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A systematic approach of bottom-up assessment methodology for an optimal design of hybrid solar/wind energy resources – Case study at middle east region

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ABSTRACT

In the current study, an algorithm-based data processing, sizing, optimization, sensitivity analysis and clustering approach (DaSOSaCa) is proposed as an efficient simultaneous solar/wind assessment methodology. Accordingly, data processing is performed to obtain reliable high quality meteorological data among various datasets, which are used for hybrid photovoltaic/wind turbine/storage/converter system optimal design for consequent sites in a large region. The optimal hybrid systems are consequently simulated to meet hourly power demand in various sites. The solar/wind fraction and net present cost of the systems are then used as the technical and economic clustering variables, respectively. The clustering results are finally used as input to obtain novel hybrid solar/wind GIS maps. Iran is selected as the case study to validate the proposed methodology and detail its applicability. Ten minute annual global horizontal radiation, wind speed, and temperature data are analyzed, and the optimal, robust hybrid systems are simulated for various sites in order to classify the country. The generated GIS maps show that Iran can be efficiently clustered into four technical and five economic clusters under optimal conditions. The clustering results prove that Iran is mainly a solar country with approximately 74% solar power fraction under optimum conditions. A macroeconomic evaluation using DaSOSaCa also reveals that the nominal discount rate is recommended to be greater than 20% considering the current economic situation for the renewable energy sector in Iran. An environmental analysis results show that an average 106.68 tonCO_2-eq/year is produced for such hybrid systems application in Iran during a cradle to grave life cycle. Thus, Iran energy sector can be eminently promoted to an environmentally efficient stage with regard to the proposed classification plan and economic considerations.

1. Introduction

An increase in energy demand, the depletion of conventional fossil fuel resources, and the deterioration of environmental conditions have seriously called into question traditional global energy trends. Therefore, many developing and developed countries have concluded that elaborate investment in renewable energies is a promising approach to reach sustainable growth, so that approximately 18% of the total global energy demand is currently being met by green energies [1].

Following the global trend, the European Union, the wealthiest economic body in the world, has committed to producing 27% of its electricity using renewable energy sources by the year 2030 in order to reduce its fast growing energy imports [2]. The United States aims to increase the renewable share of its energy sector from the current 9% to 12% of total domestic consumption by 2020 [3]. Bringing CO_2 emissions under control has motivated developing countries to invest in alternative energies. China, which is the fastest developing country, set a goal of having an approximately 20% share of non-fossil fuels by 2030 [4]. It is also anticipated that Middle Eastern countries, the heart of the world's fossil fuel reserves, will increase renewable sources utilization by 16% until 2035 [5]. Iran, as an instance, has planned to meet 2 GW of its energy-intense market requirements using renewable energies [6].

The above-mentioned long-term ambitious energy goals will be achieved if and only if accurate plans are set. As a first step, the

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Nomenclature

i	time interval
j	scenario indicator
K_T	clearness index
$T_{\min}$	minimum temperature
T_{acc}	acceptable temperature
$T_{\max}$	maximum temperature
$WS_{\min}$	minimum wind speed
WS_{acc}	acceptable wind speed
$WS_{\max}$	maximum wind speed
c_k	cluster centroid
n_k	number of data points
$x_i^{(k)}$	ith data point in the cluster k
$E(C)$	sum of Euclidean norms
x_i	available data
d_j	difference between a pair of data
s_d	data standard deviation
s_d^2	data variance
P_{load}	design population demand load
P_{peak}	population peak demand load
N_B	battery bank size
N_C	converter size
N_{PV}	photovoltaic bank size
N_{WT}	wind turbine size
f_{PV}	PV derating factor
$G_{T,STC}$	solar radiation incident in standard test conditions
G_T	total solar radiation
$T_{C,STC}$	PV cell temperature under standard test conditions
T_C	PV cell temperature
T_a	ambient temperature
$T_{C,NOCT}$	nominal operating cell temperature
$G_{T,NOCT}$	solar radiation of *NOCT*
G_B	direct solar beam
G_D	diffuse irradiance
G_R	grand reflected irradiance
G_g	global radiation on a horizontal surface
G_d	diffuse radiation on a horizontal surface
R_b	average beam ratio
G_o	extraterrestrial daily radiation
n	day of a year given for each month
P_{theory}	theoretical wind power
C_P	maximum theoretical efficiency
$F_{downtime}$	downtime loss factor
F_{icing}	icing/soiling loss factor
$P_{WT,gauge}$	gauge wind turbines practical power
Q	total capacity of the battery bank
c	battery capacity ratio
Δt	time step length
V_{nom}	nominal voltage
$P_{load}(i)$	demand load at a time interval i
f	inflation rate
$P_{PV,module}$	total PV module power
U_i	wind speed at time interval i
k	Weibull shape factor
c	Weibull scale factor
$\overline{U}$	average wind speed
V_{hub}	wind speed at a turbine hub height
V_{anem}	wind speed at anemometer height
Z_{hub}	wind turbine hub height
$\overline{GHR}$	mean global horizontal radiation
Q_1	available energy in the battery
$Q_{\max}$	total capacity of the battery bank
k	rate constant
$I_{\max}$	battery's maximum charge current
$P_{B,charge,\min}$	the minimum battery charge limit
i_{nom}	nominal discount rate
lc	project lifetime
d	distance between a pair of items
N_Z	number of items in cluster Z
$P_{WT,farm}$	total wind power
F_{total}	total loss factor
F_{array}	array loss factor
F_{other}	wind turbine contingency losses
R_d	global gas constant
P_{hub}	wind power density
A	swept area by the turbine rotor

Abbreviations

RE	renewable energy
PV	photovoltaic
WT	wind turbine
KNN	*K* nearest neighborhood
LPSP	loss of power supply probability
kbm	kinetic battery model
mcc	maximum charge current
NPC	net present cost
TAC	total annual cost
ir	interest rate
ACC	annualized capital cost
WF	wind fraction
GIS	geographic information systems
mcr	maximum charge rate
ACF	one hour autocorrelation factor
SF	solar fraction
CRF	capital recovery factor
AOC	annualized operating cost
IDW	inverse distance weight
LF	load factor
DPS	diurnal pattern strength
HPWS	hour of peak wind speed
GWP	global warming potential
GHG	greenhouse gas

Greek letters

α	type I error probability
mu_{sat}	satellite-based data mean
μ_{site}	ground-based data mean
α_P	temperature coefficient of power
$\eta_{mp,STC}$	maximum power point efficiency under standard test conditions
τ	solar transmittance
ν	PV array solar absorptance
φ	latitude
δ	solar declination
ωss	hour angle
ρ	ground albedo
β	tilt angle
Γ	gamma function
ρ_{hub}	air density at hub height
$\eta_{B,rt}$	battery round trip efficiency
$\eta_{B,charge}$	battery charge efficiency
η_C	converter efficiency