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Performative analysis of an eccentric solar–wind combined system for steady power yield

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ABSTRACT

The solar and wind power generation is stochastic in nature. Consequently, it is difficult to obtain steady power output from these renewable sources. Storage element (mainly battery) used in typical solar/wind hybrid system has also its inherent shortcomings. However, power generation from renewable energy sources like solar and wind is having paramount significance in the context of impending fossil fuel shortage, environmental degradation, remote electricity supply, etc. Hence, an alternate mechanism for hybridization of solar and wind resources to obtain a steady power output could undoubtedly be a great accomplishment in prevailing energy scenario across the world. The present paper analyses the performance of such an eccentric solar–wind hybridized model with spring storage system which is capable of delivering steady power yield despite intermittency of the sources. The likely annual performance of this unusual solar–wind hybridized model is evaluated under a sub-tropical climatic condition in north-east India in terms of various characteristics and effective performance indicators such as energy generation characteristics, effect of storage capacity, efficiency of the generating system, capacity factor of the plant, energy to load ratio, normalized power yield, and plant utilization factor. The considered system in the paper has been designed and simulated in LabVIEW graphical programming environment. It has been found for the given climatic condition that maximum wind energy and solar energy fraction of the plant reaches up to 84% and 16% respectively with annual average efficiency of 24.21% for wind turbine unit and 65.52% for solar thermal unit. To make evident the success of the system, a performative comparison has been drawn with obtained results in the proposed scheme and the testified results in existent solar–wind renewable energy system. The analysis in the study substantiates that performance of the proposed hybridized model is considerably superior to that of conventional and established solar–wind based hybrid technologies.

1. Introduction

The global warming, air pollution and rapid depletion of conventional fuel resources are matters of concern triggered by continuous burning of fossil fuels to generate power on a worldwide basis [1]. Emission of carbon dioxide (CO_2) due to combustion of fossil fuel contributed to 78% of total emission increase of greenhouse gas (GHG) from 1970 to 2010 [2]. Global emission in 2035 will double itself from the value of 1990 [3]. Emission of GHG is contributing in global warming. Continuation of emission will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. This affect can be reduced by limiting the emission of GHG [2]. The situation has necessitated for obligatory utilization of clean renewable energy sources [4] such as solar, wind, hydro, biomass, and geothermal to cater for future energy demand [5]. Solar and wind energy, which are clean, inexhaustible and environment-friendly, are considered excellent power generation sources. However, the difficulties that inhibit wind and solar energy been extensively used are their unpredictable nature and reliance on weather and climatic changes. For domestic applications, the variation of wind and solar energy may not match with the time distribution of the household electrical load. These problems can be somewhat overcome by integrating the two sources in a proper combination to form a hybrid system, using one source's strength to overcome the weakness of the other. The utilization of both wind and solar energy allows an improvement in the reliability of the energy supply and the economic viability by circumventing design over-sizing [4]. However, as naturally renewable sources are not constant so virtually all renewable energy based hybrid systems are linked with conventional ones in order to provide continuous power

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Nomenclature

a	Stirling engine constant
b	Stirling engine constant
b_s	width of the spring
c	Stirling engine constant
d	day of the year
n	engine speed
r_n	natural radius of the spring spool
r_o	outer radius of the spring spool
s	Stirling engine constant
t	ratio of compression temperature and expansion temperature of fluid
t_s	thickness of the spring
v	ratio of swept volume of compression and expansion
x	crank angle
z	time in second
AM	air mass
B	variable
C_{pd}	coefficient of power for H-blade
C_{ps}	coefficient of power for S-blade
D_a	angular deflection of spring
E	Young's modulus
EoT	equation of time
H_d	height of H-blade
H_s	height of S-blade
HRA	hour angle
I_s	solar irradiance
L_a	area of Fresnel lens
L_t	active length of spring
LT	local time
LST	local solar time
LSTM	local standard time meridian
M_g	mass of working gas
P_e	engine pressure
P_m	mean engine pressure
P_o	output power of engine
P_{ss}	spring power
P_t	turbine power
P_w	wind power in the swept area of the blades
R	gas constant
R_d	radius of H-blade
R_s	radius of S-blade
T	spring torque
T_c	compression temperature
T_e	expansion temperature
TC	time correction
V	wind speed
V_{dc}	dead volume of compression
V_{de}	dead volume of expansion
V_r	regenerator volume
V_{sc}	swept volume of compression
V_{se}	swept volume of expansion
W_c	rejected heat from the engine to environment
W_e	expansion energy i.e. input thermal energy from the sun to the engine
W_i	indicated energy
X_{dc}	ratio of dead volume of compression and swept volume of expansion
X_{de}	ratio of dead volume of expansion and swept volume of expansion
X_r	ratio of regenerator volume and swept volume of expansion
α	elevation of sun
δ	declination angle
φ	latitude
θ	zenith angle
λ	tip speed ratio
ω_s	angular velocity of S-blade
ω_d	angular velocity of H-blade
ρ	air density
₹	rupees (Indian currency)
$	US dollar

generation [6]. Thus, typical hybrid energy systems combine two or more complementary renewable sources like solar and wind and one or more conventional sources like diesel generator [7].

Owing to the merits of solar–wind hybrid technology, several works on characterization, design, modeling, and analysis of solar–wind hybrid system have been performed in foregoing studies. Also, most of the hybrid technologies incorporate energy storage systems like electrochemical, inertial and hydrogen [7]. Battery – the most preferred storage device, is sensitivity to the environment, has large charge to discharge time ratio, also, its life span is dependent on operating temperature [8]. Hill et al. [9] have reported that springs made up of carbon nano tube (CNT) have higher lifespan and can store significant amount of energy (comparable to lithium ion batteries) due to their high modulus of elasticity and strong network of carbon–carbon bond. Acharya and Bhattacharjee [10] have described a method of solar–thermal (Stirling engine based) uninterrupted power generating system with thermo-chemical storage. Ma et al. have considered both battery storage [11] and pumped hydro storage [5] to support stand-alone microgrid hybrid PV–wind system. Bhattacharjee and Acharya [12] have carried out a techno-economic feasibility analysis of PV–wind–battery hybrid power system along with practical experience with an existent set up. Possibilities of supplying electricity in remote areas from PV–wind–diesel–battery hybrid power system have been investigated for various countries. Rohani and Nour have designed a hybrid renewable energy system for the remote area of Abu Dhabi [1]. Hassiba et al. have explored the PV–wind–diesel–battery hybrid options for Algeria [13]. Islam et al. have investigated optimal configuration of such hybrid system for an island in Bangladesh [14]. Bekele and Palm have examined the viability of supplying electricity from this kind of solar–wind hybrid system for remote part of Ethiopia [15]. Rehman et al. [16] have explored the possibility of PV–wind–diesel hybrid system without battery backup to meet the energy requirement of a rural area. Ngan and Tan [17] have shown that PV–wind–diesel–battery hybrid configuration has great potential to replace the stand-alone diesel system. Ekren and Ekren [18] have presented simulated annealing approach for optimizing size of a PV–wind hybrid energy conversion system with battery storage.

But, it is noticed that common PV–wind hybrid energy system suffers from capacity shortage and unable to always deliver steady output in varied climatic conditions. Taking into account the difficulties, it is justifiable to consider a different approach for hybridization of solar and wind resources for power generation. In view of these, the authors have proposed an eccentric wind–solar thermal hybridized model with spring storage system which is expected to perform an effectual role in combating the downsides related to renewable power generation. The preset paper gives a comprehensible description of the system and attempts to investigate the likely annual performance of this unusual solar–wind hybrid model in terms of various performance param-