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The Effect of Demand Response in Improvement Solar manufacturers Profit Connected to Grid in Deregulated Power Market

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Demand response, Load uncertainty, Distribution network, GAPSO algorithm, Renewable energy.

Abstract

The aim of this study is to incorporate solar and wind-based systems into load management such that this collective performance benefit both energy suppliers and consumers. In this modelling, initially equations of the system in market are written and merged with each other. Uncertainty is also considered to increase profit and it will be shown that uncertainty can affect the profit of system. The utilized method for price forecast is day-ahead price forecasting and the main goal is to increase system's profit. The selected software for system simulation is MATLAB and a mathematical method will be used to optimize market. Furthermore, hybrid GAPSO algorithm Has been used to problem optimization.

1. Introduction

Solar energy is a renewable energy source that has seen tremendous growth in recent decades and has been used in different countries.For example, the increased installation of photovoltaic systems in developed countries, use of solar panels in buildings and installation of great solar power plants around the world in recent years are the samples of this countless increment. Several methods have been introduced to incorporate hybrid renewable systems such as solar energy into restructured electricity market. Incorporating these energies in load management has been proposed to reduce costs and support renewable power resources. However, it is necessary to introduce a coordination method for load management and solar energy integration. The coordination also can lead to system exploitation by reducing commitment of thermal units during peak hours.

Gilmore et al. [1] investigated the solar generations and reviewed reasons for increasing the use of these generators and their contribution in energy supply of the system. A general model of electricity market and incorporation of solar generations in energy market of Australia were presented in detail. The system was studied in the presence of storage systems in a long-term horizon until 2030. In a study by Ramon-Marin et al. [2] in 2014, a method was presented to estimate generated reactive power by PV plant for operation goals in LV and MV power systems. This method was presented using historical information of the system and based on correlation model development. It was implemented on three different test networks by using load forecasting models based on real data. In other projects, conducted by Halldrsson [3] and Bacher et al. [4], a method was prepared to forecast the sun radiation. The higher accuracy of such methods can lead to increase in profit of these resources in electricity market. Moreover, a probabilistic optimization method was proposed by Dominguez et al. [5] to incorporate generation of new energies into power system; inmost of such methods, scenario making and optimization based on the scenarios were common.

In 2011, Mohammadi et al. [6] proposed the incorporation of the solar power plants and suggested a price in electricity market and maximized the expected profit based on the profit curve. In this study, salt marsh heat storages were integrated with solar energy to increase efficiency and profit of the solar energy; moreover, the uncertainty of solar generation was considered.

Ho et al. [7] proposed an economic model of profit maximization for PV generation in electricity market. To simulate case study—a PV auction in trade market of Amsterdam—a simple model was employed by using standard neighborhood of PV generation data. Mont Carlo method was used to calculate fines due to sun radiation forecast. Moreover, Mont Carlo simulation was used to study some unbalanced random capacities and their corresponding

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prices in Gaussian distribution resulted from iteration of computational loop. The sensitivity to forecast error has been challenged by simulating different levels of unpredictability of solar radiation. Simulation results showed a little difference between benefits of PV generation when it was incorporated in electricity market and when it was supplied with a certain price.

Marano et al. [8], showed a technical-economic analysis of investing in PV systems installed on roofs by considering incentive policies and then it was applied to important case studies of the countries that the PV market has been successful in (Germany and Italy). The analysis showed PV investment difference between past and present from 2006 to 2012. Four case studies from 3 MWp to 1 MWp were explored accurately. The profitability indices have been assessed as net percentage and the internal rate of return in a 20-years period with incentive policies—the assessment was most interesting in the case of Italy. In Italy, the best profit difference was accomplished for great PV power plants and it was weakly balanced with tariff reductions until 2012 when a new framework filliped investment. While in Germany, the best profit difference was accomplished for medium PV power plants and was matched with tariffs. Nevertheless, it could be predicted that Germany tariffs will be reduced because the profit difference has been increased compared to past years. The optimum price of Vales and England electricity market has been calculated by considering constraints and losses of transmission network in Audun et al. [10]. In this study, welfare function has been maximized by considering market balance constraints, limitations of transmission network, generation of each generator and whole generation of the network. The mentioned model was implemented for 13 different points of these two countries and results showed that the welfare is maximized by presenting optimum price in each point. The optimum price has been calculated by maximizing socioeconomic welfare function in short-term and considering effective constraints on competitive market such as market balance, limitation of generation capacity of power plants, demand of different parts and maximum capacity of transmission lines in the international exchanges that all of them are constraints of the model [11]. By the way, the study calculated a unit price for the entire market without considering the complexities of the transmission network. Optimum generation, demand, export, and import were other obtained results of the model implementation.

The main aim of this study is to incorporate solar and wind-based systems into load management such that this collective performance benefits both energy suppliers and consumers. In this modelling, initially equations of the system in market are written and merged with each other. The impact of uncertainty on system profit will also be considered. Moreover, predicting unbalanced load and energy is modelled as fuzzy logic and the main goal is to increase system profit.

2. Mathematical Modeling of the System

In the present section, first by assuming the prices of the system as fixed and regardless of the uncertainty, a long-term model is provided for regional power supply using solar panels in an area that is connected to the network, and in the following, an economic model will be proposed for the system.

2.1. Modeling of the Problem

In this section, the general model of a hybrid power plant is presented including solar panels in conjunction with the network. Power produced by each solar array in proportion to the emitted solar energy is obtained by (1):

$$P_{\mathrm{pv}} = \frac{\mathrm{G}}{1000} \times \mathrm{P_{pvrated}} \times \eta_{\mathrm{pv}} \tag{1}$$

Where G is perpendicular radiation to the plane of each array in W/m^2, $\mathrm{P_{pvrated}}$ is the rated power per array obtained as G=1000 w/m2, and η_{pv} stands for the efficiency of DC/DC mounted converter between each array and DC bus bar.

Power produced by the wind turbine is determined by the manufacturer based on wind speed. Wind turbine used in this article has a rated power of 3 kW.

$$P_{\mathrm{WG}} = \begin{cases} 0 & \mathrm{V_{ws}} < \mathrm{V_{cutin}}\ , \quad \mathrm{V_{ws}} > \mathrm{V_{cutout}} \\ \mathrm{P_{WGmax}} \times \left(\frac{\mathrm{V_{WS}} - \mathrm{V_{cutin}}}{\mathrm{V_{rated}} - \mathrm{V_{cutin}}}\right)^3 & \mathrm{V_{cutin}} < V_{\mathrm{ws}} < \mathrm{V_{cu}} \\ \mathrm{P_{WGmax}} & \mathrm{V_{rated}} < V_{\mathrm{ws}} < \mathrm{V_{cutout}} \end{cases} \tag{2}$$

In which V_{cutin}, V_{cutout}, V_{rated} are respectively low cut-in speed, high cut out speed and rated speed (nominal speed) of the turbine and $P_{WG\max}$ is the maximum power output of the turbine in (kW).

DC/AC converter; in order to convert the total DC power, the combined AC power with optimum frequency is used. Electrical power supplied by the converter is calculated as follows

$$P_{\mathrm{inv-load}} = (\mathrm{P_{fc-inv}} \times \mathrm{P_{ren-inv}}) \times \eta_{\mathrm{inv}} \tag{3}$$

Battery bank that is usually Lead-acid made, is utilized for additional electrical energy storage, for regulating the system voltage and offering power supply to the load and also in the events of low wind speed or low solar conditions. Lead-acid batteries in the solar-wind hybrid systems are used under very specific circumstances, therefore, prediction of the time when the energy will be extracted from or exposed to the battery, will become problematic. The energy will be stored when the power produced by the wind turbine and photovoltaic array is more than the load. Whenever production capacity cannot meet the needs of the load, energy will be extracted from the battery and when power generation array is insufficient both by the wind turbine and photovoltaic array and the storage is empty, the load will be disconnected in time hour t. Battery function is determined from the following equation

$$\mathrm{Ebat(i,t)} = \mathrm{Vbat\,.\,Cbat(SOC(i,t-1) - SOC(i,t))} \tag{4}$$

Here, Cbat is the Rated capacity of the battery (AH), Vbat is battery's rated voltage, SOC is battery charge level.

$$SOC(i,t) = SOC(i,t-1).(1-\sigma) - \frac{I_{bat}(i,t).\Delta t.(\eta_{ch})^{k}}{C_{bat}} \quad (5)$$

in which σ is the hourly self-charge rate, Kηch is Efficiency battery charging, K is a variable for battery charge status.

$$I_{bat}(i,t) = \frac{PL(i,t)/\eta_{inv}}{V_{bat}} - \frac{P_{pv}(i,t)}{V_{bat}} - \frac{P_{WG}(i,t)}{V_{bat}} \quad (6)$$

The type of battery used in the software Homer, is the Trojan L16P. Capacity intended for the program in the software Homer are 0, 10 and 25 kW and a voltage of 6 V and a rated power of 360 mAh have been selected.

2.2. Mathematical Modeling of the Objective Function of the Whole System (For Long-term Design of Balanced System)

This part of objective function is divided into two parts and the first part is related to fixed costs including the initial investment costs which must be spent at the beginning of planning period and the second part is related to variable (changing) costs which includes the cost of maintenance and this second cost is spent during the planning period in the system. In this section we examine economic relations and the costs governing multiple source combined power of the system [3]. The cost of each resource can be divided into three categories which includes: Investment cost, replacement cost, the cost of maintenance.

Regarding the optimal design of hybrid multi-source power systems, the total annual cost must be calculated. Annual costs as total annual investment cost, annual replacement cost, and annual maintenance cost is defined for each resource. To calculate the costs, project's lifetime will be defined with the help of the following equations:

$$f_{pw} = \frac{1+infr}{1+intr} \quad (7)$$

$$C_{rep_i} = \sum_{t=1}^{ny} (f_{pw})^{t}.CR_i.Cap_i \quad (8)$$

$$Ca_i = C_i.Cap_i \quad (9)$$

$$C_{mc_i} = \sum_{t=1}^{ny} (f_{pw})^{t}.COm_i.Cap_i \quad (10)$$

infr: The annual inflation rate,

intr : The annual interest rate,

Cri: The cost of replacing the system,

Capi: System capacity,

i: Device type (wind, solar, ...),

Ti: lifespan,

Ty: lifetime of the system,

Co.mi: cost of repairs and maintenance,

Ci: cost of the system.

The main objective of this paper is to determine the optimal values of the wind turbine, solar panel and battery connected to the network in order to provide the intended load with the improvement of the two objectives, and these goals include:

1) Improving Loss of Power Supply Probability (LPSP)

2) The cost of the entire system.

$$f_{pw} = \frac{1+infr}{1+intr} \quad (11)$$

$$C_{rep_i} = \sum_{t=1}^{ny} (f_{pw})^{t}.CR_i.Cap_i \quad (12)$$

$$Ca_i = C_i.Cap_i \quad (13)$$

$$C_{mc_i} = \sum_{t=1}^{ny} (f_{pw})^{t}.COm_i.Cap_i \quad (14)$$

$$F_{total} = A_1.F_c + A_2F_{lpsp} \quad (15)$$

$$F_c = F_{pv} + F_{wg} + F_{conv} + F_{net} \quad (16)$$

$$F_{lpsp} = \frac{\sum_{t=0}^{T} Power.failure.time}{T} = \frac{\sum_{t=0}^{T} Time(P_{availabe}(t) < P_{needed}(t))}{T} \quad (17)$$

Each of the objective function parameters are included in the cost of construction and repair and replacement of equipment. In this study, to calculate replacement costs and investment costs of each resource, the cost curves of each resource is determined according to the selected resource model.

2.3. Economic Model of Profit Maximization for Unbalanced System

In a study by Gilmore et al. [1] for the daily market, the independent network optimization is proposed. It is an independent power network, a gathering of producers and consumers in the form of a single power system. In order to make the best decision in the business environment, a problem is formulated regarding independent optimization of the distribution network, taking into account the cost of fines for each independent network. For self-planning of the companies and maximizing profits in new electricity market, in [2] a new model is presented based on luck for manufacturing companies with considering the possibility of summoning and making reservation market. The aim of photovoltaic manufacturers, is performing roles in the energy system and unbalanced system to maximize the profits by taking into account all the constraints such as transmission system constraints, photovoltaic capacity constraints, and solar radiation. For more realistic modeling unbalanced system load and the amount of sunlight at different times of the year and the system load is modeled using phasic method.

$$\text{Maximization of profit} \quad \underset{E,I}{\text{Maximize}}(\text{Pr}) \quad (14)$$

Annual profit — Annual profit [€]

$$Pr = R - C - Pe \quad (15)$$

The annual revenue — Annual revenue [€] (16)

$$\widetilde{R} = P_E(t).\widetilde{E}(t) + \widetilde{E}_{Net}(t).(P_E(t) - P_{Net}(t))$$

Annual costs — Annual costs [€] (17)

$$C = \sum_{i}^{N_{el}}[C_i.Cap_i + \sum_{t=1}^{ny}(f_{pw})^t.[Co.m_i \times Cap_i + CR_i \times Cap_i]]$$

Annual penalty costs — Annual penalty costs [€] (18)

$$Pe = P_{\Delta E}(t).\Delta E(t)$$

In which:

t equals 1,2, … 8760 (hours)

i equals 1,2, … 3 (equals to the number of elements which in here includes photovoltaic and battery and the converter).

E is unbalanced power supply by the photovoltaic system on the market unbalanced system power (MWh)

E_{Net} Exchanged unbalanced power with network in power market of unbalanced system (MWh)

P_E: The anticipated cost of market power, unbalanced system (€/MWh)

P_{Net}: anticipated Network costs of upstream market power, unbalanced system (€/MWh)

$P_{\Delta E}$: Costs of estimated fines in the energy market unbalanced system (€/MWh)

ΔE: Estimated energy, an unbalanced system that there is no possibility of commitment to its delivery (MWh).

2.4. GAPSO Algorithm

GAPSO algorithm implementation process is as follows:

At first we randomly select the population that is in fact the components of GA and PSO particles.

The fitness of the components are calculated.

Half of the population with higher fitness are selected and PSO operations are performed on them. But in some references the coefficient is defined as Breeding ratio (ψ). The coefficient determines what percentage of the population must be under PSO operations. If N is the number of the total population, we select a number of N ψ particles with higher fitness and by running PSO calculations on them, T grown Elite (enhanced elite) are produced. Thus, the PSO particles are coordinated with the problem condition and environment which is similar to growth of creatures in nature. Enhanced elite will be transferred directly to the next generation and the remaining population will be produced with mutation and recombination operations. The following figure shows the above mentioned stages.

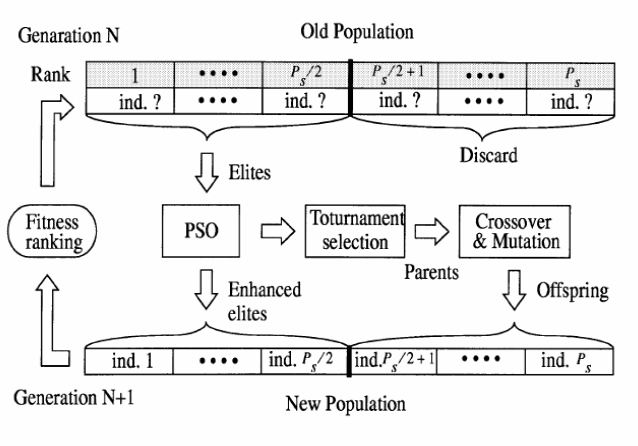

Figure 1. GAPSO algorithm implementation steps

3. Numerical Studies

In this section, initially an experiment is accomplished for under-study region and long-term period of 20-years. In the first state of experiment, the required power of region is supplied by a hybrid power plant composed of photovoltaic panels, wind turbines and diesel generator that work network-independent. In the second state the problem is solved by considering network-dependent performance. It is worth noting that the prices are considered constant in the experiment. In the second experiment, the problem is designed for short-term and with the aim of increasing profit of solar generators. In the experiment the power generation of solar panels and load amount is modeled as fuzzy logic.

3.1. Simulation of Studied Network

The studied network contains PV, wind and diesel generators which are connected to 480 kW network. The diagram of the studied network that has 13 bus-bars is shown in Figure 2. Moreover, the annual load curve of the system is presented in Figure 3. It is noteworthy that this load has been considered as fuzzy logic in unbalanced system.

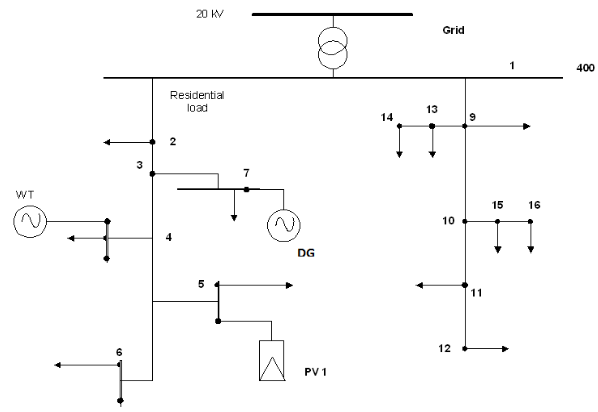

Figure 2. Diagram of studied network and system resources

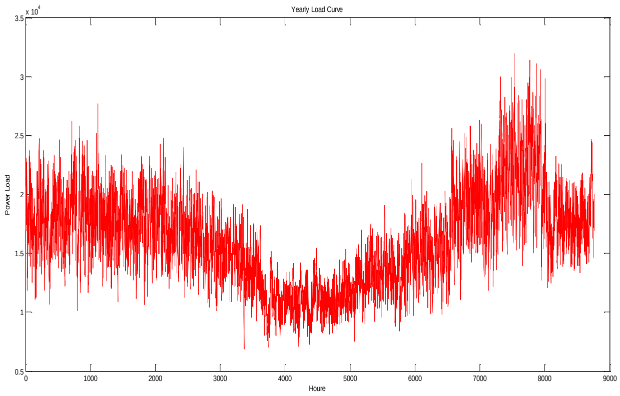

Figure 3. Annual load curve of studied system

3.2. Input Data

Here, the data related to daily price in the states of stagnation, peak demand and hyper-demand are presented. The specified prices for stagnation period and peak demand period are 50 $/MWh and 85 $/MWh respectively.

3.3. Calculation of Benefits

As it is also indicated in Table 1, the electricity sale price for a supplier is dependent on annual supply.

Table 1. Sale prices of electricity for a supplier (for use at a fixed price) according to annual supply

Annual supply	Sale price
For the first 3 MWh	Fixed price (Stagnation: 159.8 €/MWh, Peak demand: 214.10 € /MWh)
From 3 MWh to 5 MWh	82 €/MWh
For more than 5 MWh	Average price of APX (58.88 €/MWh in 2006)

3.4. Price of Equipment Installation and Climate Information

We took solar data for every days of week, once every ten minutes for one year, from new energies' organization of Iran (SANA).

Table 2. System costs

	Repair and maintenance	Replacement cost	Initial cost	Capacity (KW)
PV	1	2300	2300	0
Battery	2.5	60	50	4
Converter	4	3600	3600	40
WG	3	15000	12500	10

In this study, we have used a 4-Volt battery with capacity of 60 Ah that its outcome is 0.25 kWh with the useful life of 4 years. Other characteristics of the battery is presented in the following table.

3.5. Results Obtained from the First Experiment Implementation (20-Year Plan)

The results obtained from Implementation of problem on a test network using GAPSO algorithm are presented in the Table 3. These results that are achieved by GAPSO algorithm are obtained for proposed model.

The parameters of GAPSO algorithm for the problem are as below

Initial population size: 100

Number of generations: 20

Inertia Weight (ω): 0.8

Crossover probability (Pc): 0.8

Mutation probability (Pm): 0.15

In addition, interest and inflation rates are 0.07 and 0.12 in the problem respectively.

To show performance and effectiveness of this system, initially in the first experiment, the whole load of system is supplied by hybrid system and considering solar panels, wind units and batteries that is a report of system's base state. Then, the problem is initialized, optimized and designed by considering wind units and solar panels connected to the network; and finally the obtained results are compared.

Table 3. Obtained results using GAPSO algorithm resulted from experiment implementation

Item	Results of the first experiment	Results of the second experiment
Number of selected wind turbines	6	11
Number of selected solar panels	5	6
Number of selected batteries	50	50
Whole exchanged power with upstream network during period (KW)	0	1462.88
Cost of exchanged power with upstream network during period ($)	0	9373.569
Construction cost of installed wind turbines ($)	45000	82500
Construction cost of installed solar panels ($)	6900	6900
Construction cost of installed battery ($)	3000	3000
Construction cost of installed DC-to-AC converter ($)	3600	3600
Repair and maintenance cost of installed equipment ($)	3844.56	4485.329
Replacement cost of installed equipment ($)	14240.07	14240.07
Cost of the entire equipment during planning period ($)	76564.64	105351.8
The whole objective function	0.2563571	0.2560613
Probability of power losses	0.03424	0.01027397
System outage interval in year (hour)	300	90

As observed in Table 3, changing operation process, adding distributed generation to the system, and changing sale process in the system increase the use of solar and wind generators and thus increase profits.

4. Conclusions

In this study, initially the costs related to hybrid system composed of wind units, solar panels and batteries were minimized and LPSP index was increased to obtain appropriate results. The use of multi-objective method is necessary due to inconsistency of problem objectives. The optimization of the problem is very complicated due to a lot of factors involved in the issue. Therefore, we have used powerful GAPSO algorithm for optimization. The results of optimization implemented in under-study region and implementation of hybrid power plant composed of wind units, solar panels and batteries in the site showed considerable improvement in the mentioned objectives in addition to supplying the required energy through renewable and permanent resources. In the second step, a model was solved to supply the region's load through solar panels—initially for a period of one year—without considering uncertainty and by assuming constant prices; and then an economic model was designed for system. By using this model, the generators of wind and photovoltaic energy maximized their profit in an unbalanced-energy system by considering all constraints including transmission restrictions of the system, limitations of PV capacity and the solar radiation. Moreover, LR fuzzy method was used to make more realistic,the modelling of unbalanced loads and sun radiations in different hours of the year.

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