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DETERMINATION OF THE OPTIMAL POWER GENERATION AND CO-GENERATION OF POWER AND ENERGY IN SOLAR AND WIND UNITS

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RESUMEN: Las microgrillas se utilizan para satisfacer las demandas de energía en los hogares, la industria y la agricultura, y su costo se estima en base a políticas de precios en el mercado de la electricidad. Las áreas remotas se enfrentan con frecuencia a problemas debido a la falta de acceso a las redes eléctricas principales. Considerando las cuestiones ambientales y económicas en áreas remotas, las Micro-redes podrían servir como una buena fuente de generación de energía en estas áreas. En el presente estudio, se intentan determinar el tamaño óptimo de un sistema híbrido independiente de la red. El sistema híbrido a investigar en este estudio consiste en aerogeneradores, paneles solares, pilas de combustible con acumuladores de hidrógeno y generadores diesel. El objetivo de este trabajo es minimizar el costo del sistema y reducir las contaminaciones ambientales en el período de estudio. Los costos del sistema incluyen costos anuales de capital (ACC), costos de reemplazo anuales (ARC), costos anuales de combustible del generador diesel (AFC) y costos operativos anuales (AOC) [3]. El software GAMS, que es uno de los más potentes software de optimización comercial, se ha utilizado con fines de optimización en el presente estudio.
Palabras clave: planta de energía solar, cogeneración de calor y energía, optimización

ABSTRACT: Micro grids are used to supply the demands for energy in households, industry and agriculture, and their cost is estimated based on pricing policies in the electricity market. Remote areas are often faced with problems due to lack of access to the main power grids. Considering the environmental and economic issues in remote areas, Micro-grids could serve as a good source of energy generation in these areas. In the present study, attempts are made to determine optimal size of a grid- independent hybrid system. The hybrid system to be investigated in this study consists of wind turbines, solar arrays, fuel cells with hydrogen storage and diesel generators. The objective of this paper is to minimize the system cost and reduce environmental pollutions in the study period. System costs include annual capital costs (ACC), annual replacement costs (ARCs), annual fuel costs of diesel generator (AFC), and annual operating costs (AOCs) [3]. GAMS software, that is one of the most powerful commercial optimization software, has been used for optimization purposes in the present study.

Keywords: solar power plant, co-generation of heat and energy, optimization

1. INTRODUCTION

Micro-grids are a set of small energy-generation sources that are connected to the main grid. Multiple interconnected micro-grids can supply the thermal and electrical needs of more subscribers.
Effective utilization of waste heat in CHP systems is one of the most important advantages of micro grids. Distributed generation sources used in grids can include various types of power generation technologies with negligible carbon emission. Typically, Micro-grids are operated in two modes: grid-tied mode and off-grid mode, in both operation modes, the micro grids will affect the subscribers as well as the main grid in some ways. Figure 1.2 shows a grid consisting of renewable and non-renewable energy sources with battery and grid-connected storage system.

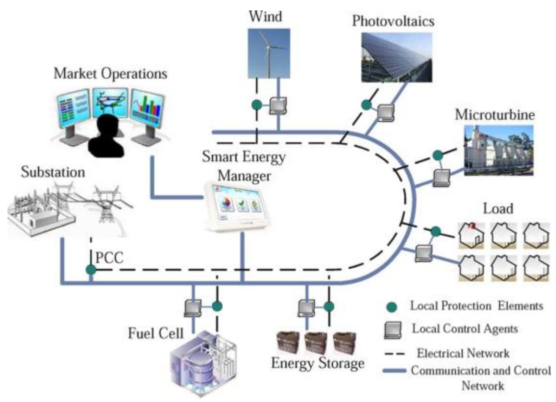

Figure. 1. Components of a micro-Grid (Zhao, Haoran, et al 2015)

Combined Heat and power (CHP) systems are designed in small scale and low voltages (LV), to supply the thermal and electrical needs of a limited number of subscribers.
Micro-grids will have significant impacts on gas and electricity markets in the future. To take advantage of the benefits of micro-grids, attempts should be made to expand their contribution to gas and electricity markets. This goal requires appropriate

market reforms, as well as financial incentives for investment on Micro-grids (Fabra, Reguant 2014)..
Recently, the electricity market of some countries has undergone significant changes. The participation of micro-grids in the market will increase the quality of the service potentials in the main grids. Micro-grids can provide main grids with important side services such as voltage regulation through reactive power supply or power storage.

Extensive studies have been conducted on determination of the optimal size of energy resources in micro-grids and distributed generation sources. The goal of most of these studies is to incur minimum generation cost, minimize pollution levels, increase system reliability, maximize power generation, or a combination of the above-mentioned goals with setting priorities for each of them. Various algorithms are used to determine the size of energy resources in the system and a variety of software have been developed to achieve this goal, but there are some constraints that need to be addressed in each optimization process.

The genetic algorithm is one of the most important optimization techniques used for micro-grid sizing, this algorithm has been addressed in references (Fabra, Reguant 2014). – (Zugno, Marco, and Conejo 2015). The particle swarm optimization algorithm addressed in references (Papalexopoulos, Alex, and Panagiotis 2014), (Su, Member, Yuan, and Chow 2010), (Moeini-Aghtaie and Othman 2013*)* has been frequently used to optimize energy sources in micro-grids and smart grids. Other techniques used in grid optimization include linear programming, neural network (Celli, Pilo, Pisano, and Soma (2005), (Kamel, Chaouachi, and Nagasaka 2010), hybrid algorithm (Watanabe and Rengarajan (2011), repeatable probability-based method (Yang, Zhou, Lu, and Fang Z 2008) – (Liu, Wen, Ledwich, and Member 2011).
Reference provides several scenarios and multi-objective optimization methods for a distributed generation unit operating in parallel with a grid. The objectives include grid construction, operating costs and reliability costs. The samples in this study includes solar arrays, wind turbines, diesel generators, converters and energy storage batteries.
Drawing on advantages such as generation decentralization, efficient adaptation of supply and demand, reducing the impact of high and definite output transfer, Micro-grids can improve power quality and reliability. Sometimes the development of generation and transmission grids is difficult due to technical and economic problems, and solving the problems associated with load growth meeting incurs significant costs. Therefore, in these cases, micro-grids can be used to meet the demand for load growth. Using the electronic converters embedded in them, the distributed generation sources can control active and reactive power and improve the quality of power in the distribution network (Mohammadi, Hosseinian, and Gharehpetian 2012).
Reference (Behrang, Assareh, Noghrehabadi, and Ghanbarzadeh 2011), proposes an effective way for solving the problems associated with economic distribution of power with consideration of minimizing biological pollution of the fossil generators. This method is applied on a three-generator system and its results indicate high quality responses from the algorithm.
Reference (Garcia and Weisser 2006) presents a hybrid grid consisting of renewable sources and heat and power co-generators with an energy storage system. The center of Energy Management System (CEMS) is responsible for optimization of the micro grids in both grid-tied and off-grid modes. Simulation has improved the reliability of the system and has provided a satisfactory solution for the economic distribution of power.
Reaching a compromise between the minimum generation cost and the minimum environmental pollution, that are usually in conflict, is one of the most important factors in micro-grid planning. Since distributed generation sources in micro-grids include renewable energy sources such as wind turbines, solar cells, and so on, and due to the variability and dependence of renewable energy generators on climate conditions, planning is performed according to the product availability index (Mellit, Kalogirou, and Drif 2010).
In the present paper, attempts are made to minimize system costs and reduce environmental pollution during the study period. So first, we will state the problem, introduce the simulation algorithm, the objective function, the simulation constraints, and micro-grids, and finally present simulation results.

2. ECONOMIC MODEL OF THE STUDY SYSTEM

The economic model in this thesis is designed based on the annual cost of the system (ACS) and the generation cost minimization. The annual cost of the system consists of annual capital costs (ACC), adjusted replacement costs (ARCs), annual fuel costs of diesel generator (AFC), and annual operating costs (AOCs).

$$ACS = ACC + ARC + AFC + AOC \qquad (1)$$

2.1. Annual Capital Cost (ACC)

The annual capital cost is determined according to the following equation.

$$ACC = C_{cap} * CRF(i,n) \qquad (2)$$

C_{cap} : Annual equipment capital costs

CRF : Capital recovery factor defined as follows:

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3}$$

n: life cycle of the project (years)
i: Real interest that is defined in terms of nominal interest rate and annual inflation rate.

$$i = \frac{i_{loan} - f}{1+f} \tag{4}$$

i_{loan} : Nominal interest

f : Annual Inflation rate

2.2. Annual replacement cost (ARC)

Units that need to be replaced during the project life cycle are those units whose life span is less than the project period or become inoperable during the operation. The annual replacement cost is defined as follows.

$$ARC = C_{rep} * SFF(i, n_{rep}) \tag{5}$$

C_{rep} : The unit replacement cost

n_{rep} : Life span of units

SFF : The sinking fund factor that is defined as follows.

$$SFF(i, n_{rep}) = \frac{i}{(1+i)^{n_{rep}} - 1} \tag{6}$$

2.3. Annual Fuel Cost (AFC)

The fuel cost of diesel generators is defined as follows.

$$AFC = T_{fc} * CRF(i,n) \tag{7}$$

T_{fc} : The total fuel cost of the generator over the life span of the project

2.4. Annual operating Costs (AOC)

The equipment operating cost is calculated as follows.

$$AOC = AOC(1) * (1+f)^n \tag{8}$$

Where $AOC(1)$ is the system operating cost per year

2.5. The objective function and the constraints of the problem

$$P_{fc,k} + P_{diesel,k} + P_{uncertain,k} - P_{elec,k} - P_{load,k} = 0$$

The present paper is an attempt to minimize the power generation cost in the hybrid system. The units' size and fuel consumed by the diesel generator can affect the system costs. In the present thesis, the optimum size of the system components, namely, the capacity of electrolysis, hydrogen tank, fuel cell, diesel generator and DC / AC converter, for generation of electricity at minimum cost will be determined. Due to uncertainties in power generation of wind turbines and solar arrays, the generation capacity of these resources is determined by the mode scenario and is then introduced to the system, any surplus power consumption or generation will be supplied or stored by other micro-grid equipment. System costs include annual capital costs, annual replacement costs, fuel costs, and annual operating costs per year plus fines for environmental pollution. Annual Simulation is presented through the following objective function.

$$Cost = k_{fc} * P_{fc,\max} + k_{elec} * P_{elec,\max} + k_{diesel} \sum_{k=1}^{N} P_{diesel,k}$$

Where $P_{fc,\max}$ and $P_{elec,\max}$ indicate the nominal capacity of the fuel cell and the electrolysis cells respectively. $P_{diesel,k}$ Shows the generation capacity of the diesel generator at k-th hour.

$k_{fc}, k_{elec}, k_{diesel}$ are extracted from the economic equations of the system and are considered constant for all equipment.

$$k_{fc} = ACC_{fc} + ARC_{fc} + AOC_{fc} \tag{10}$$

$$k_{elec} = ACC_{elec} + ARC_{elec} + AOC_{elec} \tag{11}$$

$$k_{diesel} = AOC_{diesel} + AFC_{diesel} \tag{12}$$

$$AOC_{diesel} = 1000 * (1+f)^{n1} \tag{13}$$

$$AFC_{diesel} = diesel_c * 20 * diesel_e * CRF_1 + CO_{2cost} * 20 * diesel_e * CRF_1 \tag{14}$$

In the above equations, $diesel_c$ and $diesel_e$ indicate the price of diesel fuel and the diesel generator's energy per year respectively. $CO_{2\cos t}$ is the fine paid for emission of carbon (generation of 20 units of pollution per unit of energy).

N is dependent on the simulation interval and sampling interval, and samples in the present article are obtained from hour per year intervals, so N is equal to 8760.

2.6. Constraints of the problem

The objective function of cost should be optimized according to the following constraints.

$$(P_{uncertain,k} + P_{diesel,k} - P_{load,k}) - P_{elec,\max} \le 0 \quad (15)$$

$$(P_{load,k} - P_{uncertain,k} - P_{diesel,k}) - P_{fc,\max} \le 0 \quad (16)$$

$$P_{fc} - P_{fc,\max} \le 0 \quad (17)$$

(18)

$$P_{elec,k} - P_{elec,\max} \le 0 \quad (19)$$

$$\sum_{k=1}^{N} (P_{fc,k} - P_{elec,k}) \le 0 \quad (20)$$

$$P_{diesel,k} - P_{diesel,\max} \le 0 \quad (21)$$

Table 1. Optimal results of the micro-grid based on mode scenario

Units scenarios	the number of solar cell units	the number of wind turbine units	the number of CHP units	prime cost
based on the base scenario	50	4	10	3232,778

2, which shows the improvement in the profit and cost of solar and wind power plants with the CHP unit, it can be concluded that the results of this research are valid and can be used to increase the profit of the energy generation system.

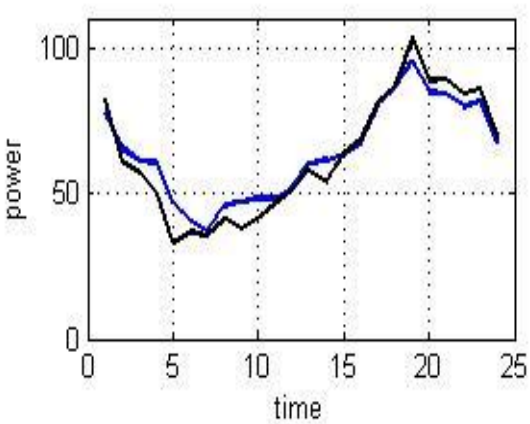

Figure. 2. Power fluctuations in 24 hours for the normal mode and the proposed method

The most optimal size of units is obtained and system costs are investigated in all potential scenarios. These results are obtained from the GAMS software.

$$\sum_{k=1}^{N} (P_{felec,k} - P_{fc,k}) \le CH_2 \quad (22)$$

Where shows the capacity of hydrogen tank.

CH_2

3. SIMULATION RESULTS:

The following table summarizes the micro-grid sizing results and uncertainties in renewable power generation of wind and solar units along with the total power generation and diesel generator production costs.

As already mentioned, power generation from wind and solar sources is quite irregular and we should find solutions to reduce this dependency. According to the results presented in the above table and Figure The following results are obtained from the GAMS software, which is the best optimization software in this field.

Table 2. Combined production system optimal results for one year

scenario month	diesel generation in the base scenario	month	diesel generation in the base scenario	month	diesel generation in the base scenario
Jun	56	May	66	Sep	38
Feb	37	Jun	64	Oct	43
Mar	51	Jul	39	Nov	25
Apr	47	Aug	43	Dec	50

4. CONCLUSION

Simulation results are obtained in all potential scenarios. The results indicate a reduction in system costs during operation of the system used for optimum sizing of renewable energy and non-renewable energy sources. In order to get a better understanding, the required power demands of the area is finally supplied by diesel generator. The advantages of the parallel operation of non-renewable energy sources and renewable energy sources include increased reliability of the system and reduced cost of the system.

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