A Generalized Framework for a Cost Optimization Scheme in a MicroGrid

G. S. Gayathri and V. Annapeachi

M. Kumarasamy College of Engineering, Karur – 639113, Tamil Nadu, India; gayathrigs.eee@mkce.ac.in, annapeachiv.eee@mkce.ac.in

Abstract

Objectives: To develop a generalized formulation to determine the cost optimization scheme for a MicroGrid (MG) source by implementing Artificial Bee Colony algorithm. The generating resource with microgrid is a two-objective problem which consists of pv cell (solar cell) array, Wind Turbine (WT), Micro Turbine (MT), diesel generator and Fuel Cell (FC). Methods: The generating energy sources of the microgrid units are essential to minimize the operating cost of the output power which is generated. Here, the ABC algorithm is modelled into two stages. The optimum configuration of the microgrid at a minimum fuel cost is obtained by the first stage of the ABC algorithm. Findings: By using the minimum cost function, the second stage of the ABC algorithm was attained at the reduced operating and maintenance cost. The main aim is to minimization of fuel cost, fuel consumption cost and the emission such as NO\textsubscript{X}, SO\textsubscript{2}, and CO is reduced in these microgrid sources. Applications: For any required load demand the minimum fuel cost is obtained by using artificial bee colony algorithm.

Keywords: Artificial Bee Colony Algorithm, Consumption of Fuel Cost, Emission Cost, MicroGrid (MG), Operating and Maintenance Cost

1. Introduction

Microgrid is evolved because of the requirement for more extensible power systems, varying regulatory and various fiscal states, tradable of energy sources and environmental effect are gives lowers to the betterment of microgrid, which are adding main role in the power generation close to the time ahead. Here, the problem is handled by introducing multiple steps, starts with constructing the microgrid architecture model and the development of Artificial Bee Colony (ABC) algorithm. The Artificial Bee Colony algorithm is used to obtain the optimum usage of the microgrid generating energy resources and In ABC system model, irradiation, wind speed and temperature are the inputs. The algorithm proceeds to the next level of the other alternatives such as micro turbine, diesel engine fuel cell when the generating power from the photovoltaic panel and wind turbine is less than the customer demand. These are used depend on the total amount of load and the corresponding consumption of energy resources cost\textsuperscript{1-2}.

2. Microgrid Topology

The name microgrid (\muG) defined as the notion of small electrical power system related with a small scale power grid. It can operate independently or it can operate by combination of the other small power resources. One of the main aims of microgrid is to collective prosperities of nonconventional or conventional lower carbon generation services and high proficient combined heat and power systems. As shown in the Figure 1, the power generation in gross is equal to the power demand in gross.

The Figure 1, which shows that a micro grid system usually comprises of distribution generating resource, energy storage systems, distribution systems, and communicating devices and control systems.

3. System Modelling

The sustaining properties of the development of MicroGrids (MG) are malleable electric power systems,
dynamic regulation with fiscal outline, savings of energy and environmental impingement. The management of the MG units stand in need of precise economic model to report the operating as well as maintenance cost are taking into account. MG model is nonlinear and distinct in nature and to minimize the operating and maintenance costs, optimization tools are used here⁹.

3.1 Wind Turbine

Bellow model is used to estimate the wind turbine generator output. The start up speed is defined as the speed at which the rotor and blade impel to rotate. The lowest wind speed is referred as cut-in speed at which the wind turbine will generate serviceable generated power. The wind turbines wind speed is between 7 to 10 mph. The wind turbine will generate electric power at least wind speed is called as rated wind speed. Normally, 25 to 35 mph is the range of wind speed for large machines. If the blade of the wind turbine starts rotating at the speed of 45 and 80 mph, then it's called as cut out speed. The cut-put speed is as the speed when its starts shutdown the wind speed at which turbine stops to rotate is called the cut-out speed/curling speed.

The output power generated by wind turbine generator:

\[ P_{\text{WE}} = 0 \quad \text{if} \quad V < V_{\text{cin}} \tag{1} \]

\[ P_{\text{WE}} = q \cdot V^2 + w \cdot V + e \quad \text{if} \quad V_{\text{cin}} < V < V_{\text{r}} \tag{2} \]

\[ P_{\text{WE}} = P \quad \text{if} \quad V > V_{\text{cout}} \tag{3} \]

where \( P_{\text{WE}} \) - The rated power

\( V_{\text{cin}} \) - cut-in wind speed

\( V_{\text{cout}} \) - cut-out wind speed

\( V_{\text{r}} \) - rated wind speed

\( V \) - actual wind speed

The parameter model are as follows:

\( q = 3.4 \quad w = -12 \quad e = 9.2 \quad P_{\text{WE, r}} = 120 \text{ watt} \)

\( V_{\text{cin}} = 4 \text{ metre/sec} \quad V_{\text{cout}} = 20 \text{ metre/sec} \quad V_{\text{r}} = 17.5 \text{ metre/sec} \)

3.2 Photovoltaic

The optimal Photovoltaic cell contains a separate diode associated with current source which is light generated one, \( I_{\text{ph}} \), here, its output current, \( I \), can be expressed as:

\[ I = I_{\text{ph}} - I_s \left[ \exp \left( \frac{V}{nV_T} \right) - 1 \right] \tag{4} \]

Where is cell saturated current, \( V_T \) is voltage with thermal constraint \( kT_c/q \), where \( k \) is Boltzmann's constant \( = 1.38 \times 10^{-23} \text{ J/K} \), \( T_c \) = cell temperature, \( q = \text{charge of electron} \left(1.6 \cdot 10^{-19} \text{ C} \right) \). The below model is used to surmise the generated output by the Photovoltaic cell.

\[ P_{\text{pv}} = P_{\text{STC}} \frac{G_{\text{IN}} (1 + k(T_{\text{a}} - T_{\text{r}}))}{G_{\text{STC}}} \tag{5} \]

where \( P_{\text{pv}} \) - output power of the module at Irradiance

\( P_{\text{STC}} \) - Module max power at standard test condition

\( G_{\text{IN}} \) - incident irradiance

\( G_{\text{STC}} \) - irradiance at STC 1000(wb/m²)

\( k \) - Temperature coefficient

\( T_{\text{a}} \) - pv cell temperature

\( T_{\text{r}} \) - reference temperature

3.3 Diesel Generator

A diesel generator is the mixture of a diesel engine and an electric generator which generates electrical energy. This
is an exact case of engine-generator. The energy generated by a distributed generation with rated power output is expressed as

$$C_{DG,j} = \sum_{j=1}^{N} d_j + e_j P_{DG,j} + f_j P_{DG,j}^2$$

where $N$ -number of generators:
- $d_j, e_j, f_j$ are the coefficients of the generator
- $P_{DG,j}$ - output power of diesel generator $j$, $j = 1, 2, ..., N$
- $d_j = 0.4333$, $e_j = 0.2333$, $f_j = 0.0074$

### 3.4 Fuel Cell Cost

The static energy conversion device which gets electrical energy from chemical energy and also produces water as a product is defined as Fuel cells. The ratio of the electrical power output and the fuel input is called as efficiency of fuel cell and it must be in the same units (Watt). The fuel cost for the fuel cell is calculated as:

$$C_{FC} = C_{nl} \sum_{g} P_{g} / \eta_{g}$$

where
- $C_{nl}$ - natural gas price to supply the fuel cell
- $P_{g}$ - Electrical power produced at interval $g$
- $\eta_{g}$ - cell efficiency at interval $g$

### 3.5 Micro Turbine

Micro turbines are mini combustion turbines nearly the size of a refrigerator within the range of 25 kW to 500 kW. They developed for truck turbocharger, supplementary power units of planes, and small jet engines. The fuel cost for the fuel cell is calculated as:

$$C_{MT} = C_{nl} \sum_{g} P_{g} / \eta_{g}$$

where
- $C_{nl}$ - natural gas price
- $P_{g}$ - Electrical power produced at interval $g$
- $\eta_{g}$ - cell efficiency at interval $g$

### 3.6 Battery Model

A battery is defined as a combination of multiple singular cells. A cell is the combination of materials and electrolyte starting with the simple chemical energy into electric energy. The chemical reaction takes place in the singular cell when it is discharged and reversed. Thus in the charged cell, electrical energy stored as chemical energy which can be recover as electrical energy when the cell is discharged. As energy storage device is very difficult to compress negative energy the supreme state of charge (SOCmax) is increased to 100% and state of charge (SOCmin) is decreased 20% of its amp hour capacity (AH), respectively.

### 4. Proposed Method

The microgrid units can be chosen in such a way that it full fill the customer side load demands at lowest cost. The accurate economic model is required to manage the MG units. Here for producing the output power the operating case is also considered. The proposed method include Artificial Bee Colony (ABC) algorithm to minimizing the fuel consumption cost, maintenance costs, operating cost and emission cost. The major impartial function of MG is obtained based on the following necessities to lessening the operating costs in $/h$ of the microgrid:

$$CF = \sum_{j=1}^{T} (C_j F_j + OM_j) + \sum_{j=1}^{T} \sum_{i=1}^{M} \alpha_i (EF_j P_j)$$

where
- $C_j$ - generating unit fuel cost $j$ $$/L$ for the diesel, and $$/kW for natural gas
- $F_j$ - Fuel consumption rate of generator unit $i$
- $OM_j$ - Operation and maintenance cost of generating unit $j$ in $$/h$
- $\alpha_i$ - Externality cost of emission type $i$
- $EF_j$ - Emission factor of generating unit, emission type $i$
- $M$ - Emission types(NO or CO or SO2)
- $T$ - Number of generating units $j$

Where

The Equality constraints are Power balance constraints:

$$\sum_{i=1}^{T} P_j = P_D + P_{loss}$$
where

\[ P_i^\text{gen} \leq P_i \leq P_i^\text{max}, \quad j = 1, \ldots, T \]

The Inequality constraints are power generation capacity constraints:

\[ P_i^\text{min} \leq P_i \leq P_i^\text{max}, \quad j = 1, \ldots, T \]

where

\[ P_i^\text{min} \] - generation with minimum limit,
\[ P_i^\text{max} \] - generation with maximum limit,

Exterality or spill over's cost is the profits or costs of a product or its manufacture that upset people exterior to the market for the product henceforth, the name is called externality Table 1.

\[ \varphi = \min_{C_i \in F} \{ f_1(C), f_2(C), f_3(C) \}, \quad (13) \]

The three groups of bees are considered in the ABC model viz: the employed bees, the onlooker's bees and the scout's bees. Here it assumes that each food source is assigned to each one of the artificial employed bee. A random initial population of food sources (NS) is generated as:

\[ x_{ij} = (x_i^\text{min} + r \cdot (x_i^\text{max} - x_i^\text{min})) \]

Where, \( i = 1, 2, 3, \ldots, SN \), \( j = 1, 2, 3, \ldots, D \) and \( r \) is a random number between 0 and 1.

The employed bees transfer the information about the food source to the onlookers. The onlookers tend to further looks for the food around the informed food source. Based on the probability value, the onlooker selects the food source (Table 3).

\[ x_{i,j} = x_{i,j}^\text{new} + r \cdot (x_{i,j}^\text{max} - x_{i,j}^\text{new}) \]

Where, \( i = 1, 2, 3, \ldots, SN \), \( j = 1, 2, 3, \ldots, D \) and \( r \) is a random number between 0 and 1.

Table 2. Various power generations

| Demand | Fuel Cell | Microturbine | Diesel engine | Normal Cost | ABC cost |
|--------|-----------|--------------|---------------|-------------|----------|
| 3.6    | 0         | 3.6          | 0             | 0.7549      | 0.6108   |
| 4.4    | 0.4       | 4            | 0             | 1.0113      | 1.0002   |
| 5.55   | 1.55      | 4            | 0             | 1.2178      | 1.1119   |
| 6.4    | 2.4       | 4            | 0             | 1.5175      | 1.3379   |
| 8.1    | 4         | 4            | 0.1           | 2.4542      | 2.4003   |
| 9.2    | 4         | 4            | 1.2           | 2.3576      | 2.3152   |

Table 3. Load remained from PV and wind

| Sl. No. | Total Demand | Demand | PV | Battery | Wind |
|---------|--------------|--------|----|---------|------|
| 1       | 14.5000      | 3.5000 | 2  | 6       | 3    |

The following process is involved in artificial bee colony algorithm,

- Initially the food sources were generated for every employee bees.
- Repeat the below process.
- Every employed bee goes to food source, form a neighbour source around them and then assess its nectar amount and dances in the hive. This process is done in their memory.
- Each onlooker looks out the dance of the employed bees and selects one of their sources...
subject to the dances, and then goes to that corresponding sources. After selecting a neighbour around that, the bees assess its nectar amount.

- Surplus food sources are replaced by a new food sources. These new food sources are found by scout’s bee.
- The optimal food source determined so far is recorded.

The above process is repeated until the requirements are met as shown in Figures 2-4.

**5. Results**

The proposed method is studied in the Matlab 7.10.0(R2014a) platform. The optimization problem contains a diversity of energy sources that are probable to be making in a microgrid. Here the minimization of fuel cost, operating and maintenance costs as well as emission cost were obtained by using artificial bee colony algorithm. Figure 5 shows the minimized cost of MG.

**6. Conclusion**

The optimum configuration of the microgrid at a minimum of fuel consumption cost and minimum of operating and maintenance cost can be attained for different microgrid units using proposed artificial bee colony method. It is clearly examined from the gained results that the ABC method has attained the best selection of the power generators of the MG under various power demands at a minimum cost. The proposed method is an effective technique to model and manage the MG connected system, which is more proficient compare to the other techniques. It can also be applied using Particle Swarm Optimization, Genetic Algorithm to obtain an efficient result.

**7. References**

1. Hernandez-Aramburo CA, Green TC, Mugniot N. Fuel consumption minimization of a microgrid, IEEE Transactions on Industry Applications. 2005; 41(3):673–81. https://doi.org/10.1109/TIA.2005.847277.
2. Campanari S, Macchi E. Technical and tariff scenarios effect on microturbine trigenerative applications, Journal of Engineering for Gas Turbines and Power. 2004; 126:581–89. https://doi.org/10.1115/1.1762904.

3. Mohamed F, Koivo H. System modelling and online optimal management of MicroGrid, WindFarms, IEEE Transactions on Industry Applications. 2006; 29(1):26–28.

4. Mohamed FA, Koivo HN. System modeling and online management of microgrid mesh adaptive direct search, International Journal of Electrical Power and Energy Systems. 2010; 32(5):398–407. https://doi.org/10.1016/j.ijepes.2009.11.003.

5. Chen C, Duan S, Cai T, Liu B, Hu G. Smart energy management system for optimal microgrid economic operation, IET Renewable Power Generation. 2011; 5(3):258–67. https://doi.org/10.1049/iet-rpg.2010.0052.

6. Basu AK, Bhattacharya A, Chowdhury S, Chowdhury SP. Planned scheduling for economic power sharing in a CHP-based micro-grid, IEEE Transactions on Power Systems. 2012; 27(1):30–38. https://doi.org/10.1109/TPWRS.2011.2162754.

7. Azmy AM, Erlich I. Online optimal management of PEM fuel cells using neural networks, IEEE Transactions on Power Delivery. 2005; 29(2):1051–58. https://doi.org/10.1109/TPWRD.2004.833893.