CHEMICAL ENGINEERING TRANSACTIONS Volume 18, 2009
Editor Jiří Klemeš
Copyright © 2009, AIDIC Servizi S.r.l., ISBN 978-88-95608-04-4 ISSN 1974-9791
DOI: 10.3303/CET0918102

Optimal configuration of island's energy supply system

Sandrina Pereira*, Raquel Segurado, Anildo Costa, Ana Pipio, Luís Alves
Department of Mechanical Engineering - Instituto Superior Técnico
Avenida Rovisco Pais, Pavilhão de Mecânica I, 2nd floor, 1049-001 Lisboa
sandrinapereira@ist.utl.pt

Most islands depend mainly on imported fossil fuels for electricity production while presenting a considerable potential in renewable energies. However, unlike hydro or geothermal energy sources that can account for the base load, intermittent renewable energy sources, such as wind and solar energy, have to tackle the need for energy storage. Advanced energy planning must be used to combine different intermittent and regular sources in order to match electricity demand and assure security of supply.
In this study, the Genetic Algorithm (GA) approach is used to determine the optimal configuration of power generating systems in an island with renewable energy using hourly data over one year. The energy system analysed is a hybrid system constituted by a photovoltaic system, batteries and the existing diesel generator in Monte Trigo village, in the island of Santo Antão, Cape Verde.
The objective function of the GA is the total cost of the electricity produced over one year. The result is the least costly electrical power system for the village

1. Introduction

Access to energy is essential to economic and social development. It is also the aspiration of every human being and they are willing to spend a significant proportion of their income in better energy (World Bank, 1996). However for small islands developing states (SIDS) a single unit of energy can cost double even compared to continental developing countries. Finally, the costs of providing access to energy for isolated regions in SIDS are often prohibitive.
Nevertheless, in some case, for social or political reasons some isolated villages become electrified by the means of fossil fuelled electrical generators connected to mini-grids. The result is often an intermittent supply system conditioned by the scarcity of fuel. Renewable Energy Sources (RES) are significant in SIDS and Renewable Energy Technologies (RETs) may have an important role to play in the provision of electricity with potentially significant economic benefits (Weisser, 2004).
The intermittent nature of RES implies the necessity for a backup system (fossil fuel) or storage or even both. While the cost of operation and difficulties of fuel provision would recommend opting for 100% RES supply system, if there is already a fossil fuelled system, one should analyse the economic aspects in order to chose the best configuration. In terms of reliability, fossil fuel can be a backup in case of lack of

Please cite this article as: Pereira S., Segurado R., Costa A., Pipio A. and Alves L., (2009), Optimal configuration of island's energy supply system, Chemical Engineering Transactions, 18, 629-634 DOI: 10.3303/CET0918102

renewable resources and the availability of RES can compensate the scarcity and cost of fossil fuels.

2. The energy system in Monte Trigo

The island of Santo Antão is located in the Archipelago of Cape Verde, western Africa. Santo Antão, as most islands, depends mainly on imported fossil fuels for energy production (Alves et al, 2000). Monte Trigo is a small village in the southwest of the island of Santo Antão. This village has about 300 inhabitants, and is isolated, being only accessible by boat.

Currently, Monte Trigo is not connected to the main grid, and electricity is supplied through a mini-grid by a diesel generator with 29 kVA operating only four hours a day (due to the high fuel cost 0.27€/kWh). This high cost is related to the difficulties to transport the fuel to the village.

To increase electricity production from the actual 4 hours/day to 24 hours/day we propose an alternative hybrid supply system based in RES. This hybrid system is composed by the existing diesel power generating system, to which is added photovoltaic (PV) panels and batteries. We consider that the generator is able to function 24 hours per day and that it can be turned on and off according to the demand needs.

2.1 Monte Trigo's Electricity demand

In the scope of the European project SESAM-ER (Servicio Energético Sostenible para Poblaciones Rurales Aisladas mediante Micro-redes con Energia Renovables en la Isla de Santo Antão – Cabo Verde), work has been carried out in order to predict the annual electricity consumption in the village, the daily profiles and the hourly load (Roque, 2008). The projections resulted in an annual electricity consumption of 28,826 kWh with a peak power of 14.21 kW.

2.2 Photovoltaic System

Solar resources input for the PV station, were derived from data obtained using the program MeteoNorm for a neighbouring island, São Vicente (which has a meteorological station).

The electricity output of the PV energy system (PV_e) depends of the hourly global irradiation (I_g) in the PV panels inclined with an angle equal to the latitude, the efficiency (η_{PV}), the area (A_{PV}) and the number (PV_n) of the solar panels considered.

$$PV_e = I_g \times \eta_{PV} \times A_{PV} \times PV_n \tag{1}$$

The solar energy from the PV is stored in a bank of batteries. The depth of discharge was assumed to be 50%. The DC electricity from the batteries is converted to AC by a set of inverters connected to the mini-grid. Total losses were estimated to be 20%.

The characteristics of the different equipments are described in the next table, and were retrieved from the catalogue of the Portuguese company FFSolar. It was considered that the system needs 5 inverters.

Table 1 Characteristics of the equipments (FFSolar)

PV panels, batteries and inverters	
Model of the PV panels	BP 3230 N
Rated power	230 W
Efficiency	14%
Area	1.667 m^2
Cost	1,192 €
Life time	25 years
Maximum number of equipments	63
Model of the batteries	Autosil E12-255
Nominal voltage of the batteries	12 V
Capacity of the batteries	255 Ah
Minimum state of charge of the batteries	50%
Cost of the batteries	397 €
Life time of the batteries	5 years
Maximum number of equipments	20
Model of the inverters	OutBack VFX 3048E
Nominal DC Input Voltage of the inverters	48 V
Cost of the inverters	2,165 €
Life time of the inverters	10 years

3. Problem Formulation

The objective function of this problem is the total cost of the electricity generated in one year by a hybrid system composed by PV panels, batteries and a diesel generator to make face to the projected needs of the village of Monte Trigo. The total cost of the energy system for one year (Tc) is the sum of the installation costs of the PV and batteries facilities, including the cost of inverters, and the operational costs of the diesel generator (Dc), for one year. The operational costs of the photovoltaic and batteries facilities are neglected. The installation costs of the diesel generator are not considered because this equipment is already installed in the island.

$$T_C = \frac{PV_n \times PV_C}{Y_{PV}} + \frac{B_n \times B_c}{Y_B} + \frac{I_n \times I_c}{I_I} + D_C \tag{2}$$

Regarding the PV panels, the batteries and the inverters, their yearly costs are obtained dividing the total cost of the equipments (PVc, Bc and Ic) by their life time (Y_{PV}, Y_B and Y_I). The operational costs of diesel are the fuel costs. PVn, Bn and In are the number of PV panels, batteries and inverters, respectively.

4. Optimal configuration: the Genetic Algorithm

The aim of this work is to determine the optimal composition of a hybrid energy system with minimum yearly cost, the goal is to find the optimal number of PV panels (PVn) and batteries (Bn) that are able to meet the electricity demand, together with the diesel generator, with least costs. The optimization method used is the Genetic Algorithm (GA) and the objective function is the total cost. Firstly, the GA creates randomly the initial population with n individuals composed by a random number of PV panels and a random number of batteries. For each individual, the energy system is simulated and the total cost is estimated and evaluated. Each individual is represented by a string of twelve binary digits. The two individuals with lower total cost are selected as clones for the next generation. The remaining generation is obtained based on one-point crossover and mutation, with a mutation rate of 2%. The selection of parents and the position of the point from which the one-point crossover is done, are made randomly.

The simulation is based in the hourly data over a year of global irradiation and electricity demand. The flowchart of the energy system's simulation is showed in the following figure:

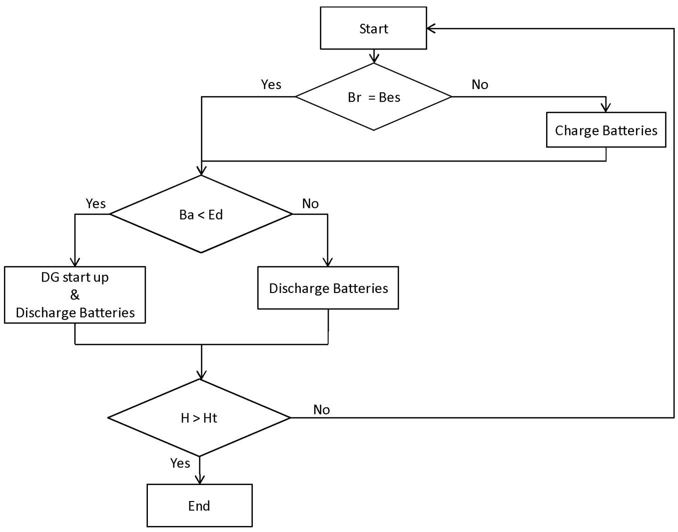

Figure 1 – Flowchart of the system operation

To determine the optimal configuration the algorithm performs iteratively the following steps:

1st step: Verify if the charge remaining in the batteries (Br) is equal to the total batteries' capacity (Bes); if yes go to the 3rd step, else go to the 2nd step.

2nd step: Charge the batteries with electricity from the PV panels until they become full and go to the 3rd step.

3rd step: Compare the electricity demand (Ed) with the energy available in the batteries (Ba); if Ba is lower than Ed go to the 4th step, else go to the 5th step.

Considering that the minimum state of charge of the batteries is 50%, Ba is equal to the energy remaining in them (Br), minus 50% of their total capacity.

4th step: Discharge the available energy in the batteries and start up the diesel generator to meet the electricity demand. Go to the 6th step.

5th step: Discharge the batteries to cover the electricity demand. Go to the 6th step.

6th step: If hour, H, is lower that the number of hours in a year, go to the 1st step (new iteration), else end the simulation.

5. Results

This simulation was made with populations of 20 individuals. The total number of generations (iterations) chosen was 1,000. The following graphics present the best individual of each generation, that corresponds to the number of PV panels (PVn) and batteries (Bn) that minimize the objective function – the total cost (in Euros).

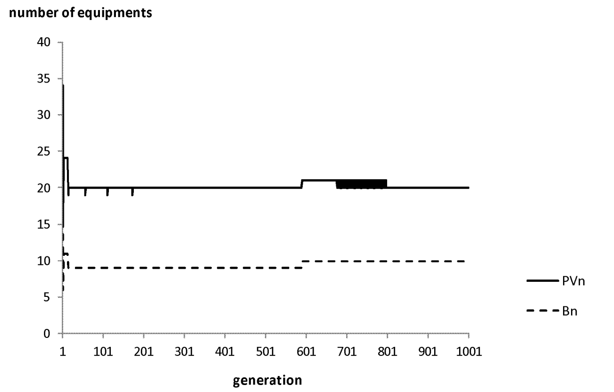

Figure 2 – Number of equipments for each generation

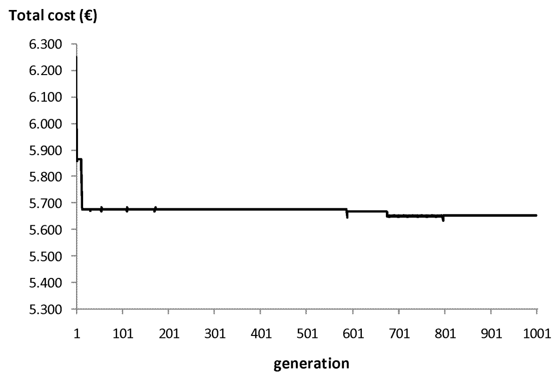

Figure 3 – Minimum total cost for each generation

Considering the diesel system already installed in the island and the addition of PV panels and batteries, the configuration that minimizes the costs of the production of

electricity for one year is 20 PV panels and 10 batteries. This total cost is 5,653€. The yearly penetration of RES is about 64%.
As mentioned above, the use of a hybrid energy system to meet the electricity demand is the most sustainable solution for these realities; on the other hand, with these results we can conclude that this solution is economically viable.

5.1 Sensitivity analysis

A sensitivity analysis was performed varying some of the cost variables. Firstly, the diesel cost was increased to 0.40€/kWh maintaining the cost of the PV panels, batteries and invertors. A second sensitivity analysis was done considering a grant in the order of 50% to finance the solar energy system. The results obtained are summarized in the following table.

Table 2 Sensitivity analysis results

Results	Reference values	Dc = 0.40 €/kWh	50% grant
PVn	20	42	42
Bn	10	20	20
Cost per year (€)	5,653	7,008	3,903
RES penetration	64%	80%	80%

With an increase of diesel costs, the optimal configuration of the energy system is modified; the optimal number of PV panels and batteries becomes two times higher, leading to a significant increase of the yearly penetration of renewable energy. This occurs because the price of diesel is very high and balances the price of the solar energy system. As expected, the 50% grant to finance the solar energy system, results in a significant increase of the number of PV panels and batteries.

References

Alves L., Costa A Carvalho, M.. Analysis of potential for market penetration of renewable energy technologies in peripheral islands. Renewable Energy 19 311-317, 2000.

Duić N., Carvalho M.G.. Increasing renewable energy sources in island energy supply: case study Porto Santo. Renew Sust Energy Rev 8 383–399, 2004.

FFSolar – Sistemas de Energias Alternativas Portugal, Lda. www.ffsolar.com

Meteonorm – Global Meteorological Database for Engineers, Planners and Education. www.meteonorm.com

Roque A., Optimal Integrated Energy Solutions for Isolated Sustainable Communities - Case study on Santo Antão Island, Cabo Verde, Master Thesis, IST 2008.

Senjyu T., Hayashi D., Yona A., Urasaki N., Funabashi T.. Optimal configuration of power generating systems in isolated island with renewable energy. Renewable Energy 32 1917–1933, 2007.

Weisser, D.. On the economics of electricity consumption in small island developing states: a role for renewable energy technologies. Energy Policy 32(1) 127-140, 2004.

World Bank, Rural Energy and Development for Two Billion People 1996, www.worldbank.org