renewable power as a negative load and formulate demand equation on this basis [11, 16, 18]. The amount of dispatching active and renewable power is calculated based on the data conveyed by the Environmental Information Systems and Load Dispatch Centers, using any commercially available software package [8]. In this paper, the OPD is formulated with and without renewable sources. The objective functions and constraints of OPD problems are described next.

II. OBJECTIVE FUNCTIONS AND CONSTRAINTS

The main objective of ED is to minimize fuel cost. Hence, the objective function is fuel cost function.

The fuel cost function $F_f(P_{gi})$ in \$/h is represented by a quadratic equation of the type as;

$$F_f(P_{gi}) = \sum_{i=1}^{N_g} \left(a_i + b_i P_{gi} + c_i P_{gi}^2\right) \qquad (1)$$

In (1), a_i, b_i and c_i are the appropriate cost coefficients for individual generating units, P_{gi} is the real power output of the i^{th} generator and N_g is the number of total generators.

Main emissions in thermal power plants are SO_2 and NO_x. The emission of SO_2 depends on fuel consumption and emission quantity has the same form as the fuel cost function. The emission of NO_x is related to many factors such as the temperature of the boiler and content of the air. The objective function of EFD is emission function $F_e(P_{gi})$ and can be expressed in ton/h as;

$$F_e(P_{gi}) = \sum_{i=1}^{N_g} \left(\alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2 + \lambda_i e^{\delta_i P_{gi}} \right) \qquad (2)$$

Here α_i, β_i, γ_i, λ_i and δ_i are emission coefficients of the i^{th} generating unit. The EED problem optimizes both fuel cost and emissions simultaneously. Hence, its objective functions contain both fuel cost and emission functions.

The power extracted from the renewable source varies and can be considered as a variable load. Therefore solar power P_s and wind power P_w are deducted from the total demand $\left(P_D^t\right)$. The net actual demand is thus expressed as;

$$P_D^a = P_D^t - (P_s + P_w) \qquad (3)$$

The main constraints of OPD can be formulated as follows:

- The total power generation must cover the actual demand and the power loss (P_L) in transmission lines so as to ensure power balance, i.e.
-

$$P_D^a + P_L - \sum_{i=1}^{N_g} P_{gi} = 0 \qquad (4)$$

- The generated real power of i^{th} unit is restricted by the lower limit P_{gi}^{min} and the upper limit P_{gi}^{max} i. e.

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max}, \text{ i=1, 2, ….., Ng} \qquad (5)$$

- Active power loss of the transmission line is positive, i.e.,
-

$$P_L > 0 \qquad (6)$$

- The dispatched amount of renewable power is limited to some part (x) of the total actual demand, i.e.

$$(P_s + P_w) \le x P_D^a \qquad (7)$$

III. OPD FORMULATION

The optimization of OPD problems based on their objectives and constraints are formulated as follows;

The optimization of ED can be summarized as;
Minimize [F_f (P_{gi})]
Subjected to the constraints given in (4) to (7).

EFD can be summarized as;
Minimize [F_e (P_{gi})]
Subjected to the constraints given in (4) to (7).

EED optimization can be summarized as;
Minimize [F_f (P_{gi}), F_e (P_{gi})]
Subjected to the constraints given in (4) to (7).

A comparative analysis of OPD problems are carried out using MATLAB simulations and are discussed next.

IV. RESULTS AND DISCUSSIONS

The simulations of OPD problems with given constraints were performed using MATLAB. The values of the fuel and emission coefficients which were used for illustration are given in Tables 1. Optimization is done in presence of with and without renewable energy sources. The lower and upper limits of generated power of each generator are given as;

$$0.05\,pu \le P_{gi} \le 1.5\,pu \text{ ; i=1, 2, ….., 6} \quad (8).$$

TABLE 1: Generator Cost and Emission Coefficients [1]

	a	b	c	α	β	γ	λ	δ
P_{g1}	10	200	100	4.091	-5.554	6.490	2x10-4	2.857
P_{g2}	10	150	120	2.543	-6.047	5.638	5x10-4	3.333
P_{g3}	20	180	40	4.258	-5.094	4.586	1x10-6	8.000
P_{g4}	10	100	60	5.326	-3.55	3.380	2x10-3	2.000
P_{g5}	20	180	40	4.258	-5.094	4.586	1x10-6	8.000
P_{g6}	10	150	100	6.131	-5.555	5.151	1x10-5	6.667

The variation of fuel cost for a specified power demand is shown in Fig. 1. The cost without the use of renewable power (C_N) is always more than that of with renewable power (C_R). The percentage reduction in the fuel cost %ΔC with power demand is shown in Fig. 2. More than 30% of fuel cost can be reduced while dispatching 3 pu power demand in presence of renewable power.

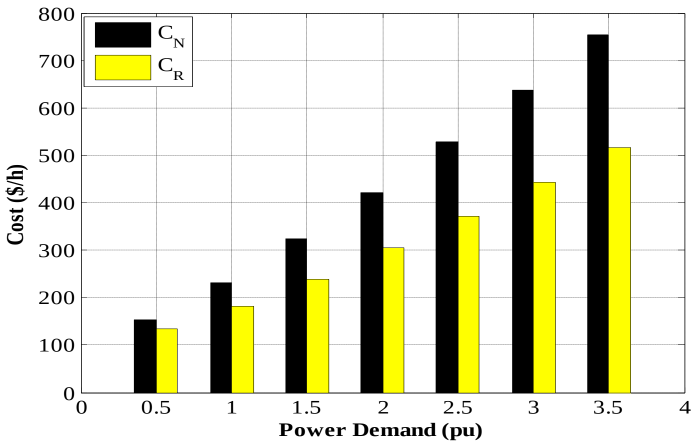

Fig. 1 Variations of Fuel Cost with Power Demand

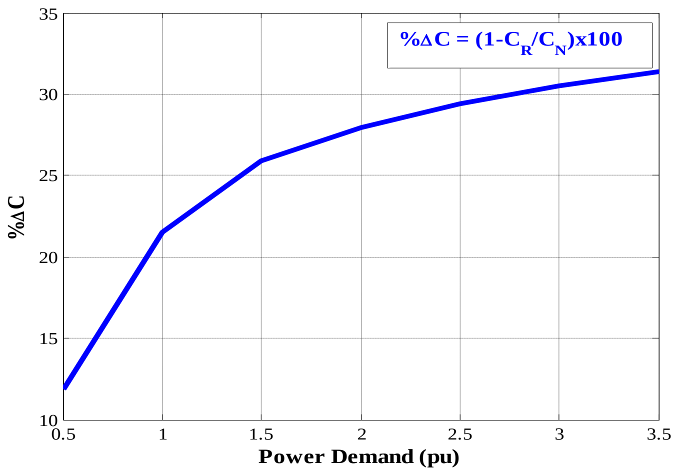

Fig.2 Variation of %ΔC with Demand

The variation of pollutants emission for a specified power demand is shown in Fig. 3. If the demand is high then the emission without the use renewable power (E_N) is more than that obtained with the use renewable power (E_R). At low power demand the dispatched power from renewable source is negligible. The percentage reduction in the fuel cost %ΔE with power demand is shown in Fig. 4.

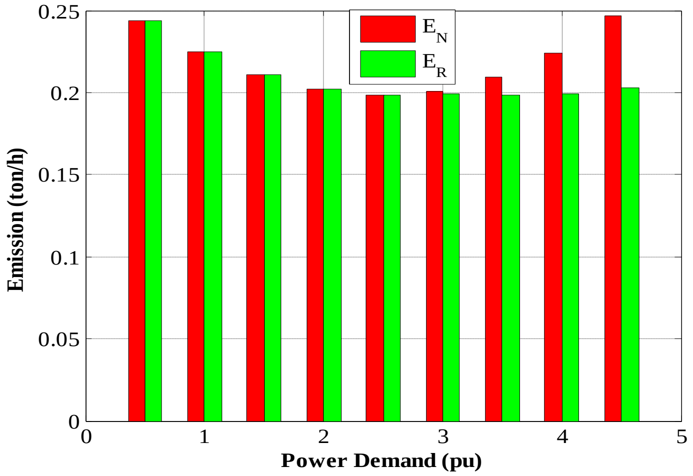

Fig. 3 Variations of Emissions with Power Demand

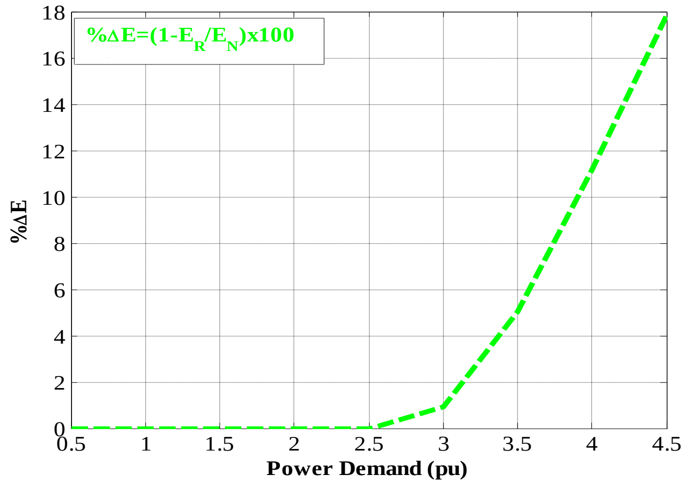

Fig. 4 Variation of %ΔE with Demand

The variation of fuel cost and emissions with power demand is shown in Fig. 5. With increase in power demand the cost is always less for EED when renewable source is used. However, the amount of emissions is slightly higher for low demand if renewable sources are used, but it is lesser for higher demand. Te percentage reductions of both fuel cost and amount of emissions are show in Fig.6.

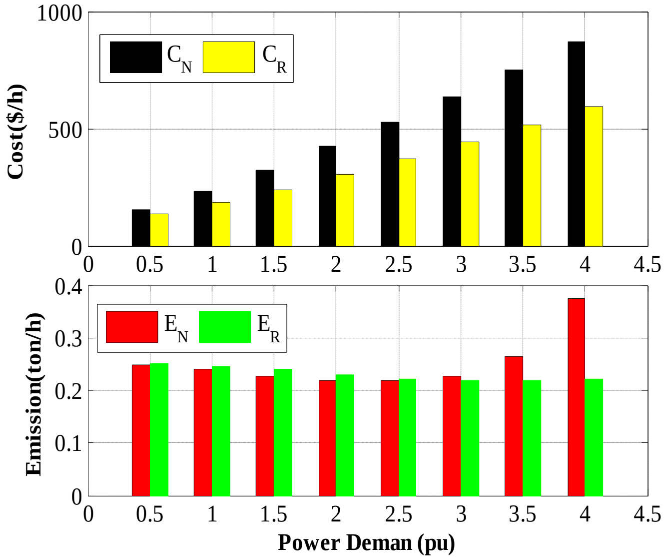

Fig. 5 Variations of Fuel Cost and Emissions with Power Demand

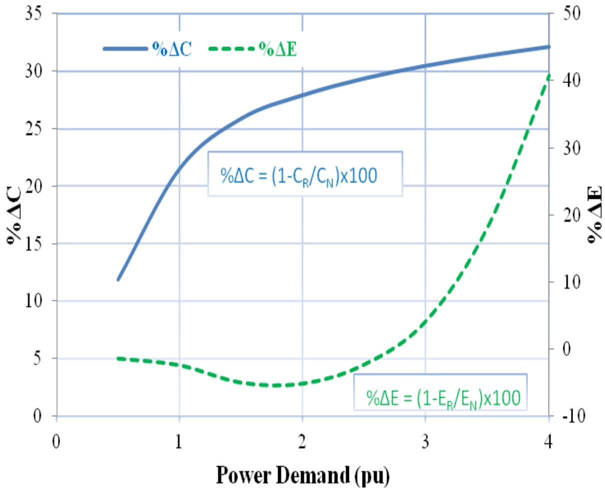

Fig.6. Variation of %ΔC and %ΔE with Demand

The values of C_N and C_R obtained by ED optimization are slightly less than the corresponding values obtained by EED optimization. Similarly, Comparing EFD and EED, less values of E_N and E_R are obtained from EFD optimization. In other words, best saving of fuel cost only obtained with ED optimization while best reduction in emission obtained by EFD optimization. However, the optimum values of both fuel cost and emission are achieved by minimizing EED problems.

V. CONCLUSION

OPD problems are formulated in this paper for a hybrid system which includes thermal generating units as well as solar and wind based generations. Analyses were carried out using MATLAB simulation for each OPD problem with and without the use of renewable sources. From the analysis it is clear that the efficient use of renewable power can help to reduce both fuel cost and the amount of pollutants emissions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Research Center, King Saud University and CAIRO, Universiti Teknologi Malaysia, for supporting this work.

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