Optimal Control Approach for a Smart Grid

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Abstract
The current electricity networks will undergo profound changes in the years to come to be able to meet the growing demand for electricity, while minimizing the costs of consumers and producers, etc. The electricity network of tomorrow or even the intelligent « Smart Grids » network will be the convergence of two networks: the electricity network and the telecommunications network. In this context falls our work which aims to study the impact of the integration of energy decentralization into the electricity network. In this sense, we have implemented a new smart grid model where several coexisting suppliers can exchange information with consumers in real time. In addition, a new approach to energy distribution optimization has been developed. The simulation results prove the effectiveness of this approach in improving energy exchange and minimizing consumer purchase costs and line losses.
Keywords:
Smart Grid, decentralized production, renewable energy, energy distribution, control.

1. Introduction

The power grid is currently undergoing the biggest change since the interconnection of several power stations over a wide area. Recently, a vision of a power grid modern commonly called smart grid "Smart grid" (SG) is in the process of take shape in several countries [1]. The emergence of these visions around the world gives birth to several definitions of what the electrical network of tomorrow could be. All the everyone agrees that the latter will be the convergence of the two networks: the network electricity and telecommunications. This fundamental characteristic of the SG makes it extremely flexible, but makes its modeling and analysis more complicated [2].
The life cycle of electrical energy can be subdivided into three phases: generation, transmission and distribution. The transmission of the electricity generated in stations of production through transmission lines inevitably leads to losses [1]. In order to minimizing these transmission losses industrialists and researchers have taken an interest in the Distributed Generation (DG). Indeed, this solution aims at production of electricity while minimizing the distance with the final consumer [5].

Thus, the grouping of one or more energy sources, called microsources and power consumption zones will create small power grids called "Microgrids" [1], [4].
DG planning, integration and management are challenges to be met in order to manage the microgrids in a more efficient way [3]. Optimizing the integration of microsources into the electrical network will therefore no longer be based on the optimization of an objective function centralized, the electrical network of tomorrow allowing the interconnection of several microgrids in a decentralized way [1]. It is in this context that our research master's dissertation falls on the subject of modeling and optimal control of a smart grid.

The electricity network of tomorrow or even the intelligent "Smart Grids" network will be the convergence of two networks: the electricity network and the telecommunications network. In this context falls our work which aims to study the impact of the integration of energy decentralization in the electricity network. In this sense, we have implemented a new smart grid model where several coexisting suppliers can exchange information with consumers in real time. In addition, a new approach to energy optimize distribution has been developed.[1]

2. Presentation of a smart grid

Smart grids are electricity grids which, using computer technologies, adjust the flow of electricity between suppliers and consumers.[2]

By collecting information on the state of the network, smart grids help to match production, distribution and consumption. It is necessary to differentiate between smart grid and smart meter, which informs consumers about their demand for electricity. "Smart grids" is a general name for all the "smart" technologies and infrastructures installed. For individuals, the smart meter is a first step in the implementation of smart grids.[3]

Smart grids can be defined according to four characteristics in terms of:[3]

- Flexibility: they make it possible to manage the balance between production and consumption more finely.

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- Reliability: they improve the efficiency and security of networks.
- Accessibility: they promote the integration of renewable energy sources throughout the network.
- Economy: they bring, thanks to better management of the system, energy savings and lower costs.

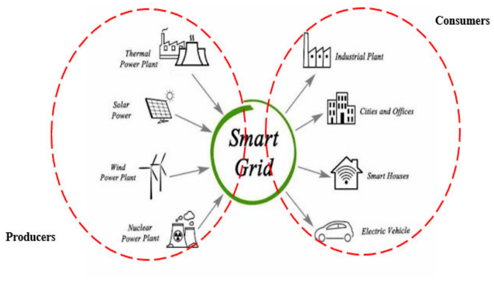

Figure1: Smart grid architecture

3. Modeling of the studie smart grid

An electricity market model is developed for the smart grid under Matlab/Simulink environment. This model is composed of several producers, consumers and a distribution network. This consumer model is a residence made up of several houses. All these consumers are equipped with a smart meter which measures the energy consumption and sends the consumption request to the distribution manager in real time. Also, the producers model contains mainly four different sources of renewable energy.

All producers send their production and price offers in real time to the distribution manager which is connected to the network. The distribution network operator, balances electricity supply and demand by applying the implemented optimization approach.

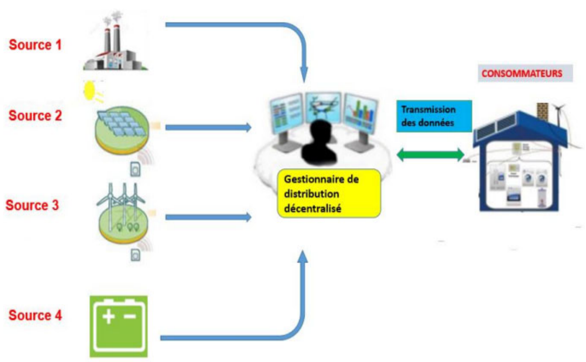

Figure 2: Smart grid model selected

3.1. Optimization problem formulation

The study focuses on the minimization of consumers and producer's costs: The first objective is to minimize the consumer's consumption costs in order to satisfy his demand ED_c^t at each instant t.

The second objective is also to reduce the production costs of producers during the day by decreasing line losses $E_{n,c}^{t,loss}$.

This multi-objective problem has been translated into a single-objective problem sol attainment method as follows:

$$\begin{cases} \min(f) \\ f(P_{n,c}^t, E_{n,c}^t, D_c^t) = \sum_n P_n^t (D_c^t + E_{n,c}^{t,loss}) \\ ED_c^t = \sum E_{n,c}^t \\ E_{n,c}^{t,loss} = \beta L_{n,c} I_{n,c}^2 \\ I_{n,c} = E_{n,c}^t / U_{n,c} \end{cases}$$

Where:

$E_{n,c}^t$: Energy received by each consumer C from the producer at an instant t

ED_c^t: Demand of each consumer C at a time t

P_n^t: Real-time production costs at an instant t with respect to the unit of power for n

$I_{n,c}$: Line current

$L_{n,c}$: Separation length

$E_{n,c}^{t,loss}$: Line losses

n: Number of production sources

β: Gain

3.2. Optimization approach description

In each instant t, if a consumer sends his request, the destination manager sorts the available producers on the network in total cost ascending order f. Then, it cycles through these producers in order to serve all of the consumer's needs. For each producer browsed, it checks if it is free, otherwise it automatically goes to the next one. If it is free, it checks whether the amount of available energy meets the total consumer's energy need, taking into account line losses.

In this case, it purchases and updates the producer's output; otherwise, it purchases all of the output from the current source, computes the rest of the requirement energy, and moves on to the next source and redoes the output. The same operation is repeated in order to buy the rest of the need. When all consumer demand is satisfied, this operation will stop as shown in Figure 3.

This approach is applied to the optimization of the electricity distribution of a free market which is composed of four producers and one consumer.

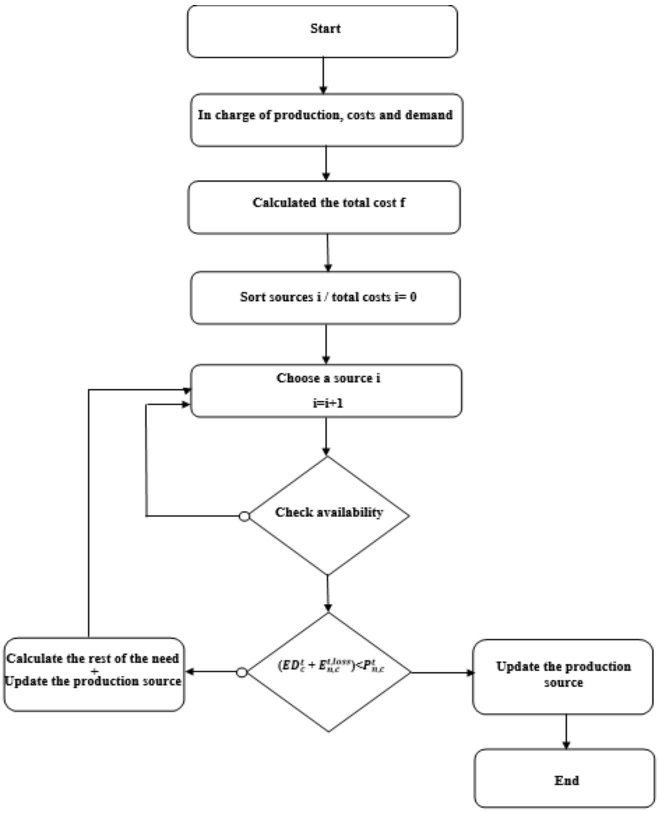

Figure3: Flowchart of the proposed demand reponse

3.2.1 Producer's models

Figure 4 illustrates the energy available by each producer during 24 hours. While Figure 5 shows the costs of microsources during the day. The cost of producers is evenly distributed between 0 and network parity.

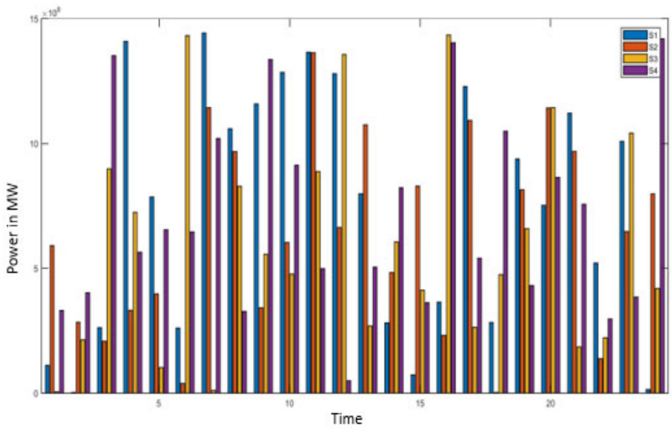

Figure 4: Energy available by microsource during the day

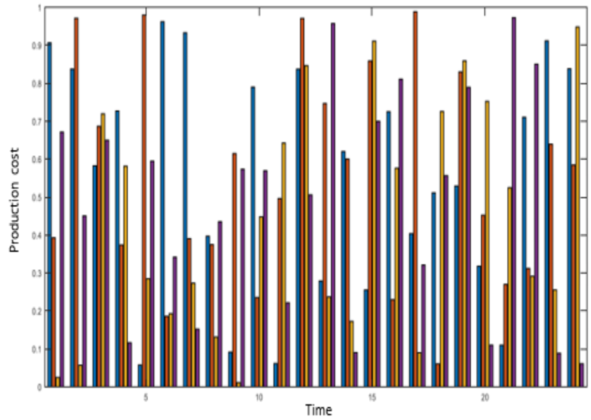

Figure 5: Production costs

3.2.2 Consumer model

This model is implemented our modeling and simulation methods is to use real data, which results in a load consumption connected to the network smart grid. Figure 6 illustrates the load request of the consumer during 24 hours.

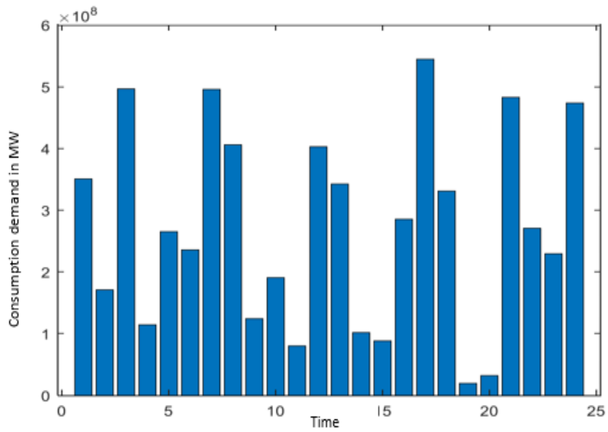

Figure 6: Demand for consumption during the day

4. Results and Discussion

As an interpretation, we studied in this case the coexistence of several producers interconnected with consumers.

Figure 7 shows the distribution of energy during the day for the consumer.

At 4 a.m., the consumer has to buy all of his energy needs from source 4, Figure 7.

In the first hand, this source offers the lowest price compared to the others, Figure 5. In the second hand, the amount of available energy exceeds consumer demand, figure 4.

In addition, on the producer side, production costs are

almost negligible, Figure 8.
Figure 9 illustrates the total cost that the consumer must pay if he has purchased all of his energy need from renewable energy sources or from the STEG.
The application of our optimization approach to control distribution electricity on our intelligent network enabled us to minimize both consumption costs and production.
The total cost is reduced by 99% compared to the network at 9 am, Figure 10.

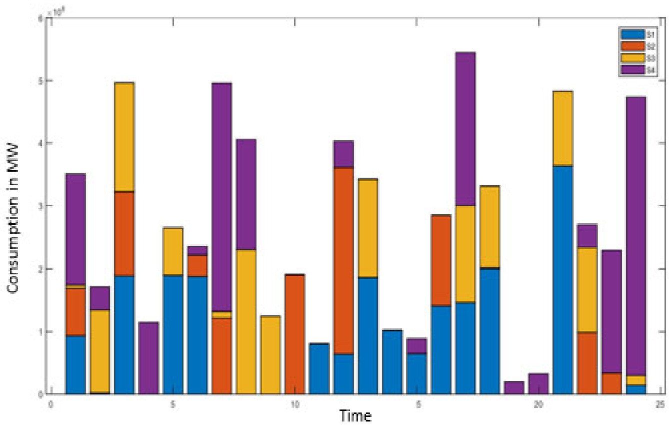

Figure 7: Distribution of energy to the consumer during the day

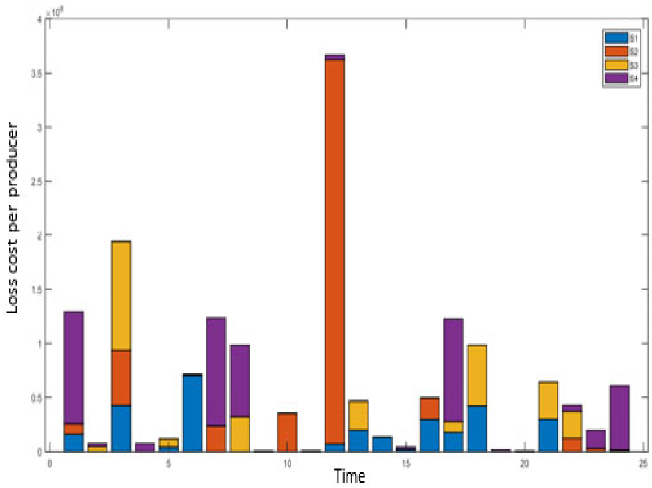

Figure 8: Costs of losses

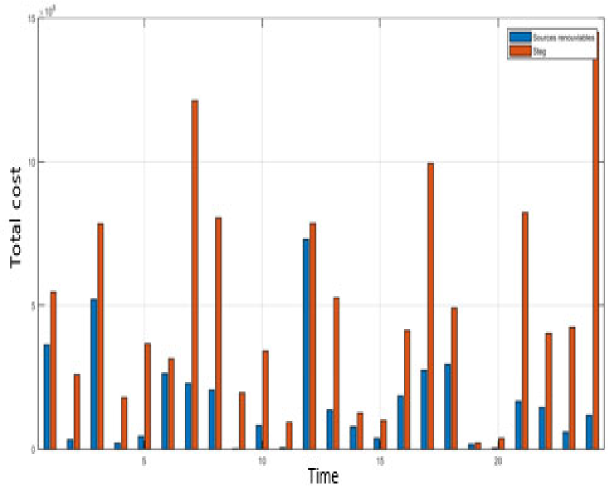

Figure9: Total cost of the consumer and the STEG

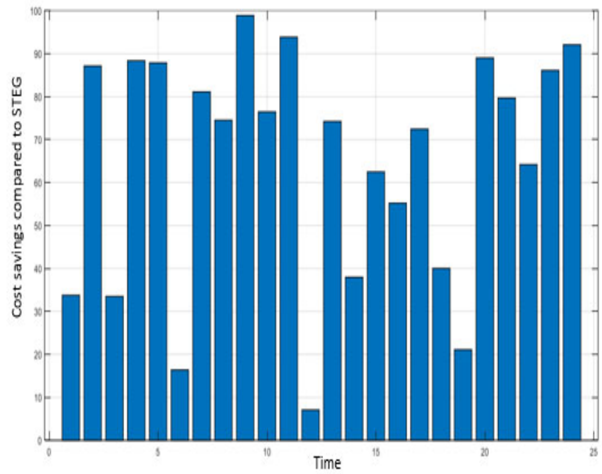

Figure 10: Cost savings compared to STEG

5. Conclusion

In this article, we have developed a new energy exchange model based on the optimization approach that we have developed within our platform. This approach takes into account the distance separating microsources from the consumer, the available energy and their costs. We have shown by simulations that this model reduces costs and losses online. As future perspectives of this work, it would be possible to:

- develop other Pareto optimal strategies based on optimization methods multi-objectives.
- finding the Pareto optimal strategies allow both to decrease emissions of carbon.

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