Renewable Energy 78 (2015) 157–164

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

# Economic analysis to implement distributed generation system in a rail-way rake maintenance depot

A. Hazra*, M. Basu

*Department of Power Engineering, Jadavpur University, Kolkata 700098, India*

ARTICLE INFO

*Article history:*
Received 15 August 2014
Accepted 18 December 2014
Available online

*Keywords:*
Distributed generation
Economic feasibility
Optimal power operation
Distributed energy resources
Gravitational search algorithm

ABSTRACT

Distributed generation (DG) with renewable energy resources is gaining importance in modern power systems for its environmental beneficiaries. In this work, decentralized generation system is introduced using distributed renewable energy resources considering its economic feasibility a comparative study has made to find the optimal power operation and optimum installable capacities of distributed energy resources (DER) for minimum energy cost. Gravitation search algorithm (GSA) is used to solve this optimization problem.



## 1. Introduction

A civilization cannot be imagined without consumption of energy. Energy demand is continuously increasing with the development of our society. Electricity is the most compact form of energy. To manage this form of energy our civilization has set up power systems. We are facing the need to optimize power systems in various aspects as per requirements.

With the increasing awareness about the need of economic power production measuring the issue of environmental protection, most of conventional energy resources in centralized power providing schemes are losing popularity. Whereas a newly developing technology of dispersed generation namely decentralized generation or distributed generation is coming in the front. Distributed Energy Resources (DER) are playing a vital role to check the environmental pollution through utilization of non-conventional and renewable energy sources such as fuel cells, solar modules, wind power, and biomass gasifier units etc. Many researches related to the design and operations of DERs are being done [1–6]. Possibilities of implementing micro-grid with the DERs are also discussed somewhere [7–9]. Attentions are also paid to the economics of Hybrid Distributed Energy Resources [10].

A Rail Ways rake maintaining depot, where electrical and mechanical maintenance of Traction Rolling Stocks are performed, namely “Sonarpur TRS/EMU Railways Car-shed, E.Rly” was established in the year 1979. It is situated in Sonarpur, the south suburban of Kolkata City. Total premises area of this car-shed is about 68,550 $m^2$, where total covered space is 8850 $m^2$ and area of open space is about 59,700 $m^2$. This depot has an average electrical consumption of about 50 KVA with a maximum demand contract of 200 KVA. This power is drawn from Sonarpur 33/11 KV Substation of West Bengal State Electricity Distribution Company Ltd (WBSEDCL).

In this paper a proposal is introduced to implement Distributed Energy or Decentralized Energy Generation system in the aforesaid campus of Eastern Railways. This car-shed is in the run of 24X7 hours by 3 shifts per day. The load profile of 24 h is examined and it is noted that the load scheduling is very tight and highly optimal (considering all constraints regarding their routine working schedule) with average load of 50 KVA, maximum demand of 120 KVA and with connected load of 400 KVA. They maintain their power factor 0.98 to 1 placing capacitor bank in their sub-station. So optimal power operation planning is to be done mitigating the hourly demand.

Solar and wind potential of this area was taken from West Bengal Renewable Development Agency (WBREDA) and as per the reports wind power generation is not suitable there but its solar potential is fair enough to generate power. In the premises large amount of spare area is available to set up renewable power generators like biomass gasifier units, fuel cells, etc. Considering this scenario, only solar power system (SPS), biomass gasifier unit (BMGU) and phosphoric acid fuel cell (PAFC) are proposed as DERs here along with a battery energy storage system (BESS).

* Corresponding author. Tel.: +91 9836486556.
*E-mail address:* abhik.hazra@gmail.com (A. Hazra).

http://dx.doi.org/10.1016/j.renene.2014.12.043
0960-1481/

Beside the environmental benefits, the main objective for introducing distributed generation here is to minimize the electricity bill charged by WBSEDCL to Eastern Rail Ways and if possible to earn back some money feeding surplus power to the grid, so that this proposal becomes attractive to the consumer i.e. the Rail Ways company.

To fulfill the objective, optimal power operation planning and the optimal capacity of the above mentioned renewable power generators are proposed. A comparative study is also done for three set of generators. i.e. Cases I, II & III.

Case I. Biomass gasifier unit (BMGU) and solar power system (SPS), along with a battery energy storage system (BESS).

Case II. Phosphoric acid fuel cell (PAFC) and solar power system (SPS), along with a battery energy storage system (BESS).

Case III. Biomass gasifier unit (BMGU), phosphoric acid fuel cell (PAFC) and solar power system (SPS), along with a battery energy storage system (BESS).

Here Gravitational Search Algorithm (GSA) is chosen to optimize this highly constrained problem. Gravitational Search Algorithm is a strong heuristic search algorithm. It is based on the law of gravity and mass interactions [11]. Though GSA is not very common to solve such optimization problems, it has success solving various optimization problems in other field like symmetric traveling salesman problem [12], flow shop scheduling problem [13], DNA sequence design problem [14] etc. Considering these, GSA is chosen to solve this optimization problem. To ensure the reliability of the performance of GSA for this optimization problem, the problem is also solved by Particle Swarm Optimization (PSO) technique.

## 2. Problem formulation

The cost evolution for this distributed generation system, three set of generators are considered as mentioned above. The test cases have been chosen in anticipation of the scenario that as per our present technology, BMGU has low installation cost and operating cost but power density is less. Whereas, PAFC has high installation and operating cost, but it has high power density, i.e. less space is required to install a high capacity power plant comparative to other DERs.

Among various type of fuel cells, PAFC, with high efficiency, low chemical and thermal emissions, fuel flexibility, reliability, low maintenance, excellent part-load performance, is considered as most advanced in the range of 50 KW–1000 KW [15–17]. Presently it is proved that, in micro-power systems, Solar power system (SPS) performs good with economic merit to mitigate nearby loads [23,24]. As per the scenario of Indian context, BMGUs are also playing a vital role in the area of decentralized energy generation systems [18–22]. Among existing batteries, VRLA (valve regulated lead acid) shows most technological maturity in respect of efficiency, initial cost etc [20].

### 2.1. Objective functions

Here the objective function is total annual cost of this distributed generation system which is given by

$$R = R_O + R_I + R_M + R_U \tag{1}$$

where $R_O$, $R_I$, $R_M$, $R_U$ are operating cost, initial cost, micro-grid cost, and utility cost, respectively.

Here the objective is to minimize the total annual cost $R$, with optimal power operation and to find the optimum installed capacity of various DERs. It is considered that, the control variables, $P_{bm}$, $P_{fc}$, $P_{bt}$, $P_{so}$ are the vectors which represent the hourly basis power generation of a day in KW and $IC_{bm}$, $IC_{fc}$, $IC_{bt}$, $IC_{so}$ are the installed capacities of Biomass, fuel cell, battery energy storage system and solar power system respectively.

Operating cost varies for different type of DERs. $O_{bm}$, $O_{fc}$, $O_{bt}$, $O_{so}$ are the operating costs per KW of BMGU, PAFC, BESS, SPS respectively. That implies,

For Case I

$$R_O = 365 \cdot \sum_{hr=1}^{24} P_{bm} \cdot O_{bm} + P_{bt} \cdot O_{bt} + P_{so} \cdot O_{so} \tag{2}$$

For Case II

$$R_O = 365 \cdot \sum_{hr=1}^{24} P_{fc} \cdot O_{fc} + P_{bt} \cdot O_{bt} + P_{so} \cdot O_{so} \tag{3}$$

For Case III

$$R_O = 365 \cdot \sum_{hr=1}^{24} P_{fc} \cdot O_{fc} + P_{bm} \cdot O_{bm} + P_{bt} \cdot O_{bt} + P_{so} \cdot O_{so} \tag{4}$$

Different DERs have different initial costs. Let $I$ be the market rate of interest, $IC_{bm,\ fc,\ bt,\ so}$ and $C_{bm,\ fc,\ bt,\ so}$ are the optimal installed capacities and installation costs per KW capacity of BMGU, PAFC, BESS, SPS respectively. The $IC_{bm,\ fc,\ bt,\ so}$ are calculated as

$$IC_{bm,\ fc,\ bt,\ so} = max\left|P_{bm,fc,bt,so}\right| \tag{5,6,7,8}$$

So the equated annual cost for installations considering depreciation,

for Case I

$$R_I = (f_{bm} + I) \cdot IC_{bm} \cdot C_{bm} + (f_{bt} + I) \cdot IC_b t \cdot C_{bt} + (f_{so} + I) \cdot IC_{so} \cdot C_{so} \tag{9}$$

for Case II

$$R_I = (f_{fc} + I) \cdot IC_{fc} \cdot C_{fc} + (f_{bt} + I) \cdot IC_b t \cdot C_{bt} + (f_{so} + I) \cdot IC_{so} \cdot C_{so} \tag{10}$$

for Case III

$$R_I = (f_{bm} + I) \cdot IC_{bm} \cdot C_{bm} + \left(f_{fc} + I\right) \cdot IC_{fc} \cdot C_{fc} + (f_{bt} + I) \cdot IC_b t \cdot C_{bt} + (f_{so} + I) \cdot IC_{so} \cdot C_{so} \tag{11}$$

Where$f_{bm,fc,bt,so}$ are factors associated with sinking fund depreciation value, which are given below.

$$f_{bm,fc,bt,so} = dr \cdot \frac{(1 + dr)^{\left(Lft_{sw,tfm,cbl,ctrl} - 1\right)}}{(1 + dr)^{Lft_{bm,fc,bt,so}} - 1} \tag{12,13,14,15}$$

Here,$Lft_{sw,tfm,cbl,ctrl}$ are the estimated life times of these various DER power plants, with $dr$ as the rate of depreciation.

The micro-grid installation cost (including depreciation and interest on the invested money for these installations) can be expressed as

$$R_M = (f_{sw} + I) \cdot C_{sw} + \left(f_{tfm} + I\right) \cdot C_{tfm} + (f_{cbl} + I) \cdot C_{cbl} + (f_{ctrl} + I) \cdot C_{ctrl} \tag{16}$$

Where $C_{sw,tfm,cbl,ctrl}$ are the costs of optimum installed capacities of switch gears (including CTs, PTs, LAs), transformers (1100/415 V), cable and controller (including panel) respectively. Here, the subjected site for implementing distributed generation is not very large. Transformers (1100/415 V) are needed here as the interface between the grid and the micro-grid. As the DERs will be existed near the loads, the local network is proposed of 415 V. $f_{sw,\ tfm,\ cbl,\ ctrl}$ are the factors associated with sinking fund depreciation value, and are expressed as