MODELLING AND FORECASTING OF PHOTOVOLTAIC POWER OUTPUT BASED ON MACHINE LEARNING TECHNIQUE

By

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January 2014

Chairman : Associate Professor Hashim Hizam, PhD

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The sun is one of the primary sources of energy for most of the processes on the earth. It is the energy source for heat, wind, and rain. Currently, human kind is using fossil fuels as its primary energy source, but the fossil fuels are non-renewable and they contribute to also air pollution, environmental hazards and etc . This leads to the usage of sunlight as a renewable source of energy to produce electricity, called solar energy. Moreover, solar energy is green energy and it is environmentally friendly. Despite the advantages of solar energy, the generated power in photovoltaic panels depends directly on solar radiation, temperature, humidity, and other factors. These parameters are not constant during the day and therefore the amount of power generated, is typically unknown. Therefore, efficient power planning is impossible unless power generation can be predicted. In this regard, this research aims to propose a method for photovoltaic generated power forecasting. This method consists of neural network and PSO, which finds the optimum structure based on the defined cost function to maintain both accuracy and complexity of the network. It has to be noted that the data which are used in this thesis are collected from KLIA Sepang meteorological data and therefore it does not contain any power values. Therefore, two neural network structures, namely General Regression Neural Network and Feedforward Back Propagation, have been used to model a photovoltaic panel and approximate the generated power. As the results show, the prediction of power using FFBP was more accurate comparing with GRNN. The results then can be used for forecasting part. Such networks are selected due to their popularity, effectiveness, and high level of accuracy. These systems are then validated by the meteorological data of KLIA Sepang at latitude 02°44'N, a longitude of 101°42'E to evaluate their performances. For the modelling part, the five years of data are divided into two parts. From 2006 until 2009 the data used for training and the whole year of 2010 used for testing. However, due to the discontinuity and inconsistency of data because of fault or maintenance in the system, only 814 data have been selected for the forecasting part in which half of data are used for training and the rest for testing. The cost function includes a parameter k which maintains the complexity versus accuracy. In this regard, the increment of k and selection of a value near 1 for this parameter causes the network to become more accurate while the evolved structure will be more complex.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMODELAN DAN PERAMALAN OUTPUT KUASA FOTOVOLTA BERDASARKAN TEKNIK MESIN PEMBELAJARAN

Oleh

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Matahari adalah salah satu sumber utama tenaga untuk kebanyakan proses di bumi. Ia adalah sumber tenaga untuk haba, angin, dan hujan. Pada masa ini, manusia menggunakan bahan api fosil sebagai sumber tenaga utama, tetapi bahan api fosil adalah tenaga yang tidak boleh diperbaharui dan ia memben kesan seperti pencemaran udara, bahaya alam sekitar dan lain-lain. Ini membawa kepada penggunaan cahaya matahari sebagai sumber tenaga yang boleh diperbaharui untuk mengeluarkan tenaga elektrik, yang dipanggil tenaga solar. Selain itu, tenaga solar adalah tenaga hijau dan ia adalah mesra alam. Sungguhpun terdapat kelebihan tenaga solar, kuasa yang dihasilkan dalam panel fotovolta bergantung secara langsung ke pada radiasi solar, suhu, kelembapan, dan faktor-faktor lain. Parameter ini tidak tetap pada siang hari dan oleh itu jumlah kuasa yang dihasilkan, biasanya tidak diketahui. Oleh itu, perancangan kuasa yang cekap adalah mustahil melainkan penjanaan kuasa boleh diramalkan. Dalam hal ini, kajian mencadangkan satu kaedah untukkuasa ramalan terjana fotovolta. Kaedah ini terdiri daripada rangkaian saraf dan PSO yang mendapati struktur yang optimum berdasarkan fungsi kos ditakrifkan untuk mengekalkan ketepatan dan kerumitan kedua-dua rangkaian. Perlu diambil perhatian bahawa data yang digunakan dalam tesis ini ialah data meteorologi diambil dari KLIA Sepang dan oleh itu ia tidak mengandungi sebarang nilai-nilai kuasa. Oleh itu, dua struktur rangkaian saraf, iaitu rangkaian saraf dan Suap Depan Rambatan Balik, telah digunakan untuk model panel fotovolta dan kurang bersamaan dengan tenaga. keputusan menunjukkan, ramalan kuasa menggunakan FFBP lebih tepat berbanding dengan GRNN. Keputusan kemudiannya boleh digunakan untuk bahagian ramalan. Rangkaian tersebut dipilih kerana popularity mereka, keberkesanan dan ketinggian tahap ketepatan. Ini kemudiannya disahkan oleh data meteorologi KLIA Sepang pada latitud 02°44'N, longitud 101°42'E untuk menilai persembahan mereka. Untuk sebahagian model, data ini dibahagikan kepada dua. Dari tahun 2006 sehingga tahun 2009 data yang digunakan untuk latihan dan seluruh tahun 2010 digunakan untuk ujian . Walau bagaimanapun, disebabkan oleh ketakselanjaran dan data tidak konsisten kerana kesalahan atau penyelenggaraan didalam sistem itu, hanya 814 data telah dipiliah untuk ramalan, di mana separuh daripada data yang digunakan untuk latihan dan selebihnya untuk ujian. Fungsi kos yang mengandungi parameter k mengekalkan kerumitan berbanding ketepatan. Dalam hal ini, kenaikan k dan pemilihan parameter bemilai berhampiran 1 menyebabkan rangkaian ini menjadi lebih tepat manakala struktur yang dibebaskan akan menjadi lebih kompleks.

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I certify that a Thesis Examination Committee has met on 28 January 2014 to conduct the final examination of Aminmohammad Saberian on his thesis entitled "Modelling and Forecasting of Photovoltaic Power Output Based on Machine Learning Technique" in accordance with the Universities and University Colleges Act, 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

C_1	Acceleration coefficient
C_2	Acceleration coefficient
P_i	Best location
ɣ	Complexity of network
k	Cost constant
δ	Declination angle
P_g	Global optimum point
w	Inertia weight
L	Latitude
y_{max}	Maximum for normalization
MJ/m^2	Megajoules per meter square
y_{min}	Minimum for normalization
b	Non-normalized one
N_T	Normal thermal coefficient
a	Normalized value
N	Number of days
P	Power
x	Raw data
x_{max}	Raw data with the maximum
x_{min}	Raw data with the minimum
$\dot{Z}$	Vector of N prediction
Z	Vector of real values
V_i	Velocity of the particle for distance
V_{mpp}	Voltage at maximum power point
Wh/m^2	Waat hour per meter square
φ	Weight for each particle

CHAPTER 1

INTRODUCTION

1.1 Background

Electricity consumption is one of the main factors in the quality of human life because electrical energy is needed for basic human activities. Therefore, the optimization of energy consumption on the one hand and the development of energy sources on the other hand will become more important. Energy has a significant place in national and international strategies and major policy in various fields. In fact, energy has changed to become a strategic factor in the survival of nations.

Without doubt, the close relationship between energy and industrial development and the cost of energy in recent years, and the role of energy in all economic sectors, has created the need for research into energy consumption and the price of energy. Therefore, there is a special importance in the case of energy efficiency consumption for governments, politicians, and managers of economic businesses.

Photovoltaic panel and solar thermal are the main sources for electricity generation from solar energy. Furthermore, the prediction of power generation from solar energy is gaining considerable attention due to the increment of power generation from solar energy [1]. Numerical models have been developed to forecast weather and solar power; however, they require a powerful computing system [2, 3].Artificial neural network, on the other hand, assimilate human brain learning system and its able to find input-output relationship for linear and nonlinear systems with less computational effort. This leads to the wide usage of artificial neural networks to forecast various criteria's such as irradiance, temperature and so on [4, 5].Nevertheless, forecasting of generated power from solar energy is still an ongoing research and this thesis concentrates on this issue.

1.2 Problem Statement

Although there have been researches into the prediction of some parameters in a photovoltaic panel such as temperature and solar radiation, in recent years there has not been comprehensive research into power prediction. In this regard, a forecasting method for temperature is developed in [6]. Also, solar radiation forecasting methods are presented in[4, 7] and a method for solar power forecasting is discussed in[8]. Moreover, a forecasting method using Artificial Neural Network has been proposed for solar radiation in [9]. This show not been emphasizing on solar power forecasting. On the other hand, power planning is necessary for cost efficiency of power generation in which power forecasting is an essential part [10, 11]. Therefore, this thesis aims to focus on power forecasting for the operation of a PV system.

The power generation of photovoltaic panels depends on solar radiation, temperature, humidity, cloud cover [12-16]. These parameters are naturally variable and non-schedulable, thus the amount of generated power is generally unknown. This characteristic of photovoltaic panels requires an accurate forecasting for power generation of photovoltaic panel in order to ensure the efficiency of power planning and operation of the system.

Feedforward Back Propagation (FFBP) and the General Regression Neural Network (GRNN) have been affirmed as two effective methods in modelling and prediction by previous researchers [11]. These two models are employed for the prediction of solar power in this research since the authors have shown their effectiveness comparing with statistical and auto-regression approaches. Naini et al [17] discussed about the application of three different neural networks structures such as radial basis function network, FFBP and GRNN for prediction of the characteristics of the scour hole geometry. Vigneswaran et al [18] applied five accurate neural network models including FFBP and GRNN and concluded that GRNN has better results. The work discussed in [19]considered wind speed forecasting by using FFBP. In another work [20], the authors used FFBP to predict the velocity of crude oil. In [21]the authors applied FFBP for temperature forecasting and concluded that this model had the proper potential for complex modelling of the relation between various factors. The authors in [22] mentioned that FFBP is the best model of neural network for real-time forecasting due to least training time and fast response. In [23]the authors stated that FFBP is one of the most popular configurations of an ANN. The authors in [11]undertook load forecasting using FFBP. Shuangyi et al. [24] employed GRNN as one of the models employed to forecast wind power density. One of the major advantages of a GRNN is defined as the effective relation of the model and the input [25].

However, a few evolutionary algorithms such as particle swarm optimization (PSO) have been presented for forecasting in recent research work. PSO is also considered as an appropriate technique for solving engineering problems [26]. Chang et al [26] performed research for wind power forecasting by using PSO. The study undertaken in [27] applied PSO for load forecasting.

Thus, feedforward neural network is chosen for modeling the photovoltaic panel power output while PSO is employed for forecasting the system's output.

1.3 Aims and Objectives

This research aims to develop a model of a power output photovoltaic panel and predict its generated power also to forecast power generation of a photovoltaic. Thus, the objectives of this research are to achieve the aforementioned goal as follows:

i. To model a photovoltaic panel output power based on Feedforward Back Propagation (FFBP) and General Regression Neural Network (GRNN).

ii. To develop a machine learning algorithm in order to forecast power generation of a photovoltaic panel using Particle Swarm Optimization (PSO)

iii. To evaluate the performance of the proposed modelling and forecasting techniques using the KLIA Sepang meteorological data

iv. To design the monitoring system for a photovoltaic panel in order to collect the data and forecast generated power in offline mode.

1.4 Research Scope

i. The preliminary data used in this research were collected from the meteorological data of KLIA Sepang to evaluate the proposed methods.

ii. The Origin software was used to fit the curve plot of the solar panel datasheet to find the relation between the open circuit voltage of photovoltaic panel and irradiation which is essential to calculate the generated power.

iii. The photovoltaic panel has been modeled using feedforward back propagation and general regression neural network and their performances have been evaluated.

iv. Monitoring has been done using the National Instrument Labview © while modelling and forecasting parts have been done in MathWorks Matlab© environment.

1.5 Thesis Contributions

The contribution of this thesis lies in modelling and forecasting of generated power from photovoltaic panel. In this regard, two different models have been developed for solar panel generated power modelling based on two structures of neural network namely as GRNN and FFBP. Moreover, a novel method based on neural network and PSO has been proposed to forecast the generated power of photovoltaic panel. This method uses the data from previous days to forecast one day ahead generated power. Nevertheless, a monitoring system has been implemented in Labview where the power can be forecasted. This system has potential to be installed for UPM solar site for online monitoring.

1.6 Thesis Organization

This thesis consists of five chapters namely introduction, literature review, methodology, results and discussion, and conclusion. The first chapter presents a brief background on the solar power forecasting and its necessity. It then follows by problem statement of this thesis and the aim and objectives. Finally, the research scope of this thesis is presented. The second chapter reviews various techniques for modelling and forecasting of generated power for photovoltaic panel. It also presents a summary of previous Labview implementations for monitoring. Chapter three presents the methodologies which are employed in this thesis. This methodology consists of photovoltaic power modelling, power forecasting method, and Labview implementation of photovoltaic monitoring. In the Results and Discussions Chapter, the modelling methods and forecasting have been evaluated and their results are depicted. In addition, the Labview software for monitoring is purposed also shown in this chapter. Chapters five concludes the materials of this thesis and present a brief summary and future works.

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