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Review

Performance evaluation of a stand-alone solar dish Stirling system for power generation suitable for off-grid rural electrification

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ABSTRACT

The development of green power generation such as solar systems that have become a great interest for several countries especially for Tunisia as it presents a significant solar potential. For this purpose, this research has investigated the feasibility and the performance of standalone solar dish/Stirling micro generation plant for rural electrification. The considered hybrid system includes solar dish/Stirling engine, permanent magnet synchronous generator and a storage battery. To start with, thermal modeling and simulation have been carried out using Matlab® for the solar-driven Stirling heat engine system composed of an Alpha Stirling engine, a solar collector and a receiver, in which the radiation, convection, conduction and radiation heat loss have been taken into consideration for the selected design. For numerical validation of the receiver's thermal model, simulation results were compared with experimental measurements reported for the EURODISH system with a reasonable degree of agreement. Second, the generated torque driving the generator has been estimated by the Adiabatic model of URIELI based on the classical fourth-order Runge-Kutta. In order for an autonomous control, the dish generator is connected to the load via power electronic converters where the bidirectional power flow is possible by the use of two voltage source converters in a back-to-back configuration. They are referred to as Stirling/generator side converter and load side inverter, both are oriented control by space vector pulse width modulation. In this context, the Stirling side converter is used to adjust the synchronous generator while the inverter controls the power flow between the direct current bus and the alternative side. Detailed tests of the proposed hybrid configuration was implemented in Matlab/Simulink software, by taking as a case study a measured load profile for a rural house and solar radiation data at the target area. The analysis of simulation results has shown that solar dish Stirling/synchronous generator system achieves the objectives of system autonomy and power supply stability. The effectiveness of the management strategy was also proved. It has been obtained that the variable speed Stirling/generator system is capable to feed an uncontrollable load under variations of climatic conditions during hot, moderate and cold seasons, in remote areas in Tunisia.

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Nomenclature

Variables

A	area (m^2)
T	temperature (K)
V	volume (m^3)
L	inductance (H)
P	pressure (bar)
W	work (J)
V_s	stator voltage (V)
Is	stator current (A)
V^d, V^q	*d,q* components voltage (V)
M	fluid mass (kg)
Q	heat power (W)
I_{DN}	direct normal irradiation (W/m^2)
J	inertia
f	friction coefficient
p	pair of pole
P_a	active power (W)
Q_r	reactive power (VA)
m_c	thermal capacity
D	diameter (m)
Uglob	losses coefficient ($W\,m^{-2}\,K^{-1}$)
C_g	geometric concentration
m	mass (kg)
C_{em}	electromagnetic torque
U_{DC}	DC bus voltage (V)

Greek symbols

ϕ_m	permanent magnetic rotor flux (Wb)
η_{opt}	optical efficiency
Ω	rotational speed (rad/s)
τ	mechanical torque (Nm)

subscripts

c	compression
e	expansion
k	cooler
h	heater
r	regenerator
ck	interface between compression space and cooler
he	interface between heater and expansion space
kr	interface between cooler space and regenerator
rh	interface between regenerator and heater
s	stator
cond	conduction
conv	convection
rad	radiation
a	absorbed
u	useful
loss	losses
rec	receiver
con	concentrator
ref	reference
inv	inverter
amb	ambiant
load	load

1. Introduction

Faced with the progressive exhaustion of fossil energy reserves and their harmful impact on the environment, the interest towards sustainable and renewable energy is in continuous growth thanks to its friendliness and their efficiency.

Considering 60% of the transmitted sunlight through the atmosphere, it is surprising that the total sun's energy reaching the earth is $1.05{\cdot}10^5$ TW [1]. If this energy on only 1% of the terrestrial surface could be converted into heat and electricity with an efficiency of 10% it would provide about 105TW. That is a great resource base comparing with the total global needed energy for 2050, which is estimated to be about 25–30 TW [2].

In the field of solar power supply systems, there are different technologies such as solar cell with an efficiency of 20%, photovoltaic concentrators (PVs) at about 40% and solar thermal systems ensuring efficiencies of 40–60% [1]. Currently, solar dish Stirling power generators (SDSPG) are classified as the most efficient models by exceeding the efficacy of any other solar conversion technology [3]. They have become of a great interest to countries where solar potential is available with huge amounts such as Tunisia [4]. Several researches for small Scale (SS) SDSPG (<1 MW) have been taken in place that focus on the design and control of standalone power generation systems [5]. Each parabolic dish/Stirling system is an autonomous power generator. This special design of this technology allows its deployment individually for off-grid applications and their installation on slopes surfaces. The modularity of these systems allows their assembly to form collectors fields ranging in size from a few kilowatts to tens of megawatts [6]. For this reason, this technology seems to be the most promising to be applied in remote areas with limited or difficult access to electrical grid [7,8].

The main issues being treated by system developers are reliability, system performance, and cost. Therefore, most of researches have focused on modeling and optimization of solar dish Stirling engines (SDS) [9,10], optimization of the high temperature heat receiver for the best optical system configuration [11], optical performance of a solar dish was also treated by Gang et al. [12], Safa et al. [13], design optimization by Ferreira [14]. Other researches have put emphasis on the influence of geometrical properties of