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Control based on techno-economic optimization of renewable hybrid energy system for stand-alone applications

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ABSTRACT

This paper presents an Energy Management System (EMS) for hybrid systems (HS) composed by a combination of renewable sources with the support of different storage devices (battery and hydrogen system) that allow its operation without the necessity of grid connection (i.e. a stand-alone system).

The importance of the proposed EMS lies in taking into account economic issues that affect to the decision of which device of the HS must operate in each moment. Linear programming was used to meet the objective of minimizing the net present value of the operation cost of the HS for its whole lifespan. The total operation costs depend largely on the reposition costs of its components. Instead of considering predefined reposition years for each component and calculate their net present cost from them (as is commonly considered in other works), in this work it was proposed to use lifetime degradation models - based on the well-known statement that the lifetime depends on the hours of operation and the power profiles that the components are subjected to- from which the repositions are made to check how they affect to the cost calculation and, consequently, to the EMS performance.

The behavior of the proposed control is checked under a long term simulation, in MATLAB-Simulink environment, whose duration is the expected lifespan of the HS (25 years). A conventional state-machine EMS is used as a case study to validate and compare the results obtained. The results demonstrate that the proposed HS and EMS combination assures reliable electricity support for stand-alone applications subject to different techno-economic criteria (generation cost and sustenance of battery SOC and hydrogen levels), achieving to minimize the operation cost of the system and extend their lifespan.

1. Introduction

The development of hybrid systems (HS) which combine renewable energy sources with energy storage devices is seen as an important asset for rural electrification and reducing the greenhouse gases emissions (Alonso, Amaris, & Alvarez-Ortega, 2012; Hajizadeh & Golkar, 2010). The operation of these systems requires a thorough study of different parameters such as optimal sizing, placement, design and control that affect power generation (reliability, power quality, efficiency, etc.) and economic (acquisition, operation and replacement costs, etc.) aspects.

The transition from today's power system to a future infrastructure characterized by a higher amount of distributed renewable systems (including HS) will require the support of expert and intelligent systems to deal with the following problems: variable generation, unbalance among generators and loads, limited storage capacities of storage systems and economic issues related to electricity prices and operation costs.

Therefore, the success in a widespread usage of HS based on renewables is inevitably linked to the minimization of their costs. There are a large number of papers that propose to minimize the cost of the HS in their design stage, i.e. in the process of sizing the HS components. Finding the optimum sizing of these components subject to a broad range of technical, economic or environmental constraints is a complex problem that requires the use of expert and intelligent systems to be solved. This kind of works studies how different designs generated from complex algorithms

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Nomenclature

A, A_{eq}	matrices of coefficients of the minimization problem
b, b_{eq} and c	vectors of coefficients of the objective function, inequalities and equalities respectively
CAP_{H2}	storage capacity of the hydrogen tank
$C_{ad,bat}$	battery adquisition cost, ($)
$C_{ad,fc}$	FC adquisition cost, ($)
$C_{ad,lz}$	electrolyzer adquisition cost, ($)
C_{bat}	battery generation cost, ($/Wh)
C_{fc}	FC generation cost, ($/Wh)
C_{lz}	electrolyzer generation cost, ($/Wh)
C_{TOTAL}	HS total cost at the end of its life, ($)
$Cycle_{fc}$	a start/stop cycle from 0 to the current FC power, (W)
${Cycle_{fc}}^{nom}$	a start/stop cycle from 0 to the nominal FC power, (W)
DOD_{nom}	nominal depth of discharge of the battery
$E_{bat,chg}^{available}$	available energy that the battery can absorb, (Wh)
$E_{bat,dch}^{available}$	available energy that the battery can generate, (Wh)
${E_{bat}}^{chg}$	expected energy absorbed by the battery for the HS lifetime, (Wh)
${E_{bat}}^{dch}$	expected energy generated by the battery for the HS lifetime, (Wh)
${E_{bat}}^{nom}$	nominal energy of the battery, (Wh)
$E_{fc}^{available}$	available energy that the FC can generate, (Wh)
${E_{fc}}^{dch}$	expected energy generated by the FC for the HS lifetime, (Wh)
${E_{fc}}^{nom}$	nominal energy of the FC, (Wh)
$E_{lz}^{available}$	available energy that the electrolyzer can absorb, (Wh)
${E_{lz}}^{chg}$	expected energy absorbed by the electrolyzer for the HS lifetime, (Wh)
${E_{lz}}^{nom}$	nominal energy of the electrolyzer, (Wh)
EMS	energy Management System
${E_{net}}^{chg}$	expected surplus of energy for the HS lifetime, (Wh)
${E_{net}}^{dch}$	expected deficit of energy for the HS lifetime, (Wh)
E_{unused}	unused energy, (kWh)
$f(x)$	objective function of the minimization problem
FC	fuel cell
${H_{fc}}^{life}$	FC lifespan, (h)
${H_{lz}}^{life}$	electrolyzer lifespan, (h)
HS	hybrid system
H_{warr}	initial warranty of the FC, (h)
I_{4x4}	unitary matrix whose dimension is 4×4
K_{on}	FC operating parameter: equal to 0 when the FC is stopped and 1 when the FC is working.
L_{bat}	expected battery life, (years)
L_{fc}	expected FC life, (years)
L_{H2}	hydrogen tank level, (%)
LHV_{H2}	lower heating value, (Wh/kg)
$Life_{bat}$	nominal life of the battery, (cycles)
$Life_{fc}$	nominal life of the FC, (h)
$Life_{lz}$	nominal life of the electrolyzer, (h)
L_{lz}	expected electrolyzer life, (years)
LPS	loss of power supply, (kWh)
$LPSP$	loss of power supply probability, (%)
M_{H2}	hydrogen flow of the hydrogen system, (kg/h)
MPC	model predictive controller
N_{bat}	number of battery repositions, (units)
${N_{bat}}^{chg}$	number of battery repositions due to charge process, (units)
${N_{bat}}^{dch}$	number of battery repositions due to discharge process, (units)
N_{cycle}	portion of one battery cycle, (pu)
N_{fc}	number of FC repositions, (units)
N_{lz}	number of electrolyzer repositions, (units)
NPC	net present cost, ($)
NPC_{bat}	battery reposition net present cost, ($)
$NPC_{bat,O\&M}$	battery operation and maintenance net present cost, ($/h)
NPC_{fc}	FC reposition net present cost, ($)
$NPC_{fc,O\&M}$	FC operation and maintenance net present cost, ($/h)
NPC_{lz}	electrolyzer reposition net present cost, ($)
$NPC_{lz,O\&M}$	electrolyzer operation and maintenance net present cost, ($/h)
P_{rnw}	sum of the power generated by the renewable sources, (W)
P_{bat}	battery current power, (W)
$P_{bat,chg}$	negative portion of the battery current power, (W)
$P_{bat,dch}$	positive portion of the battery current power, (W)
${P_{bat}}^{max}$	maximum battery power, (W)
PEM	polymer Electrolyte Membrane
P_{fc}	FC current power, (W)
${P_{fc}}^{nom}$	nominal FC power, (W)
P_{lim1}, P_{lim2}, P_{lim3}, P_{lim4}	power limitations for the optimization problem, (W)
P_{load}	power demanded by the load, (W)
P_{lz}	electrolyzer current power, (W)
P_{net}	net power, (W)
P_{rnw}	power generated by the renewable energy sources, (W)
PSO	particle swarm optimization
PV	photovoltaic
Q_{bat}	battery capacity, (Ah)
${q_{H2}}^{in}$	inlet hydrogen flow to the tank, (kg/s)
${q_{H2}}^{out}$	outlet hydrogen flow from the tank, (kg/s)
R_{fc}	FC degradation rate, (−)
R_{lz}	electrolyzer degradation rate, (−)
${R_{lz}}^{\eta}$	ratio between the maximum electrolyzer efficiency without degradation and the minimum efficiency, (−)
SDO	simulink design optimization
SOC	state of charge
SOC_{min}	battery minimum SOC, (%)
$SPWF$	series present worth factor, (−)
T	one sample time (equivalent to one hour)