Operation Management of a Micro Grid Containing Photovoltaic/ Energy Storage Devices

Dr Mahdiyeh Eslami, Alireza Malekzadeh Javadi, Mohammad Ostovarzadeh Ravari

Abstract – Recently, due to technology improvements, governmental incentives for the use of green energies and rising concerns about high cost of energy fromfossil fuels, renewable energy sources (RESs) appears to be a promising approach for producing local, clean, and inexhaustible energy. This motivates the implementation of micro grids (MGs) introduced as a cluster of electrical and/or thermal loads and different RESs. This paper considers uncertainties in load demand, market prices and the available electrical power of wind farms and photovoltaic systems. A computer program has been developed to size system components in order to match the load of the site in the most cost. A cost of electricity, an overall system cost is also calculated for each configuration. The study was performed using a graphical user interface programmed in MATLAB/simulink environment.

Keywords: Photovoltaic, Energy Storage Devices, modelling, Micro Grid, Management

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1. Introduction

The rapid depletion of fossil-fuel resources on a world has necessitated search for alternative energy sources. Wind energy has been considered as promising toward meeting the continually increasing demand for energy. The solar and wind sources of energy are inexhaustible, the conversion processes are pollution-free, and their availability is free. For isolated systems such as rural electrification, the solar or wind energy has been considered as attractive and preferred alternative sources.

Recently, development in renewable energy technologies and rising concerns about high cost of energy from fossil fuels and global warming have increased the utilization of distributed energy resource (DER) units [1,2]. Penetration of DER units provides utility owners and customers various benefits such as: lower energy cost, higher service reliability and power quality [3]. The DER units are small energy sources located near local loads and categorized to distributed generation (DG) and distributed storage (DS) units [4]. The DG units include wide range of technologies such as fuel cells, micro turbines (MTs),

Diesel engines, photovoltaic (PV) systems and small wind turbines (WTs). Likewise, DS units are composed of different types of batteries, energy capacitors, flywheels and controllable loads [5]. The DER units can operate in both grid-connected and autonomous mode. This brings about the concept of microgrid (MG). An MG is defined as a cluster of electrical and/or thermal loads and DER units serviced by a distribution systemand expected to remain operational after separation from the system. The energy storage units are used along with the DG ones to make the operation of MGs more reliable and economical [6,7].

Several studies have focused on optimizing the energy and operation management (EOM) of MGs. Chen et al. [5] presented a smart energy management system based on the matrix real-coded genetic algorithm to optimize the operation of MG. A power forecasting module, an energy storage system management module and an optimization module were utilized during the optimization process.

This paper considers uncertainties in load demand, market prices and the available electrical power of wind farms and photovoltaic systems. The study was performed using a graphical user interface programmed in MATLAB/simulink environment.

2. System Configuration

The configuration of stand alone PV wind power systems is shown in Fig. 1. In this paper, we investigated

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the case that a system has PV module, wind turbine, batteries and inverter of stand alone energy conversion installation.

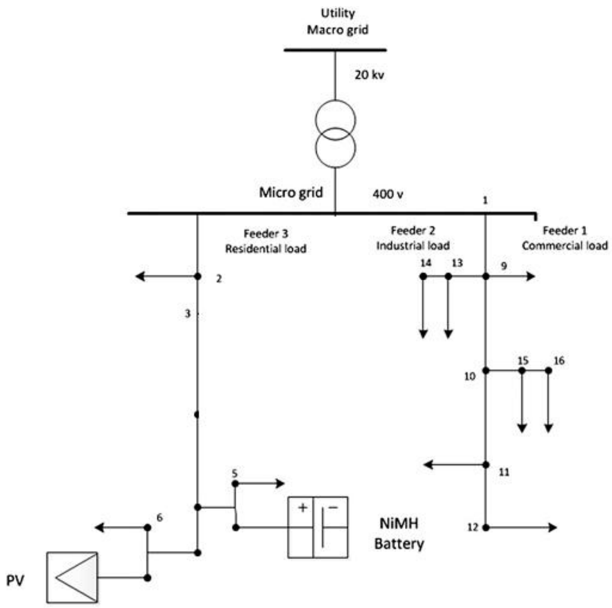

Fig. 1. A typical micro grid model

3. Modelling of photovoltaic system

Photovoltaic conversion is the direct transformation of solar energy into immediately usable direct electric current. From a technical standpoint, PV power systems have the potential to meet a large portion of energy demand worldwide [1]. A photovoltaic system contains the following components:

- Photovoltaic Array (Generator)
- Controller
- Voltage transformer
- Inverter to convert DC produced to AC current
- Storage battery

3.1 Modelling of PV Array :

A PV generator consists of modules connected in series to increase the voltage and in parallel to increase electrical output (Fig.1). The relationship between current and voltage is expressed by the following relationship:

$$\frac{I}{M_p} = I_{cc} - I_o \left[e^{\left(\frac{c_2}{n}\left(\frac{V}{Ms} + \frac{Rs.I}{Mp}\right)\right)} - 1 \right]$$

Where:
I = output current
Icc = light generated current per module
Io = reverse saturation current per module
Rs = diode series resistance per module (ohms)
N = number of modules in each series string
Ms = number of module strings in strings in series
Mp = number of module strings in parallel

This relationship holds true only if the array cells are identical and having the same characteristic I = f(V).

3.2 Temperature modeling :

Cell temperature (Tc) varies according to global solar irradiance and ambient temperature according tot the following equation:

$$T_c = T_a + \left(\frac{\text{Noct} - 20}{800} \right) . G_b$$

Noct : Normal cell operating temperature provided by manufacturer data
T_a : Ambient Temperature
G_B : Global Solar Irradiance

3.3 Modelling the battery:

Experimental testing of solar batteries leads to the following model for load and off-load [3]

$$V = V_0 \pm I.R$$

$$V = \left\{ V_o + k.\frac{Q}{\frac{C_T}{1+a.I}(1+\alpha c.\Delta T + \beta c.\Delta T^2)} \right\} \mp \left\{ \left(\frac{P_1}{1+I} + \frac{P_3}{[1-\frac{Q}{C_T}]P_4} + P_5 \right)(1-\alpha.c.\Delta T) \right\} \quad (2)$$

Where the + sign is for the charge and – sign for the discharge:

V_0 = initial voltage
K, P_1, P_2, P_3, P_4, P_5 are constant derived empirically

In practice, the battery's output is usually maximized at 85%, the nominal voltage at 2V and the average capacity at 1000Ah. Power supplied by the battery is expressed as :

$$P_{ba} = \eta_{ba} . P_g$$

where:
P_g = power of generator

3.4 Modelling of the Inverter:

The single phase inverter is characterized by its efficiency which is dependent on the power output supplied. This is expressed by the following relationship:

$$\eta c = P_s/P_b$$
$$\eta c = A_1.\exp(-Ps/Pn)$$

Where,
A_1 and A_2 = constant characteristics of converter supplied by manufacturer
P_s = utilized power during usage of system
Pn = Nominal power.

The output power supplied by the transformer is:

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$$P_c = \eta_c \, . P_b$$

Or

$$P_c = \eta_c \, . P_g \, . \eta g$$

3.5 MODELING OF THE STATIC CONVERTERS

The static inverter used is a full wave three-phases voltage inverter (Fig. 5) [10]. Each switch is made up of IGBT in antiparallel with a free wheel diode. The switches are admitted as ideals, thus as in the case of the rectifier, their conduction correspond to a short circuit and their blocking corresponds in its turn to an open circuit. On the other hand, the overlapping are taken here into account. The following figure represents the inverter feeding a three-phase load which has Z_{ch} impedance. At the output of the inverter, one obtains the three-phase and symmetrical voltage systems. The theory of the three-phase and symmetrical systems shows that the voltages and the currents of these systems have the following properties:

$i_{ach} + i_{bch} + i_{cch} = 0$; $u_{ab} + u_{bc} + u_{ca} = 0$

$$v_{ach} = \frac{u_{ab} - u_{ca}}{3} \; ; \; v_{bch} = \frac{u_{bc} - u_{ab}}{3} \; ; \; v_{cch} = \frac{u_{ca} - u_{bc}}{3} \qquad (18)$$

i_{jch} and v_{jch} are respectively the load currents and load voltages where $j = a, b, c$.

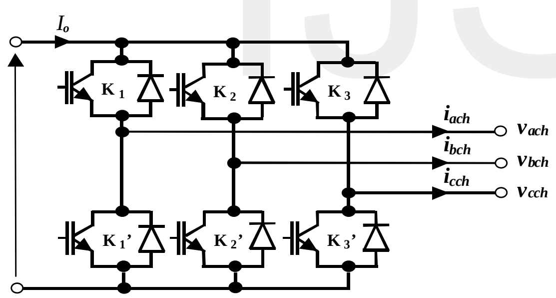


Fig. 2. Electric scheme of the inverter

$K_i = (T_i, D_i)$, $K_i' = (T_i', D_i')$, $i = 1, 2, 3$ and I_0 is the inverter input current.

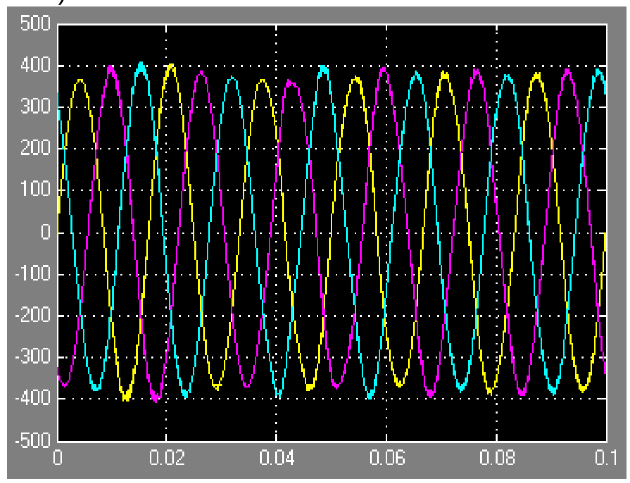
3.6 LOAD MODELING

There are two types of load utilization:

- Constant Load: Used for fixed consumption such as in telecommunication systems. The relationship between consumption and time is this linear.
- Variable Load: This is the case when the load is variable according to daily demand where it is maximum during early morning hours (7-9 AM), at mid-day (12-14 PM) and during evening hours (after 19 PM).

4. Simulation Results

The developed methodology has been applied to design a stand alone hybrid PV/wind system in order to power supply residential household located in the area of the Laboratory CNRS Ajaccio (Corsica island) (41° 55' N, 8° 44' E) .



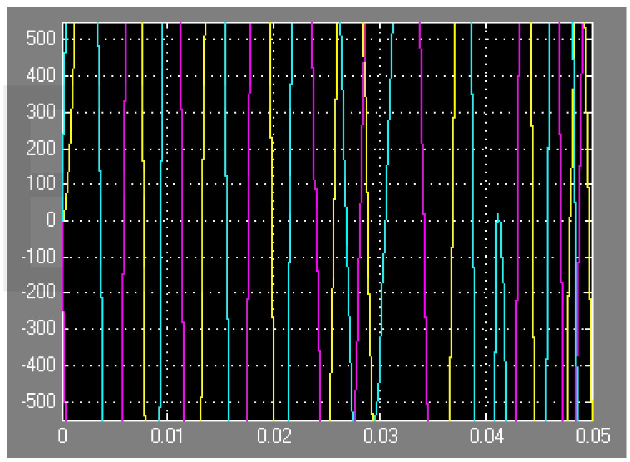


Fig. 2. Voltage and Current Photovoltaic/ Energy Storage Devices

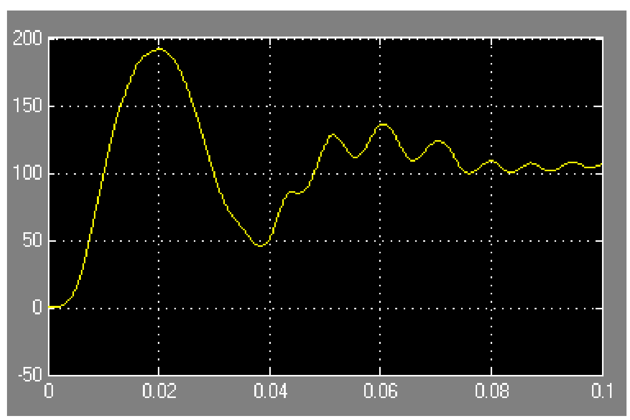


Fig. 3. Voltage PV Devices

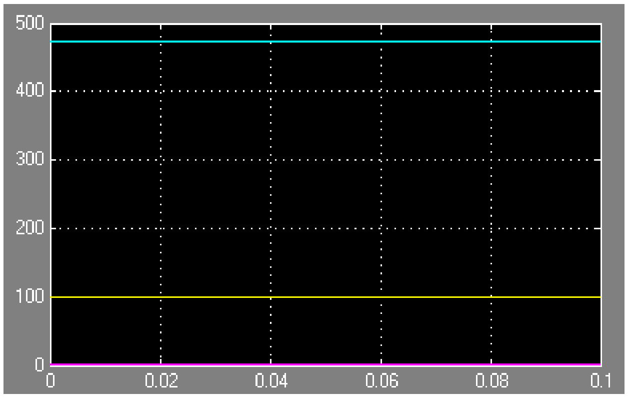


Fig. 4. Voltage Energy Storage Devices

5. Conclusions

The optimal sizing of autonomous hybrid PV/wind system with battery storage, using an optimization model, has been developed in this work. The system configurations can be obtained in terms of a system power supply reliability requirement by using the LPSP concept. The one with the lowest levelised cost of energy is considered as the economical optimal configuration. The simulation results, for a LPSP of 0 and a defined profile, show that in order to obtain a total renewable contribution (RC=1), more than 30 % of the energy production is unused unless the battery capacity is very large. On the other hand, while in a renewable contribution of about 85%, the energy excess percentage decreases to 5%, for a configuration with one wind generator and below 15% for that comprising two generators. The second important conclusion is that the system devices choice represents an important step in the optimal sizing of the hybrid PV/wind system. Including economical consideration, a 125 W module configuration is found better than a 50 W one. However, the configuration system comprising one wind generator (600 W), PV generator (using 125 W modules) and batteries storage (using 253 Ah battery) is found as the optimal one from both the economical and technical point of view.

Additionally, for different system configurations with 100 % reliability, the lowest LCE happens with the same battery capacity (750Ah), corresponding to the double daily capacity, and with an energy excess exceeding 40%. Finally, In order to reduce the energy excess, corresponding to the lowest LCE, the use of a third energy source (diesel) can bring benefit to the system.

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