Energy xxx (2014) 1–7

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Fuzzy logic based modeling and estimation of global solar energy using meteorological parameters

M. Rizwan [a,*], Majid Jamil [b], Sheeraz Kirmani [b], D.P. Kothari [c]

[a] Department of Electrical Engineering, Delhi Technological University, Bawana Road, Delhi 110042, India
[b] Department of Electrical Engineering, Jamia Millia Islamia, Delhi 110025, India
[c] J B Group of Institutions, Hyderabad 500075, India

ARTICLE INFO

Article history:
Received 19 November 2013
Received in revised form
3 March 2014
Accepted 19 April 2014
Available online xxx

Keywords:
Fuzzy logic
Meteorological parameter
Smart grid
Solar energy estimation

ABSTRACT

Global solar energy data is considered as the most important parameter in smart grid applications, particularly for sizing the photovoltaic system and demand driven supply. However the data of global solar energy is rarely available on hourly basis, even for those stations where measurement has already been done. Due to lack of such measured data, the estimation of global solar energy at the earth's surface is an important study in the present scenario to meet the energy requirement from green energy sources.

This paper is based on fuzzy logic approach for modeling and estimating the global solar energy using mean duration sunshine per hour, temperature, latitude, longitude, altitude and months of the year as input parameters. Fortunately, these important for accurate parameters estimation of solar energy are commonly available. Results obtained from fuzzy logic approach are used for the prediction of SPV system output for smart grid application.

1. Introduction

The rapid depletion of fossil fuel reserves and large greenhouse emissions are becoming the major challenge for the today's power sector. Due to increasing population and urbanization, the demand of electricity is increasing exponentially. Under such circumstances it is highly desirable to adopt the environment friendly energy sources for power generation. In order to achieve the target, renewable energy sources particularly solar and wind sources can play the important role. In addition, solar energy is one of the most promising and more predictable than other renewable energy sources. Therefore, high penetration of solar technologies into electric power system can meet the desired goals. It is well known fact that, India is located on the equatorial sun belt of the earth has great potential of solar energy with an average of about 300 solar days per year. Further, the government is also providing the incentives and other benefits for installing the power plants based on solar energy. Hence, to exploit the environment friendly source of energy, analysis and estimation of solar energy at different stations of the country is utmost important [1–3]. Keeping in view of the aforesaid, a thorough literature review is carried out and it is found that number of mathematical models for the estimation of global solar energy under cloudless skies is available in the literature [4–5]. Regression models and stochastic models for estimating the solar energy are also presented by researchers [6–11]. The results obtained using these models were satisfactory, but applicable only for clear sky weather condition. In India around 300 days in a year are clear sky and remaining days are cloudy, so it is very difficult to estimate the accurately using mathematical/regression/stochastic models. Therefore, due to uncertainty in weather conditions, fuzzy logic based models are proposed by researchers to estimate the solar energy at a given location using different meteorological parameters [12–18]. The uncertainty in atmosphere may occur due to the existence of the following: dust, moisture, aerosols, clouds, or temperature differences in the lower atmosphere. Among these factors, clouds can cause the maximum losses in the extraterrestrial solar energy reaching at earth's surface. The atmosphere causes a reduction of the extraterrestrial solar input by about 30% on a very clear day to nearly 100% on a very cloudy day [13]. Further, the use of solar energy estimation in smart grid application is rarely available in the literature. Keeping in view of aforesaid fuzzy logic based model for the estimation of global solar energy has been developed considering latitude, longitude, altitude of the location, months of the year, mean duration sunshine per hour (it is the ratio

* Corresponding author. Tel.: +91 9891558821 (mobile).
E-mail addresses: rizwaniit@yahoo.co.in, rizwaniitd@gmail.com (M. Rizwan).

http://dx.doi.org/10.1016/j.energy.2014.04.057
0360-5442/

Nomenclature

D	day of the year
H	monthly mean daily irradiance on horizontal surface
H_0	mean clear sky daily irradiance
H/H_o	clearness index
$H_{measured}$	measured value of monthly mean daily irradiance on horizontal surface
$H_{estimated}$	predicted value of monthly mean daily irradiance on horizontal surface
I_s	short circuit current of PV module at STC (A)
I_{sc}	solar constant = 1367 W/m^2
P_{max}	maximum power of module at MPP
S	monthly mean daily hours of bright sunshine
S_o	monthly mean of maximum possible daily hours of bright sunshine
S/S_o	mean fraction possible sunshine hours
T	monthly mean hourly temperature (°C)
T_o	monthly mean hourly maximum possible temperature (°C)
T/T_o	ratio of monthly mean hourly temperature to monthly mean hourly maximum possible temperature
T_a	ambient temperature (°C)
T_{cell}	cell temperature (°C)
T_{stc}	temperature of PV module at STC
V_{oc}	open circuit voltage of PV module at STC

Greek symbols

ω	hour angle
ω_s	hour angle at sunset
ϕ	latitude of the location
δ	declination angle
η_c	efficiency of the PV module

of average daily actual sunshine duration at the location to the theoretical sunshine duration), and temperature as input parameters. Obtained results are further simulated for smart grid applications using fuzzy logic approach/toolbox.

This paper is organized as follows: Section 2 presents the basics of smart grid operation. Section 3 describes the fuzzy logic based model for solar energy estimation. Fuzzy model for the prediction of SPV system output for smart grid application is presented in Section 4. Results and discussions are presented in Section 5. A Conclusion followed by the references is discussed in Section 6.

2. Smart grid

The global electricity sector and its customers are faced with a number of challenges that are unparalleled since the advent of widespread electrification. Challenges including climate change, escalating energy prices, energy security and energy efficiency are converging to drive fundamental change in the way of energy produced, delivered and utilized. Keeping in view of aforesaid the future electricity system must produce and distribute electricity which should be reliable, affordable and clean. To achieve the same, both the electricity grid and the existing regulatory system must be smarter. Hence there arises a need of grid that should be smart i.e. smart grid. Further, world is venturing into renewable energy resources like wind and solar. With such unpredictable energy sources, feeding the grid must be highly adaptive in terms of supply and demand. A good electric supply is one of the key infrastructure requirements to support overall development, hence the opportunities for building smart grid is immense [3,19–20].

Smart grid is used to predict and intelligently respond to the behavior and actions of all users connected to it. Further, it is used to efficiently deliver the reliable, economic, and sustainable electricity services to consumers. In addition, smart grid technologies are advanced electrical networks that support new generation interactive energy and communication services for the final customer. The main advantage of smart grid implementation in terms of utility benefits include reduced perturbations and outages; minimal power losses and blackout prospects; lower maintenance and operational cost; lower greenhouse gas emissions; increased energy efficiency; increased large scale renewable energy and distributed generation integration; enabled micro-grid applications and energy management systems environmental benefits and economic growth through clean power markets [19].

In the present grid system generation is following the load, but in the smart grid system the load will follow the generation. For such a system, where load follows the generation the solar energy estimation at the site is the driving contributor to the power output calculations for these systems. If a system is able to predict solar energy with a good accuracy at a particular location then load scheduling, economic load dispatch, battery sizing, time of use and pricing can be done intelligently and optimally including the supply of critical loads for those times when the sufficient amount of power is available. In addition to this when the power available from the solar energy based system is less then only critical loads can be supplied. With the correct data, solar collectors are fairly easy components to size, install, and begin generating power.

3. Fuzzy logic approach for global solar energy estimation

In the global solar energy estimation, geographical features like latitude, longitude, altitude and meteorological parameters like mean duration sunshine per hour and temperature play an

Table 1
Geographical features of Indian stations considered.

Station	Latitude (°N)	Longitude (°E)	Height above the mean sea level (m)	Climate zone
New Delhi	28.58	77.20	216	Composite
Jodhpur	26.30	73.02	224	Hot & dry
Kolkata	22.65	88.45	6	Warm & humid
Shillong	25.57	91.88	1600	Cold & cloudy

Table 2
Monthly average data of H/H_0, S/S_0 and T/T_0.

Month	New Delhi			Jodhpur		
	H/H_0	S/S_0	T/T_0	H/H_0	S/S_0	T/T_0
January	0.189	0.836	0.334	0.180	0.890	0.554
February	0.387	0.857	0.509	0.386	0.890	0.612
March	0.657	0.857	0.639	0.675	0.800	0.734
April	0.877	0.868	0.809	0.807	0.890	0.858
May	0.900	0.879	0.896	0.900	0.890	0.900
June	0.779	0.847	0.900	0.822	0.830	0.883
July	0.557	0.697	0.841	0.492	0.720	0.805
August	0.475	0.697	0.813	0.370	0.726	0.778
September	0.546	0.847	0.673	0.551	0.810	0.802
October	0.412	0.900	0.727	0.505	0.870	0.781
November	0.241	0.857	0.596	0.254	0.900	0.709
December	0.100	0.804	0.464	0.100	0.900	0.632

Please cite this article in press as: Rizwan M, et al., Fuzzy logic based modeling and estimation of global solar energy using meteorological parameters, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.04.057