PREDICTION OF GLOBAL SOLAR RADIATION USING MISO ARX MODEL

ABDULRAHMAN ABDULLAH MOHAMMED ALASHMOORI

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
Universiti Tun Hussein Onn Malaysia

FEBRUARY 2022

To my beloved parents, thank you.

ACKNOWLEDGEMENT

Foremost, I would like to acknowledge the Almighty God for His benevolence and for granting me wisdom and perseverance not only in the time of research and writing of this thesis, but indeed, throughout my life.

I express, with heartfelt appreciation, my gratitude to my supervisor, Pn. Rohaiza binti Hamdan for her sincere and invaluable intellectual guidance extended to me throughout the years of my postgraduate studies. I would like to thank Malaysia the country that embraced me during my master trip. Moreover, I would like to exploit the opportunity to thank all the lecturers and staff in University Tun Hussein Onn Malaysia who have had taught me and provided me extensive personal and professional guidance. Moreover, I am very thankful to all of those whom I have had the pleasure to obtain any information or experience with them during my study period. I extend my appreciation to all my friends for their unwavering support and who have stood by me through so many tough times.

Last but not least, special thanks to my beloved parents and fiancée for their blessings and unflinching insistence, who have always encouraged me to never stop achieving my goals in life.

ABSTRACT

The need for renewable energy sources is growing day by day because of the severe energy crisis in the world today. Renewable energy sources play a significant role in electricity generation. Several renewable energy sources (like solar, wind, geothermal, and biomass) can be used for generation of electricity and for meeting our daily energy demands. Solar energy is the most viable option for electricity generation because it is available everywhere and is free to utilize. Therefore, integration of solar energy sources has gradually become the main challenge for global energy consumption in recent decades. As a result, while predicting solar system outputs, it is essential to predict global solar radiation in a precise and efficient way. Inaccurate forecasting results in either load overestimation which leads in increased costs or failure to gather adequate supplies. However, accurate solar radiation forecasting is a challenging task because solar resources are intermittent and uncontrolled. To tackle this difficulty, several methods have been developed. This project use the system identification ARX model to predict the global solar radiation. ARX model stands for autoregressive with exogenous variables where the exogenous variables are the input terms. The project starts by collecting the meteorological data (air temperature, maximum temperature, minimum temperature, wind speed, relative humidity, solar radiation) using RETScreen software the data have been collected for a period of four years starting from 2016 to 2019 the data is then divided into two groups even and odd. The model tested for two different sets 60% of data for estimating and 40% for testing and 70% of data for estimating and 30% for testing. The project has two different ARX techniques SISO and MISO each technique has three different model with different inputs. SISO ARX model highest best fit was 72.34% when the minimum temperature set as an input. MISO ARX model shows a best fit of 89.58% when all data set as an inputs. Both SISO and MISO models gives high results when using the odd data compared to the even data.

ABSTRAK

Keperluan untuk sumber tenaga boleh diperbaharui semakin meningkat dari hari ke hari kerana krisis tenaga yang teruk di dunia hari ini. Sumber tenaga boleh diperbaharui memainkan peranan penting dalam penjanaan elektrik. Beberapa sumber tenaga boleh diperbaharui (seperti suria, angin, geoterma dan biojisim) boleh digunakan untuk penjanaan elektrik dan untuk memenuhi keperluan tenaga harian kita. Tenaga suria adalah pilihan yang paling berdaya maju untuk penjanaan elektrik kerana ia boleh didapati di mana-mana dan bebas untuk digunakan. Oleh itu, penyepaduan sumber tenaga suria secara beransur-ansur menjadi cabaran utama untuk penggunaan tenaga global dalam beberapa dekad kebelakangan ini. Akibatnya, dalam meramalkan output sistem suria, adalah penting untuk meramalkan sinaran suria global dengan cara yang tepat dan cekap. Ramalan yang tidak tepat mengakibatkan sama ada anggaran terlebih beban yang membawa kepada peningkatan kos atau kegagalan untuk mengumpul bekalan yang mencukupi. Walau bagaimanapun, ramalan sinaran suria yang tepat adalah tugas yang mencabar kerana sumber suria adalah terputus-putus dan tidak terkawal. Untuk menangani kesukaran ini, beberapa kaedah telah dibangunkan. Projek ini menggunakan model pengenalan sistem ARX untuk meramalkan sinaran suria global. Model ARX bermaksud autoregresif dengan pembolehubah eksogen di mana pembolehubah eksogen ialah istilah input. Projek dimulakan dengan mengumpul data meteorologi (suhu udara, suhu maksimum, suhu minimum, kelajuan angin, kelembapan relatif, sinaran suria) menggunakan perisian RETScreen data telah dikumpul untuk tempoh empat tahun bermula dari 2016 hingga 2019 data kemudiannya dibahagikan kepada dua kumpulan genap dan ganjil. Model diuji untuk dua set berbeza 60% data untuk anggaran dan 40% untuk ujian dan 70% data untuk anggaran dan 30% untuk ujian. Projek ini mempunyai dua teknik ARX berbeza SISO dan MISO setiap teknik mempunyai tiga model berbeza dengan input berbeza. Kesesuaian terbaik tertinggi model SISO ARX ialah 72.34% apabila suhu minimum ditetapkan sebagai input. Model MISO ARX menunjukkan kesesuaian terbaik sebanyak 89.58% apabila semua data ditetapkan sebagai input. Kedua-dua model SISO dan MISO memberikan hasil yang tinggi apabila menggunakan data ganjil berbanding dengan data genap.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

PV	–	Photovoltaic
ARX	–	Autoregressive with exogenous input
ANN	–	Artificial neural networks
SVM	–	Support vector machines
ARMA	–	Autoregressive moving averages
PB	–	Physically based
EIV	–	Error in variables
NWP	–	Numerical weather prediction
SI	–	Sky imagery
NAR	–	Nonlinear autoregressive
NARX	–	Nonlinear autoregressive with exogenous input
MA	–	Moving average
MISO	–	Multiple input single output
FPE	–	Final prediction error
MSE	–	Mean square error
SD	–	Standard deviation
SISO	–	Single input single output
MSE	–	Mean square error
Ws	–	Wind speed
Tmin	–	Minimum temperature
Tmax	–	Maximum temperature
Ta	–	Air temperature
Rh	–	Relative humidity
G		Solar radiation

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Nowadays renewable energy has become a technology and an increasingly viable alternative to the classical non-renewable sources of energy. As a result of the constant threat of climate change, the mankind must seek out new and more effective way to produce electricity. Especially when all basic needs are based on this kind of energy.

Any solar project's success depends on the availability of reasonably reliable global solar radiation data. However, due to the high cost of measuring equipment and a lack of technological capability in calibrating it, only a few meteorological stations around the world capture these data. Engineers and researchers have come up with a number of different ways to generate data in order to solve this problem

Data on solar radiation is a critical input for solar energy applications. For the design optimization and performance assessment of solar technologies for any given location the data should be reliable and readily accessible. Unfortunately, solar radiation measurements are difficult to come by in many developing countries. As a result, methods for estimating solar radiation based on more readily available meteorological data must be developed.

The growing number of solar system installations around the world indicates that a precise evaluation of solar resources is needed to make solar electric grid design easier. Therefore, solar irradiance quantification studies are critical for the optimal operation and power prediction of grid connected photovoltaic (PV) plants.

Four categories can be used to classify the different prediction techniques: the statistical approaches, the regression techniques, the satellite imagery techniques, and the artificial intelligence method. Because of their simplicity regression techniques are commonly used to predict global solar radiation. However, the completeness of the meteorological data used to forecast global solar radiation is critical to their accuracy. The statistical methods depend on the assumption that data has an internal linear structure that can be defined and used to make predictions. Satellite imagery is desirable if surface data for location does not exist. In general, using surface measurements in conjunction with a cloud index based on satellite imagery is recommended to improve prediction accuracy. The ability of artificial intelligence approaches to manage complex relationships between global solar radiation and other meteorological data has been widely praised, and as well provide better accuracy and efficiency.

1.2 Problem statement

Solar-based power generation, particularly photovoltaics (PV) has grown in popularity in recent years due to a variety of factors including concerns about greenhouse gas emissions, government legislation, and lower equipment costs. The reliable and effective integration of solar energy faces a variety of problems. The development of new tools and strategies to control the variability and uncertainty of solar electricity will be one of the most critical. Many options including increased demand side engagement, greater cooperation between balancing areas, as well as the deployment of flexible but often costly resources like energy storage can be used to manage short-term uncertainty (up to a week ahead). However, one of the most effective and least cost ways to integrate solar particularly at penetration levels currently experienced is to estimate predicted power output and use that information to operate the system more reliably and effectively.

Thus, in order to take care of this issue this research is made to predict the solar radiation using system identification method.

1.3 Aim and Objectives

Forecasting power production from photovoltaic (PV) plants requires accurate irradiance forecasts. To effectively balance electricity demand and the variable and weather-dependent supply forecasting is needed. There are several methods to forecast solar radiation this thesis is using ARX model in order to get better and accurate results of solar radiation forecasting.

This research work embarks on the following objectives:

a) To use the system identification toolbox to predict the global solar radiation using ARX with different model and polynomial order.

b) To validate and analyze each of the global solar radiation models using best fit.

c) To compare the accuracy of the developed global solar radiation models.

1.4 Scopes of study

The scopes of the research are:

a) Collect the needed meteorological data for four years starting from January 2016 until September 2019 at Saudi Arabia-Jeddah-Al Baghdadia Al Gharbia, for the project.

b) Develop the model with multiple input ((air temperature (Ta), minimum temperature (Tmin), maximum temperature (Tmax), relative humidity (Rh), and wind speed (Ws)) .

c) Simulate the developed model using MATLAB software.

1.5 Outline of the report

In this thesis, chapter 1 provide the overall introduction on the project's global solar radiation prediction. Then it comes into the problem statement followed by information about the project's purpose in objectives and project scope.

Chapter 2 is the literature review that explains the methods of prediction and the parameters that affect the prediction of solar radiation of past research journals and report documents as the references for this project will be reviewed.

Chapter 3 involves the project's methodology to explain all the techniques needed to finish the project. Each step will be discussed in detail and clarified. It involves the flow chart, processes for reaching the objectives and every process that will be outlined in detail in the project.

Chapter 4 discusses the results and the software simulation project that will be provided with the analysis from graph and tables. The values of the parameters have been highlighted for the tabulation information. The data gathered was summarized and it will conclude a conclusion.

Chapter 5, the explanation refers to the project's conclusion. The general achievements of the project depended on the presented objectives. It summarizes the report as a whole and will also show recommendations for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Solar radiation prediction has long been a major concern in the renewable energy sector. Prediction aids in the preparation and maintenance of photovoltaic systems as well as providing many economic benefits to electric utilities. Artificial neural networks (ANN), support vector machines (SVM), and autoregressive moving averages (ARMA) can all be used to predict solar radiation.

The method of solar-forecasting is strongly depend on the involved timescales which can range from a few seconds or minutes ahead (intra-hour), a few hours ahead (intraday), or a few days ahead (intraweek). Depending on the forecast application different time horizons are important.

2.2 Factors Affecting Solar Radiation

Our planet's ultimate source of energy is solar energy. It is the foundation of all other sources of energy. Organic and inorganic photovoltaic cells have recently gained more market traction than ever before. Initiatives such as International Solar Alliance have given a boost to solar energy harnessing. As a result, several attempts have been made to improve the efficiency of photovoltaic devices. However, harnessing solar energy is largely depends on the quality and quantity of insolation or solar radiation obtained by a given area on the ground. Several factors such as altitude, terrain, air quality, cloud cover, and vegetation of the region affect the solar radiation received by PV panels at any area.

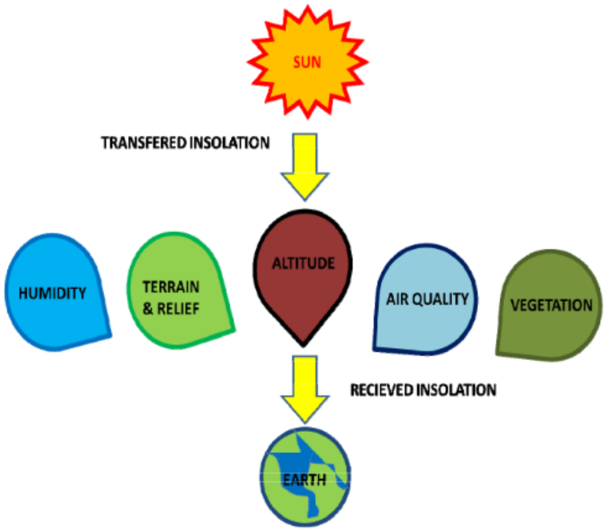

Figure 2. 1: Several factors affect the solar radiation received on earth.

Figure 2.1 shows that the solar radiation is affected by several factors such as altitude, terrain, air quality, cloud cover, and vegetation of the region before received it by PV panels at any area. Those factors are discussed in the following subtopics.

2.2.1 Effect of Altitude and Relief

The general weather of a region which includes rainfall, cloud cover, temperature, and other factors affects the intensity of solar radiation at that location. A primary feature of solar radiation is that it is not uniform and physical factors such as altitude, relief and slope have a major impact on the accessibility of solar energy in mountainous areas and thus require careful consideration. The terms 'relief' and 'altitude' are not synonymous. Altitude is an absolute term defined with respect to sea level. The kinetic energy of the mountain surface is determined by relief in a physical sense while the properties of the air mass surrounding the mountain are determined by altitude. A primary factor in determining differences between mountains is the altitudinal interval occupied by the local relief of a given mountain as shown in Figure 2.2. As a result, there are major variations in meteorological parameters in the mountains [1].

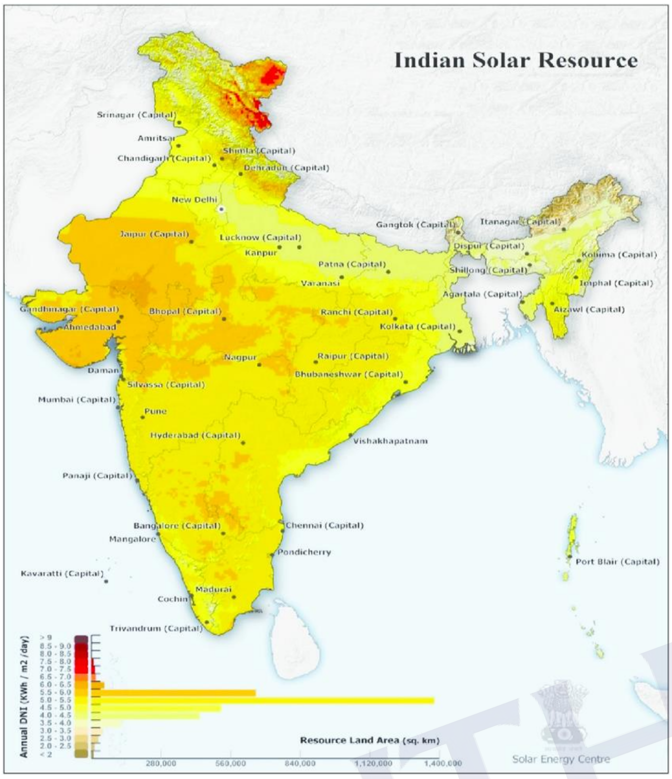

Figure 2. 2: Amount of solar radiation received by India annually.

In this region, both altitude and relief are at a maximum for the earth as a whole maximizing the effects of both altitude and relief [2]. The local relief is determined by the slope. In addition to many nearby snow peaks that act as major reflectors greatly improve the job done by large changes in height against comparatively small flat distances. As a result, the albedo factor rises as does the amount of solar radiation available at a given spot aspect which is the compass direction faced by a slope plays a crucial role in modifying the pattern of precipitation and the availability of solar insolation. For instance, 'windward' and 'leeward' slopes will be wetter and drier than regional average values respectively as the air mass rises and falls in its path through the mountains [3].

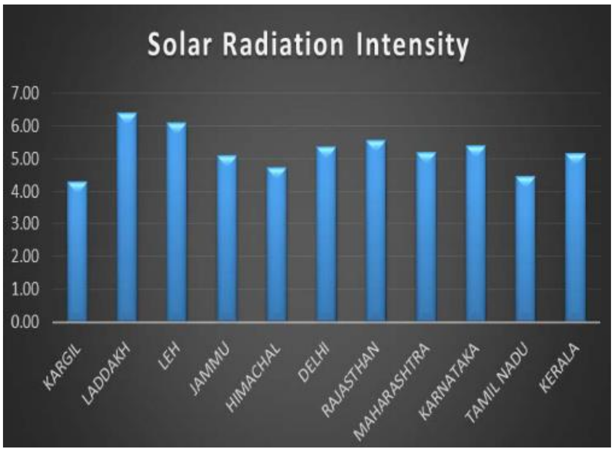

Figure 2. 3: Solar radiation received by various parts of India annually.

The difference in annual insolation obtained by various Indian states is given in Figure 2.3. Here it can be clearly seen that the states with higher altitude less precipitation and less vegetation have an annual insolation that is higher than the greener states. Since Kerala is so close to the equator it receives a high insolation even after having thick vegetation and good precipitation.

2.2.2 Effect of Latitude and Season

The overall amount of sunlight that can be received in a year is the second element correlated with aspect or season for any given latitude. North-facing slopes receive the lowest value while east-and west-facing slopes receive a mid-range value. With rising distance from the equator and altitude in any mountain range the gap between north-facing and south-facing slopes widens as the importance of sunlight increases. At least at lower altitude the windward-leeward relationships will be highest in the eastern part of the area while in the western part of the area orientation in relation to solar angle will be more significant [4].

There are four main seasons in the region's climate: winter (December to February), spring (March to mid-June), summer (mid-June to mid-September), and autumn (mid-September to November) [5]. As shown in Figure 2.4, these seasons depend on the position of earth with respect to sun. The figure shows that due to a 23.5^{o} tilt in the earth's rotational axis one side is closer to the sun and experiences summer while the other experiences winter. The fact that insolation is highest between the tropics and falls above it is also important because sun rays do not fall perpendicularly there but at an angle decreasing the overall insolation obtained in these temperate and polar regions. Furthermore, due to the folding of plains in the Indian context the Himalayas rise abruptly in sequence creating various complications in the local climatic situation in the area. As a result, vivid changes in altitude, orientation, size, slopes of mountains, plateaus, and valleys create many subdivisions and sub-climates [6].

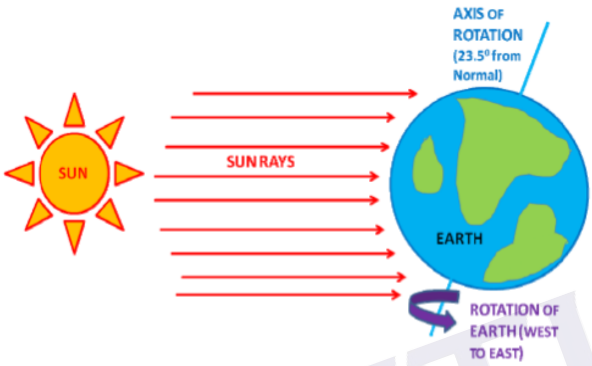

Figure 2. 4: Effect of latitude and seasons on solar radiation reception.

2.2.3 Effect of Cloud Cover, Air Quality, Humidity, and Vegetation

After cloud cover and air pollution influence solar radiation by scattering and absorbing it limiting the total amount of insolation obtained in a particular area as shown in Figure 2.5. On a bright cloudless day the earth's surface can receive close to 1000 W/m^2 of radiation. However, as light clouds appear in the atmosphere a portion of the insolation or solar radiation is dispersed and absorbed by the light cloud cover and the insolation obtained on the ground is mostly scattered and not direct. As a result, the amount of insolation obtained by the land is approximately 830 W/m^2. The overall irradiance obtained at ground is reduced to 300 W/m2 as cloud coverage becomes denser and if the clouds are hanging low radiation is limited to 230 W/m^2. Finally, during afternoons when there is a heavy overcast received solar radiation can be as low as 150 W/m^2 [7].

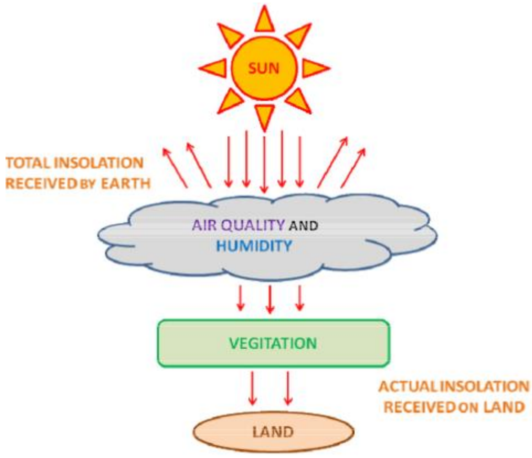

Figure 2. 5: Effect of air quality, humidity, and vegetation on solar radiation.

Air quality has a major impact on a region's ability to receive solar radiation. Smog and brown clouds (local air pollution plumes which are consist of considerable amounts of microscopic particulate suspended matter nitrates and sulfates, fly ash and other different pollutants) impact local insolation by scattering and absorbing sunlight in the same way as lights do [8]. As a result, even though the sky is clear and annual precipitation is low in areas with higher air pollution the insolation obtained by the region can be less due to air quality losses [9].

Finally, a region's insolation is influenced by the vegetation in that area. Solar radiation is restricted by forest cover in areas where vegetation is too dense or consists of tall trees such as rain forest regions and mountainous forests in the Himalayan foothills. People living in such areas are unable to rely on solar energy because the shade created by vegetation prevents large amounts of solar radiation from reaching the land. The sunlight are more diffused and dispersed rather than being focused. Arid and semi-arid regions of Indian states Gujarat and Rajasthan on the other side are among the world's top solar energy producers since vegetation cover is almost non-existent. Since the trees are scattered and short the region's insolation achieves its maximum value. The lack of pollution and low precipitation contribute to the region's high solar energy harvesting potential.

REFERENCES

[1] C. D. A. Porteous, "Profiting From Sunshine: Passive Solar Building in the Mountains," *Mt. Res. Dev.*, vol. 21, no. 1, pp. 96–97, 2001, doi: 10.1659/0276-4741(2001)021[0096:pfspsb]2.0.co;2.

[2] T. Forsyth, "Science, myth and knowledge: Testing Himalayan environmental degradation in Thailand," *Geoforum*, vol. 27, no. 3, pp. 375–392, 1996, doi: 10.1016/S0016-7185(96)00020-6.

[3] R. G. Barry, *Mountain weather and climate, Third edition*, vol. 9780521862, no. Cambridge University Press, USA. 2008.

[4] P. D. R. GEIGER, "THE CLIMATE NEAR THE GROUND," vol. 87, no. 7, p. 287, 1950.

[5] WILLIAM JAMES HOPE RAMSAY, "EROSION IN TH E MIDDL E HIMALAYA , NEPA L WITH A CASE STUDY O F TH E PHEW A VALLE Y," no. UNIVERSITY O F BRITISH COLUMBIA, p. 104, 1985.

[6] M. Carver, "Diagnosis of headwater sediment dynamics in Nepal's middle mountains: implications for land management," *Interdiscip. Stud.*, vol. PhD, p. 374, 1997.

[7] A. Cede, M. Blumthaler, E. Luccini, R. D. Piacentini, and L. Nuñez, "Effects of clouds on erythemal and total irradiance as derived from data of the Argentine Network," *Geophys. Res. Lett.*, vol. 29, no. 24, pp. 1–4, 2002, doi: 10.1029/2002GL015708.

[8] V. Ramanathan *et al.*, "Atmospheric Brown Clouds: Regional ssessment report with focus on Asia," *United Nations*, 2008.

[9] R. B. Gammon, J. R. Hurting, M. S. Reid, and J. H. Smith, "Urban air pollution and solar energy," *Int. J. Ambient Energy*, vol. 2, no. 4, pp. 183–195, 1981, doi: 10.1080/01430750.1981.9675776.

[10] G. Wu, Y. Liu, and T. Wang, "Methods and strategy for modeling daily global solar radiation with measured meteorological data - A case study in Nanchang station, China," *Energy Convers. Manag.*, vol. 48, no. 9, pp. 2447–2452, 2007, doi: 10.1016/j.enconman.2007.04.011.

[11] Z. Şen, "Simple nonlinear solar irradiation estimation model," *Renew. Energy*,

vol. 32, no. 2, pp. 342–350, 2007, doi: 10.1016/j.renene.2006.02.015.

[12] H. Bulut and O. Büyükalaca, "Simple model for the generation of daily global solar-radiation data in Turkey," *Appl. Energy*, vol. 84, no. 5, pp. 477–491, 2007, doi: 10.1016/j.apenergy.2006.10.003.

[13] S. Janjai, P. Pankaew, and J. Laksanaboonsong, "A model for calculating hourly global solar radiation from satellite data in the tropics," *Appl. Energy*, vol. 86, no. 9, pp. 1450–1457, 2009, doi: 10.1016/j.apenergy.2009.02.005.

[14] S. Rachad, H. Fouraiji, and B. Bensassi, "Identification approach for a production system using ARX model," *Proc. 2nd IEEE Int. Conf. Logist. Oper. Manag. GOL 2014*, no. June, pp. 93–97, 2014.

[15] C. F. M. Coimbra, J. Kleissl, and R. Marquez, *Overview of Solar-Forecasting Methods and a Metric for Accuracy Evaluation*. Elsevier, 2013.

[16] S. D. Miller, A. K. Heidinger, and M. Sengupta, *Physically Based Satellite Methods*. Elsevier, 2013.

[17] M. Diagne, M. David, P. Lauret, J. Boland, and N. Schmutz, "Review of solar irradiance forecasting methods and a proposition for small-scale insular grids," *Renew. Sustain. Energy Rev.*, vol. 27, pp. 65–76, 2013.

[18] M. Y. Mikheev, Y. S. Gusynina, and T. A. Shornikova, "Building Neural Network for Pattern Recognition," *Proc. - 2020 Int. Russ. Autom. Conf. RusAutoCon 2020*, pp. 357–361, 2020.

[19] X. Liu and Y. Zhu, "A Method of ARX Model Estimation of Errors-in-Variables Systems," *IFAC-PapersOnLine*, vol. 48, no. 28, pp. 302–306, 2015, doi: 10.1016/j.ifacol.2015.12.143.

[20] S. Rachad, B. Nsiri, and B. Bensassi, "System Identification of Inventory System Using ARX and ARMAX Models," *Int. J. Control Autom.*, vol. 8, no. 12, pp. 283–294, 2015, doi: 10.14257/ijca.2015.8.12.26.

[21] Z. M. Yusoff, M. A. A. Aziz, N. F. Razali, S. A. Nordin, A. F. Z. Abidin, and N. M. Zain, "The study of dynamic response using ARX model in extraction process," *J. Fundam. Appl. Sci.*, vol. 9, no. 4S, p. 145, 2018, doi: 10.4314/jfas.v9i4s.8.