Economic Dispatch Incorporating the Greenness Index of Energy Generation Sources

Haris Siraj, Syed Muhammad Shaharyar, Naveed Arshad
Lahore University of Management Sciences
Lahore, Pakistan
[16060041,15060033,naveedarshad]@lums.edu.pk

ABSTRACT

Environmental degradation has compelled the energy experts to cut down fossil fuel based energy sources. To this end ,this study is primarily aimed towards reducing the CO_2 emissions from electricity production and also towards a green economic dispatch of the energy units. In our approach we first calculate the GI (Greenness Index) of selected energy sources based on their Life Cycle Assessment (LCA). Following that an optimal dispatch of electricity based on greenness index of the sources and the cost of energy generation is determined. This work could serve as a starting point in power planning, dispatch and management of electricity sources based not only on cost but on their greenness as well. It also provides a framework for practicing a greenness index based Demand Side Management (DSM) by forecasting the GI of the electricity mix.

KEYWORDS

Economic Dispatch, Life Cycle Assessment, Greenness Index

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1 INTRODUCTION

Economic dispatch of electricity generation sources typically considers the per KWh cost of energy sources. In this work we propose a multi-criteria optimization based on both cost and emissions of CO_2 from energy sources. In order to determine the complete effect of generation sources on the environment, we consider their complete life cycle assessment (LCA) for carbon emissions [2].

Life cycle assessment is a technique to determine the environmental impacts associated with all the stages of a product's life cycle. Now a days, in power systems a combination of renewable and non-renewable energy sources is used to serve the load demand. The overall emissions is a combination of emissions from all the sources that are contributing to the energy mix. The CO_2 emissions of fossil fuel based sources are a function of fuel burnt by the source. A popular method to estimate the detrimental effects of CO_2 is to consider its socio economic cost (SCC) [3]. We can cut down the CO_2 emissions by curtailing the fuel input. But the renewable energy sources cannot be controlled and are intermittent in nature.

On the basis of the amount of CO_2 generated by these sources we have evaluated a Greenness index (GI) which can make user aware of the climate impact of energy consumption on the environment. Due to the integration of renewable sources the greenness index is not constant and it changes with time. The varying GI may prompt the user to shift its energy consumption at a later time of day when the greenness index is high (Demand Side Management).

1.1 Life Cycle Assessment and Greenness Index

In this section we discuss the life cycle assessment which is the amount of CO_2 produced by the generation sources in their expected lifetime. These are given in the form of Emission factors which is the amount of CO_2 in grams or kilograms per KWh or MWh of energy generated. The emission factor of a source multiplied by the number of units generated gives us the amount of CO_2 produced in kg. We multiply this with the social economic cost of CO_2 to get the overall cost which results due to CO_2 production. For renewable energy sources whose running cost is negligible, only leveled cost of energy (LCOE) is considered which is evaluated in (1). Moreover for renewable energy sources emission factor is based on the production,transportation and dismantling of generation source.

$$LCOE = \frac{CapitalCost + OperationalCost}{Energy \quad units \quad produced \quad over \quad lifetime} \tag{1}$$

On the basis of LCA (Life Cycle Assessment) of these sources and the results of optimization of the objective function, we then formulate a term emission index (EI). The emission index is given by equation (2) in which CO_2^i is kg of CO_2 produced by ith energy source while CO_2^{max} is kg of CO_2 produced when all the load is supplied by the energy source with worst emission index.

$$EI_i = \frac{CO_2^i}{CO_2^{max}} \tag{2}$$

The overall emission index (EI) of the energy mix is given by equation (3).

$$EI = \sum_{i=1}^{n} (EI_i) \tag{3}$$

It is noteworthy that Emission index for the grid will be equal to one when the source with maximum emissions is supplying the entire load. The emissions index will approach a smaller value (approaching zero) when a renewable energy source will be supplying the load. For user convenience and encouragement we convert this emission index to greenness index using (4) which shows the greenness of the energy being used.

$$G_{index} = 1 - EI \tag{4}$$

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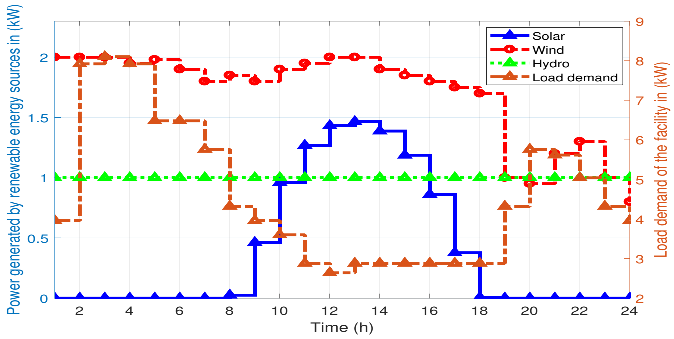

Figure 1: Power generation from renewable energy sources for one day.

2 SYSTEM SETUP

2.1 Simulation Setup

We consider six energy sources which are supplying energy to a facility whose load demand is shown in figure 3. Three of the sources considered are renewable in nature while the other three are non-renewable. The data sets of generation for solar and wind are taken from [1] and shown in figure (2) along with the generation of hydro electric turbine which is approximately constant for one season. The details about the generation capacity along with the averaged emission factors [2] of the incorporated energy sources is shown in Table I.

2.2 Problem Formulation

The first objective is the economic dispatch of energy sources and the second objective is minimization of SCC of CO_2 based on the the emission factors of the energy sources. For the first objective we multiply the per unit cost of an energy source with the energy units produced by it and find the cost of energy production. In the next objective we multiply the units generated with the emission factors of the respective sources to find the kg of CO_2 produced. We then multiply this with SCC of CO_2 to find the overall cost of detrimental effect of emissions. The combined objective is the minimization of the sum of these two costs as shown in (5).

$$F^t = \sum_{x=1}^{6} W_1(EF_x \times P_x^t \times ((SCC))) + W_2((L_x \times P_x^t)) \tag{5}$$

In the above function W_1 and W_2 are the weights associated with each objective which gives an additional level of control over the objective function. The energy generated from the source x in time interval t is the decision variable given by P_x^t. L_x is the per unit cost of generation source x while (SCC) is the socio economic cost of CO_2. Further each decision variable is lower bounded by zero and upper bounded by P_x^{max}. The only equality constraint on the above objective function is the power balance equation.

$$P_d^t + P_g^t + P_c^t + P_s^t + P_w^t + P_h^t = P_L^t; \tag{6}$$

The left side of the equation shows the amount of energy generated by the sources which must be equal to the load demand of facility in any time interval t. The time interval t is taken equal to 1 hour. The results of optimization are compared with the base case scenario which is the simple economic dispatch of energy units without any step to reduce CO_2 emissions.

Table 1: Emission factors And Unit Cost

Source	Cost($/kWh)	Emission factor (kg/kWh)	Capacity (kW)
Oil	0.20	0.825	2.12
Gas	0.18	0.690	2.17
Coal	0.15	0.855	2.17
Solar	0.17	0.1015	2
Wind	0.15	0.022	2
Hydro	0.100	0.011	1

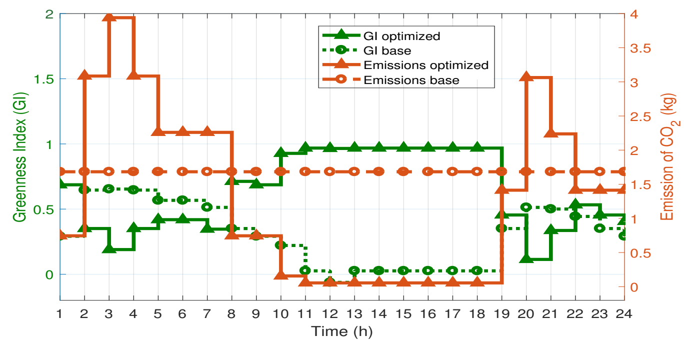

Figure 2: The greenness index and the emissions of CO_2 for one day optimization.

Table 2: Comparison of cost and emission between optimized and base case.

	Optimized	Base	Difference
Emissions (kg of CO_2)	30.67	40.39	9.72
Accumulative Cost ($)	16.28	25.39	9.11

3 RESULTS AND DISCUSSION

The greenness index along with the emissions of CO_2 is evaluated for optimized case and base case as shown in figure 2. It is evident from figure 2 that our approach is the more greener approach. This can be further verified from the emissions shown in figure 2 which are low in optimized case when GI is high and vice versa. The cumulative results of optimization for one day are shown in Table II. In optimized case 30.67 kg of CO_2 is emitted in energy production which is 24, 06% less as compared to the base case. The overall cost which includes the running cost of generator as well the SCC of CO_2 is 16.28$ for optimized case which is approximately 35% less as compared to the base case scenario.

4 CONCLUSION

In this research work a greenness index based economic dispatch of energy sources is considered. Through the life cycle assessment of the energy sources we formulated an objective function to minimize the running cost as well as the socio-economic cost of CO_2. The results of optimization shows that significant reductions in CO_2 are achieved. In addition reductions are also achieved in terms of cost when socio economic cost of CO_2 is considered. The work is simulated for a single facility with a random generated load profile but the algorithm can be applied to large scale with minimum modification.

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