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Modeling and Optimization of Micro-Grid Using Genetic Algorithm

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Abstract

This paper proposes an operating and cost optimization model for Micro Grid (MG). This model takes into account emission costs of NO_x, $SO_2$and CO_2, together with the operation and maintenance costs. Wind Turbines (WT), Photovoltaic (PV)arrays, Micro Turbines (MT), Fuel Cells (FC), Diesel Engine Generators (DEG), with different capacities are considered in this model. The aim of the optimization is minimizing operation cost according to constraints, supply demand and safety of system. The proposed genetic algorithm (GA), with the ability of fine-tuning its own settings, is used to optimize the microgrid operation.

Keywords: Microgrid, Optimization, Genetic algorithm

Introduction

Developing of Micro Grid (MG) is necessary because of the change in regulatory and economic scenarios, problem of energy sources, lack of energy, environment emission problems and so on. The role of MGs is increasing in power system in future [1]. The MG units are chosen to supply load and minimize the cost of the fuel, operation, maintenance and emission level.

First of all an exact model, which can describe accurately all of the aims, is required. Model of system is discrete and nonlinear in nature, so optimization tools are First of all an exact model, which can describe accurately all of the aims, is required. Model of system is discrete and nonlinear in nature, so optimization tools needed to reduce the operating costs and minimize the cost of fuel, operation and emission level.

Power generation with highly effective performance according to environmental issues has been developed in recent years because global gases emission level is increasing considerably.

One of the best solutions to remedy environmental issues and in the same time supplying electric demand is MGs. (Appropriate) planning of MGs will result in reduced power losses and emission level.

Recent researches in MGs reviewed many aspects in different cases, applications and sizes [1], [2].

Communication infrastructure operating between the power sources to solve the fuel consumption optimization problem has been proposed in [3]. A rational method of building MGs which is optimized for cost and subject to reliability constraints has been presented in [4].The second objective of this paper is optimizing and solving the problems in order to have an optimal management of MGs. The aim of the paper is designed based on minimization of running costs and to supply load demand in the MGs.

It can be found that optimization of the system depends on the used model. A proper model can solve the problems and manage the system efficiently .Optimization of the proposed method in this paper for modeling the system, incorporates the cost minimization applied to the MG architecture. The proposed model not only supplies load demand but also satisfies constraints. The problem has two steps; first step is designing the model of system which is the most important part of the problem solving and the next step is selection of a new algorithm and usage of it to optimize model of the MGs by the available resources, considering variables such as wind speed, temperature, and irradiation which are inputs of model.

If wind power is the major source and photovoltaic doesn't supply the load demand, proposed algorithm will proceed to the next step, and the other alternative is used according to the amount of the load and the cost of resources. The remaining parts of the paper are organized as follows. Section II and III introduce MG architecture and components. The proposed MG model is presented in section IV. Proposed objective function was introduced in section V. Then, Application of the proposed genetic algorithm for solving the optimization problem of MG operation is described in section VI. Section VII provides results, and finally, the paper is concluded in Section VIII.

System Modeling

Fig. 1 shows the MG structure of the proposed model in this paper. It has a group of radial feeders which are part of the distribution system which is consists of Point of Connection Coupling (PCC). There are sensitive loads connected to feeders 1 and 2 which must be supplied all the time. Feeders include different sources like a Photo Voltaic (PV), a Wind Turbine (WT), a Fuel Cell (FC), a Micro Turbine (MT), a Diesel Generator (DG). Feeder 3 has usual loads which are not sensitive. Fuel cost of WT and PV is free and fuel comes from nature but fuels for DG, FC and MT are not free. PV, WT, DG, MT and FC are sources of system model and each component of MGs is separately modeled according to its characteristics. Manufacturer documents are used for modeling some sources like WT and DG.

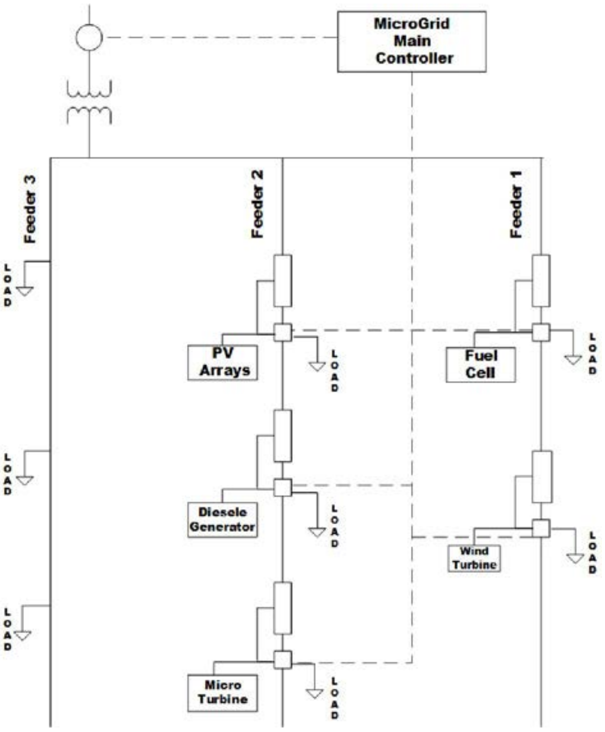

Figure 1: **S**chematic of the system

System Components

A. Wind Turbine

Output power of the wind turbine depends on wind speed. The characteristic of WT is nonlinear, so sectional modeling of the curve is considered in this paper. Cut-in, cut-out and rated wind speeds are important points in modeling the system because output power depends on these points.

A model which is described by following equations are used to calculate the output power generated by the wind turbine generator [5]:

$$\begin{cases} P_{WT} = 0 & V_{ac} < V_{ci} \\ P_{WT} = aV_{ac}^2 + bV_{ac} + c & V_{ci} \le V_{ac} < V_r \\ P_{WT,r} = 130 & V_r \le V_{ac} > V_{co} \end{cases} \quad (1)$$

where:

V_{ci}, V_{co} and $P_{WT,r}$ are cut-in and cut-out wind speed and the rated power respectively. Furthermore V_r and V_{ac} are the rated and actual wind speed.

Commercial wind turbine AIR403 power curve is modeled. Parameters used in the model are as follows: a = 3.4; b = -12; c = 9.2; $P_{WT;r}$= 130watt; V_{ci}= 3.5 m/s; V_{co}= 18 m/s; V_r=17.5 m/s.

B. Photovoltaic

Photovoltaic panel is a new energy source which converts sunlight into electricity. The output power of PV depends on the radiation of sunlight and weather conditions of the location. Sunlight radiation changes all the time so a tracker is needed to achieve the maximum power of PV array. For this purpose, Maximum Power Point tracking circuit (MPPTC) is used to adjust the terminal voltage of PV panels so that the maximum power can be extracted. For instance, Fig. 3 shows the output power versus voltage (P-V) characteristics of a PV array.

The output power of the module can be obtained from [5]:

$$P_{PV} = P_{STC} \frac{G_{ING}}{G_{STC}} (1 + K(T_c - T_r)) \quad (2)$$

where PPV is output power of the module at Irradiance, P_{STC} is module maximum power at Standard Test Condition (STC),G_{ING} is incident irradiance, G_{STC} is irradiance at STC 1000(W/m^2), k is temperature coefficient of power, T_c is cell temperature and finally T_r is reference temperature.

C. Diesel Generator

Diesel generators are usually used in MGs as micro sources. New diesel engine generator (DEG) is responsible for peak shaving and supplying load demand. Because of the quick change in output power, DEG isan important choice for using in MGs.

The fuel cost of a power system can be expressed mainly as a function of its real power output and can be modeled by a quadratic polynomial [6]. The total $/h DG fuel cost C_{DG}; can be expressed as:

$$C_{DG,i} = \sum_{i=1}^{N} a_i + b_i P_{DG,i} + c_i P^2{}_{DG,i} \quad (3)$$

where N is the number of generators a_i, b_i and c_i are the coefficients of the generator, P_{DG}; is the output power (kW)of diesel generator i, i = 1, 2, ...,N and these coefficients are assumed to be known.

Typically, the constants a_i, b_i and c_i are given by the manufacturer. From the data sheet [7] and equation (3) the parameters are obtained as follows:

a_1 = 0.4333, b_1 = 0.2333andc_1 = 0.0074.

D. Fuel Cell Cost

The efficiency of any fuel cell is the ratio between the electrical power output and the power obtained from input fuel, both of them must be at the same units (W),[7]. The fuel cost for the fuel cell is calculated as:

$$C_{FC} = C_{nl} \sum_j \frac{P_j}{\eta_j} \quad (4)$$

where C_{nl} is Natural gas price to supply the fuel cell, P_J is electrical power produced at interval J, and η_J is cell efficiency at interval J.
To model the technical performance of a fuel cell, atypical efficiency curve is used to develop the cell efficiency as a function of the electrical power and used in equation (4)[8].

E. Micro turbine Cost
The economic model is similar to the FC model. Unlike the FC, the efficiency of the MT increases with the increase of the supplied power [9].
Due to lack of the detailed information, the curves of the MT are rescaled to be suitable for a unit with less than 4kW rating. These curves are used to derive the electrical efficiency as a function of the electrical power to be used in the economic model of the MT.

Genetic Algorithm
Genetic Algorithm (GA) is a heuristic search technique based on natural inspired by the genetic and evolution. Principles of this algorithm are in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem which is formulated. Genetic algorithm is used to solve optimization and search problems. Genetic algorithm uses techniques such as inheritance, mutation, selection, and crossover.
GA includes three different steps of search:

Step 1: selecting an initial population;
Step 2: calculating afitness function;
Step 3: producing a new population.

A genetic search starts with selection of initial population within which each individual is evaluated by means of an objective function. According to the function value generations are duplicated or removed. GA has different operators to make generators. The first is the production. The production duplicates individual by a high fitness value or removes individual by a poor fitness value. Next operator is crossover (also known as the recombination) operator. Individual in these subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals. There are usually three operators in a typical genetic algorithm [6]: the first is the production operator (elitism)which makes one or more copies of any individual that posses a high fitness value; otherwise, the individual is eliminated from the solution pool; The second operator is there combination (also known as the 'crossover') operator. Crossover selects two individuals and replaces the string of both individual. This operator tries to achieve to better performance. The mutation operator is the next operator. The operator randomly flips a bit in a population of strings. So, according to application of this operator a completely random search is considered.
This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

PROPOSED OBJECTIVE FUNCTION

This section describes the proposed objective cost function for the MG. The load which is served in this paper is isolated. The formula considers environmental costs and minimizes the emissions of oxides of nitrogen (NO_x), sulfur oxides (SO_2), and carbon oxides (CO_2). Also this function minimizes the operating costs in \$/h as follow:

$$CF(P) = \sum_{i=1}^{N}(C_i * F_i(P_i) + OM_i(P_i)) + \sum_{i=1}^{N}\sum_{j=1}^{M} \alpha_j EF_{ij} P_i \quad (5)$$

where:
C_i Fuel costs of generating unit i in \$/L for the diesel and \$/kW for the natural gas,
F_i Fuel consumption rate of generator unit i in L/h for diesel generator, and kW/h for the FC and MT,
OM_i Operation and maintenance cost of a generating unit i in \$/h,
α_j Externality costs of emission j in \$/lb,
EF_{ik} Emission factor of generating unit i and emission j in lb/MWh,
N number of generating units i.
M Emission types (NO_x or CO_2 or SO_2).

Objective Constraints:
Power balance constraints: the total power generation must cover the total load demand hence

$$\sum_{i=1}^{N} P_i = P_L - P_{PV} - P_W \quad (6)$$

where:
P_i The total power generation [kW],
P_L The power demanded by the load [kW],
P_{PV} The output power of the photovoltaic [kW],
P_{WT} The output power of the wind turbine [kW]
P_{batt} The output power of the battery [kW].

Generation capacity constraints: For stable operation, real power output of each generator is restricted by lower and upper limits as follows:

$$P_i^{min} < P_i < P_i^{max} \; ; i = 1, \ldots, N \qquad (7)$$

where

P_i^{min} Minimum operating power of unit i,

P_i^{max} Maximum operating power of unit i.

The operating and maintenance cost of the generating unit i*(OM_i)* is assumed to be proportional to the produced energy, where the proportional constant is *(K_{OM})* [8].

$$OM_i = K_{OM} \sum_{i=1}^{N} P_i \qquad (8)$$

The values of the KOM for different generation units are as follows:

K_{OM} (DE) = 0.01258 \$/kWh

K_{OM} (FC) = 0.00419 \$/kWh

K_{OM} (MT) = 0.00587 \$/kWh.

Implementation of the Algorithm

Many aims are considered when MGs designed like such as minimization of fuel cost and emissions. Some goals are important and are influenced by other factors. The scenario is summarized as below:

- Output power of WT depends on the wind speed according to equation (1).
- Output power of PV depends on the temperature and the solar radiation according to equation (2).
- Because PV and wind turbine output powers are free and come from nature, they are assumed to be negative loads in the formula. If outputs of PV and WT can't supply load demand algorithm will go next steps and uses the other sources according to objective function.
- Selection of the other sources depends on fuel cost of sources and aim of algorithm is to minimizing the cost of the generation.

All the formulas can be mathematically formulated as follows:

$$\min_{P_i \in R^n} CF(P_i) \qquad (9)$$

subject to:

$$g_i = 0$$
$$h_i \geq 0$$

where:

P_i vector of generated powers

CF(P_i) calculated cost function according to equation (5)

g_i equality constraint according to the equation (6)

h_i inequality constraint according to the equation (7)

Results and Discussion

The described model is applied to 24 hours load demand shown in Fig. 2. Wind turbine and photovoltaic output power is calculated by real data. Wind speed and temperature are inputs of the model. From output power obtained of PV and WT, it is concluded that other sources are needed to serve load demand.

The algorithm goes to next step; the needed power to serve the load is calculated. Fig. 3 shows hourly output power of MG calculated by the algorithm.

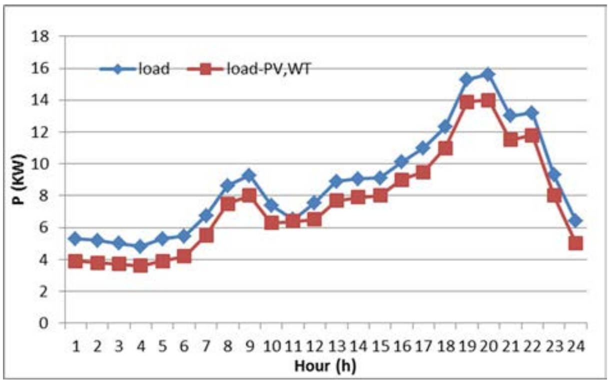

Figure 2: hourly loads

TABLE **1:** BEST SELECTION

Total load	Diesel Generator (kW)	Micro Turbine (kW)	Fuel Cell (kW)	Total Cost (\$/h)
4.2	0.0001	3.7872	0.4127	1.8282
6.3	0	5.4829	0.817	1.8886
8	0.0001	6.1594	1.8405	1.9451
14	0.0002	13.4372	0.5627	2.0914

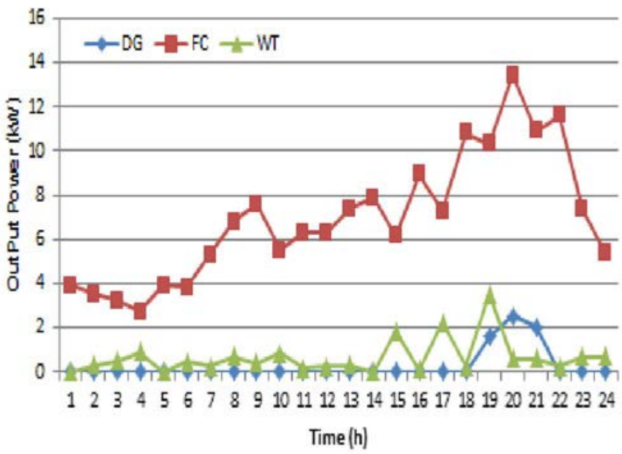

Figure 3: Output power of DGs

From this figure, it can be found that in the initial time when the load is low, the micro turbine must be used to serve the load. Next choice is to use the fuel cell and the diesel generator is switched off. At peak of the load diesel generator is switched on and WT and FC are used to serve the load. Table I shows best selection of the different loads. The diesel generator is the last selection because of its high cost. When other sources can't serve the load the diesel generator is used.

Conclusion

A model is designed to calculate the best optimum of a micro grid according to load demand and environmental issues is designed. MG model includes a fuel cell, a diesel engine, a micro turbine, PV arrays, and a wind generator. Constraint is considered in the model.

It can be obtained from results; algorithm works efficiency to achieve best optimized results. Generation of each generators is obtained from algorithm and is used to planning MG. the results depends on different variables such as weather condition, wind speed, sun radiation, emission and maintenance costs and power demand.

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