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Renewable energies: modeling and optimization of production cost

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Abstract

In this work, we aim to contribute to the modeling and the optimization of the energy production. In order to minimize the production costs, the quantity of the available green energy in the power system. The model is implemented under the GAMS 24.7.1 environment and was validated by using CPLEX.The presented model can easily combine different sources of energy, by scheduling the resources with high performance and flexibility. This optimization of production cost is applied in a real case, the cost can be reduced by 38% in winter and by 40, 89% in summer.

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Keywords: Fnergy production; GAMS modeling system; Linear modeling; optimization; renewable energy (solar and the wind)

1. Introduction

The development of using the renewable energy has experienced a strong growth in recent years. Currently, most of the world's countries are developing their energy systems by integrating unconventional sources of production based on conventional sources and increased recourse to renewables. The exploitation of renewables in electricity generation has many advantages:

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- they guarantee supplies to consumer;
- they respect the environment, and they do not produce waste;
- they are sustainable;
- they authorize a decentralized production adapted at the same time to the resources and the local needs;
- they offer significant energy independence.

In order to increase the electricity production by the renewable energies, it is necessary to determine the apparent need for the consumers to ensure the quantity of energy demanded in the power network. These requirements and environmental considerations have imposed in part of the evolution of power systems to integrate unconventional means of production and those of wind power and photovoltaics.

In this paper, a model to maximize the production based on the renewable energies was created to ensure the demand of the consumers and to put a model of optimization that allows defining the quantity of energy available in the electricity network.

Nomenclature

C_{Ei} conventional energy
R_{E_j} renewable energy
α_i, α_j quantity of conventional energy and renewable energy produced
C_{pi} , C_{pj} cost of energy production
K slice
$A_{(i,j,k)}$ availability of conventional and renewable energy in the slice
P_{RE_j} production of renewable energy
D_E demand
E^n exporting energy in network
β^{min}, β^{max} minimum, maximum energy level
α^E, α^T export, transport energy
S^b storage the energy
P^l power level of the energy produced

2. Literature review

In recent years, considerable efforts have been made to formulate and implement energy production strategies in the world. For example some of optimization methods used for this purpose are: Leonid Kantorovich developed the linear programming method in 1939, which is widely used for optimization of renewable energy technology. Saif et al. [1] formulated a problem of diesel wind hybrid system PV- as a model of linear programming with two objectives: reduce at least the total cost and the minimize total emissions of CO_2, while putting an upper limit on the not planned energy. Al Huneke et al. [2] used the linear programming to obtain an optimal configuration for a combination of the generator of electricity with wind power - solar energy - battery- diesel for two real powers except for network systems in India and Colombia. The results of optimization for both studies show the possible combination of cells- PV-and diesel generator. Lee et al. [3] developed a new optimization model based on linear programming for hybrid power systems considering many power losses and studied three cases of the primary was on minimizing the total cost of the scheme but on the reduction of the electricity supply capacity and heat storage outsourcing. Nogueira et al. [4] used a methodology for the sizing and the simulation of PV-wind battery system of hybrid energy and the linear programming with a minimum cost and high reliability. Bilal et al. [5] proposed a sizing optimized by a hybrid photovoltaic system - wind energy-battery by multi-objective genetic algorithm satisfying two primary objectives of minimization of the annualized costs and the minimization of the loss of the probability of supply. El kafazi et al. [6] adapted the MRP approach to planning between the different sources of energies conventional and renewable.

In recent years, a lot of work has been made to formulate energy planning strategies in developed or industrial countries. The goal is to present a new strategy for power generation to meet consumer needs while respecting the environment. The objective is to use the renewable energy as a necessary power with the conventional energy to minimize the production cost. Also preserving the environment. To optimize the energy production, we must have an optimization system to combine between a conventional energy and renewable energy. Gams offer this possibility to balance the different energies and to minimize the cost. As well, there should be an option to control the balance in the system according to their specific feature. It is necessary to determine the apparent need for the applicants to ensure the quantity of energy wished. This strategy can be used to create a mathematical model to minimize the cost of energy production and to define the quantity of energy used in the period.

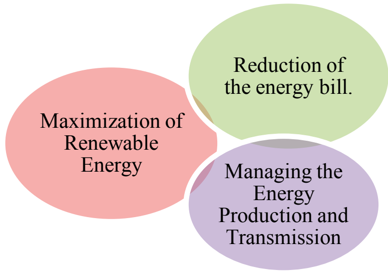

Fig. 1. The interest of the research.

2.1. GAMS

The General Algebraic Modeling System (GAMS) is specifically designed for modeling linear, nonlinear and mixed-integer optimization problems. The system is especially useful for large, complex problems. GAMS are flexible and powerful and structures safe modeling habits itself by requiring concise and exact specification of entities and relationships [7]. The aim of using GAMS is to optimize the cost of the energy production. As well as, to use the renewable energies which have no costs for raw material instead of conventional energies which have a high cost. Also, a model of optimization that allows determining the amount of energy available on the electricity network. The paper is organized as follows: i) determine the input variables, ii) modeling and optimization in GAMS environment, iii) case study and discussion of results. In summary, our contributions are: 1) the development of a model adopting a formalized modeling approach, which is suitable to be used in optimization of energy production; 2) the development of an objective function for minimizing the conventional energy running costs; 3) the presentation results showing the effectiveness of the proposed optimization.

3. Evolution of electrical network

From the 90s, the production of electricity from renewable energy has been encouraged in some countries to increase production.

The renewable energy portion the world production increased from 1.1% in 2004 to over 2% in 2012 (Fig. 2).

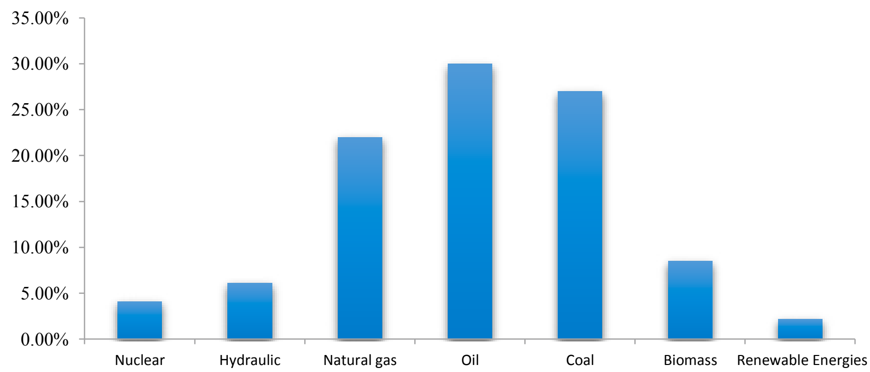

Fig. 2. Distribution by origin of the world production in 2012 (Observ'ER, 2005).

This progress of the integration of the new sources of energy in the electricity network for the power production due to the importance of these sources in the future. Also, to the obligation of preserving the environment.

3.1. Electrical system

The power system is formed using the conventional production (thermal, nuclear and hydraulic), as a modern production (the wind and solar), systems of transport and distribution.

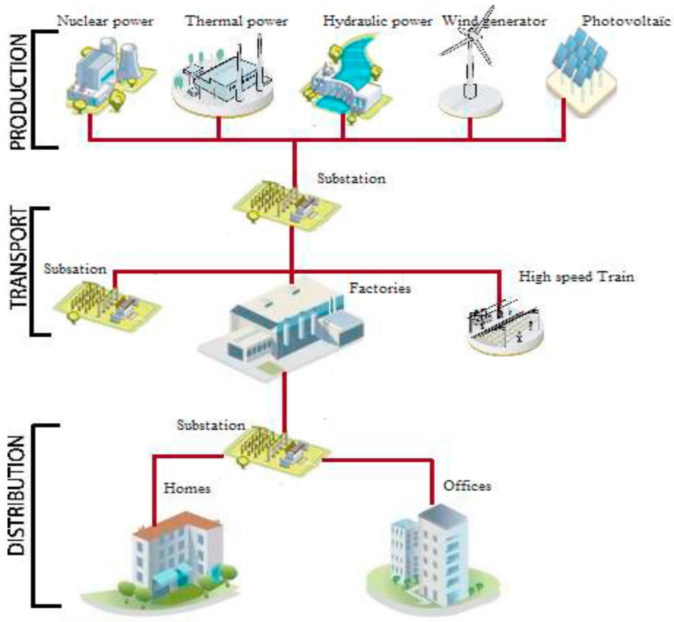

Fig. 3. Description of the electrical network.

The electrical network (transport and distribution) have the role of transporting the energy from the production sites to the consumer part with steps of lowering the voltage level in transformer stations.

3.2. Organizational chart

The organization chart allows deducting the quantity of energy demanded and the amount of energy which need to produce by the available powers.

Demand is an input; we compare the availability of renewable energy. One hand, if this energy is equal or superior to demand we can just use it only whether to transport, export or storage. In the other hand, if the energy is inferior to demand, we must compensate with conventional energy.

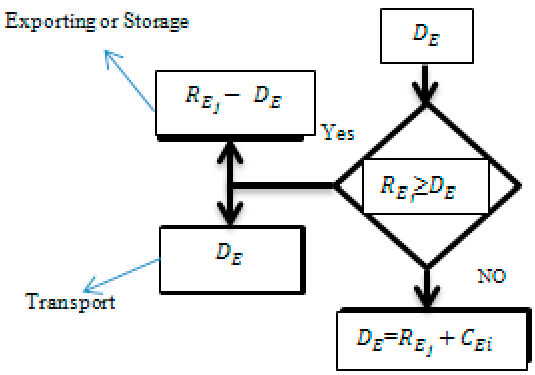

Fig. 4. Organizational Chart of Production.

4. Modeling

The electrical network operational planning consists in taking decisions to optimally schedule internal production by renewable energy and conventional energy, to cover the grid demand, minimize the conventional energy running costs and the cost of imported electricity from the utility grid in the next hours or day. At every slice, we must take high-level decisions about:

- when should each energy type be started and stopped
- how much should each energy meet this load at a minimum cost
- when and how much energy should be purchased from the utility electrical network
- Schedule time for minimizing cost.

The parameters used in the proposed formulation is described, respectively (see nomenclature), where, for simplicity the subscript *i* and *j* when referring to the i^{th} and j^{th} system.

4.1. Formulation

The function representing the production:

$$\sum_{i=1}^{3}\alpha_i C_{Ei} + \sum_{j=2}^{2}\alpha_j R_{E_j} = \begin{cases} \alpha_i = 0 \text{ for } R_{E_j} \geq D \\ \\ \alpha_i = 1 \text{ for } R_{Ej} < D \end{cases} \tag{1}$$

with:
$\alpha_i . C_{E_i}$: The quantity of conventional energy produced in a slice.
$\alpha_j . R_{E_j}$: The amount of renewable energy generated in a slice.

This function allows determining the quantity of produced energy. Also, to make a balance between the different sources of energy (conventional and renewable) meet the needs of customers.

Table 1 allows determining the primary source of energy used for all the periods of the day. The passage from a power supply to the other one is made at the time of the need. In addition, the table enables calculating the production cost in every slice k.

Table 1. Distribution energy per period in the day (24h).

Period(Slice k)	00 :00-04 :00	04 :00-08 :00	08 :00-12 :00	12 :00-16 :00	16 :00-20 :00	20 :00-00 :00
Energy product	$C_{Ei} + R_{Ej}$	$C_{Ei} + R_{Ej}$	R_{Ej}	R_{Ej}	$C_{Ei} + R_{Ej}$	$C_{Ei} + R_{Ej}$

From Table 1, at each slice k, the system model is initialized to the measured/estimated the energy production of the production systems and the cost, i.e., the energy production level, and demand levels.

4.2. Exporting energy

In the organizational chart of production Fig. 4, when we have $R_{E_j} \geq D_E$ and R_{E_j}- D_E, we can decide to export or to storage energy, it depends on demand programs and what slices at the time. The customers specify the level of curtailment of the controllable loads in every slice.

For exporting energy in the electrical network, denoting by $E^n(k)$ and P_{RE_j} *(k)* production of renewables at slice k and by S^b*(k)* the power storing at slice k, we consider the following model of energy level:

$$P_{RE_j} \geq D_E \Longrightarrow R_{E_j} - D_E \Longleftrightarrow E^n(k) = 1 \tag{2}$$

and

$$\beta^m(k+1)= \begin{cases} \beta^m(k)+\ \alpha^E P^l(k)-S^b(k),\ if\ E^n(k)=1 \\ \beta^m(k)+\ \alpha^T P^l(k)-S^b(k),\ otherwise \end{cases} \tag{3}$$

$$\alpha= \begin{cases} \alpha^E,\ if\ E^n(k)=1 \\ \alpha^T,\ \text{otherwise (transport energy)} \end{cases} \tag{4}$$

The export and transport energy account for the production level denotes P^l. If the power exchanged at slice k, is greater than demand, this will be exported. Otherwise, it will be transported in the network.

4.3. The cost function

Optimization of energy production is achieved by choosing an objective function representing the operating expenses to be minimized. The following function includes all costs associated with renewables and conventional energy.

$$Min\ \ Z = (\sum_i C_{pi} * C_{Ei} + \sum_j C_{Rj} * R_{Ej}) * A_{(i,j,k)} \tag{5}$$

With k present the slices, i means the conventional energy and j is renewable energy. C_{pi} and C_{pj} are the costs of production (conventional energy and renewable energy). C_{Ei} is a conventional energy, $R_{E_j}$is renewable energy and $A_{(\text{i,j,k})}$ is availability between a conventional and renewable energy in the slice k.
Under the constraints of the supply and demand:

$$C_{Ei} \geq 0\ ;\ R_{E_j} \geq 0 \qquad \forall_{i,j} \tag{6}$$

$$\sum_i C_{Ei} + \sum_j R_{E_j} = Demand \qquad \forall_{i,j} \tag{7}$$

$$\sum_j C_{Ei} \leq Cap_{CEi} \qquad \forall_i \tag{8}$$

Critical loads that mean the demand levels related to important processes that must be always satisfied.

This function (5) will allow us to determine the production cost of each source of energy (conventional and renewable).

Cap_{CEi} is the capacity of energy sources.

5. Simulation

In this study, the production cost of every source of energy is done to evaluate the difference in price for two seasons (winter and summer) for each type of energy using GAMS. As well, to minimize the production costs, the quantity of the available green energy in the power system, should be defined, and if needed, combined with the other conventional energy sources. The model is implemented under the GAMS 24.7.1 environment and was validated by using CPLEX. The results are shown in Fig. 7.

To test and validate the model the data is used of the daily consumption and the production cost of each type of energy.

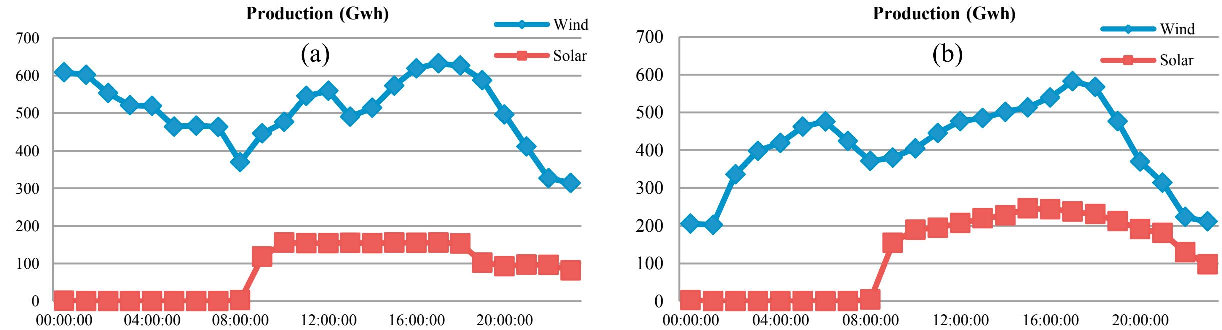

Fig.5. Energy production per period for one day, (a) in winter, (b) in summer.

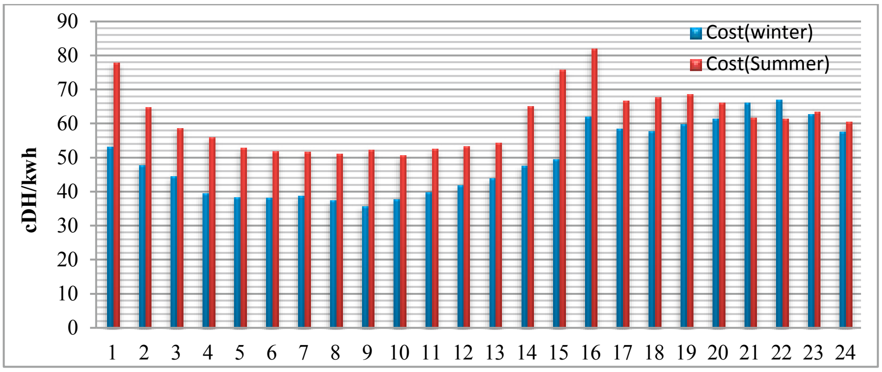

Fig. 6. Cost of energy production per period in winter and summer for one day.

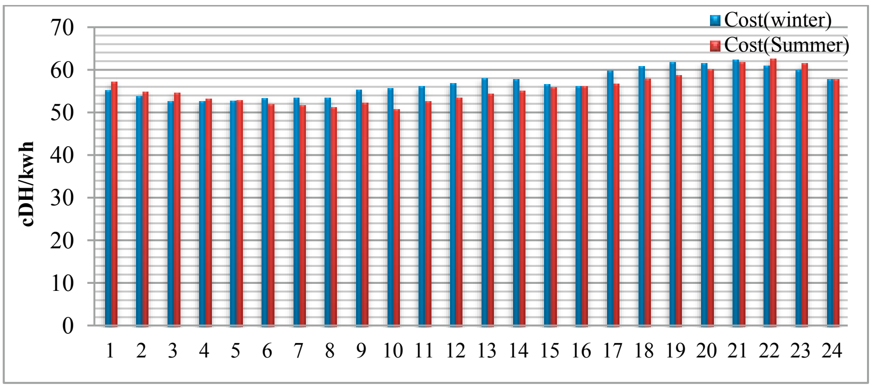

Fig. 7. The results of optimization cost of energy production per period in winter and summer for one day

Both optimizations show different results for the two time periods using Table 1. The difference can be related to the fact that they are optimal to only that period and or suboptimal for any other period. The weather data vary on inter-annual timescales, so the problem variability will always persist. Also, it has an impact on the production cost. The cost optimization of the present paper allows for an entirely new infrastructure of transmission on top of any existing network supplied within the optimization. The function representing the production with Table 1 allows efficient calculation of the energy produced in the system. The real power of the cost optimization is that one can interpret what an entirely free market would develop at certain price levels. The optimization of energy production shows how strictly a variable production dominated electric network can meet the demand, without any regard to cost.

The cost optimization will find the most economical system, which will be more realistic and meeting the needs.

During all the two experiments, the system operated with the different production systems. The ultimate purpose of Experiment 1 (winter) is the production balance between conventional and renewable energies in the winter. In other words, the system performed so as to minimize the cost energy production. In Experiment 2 (summer) due to its high maintenance and production (conventional) costs. A smaller amount of power needs to be produced from the production conventional during Experiment 1 compared with the experiment 2 in the summer. The total cost for Experiment 1 decreases by 38% and for Experiment 2 decreases by 40, 89%. The price of energy production varied according to demand and season. It is worth remarking that the decreases cost depends on the long-term utilization of renewables.

6. Conclusion

This paper presents a modeling and simulation of production cost model for the minimization and exploitation of renewable energy in the power grid. The model includes the sum of conventional energies and renewable energies, to adapt the production of renewable sources to customers' needs. Based on the GAMS modeling, a simple model of optimization has also formulated and applied to minimize the cost of energy. The use of this model shows that the cost can be reduced by 38% in winter and by 40,89% in summer.

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