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Considering Environmental Pollution in Generation Expansion Planning.

Mojtaba Shirvani*, Ali Akbar Dusti, and Iman Baghbani.

Department of Electrical Engineering, College of Engineering, Boroujen Branch, Islamic Azad University, Boroujen, Iran.

ABSTRACT

Considering environmental pollution in generation expansion planning (GEP) is an important and considerable subject. This paper deals with GEP problem in the presence of environmental pollution. The problem is formulated as an optimization programming which aims at minimizing investment and pollution costs at the same time. The proposed optimization problem is solved by using firefly algorithm (FA). Simulation results verify the viability and capability of the proposed methodology.
Keywords: Environmental Pollution; Generation Expansion Planning; Optimization Programming; Investment Cost; Pollution Cost; Firefly Algorithm

Corresponding author

INTRODUCTION

Environmental pollution plays a major role in power system planning and operation. Nowadays, new and modern power plants do not produce a large volume of environmental pollutions, but, the old power plants produce pollutions such as CO2 and NOx. In this regards, considering the pollution of generation units in the planning is required. Many investigation have been carried out about environmental pollution of power plants and generation units [1-5]. Some of these researches are briefly reviewed at below.

Paper [6] describes the development and usage of a generation expansion planning (GEP) tool based on dynamic programming, probabilistic production simulation, and environmental assessment. The problem of GEP is solved in stages using tunnel dynamic programming to determine the optimal investment plan of unit additions. The objective function of the planning exercise is to minimize either the cost or the environmental impact or some weighed function of the two. The production costing methodology is based on combining a probabilistic generation model with the load duration curve of the system to deduce a risk model from which the expected energy not supplied and the expected energy produced by each unit are estimated. Estimation of environmental emissions is conducted based on fuel type, heat rate, and energy produced by each unit. The program can model hydroelectric units as well as energy limited units, under economical and environmental load dispatches. The model is illustrated by a planning case study of the Lebanese electric power system to examine the impact of various technical, economic and environmental parameters on the proposed plans. Paper [7] describes a methodology to incorporate the environmental costs associated to the construction and operation of power plants in the long-term expansion planning process of hydrothermal generation systems. These external costs are estimated in terms of monetary values, according to the nature of their impacts and endogenously included in the formulation of the expansion planning model. The minimization of the maximum regret framework used in the modeling process enables the development of a single expansion strategy that allows for corrections in the expansion trajectory, according to the behavior of electricity demand. A case study based on the Brazilian system and previous environmental valuation studies is presented and discussed. The results found contemplate a reduction in the total cost of the electricity system expansion planning. Paper [8] studies the impacts of biomass power generation and CO2 taxation on electricity generation expansion planning and environmental emissions. This paper describes that Thailand has a high potential to utilize renewable energy for electricity generation especially from agricultural waste; however, at present only a small fraction of biomass is used for energy purposes. This study aims to estimate the potential of biomass power generation and its impact on power generation expansion planning as well as mitigating carbon dioxide emission from the power sector. The harvest area and crop yield per area are taken into consideration to estimate the future biomass availability. The supplies of biomass are then applied as a constraint in the least cost electricity generation expansion-planning model. The cost of CO2 emissions is also added to the fuel costs as carbon taxation to make biomass power generation competitive to fossil fuels, then the optimum value of CO2 charge is found out. In addition, levels of CO2 limitation from power generation are also introduced to mitigate CO2 emissions. Paper [9] applies WASP-IV model and develop methodology to estimate the impact of several environmental externality costs on the electricity sector development plan. For this purpose, 22 cases were generated which were later on reduced to only seven non-dominated cases by considering this problem as a dynamic multiple objective programming model. The major impact of internalizing the external cost is on fuel use. In the electricity generation system more natural gas and less coal has been used. A cost benefit analysis (CBA) of three scenarios has been performed focusing on taxing only one pollutant while looking at its overall implication. The benefit cost ratio was about 4.5 while the net benefit was about 200 million USD (depending on the scenario). Multi-objective analysis among the different scenarios was carried in a dynamic setting. Seven scenarios appear in the non-dominated set. Out of them five appears in every year and those should have a higher weight placed on them by policy makers. Out of those five, two are a single tax on one pollutant. Thus, policy makers might want to consider a mixture of taxes but for the sake of simplicity can also use a simple one tax on a given pollutant.

This paper deals with GEP problem in the presence of environmental pollution. The problem is formulated as an optimization programming which aims at minimizing investment and pollution costs at the same time. Simulation results verify the viability and capability of the proposed methodology. The proposed optimization problem is solved by using firefly algorithm (FA). Therefore, this algorithm is presented in the next section.

Firefly algorithm

The firefly algorithm (FA) is a meta-heuristic algorithm, inspired by the flashing behavior of fireflies. The primary purpose for a firefly's flash is to act as a signal system to attract other fireflies. Xin-She Yang formulated this firefly algorithm by assuming all fireflies are unisexual, so that one firefly will be attracted to all other fireflies; attractiveness is proportional to their brightness, and for any two fireflies, the less bright one will be attracted by (and thus move to) the brighter one; however, the brightness can decrease as their distance increases; if there are no fireflies brighter than a given firefly, it will move randomly. The brightness should be associated with the objective function. Firefly algorithm is a nature-inspired meta-heuristic optimization algorithm [10]. The pseudo code can be summarized as follows [10]:

Begin
1) Objective function: $f(x)$, $x=(x_1,x_2,\ldots,x_d)$;
2) Generate an initial population of fire flies x_i $i=(1,2,\ldots,n)$;.
3) Formulate light intensity I so that it is associated with $f(x)$.
   (For example, for maximization problems, $I \propto f(x)$ or simply $I = f(x)$;
4) Define absorption coefficient γ
      While (t < Max Generation)
            For i = 1 : n (all n fireflies)
                  For j = 1 : n (n fireflies)
                        If ($I_j > I_i$),
                        Move firefly i towards j;
                        End if
                  Vary attractiveness with distance r via $exp(-\gamma r)$;
                  Evaluate new solutions and update light intensity;
                  End for j

End for *i*
Rank fireflies and find the current best;
End while
Post-processing the results and visualization;
End

The main update formula for any pair of two fireflies x_i and x_j is as (1).

$$x_i^{t+1} = x_i^t + \beta \exp\left[-\gamma r_{ij}^2\right]\left(x_j^t - x_i^t\right) + \alpha_t \varepsilon_t \quad (1)$$

Where α_t is a parameter controlling the step size, while ε_t is a vector drawn from a Gaussian or other distribution. It can be shown that the limiting case $\gamma \to 0$ corresponds to the standard Particle Swarm Optimization (PSO). In fact, if the inner loop (for *j*) is removed and the brightness I_j is replaced by the current global best g*, then FA essentially becomes the standard PSO [10].

Mathematical Formulation considering pollution

Considering environmental pollution in the objective function leads to following mathematical formulation for GEP problem:

$$\text{Min}\left(\left[\sum_{t=1}^{T}\sum_{j=1}^{C}\left(IC_t^j \times XT_t^j + OC_t^j \times XT_t^j\right)\right] + \left[\sum_{t=1}^{T}\sum_{j=1}^{C}\left(PC_t^j \times XT_t^j\right)\right]\right) \quad (2)$$

Subject to

$$XT_t^j \le Max\_XT_t^j \qquad t = 1,2,3,\ldots,T; \quad (3)$$

$$\sum_{j=1}^{C} XT_t^j \le XC_t \qquad t = 1,2,3,\ldots,T; \quad (4)$$

$$RM^{\min} \le RM \le RM^{\max} \quad (5)$$

$$\sum_{t=1}^{T}\left(IC_t\right) \le Max\_IC \quad (6)$$

$$t = 1,2,\ldots,T; \quad (7)$$

$$j = 1,2,\ldots,M; \quad (8)$$

Objective function (2) comprises two terms as planning cost and pollution cost, and equations (3) to (8) indicate the constraints. The objective function (2) minimizes the planning cost as well as pollution cost at all stages. Where, the investment and operation costs are minimized. The first term shows the investment cost (IC) of the installed technology *j* at stage *t* of the horizon planning *T*. The second term shows the operation cost (OC) of the installed technology *j* at stage *t* (XT^j_t) of the horizon planning *T*. In addition, the second part of objective function shows the pollution cost (PC). Constraint (3) demonstrates that the installed technology *j* at stage *t* should be smaller than a specified value at all stages. Constraint (4) denotes the total installed capacity at stage *t* should be smaller than a specified value at all stages. Constraints (5) shows the reserve margin and constraints (6) represents the maximum invest cost of planning as a constraint. Relationship (7) indicates the stages of the horizon planning and constraint (8) shows the number of included technologies in the planning.

Illustrative Test case

In order to evaluate the proposed method, a test system is considered and data are provided in Table 1 [11]. The proposed test system comprises five generation types as hydro, nuclear, coal, oil and combustion turbine and each generation type contains several units. The total capacity before planning is 4100 MW and peak demand is 3550 MW. The load levels over the horizon planning are presented in Table 2 [11]. Where, three stages are considered for expansion. The other necessary data for planning are provided in Table 3 [11]. Costs of CO_2 taxation by type of power plant (cent/106 kcal) is listed at Table 4.

Table 1: The data for generation units

Unit Type	Number of Units	Capacity (MW)	Fuel Cost ($/kWh)	Operation Cost ($/MW)	FOR
Hydro	4	200	0	235	0.12
Nuclear	2	650	2.41	113.75	0.055
Coal 1	2	400	4.21	450	0.09
Coal 2	2	200	4.21	516	0.15
Oil	2	300	11.3	195	0.36
Combustion Turbine 1	2	50	12.16	235	0.015
Combustion Turbine 2	4	25	12.15	140	0.0075

Table 2: Forecasted peak demand

Stage	0	1	2	3
Peak Demand (MW)	3550	5500	6800	8200

Table 3: The technical and economical data of generation units

Unit Type	Capacity (MW)	Capital Cost ($/kW)	Fuel cost ($/kWh)	Operation Cost ($/MW)	Life time (year)
Nuclear	650	625.5	2.41	113.75	30
Coal 1	400	635	4.21	450	25
Coal 2	200	595	4.21	516	25
Oil	300	255.75	11.3	195	25
Combustion Turbine 1	50	152	12.16	235	5
Combustion Turbine 2	25	100	12.15	140	10

Table 4: Costs of CO_2 taxation by type of power plant (cent/106 kcal)

Power plant type	US$ 5/tonne CO_2	US$ 7/tonne CO_2	US$ 10/tonne CO_2
Coal 1	207.58	311.36	415.15
Coal 2	207.58	311.36	415.15
Oil	160.31	2240.46	320.62
Combustion Turbine 1	153.47	230.21	306.94
Combustion Turbine 2	153.47	230.21	306.94

Simulation Results

The proposed GEP is simulated based on the given test system. Table 5 shows the simulation results. The generation units are installed in different stages in order to cope with the system conditions and satisfying the constraints. It is clear that the units with more pollution are installed at end stages and the units with less pollution are installed at the beginning of the planning in order to reducing the planning cost.

Table 5: the installed technologies in stages of horizon planning

Stage	1	2	3
Hydro	1	0	0
Nuclear	1	0	0
Coal 1	0	0	1
Coal 2	0	0	1
Oil	0	0	1
Combustion Turbine 1	0	1	0
Combustion Turbine 2	0	1	0

CONCLUSION

This paper addressed a generation expansion planning in the presence of environmental pollution. The problem was formulated as an optimization programming, which aimed at minimizing investment and pollution costs at the same time. The proposed optimization problem was solved by using firefly algorithm (FA). Simulation results demonstrated the effectiveness of the methodology.

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