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Impact of factors influencing the performance of hybrid energy system

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Abstract

Objective of this study is to analyse the impact of main factors, viz., load being supplied, wind speed, global irradiance, ambient temperature and battery bank capacity (BBC), on the performance of Hybrid Energy System (HES). Levelised Cost of Energy (LCE) and Loss of Power Supply Probability (LPSP) have been considered as performance indicators. Energy balance approach is used for calculating BBC and corresponding LCE at desired LPSP for the selected system configuration and inputs.

It is concluded that for a given load, with increase in BBC, the LCE increases linearly, whereas LPSP decreases exponentially. With increasing load, the BBC required for supplying power at a given LPSP, and corresponding LCE initially increase gradually and then sharply and linearly. With increase in wind speed, BBC and corresponding LCE initially decrease sharply and then gradually; this variation is more prominent for higher loads. The BBC and corresponding LCE decrease with increase in global irradiance, the decrease is gradual for low loads; whereas, for large loads the decrease is initially sharp and then gradual. The BBC required for supplying power to a given load at a given LPSP, and corresponding LCE, increase almost linearly with increase in annual average of hourly ambient temperature.

Keywords: Hybrid Energy System (HES); Loss of Power Supply Probability (LPSP); Levelised Cost of Energy (LCE); Wind Turbine Generator (WTG); Photovoltaic (PV)

1. Introduction

The need for generation of electricity through renewable energy sources is growing rapidly due to their well perceived advantages. Of these sources wind and solar have received plenty of attention in recent years due to their direct availability globally and numerous other advantages. In general, the variations of solar and wind energy do not match with the time distribution of demand. Therefore, independent use of these resources requires a large battery backup and results in considerable over-sizing for system reliability, which in turn makes the design costly. Fortunately, these problems can be partially overcome by integrating the two resources in a proper combination along with a storage facility to form a Hybrid Energy System (HES), using the strengths of one source to overcome the weaknesses of the other (Bayod-Rújula et al., 2013; Belmili et al., 2014; Chen, 2013; Papaefthymiou and Papathanassiou, 2014; Torreglosa et al., 2015).

The HES may or may not be grid connected. The isolated HESs are being extensively used in feeding loads like, a remotely located single family, a military post, a microwave station, a telecommunication tower, a village community or a small industry. These also find applications in rural electrification and for supplying electricity to far-flung areas having difficult access due to geographical restrictions such as islands, tourist spots.

Optimum sizing of components of HES is required for its techno-economic feasibility. A large number of research

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Nomenclature

AM air mass
BBC battery bank capacity (Wh)
CRF capital recovery factor
$C_{bat}(t)$ battery bank capacity at hour t (Wh)
$C_{bat}(t-1)$ battery bank capacity at hour $t-1$ (Wh)
C_{bat} nominal capacity of the battery bank (Wh)
$C_{bat\,max}$ maximum capacity of the battery bank (Wh)
$C_{bat\,min}$ minimum allowable capacity of the battery bank (Wh)
d discount rate (%)
DOD_{max} maximum depth of discharge of the battery
$\frac{dI_{sc}}{dT_c}$ current temperature coefficient of solar cell ((A/A)/°C)
$\frac{dV_{oc}}{dT_c}$ voltage temperature coefficient of solar cell (V/°C)
$E_g(t)$ net AC energy generated by the system at hour t (Wh)
$E_L(t)$ load demand at hour t (Wh)
$EXCE$(t) excess or wasted energy (Wh)
FF fill factor of PV cell
FF_0 fill factor of an ideal PV cell
G^* global irradiance under STC (1000 W/m^2)
G_e effective global irradiance (W/m^2)
HES Hybrid Energy System
i inflation rate
IC_k initial investment cost of the k^{th} component of HES ($)
I_{sc} short circuit current of the PV cell (A)
k_B Boltzman's constant (1.38e−23 J/K)
LCC life cycle cost ($)
LCE Levelised Cost of Energy ($/kWh)
$LPSP$ Loss of Power Supply Probability
LPS Loss of Power Supply
m ideality factor (varies between 1 and 2)
n life span of the system (years)
n_r life span of the component requiring replacement (years)
N_{cs} number of solar cells connected in series in each PV module
N_{cp} number of solar cells connected in parallel in each PV module
N_{ms} number of PV modules connected in series
N_{mp} number of PV modules connected in parallel
OM_{pk} present worth of operation and maintenance cost of k^{th} component ($)
OM_{0k} maintenance cost in the first year of k^{th} component ($)
P_e electrical power produced by the WTG at any specific speed v (W)
$P_L(t)$ electrical load on the system at hour t (W)
P_{mp} maximum output power of PV generator (W)
$P_{pv}(t)$ DC power generated by the PV generator at hour t (W)
$P_w(t)$ AC power generated by the wind turbine at hour t (W)
q magnitude of charge on an electron (1.69e−19 C)
RC_{pk} present worth of replacement cost of k^{th} component ($)
R_s series resistance of the solar cell (Ω)
r is the number of replacements required by the k^{th} component
r_s normalised value of cell resistance
S_{0k} salvage value of k^{th} component ($)
S_{pk} present worth of salvage value of k^{th} component ($)
STC Standard Test Conditions
T total operation time (h)
T_a ambient/air temperature (°C)
T_c operating cell temperature (°C)
v wind speed at any instant (m/s)
v_c cut-in speed of the wind turbine (m/s)
v_f furling (or cut-out) speed of the wind turbine (m/s)
V_{oc} open circuit voltage of the PV cell (V)
v_{oc} normalised value of open circuit voltage of the PV cell
V_t thermal voltage (V)
$W–PV–B$ Wind–PV–Battery
Δt time interval used for computations (h)
η_{batch} battery charging efficiency
η_{batdch} battery discharging efficiency
η_{inv} efficiency of inverter or dual inverter
η_{oth} efficiency of other control and converter circuits of the PV generator
η_{rec} efficiency of rectifier/dual inverter
σ_B daily discharging rate of the battery bank (% per day)

papers have been published dealing with the design and sizing of HES. Borowy and Salameh (1994) demonstrated a methodology for calculating the optimum size of the PV array for a Wind/PV hybrid system for a specific wind turbine operating at a given load. It has been concluded that optimal mix of wind and photovoltaic generators depends on the particular site and load profile. Kellog et al. (1998) have developed a simple numerical algorithm for finding the optimum component sizes for the HES, to supply a known load pattern at a given site, taking into account economic factors. Yang et al. (2007) have developed the Hybrid Solar-Wind System Optimization Sizing model to optimise the capacity sizes of different components of HES, and have carried out optimisation studies for a telecommunication relay station at a remote island in Guangdong province, China.