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EEU Lab
Department of Electrical Engineering
Delhi Technological University
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Professional Qualifications

PhD Delhi Technological University, Delhi, India — 2021
Electrical Engineering
Dissertation: "Optimal Design of SPV System and Applications"

MTech Delhi Technological University, Delhi, India — 2015
Electrical Engineering
Specialization: Control and Instrumentation with 8.2 CGPA

BTech Uttar Pradesh Technical University, Uttar Pradesh, India — 2013
Electrical Engineering with 75.56% (1st Division Hons.)

Honors and Awards

Research Excellence Award — 2021
Recipient of commendable research award for excellence in research.

International Travel Grant — 2019
Received for presenting paper in IEEE ISAECT 2019 conference held in Rome, Italy.

DTU Fellowship — 2016-2021
Received for completion of doctoral research.

MHRD PG Fellowship — 2013-2015
Received for pursuing post-graduation study (Master of Technology).

Qualified GATE — 2013
Cleared Graduate Aptitude Test in Engineering (GATE) in Electrical Engineering.

Research Highlights

- Member-**IEEE**
- Member-**IEEE Young Professionals**
- Lifetime Member-**IAENG**
- **Published** research articles in refereed journals and conference proceeding of international repute such as:
  - **IEEE**-CSEE Journal of Power and Energy Systems
  - **IEEE** Access
  - International Journal of Hydrogen Energy (**IJHE**)
  - Arabian Journal of Science and Engineering (**Springer**)
  - Sustainability (**MDPI**)

    - International Journal of Advanced Intelligence Paradigms (**Inderscience**)
    - IEEE Conferences, Springer Lecture Notes, IOP Conference Series (Scopus Indexed)
- **Review Editor** for journals such as: Frontiers in Energy Research
- **Reviewer** for journals such as: IEEE, Springer, Wiley, etc.

RESEARCH EXPERIENCE

Research Associate Oct 2021-Present
Project: Smart Dynamic Energy Management for the Built Environment with Integrated Renewable Energy
Funding Agency: Department of Science and Technology
Science and Engineering Research Board, Government of India

Senior Research Fellow Aug 2018-Sept 2021
Department of Electrical Engineering
Delhi Technological University, Delhi, India

Junior Research Fellow Aug 2016-July 2018
Department of Electrical Engineering
Delhi Technological University, Delhi, India

PROJECTS AND EXPERIENCE

- Experience from 2016-2021(present) at Utilization of Electrical Energy (UEE) Laboratory, Electrical Engineering Department, Delhi Technological University, Delhi, India.
- Installed smart energy metering system for $5kW_p$ grid connected SPV system in UEE Lab, Electrical Engineering Department, Delhi Technological University, Delhi, India.
- Hands on experience of using MECO Solar Analyzer 9018BT for $5kW_p$ SPV system, microgrid systems with energy storage elements.
- Hands on experience of hybrid microgrid system with WT emulator, SPV emulator, fuel cell and utility grid present at UEE Lab, Electrical Engineering Department, Delhi Technological University, Delhi, India.
- Experience of performing load demand analysis and its forecasting for energy management in different applications.
- Performed research on aspects of investment cost and energy auditing for the retail outlet of fuel in Uttar Pradesh, India.
- Proficiency in using computational software(s) such as MATLAB, PVSYST, LABVIEW, HOMER etc.
- Expertise in developing and implementing of artificial intelligent techniques in renewable energy systems.
- Conceptual and modelling knowledge of grid integrated systems with energy storage systems for building energy management systems.
- Currently working on energy management for renewable energy based smart grids.
- Developed solar data measurement device using sensors and PIC microcontrollers.
- Experience in the field of sensor technology and microcontroller coding using MickroC platform

- Assisted post-graduate scholars on developing IoT based control of lighting loads for UEE Lab, DTU.

PUBLICATIONS

Journal Publications

- **A. Kumar**, M. Rizwan and U. Nangia, "*A New Approach to Design and Optimize Sizing of Hybrid Microgrid in Deregulated Electricity Environment*," CSEE Journal of Power and Energy Systems, vol. 8, pp. 1-10, 2020. SCI Indexed, **IF: 3.938**, Publisher: **IEEE.**

  DOI: *https://doi.org/10.17775/CSEEJPES.2020.03200*

- **A. Kumar**, M. Rizwan and U. Nangia, "*A Hybrid Optimization Technique for Proficient Energy Management in Smart Grid Environment*," International Journal of Hydrogen Energy, vol. 47, pp. 5564-5576, 2022. SCI-E Indexed, **IF: 5.816**, Publisher: **Elsevier.**

  DOI: *https://doi.org/10.1016/j.ijhydene.2021.11.188*

- **A. Kumar**, M. Rizwan, U. Nangia and M. Alaraj, "*Grey Wolf Optimizer-Based Array Reconfiguration to Enhance Power Production from Solar Photovoltaic Plants under Different Scenarios*," Sustainability, vol. 13, pp. 13627-13642, 2021. SCI-E Indexed, **IF: 3.251**, Publisher: **MDPI.**

  DOI: *https://doi.org/10.3390/su132413627*

- **A. Kumar**, M. Alaraj, M. Rizwan, and U. Nangia, "*Novel AI Based Energy Management System for Smart Grid with RES Integration,*" IEEE Access, vol. 9, pp. 162530-162542, 2021. SCI Indexed, **IF: 3.367** Publisher: **IEEE.**

  DOI: *https://doi.org/10.1109/ACCESS.2021.3131502*

- **A. Kumar**, M. Alaraj, I. Alsaidan, M. Rizwan and M. Jamil, "*Energy Production Forecasting from Solar Photovoltaic Plants based on Meteorological Parameters for Qassim Region, Saudi Arabia*," IEEE Access, vol. 9, pp. 83241-83251, 2021. SCI Indexed, **IF: 3.367** Publisher: **IEEE.**

  DOI: *https://doi.org/10.1109/ACCESS.2021.3087345*

- **A. Kumar**, M. Rizwan and U. Nangia, "*Development of ANFIS-Based Algorithm for MPPT Controller for Standalone Photovoltaic System*," International Journal of Advanced Intelligence Paradigms, vol. 18, pp. 247-264, 2021. Scopus Indexed, Publisher: **Inderscience**.

  DOI: *https://doi.org/10.1504/IJAIP.2021.112906*

- **A. Kumar**, M. Rizwan and U. Nangia, "*A Hybrid Intelligent Approach for Solar Photovoltaic Power Forecasting: Impact of Aerosol Data*," Arabian Journal for Science and Engineering, vol. 45, pp. 1715-1732, 2020. SCI-E Indexed, **IF: 2.334**, Publisher: **Springer.**

  DOI: *https://doi.org/10.1007/s13369-019-04183-0*

Conference Papers

- **A. Kumar**, M. Bilal, M. Rizwan and U. Nangia, "*Grey Wolf Optimization Inspired Maximum Power Extraction from SPV System for Water Pumping Application,*" IEEE International Conference for Advancement in Technology (ICONAT), Goa, India, 21-22 Jan. 2022.
- M. Bilal, **A. Kumar** and M. Rizwan, "*Coordinated Allocation of Electric Vehicle Charging Stations and Capacitors in Distribution Network*," IEEE International Conference on Electrical Power and Energy Systems (ICEPES), Bhopal, India, 10-11 Dec. 2021.

- D. Karna, A. Vikram, **A. Kumar** and M. Rizwan, "*A Novel Fuzzy based Intelligent Demand Side Management for Automated Load Scheduling*," IEEE International Conference on Green Energy and Applications (ICGEA), Singapore, 7-9 Mar. 2020.
- A. Vikram, D. Karna, **A. Kumar** and M. Rizwan, "*An Analytical Approach of Integrating Automated Load Scheduling to a Smart Energy Meter using Differential Evolution Algorithm*," IOP Conference Series: Materials Science and Engineering (ICIPCE), Berkeley, USA, 27-29 Jun. 2020.
- **A. Kumar**, M. Rizwan and U. Nangia, "*Optimal Sizing of Renewable Energy Resources in a Microgrid for a Distributed Generation System*," IEEE International Symposium on Advanced Electrical and Communication Technologies (ISAECT), Rome, Italy, 27-29 Nov. 2019.
- **A. Kumar**, M. Rizwan and U. Nangia, "*Artificial Neural Network based Model for Short Term Solar Radiation Forecasting considering Aerosol Index*," IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, 22-24 Oct. 2018.
- **A. Kumar**, P. Chaudhary and M. Rizwan, "*Development of Fuzzy Logic based MPPT Controller for PV System at Varying Meteorological parameters*," IEEE India International Conference (INDICON), Delhi, India, 17-20 Dec. 2015.

Book Chapters

- D. Karna, A. Vikram, **A. Kumar** and M. Rizwan, "*Extraction of Maximum Electrical Power from Solar Photovoltaic-Based Grid-Tied System*," Advances in Energy Technology. Lecture Notes in Electrical Engineering, vol. 766, pp. 1-10, 2022.

  DOI: *https://doi.org/10.1007/978-981-16-1476-7_33*

RESEARCH CONTRIBUTIONS

Paper Presentations in International/National Conferences

- IEEE International Conference for Advancement in Technology (ICONAT), Goa, India, 2022.
- 2nd IEEE International Symposium on Advanced Electrical and Communication Technologies (ISAECT), Rome, Italy, 2019.
- 2nd IEEE IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES), Delhi, India, 2018.
- 12th IEEE Annual India Conference (INDICON), Delhi, India, 2015.

Professional Training/Seminars/Short Term Courses/Summer/Winter School

- Online Faculty Development Program on "***Modern Trends in Manufacturing Processes and Control Techniques in Renewable Energy System***" from 16th – 21st Nov, 2021 at National Institute of Technology, Delhi, India.
- AICTE Training and Learning Academy Online Faculty Development Program on "***Artificial Intelligence***" from 14th – 18th Dec, 2020 at ABES Engineering College, UP, India.
- TEQIP-CEP course on "***Agribusiness Planning and Project Appraisal Techniques***" from 2nd – 8th Dec, 2018 at Indian Institute of Technology, Delhi, India.
- TEQIP-CEP course on "***Low-Cost Technology Development for Physical Pest Management***" from 13th – 17th Oct, 2018 at Indian Institute of Technology, Delhi, India.
- Short term training program on "***Electric Transportation***" from 20th – 24th Aug, 2018 at Delhi Technological University, Delhi, India.

- GIAN course on "***Recent trends in Protection of Microgrids with high DER penetration: Issues, Challenges and Mitigation***" from 12th – 16th Feb, 2018 at Delhi Technological University, Delhi, India.
- GIAN Course on "***SMART Power Flow Controller for Smart Grid Applications***" from 18th – 23rd Dec, 2017 at Delhi Technological University, Delhi, India.
- GIAN course on "***Emerging Trends in Advance Control systems in Intelligent Transport System***" from 4th – 8th Dec, 2017 at Delhi Technological University, Delhi, India.
- UGC Sponsored STTP on "***Integrating Renewable Energy Sources into Emerging Electrical Power Systems***" from 8th – 19th, Dec, 2014 at Delhi Technological University, Delhi, India.

SKILLS

- Conceptual knowledge of hybrid energy management system with renewables and EV
- Well versed with metaheuristic optimization techniques
- Good team player for collaborative research
- Capable of producing high quality research articles
- Proficiency in MATLAB-Simulink and R-Studio
- Hands on experience with high quality data recording and measurement instruments

EXTRA-CURRICULAR ACTIVITIES

- **Tutored** and instructed under graduate students for various **courses** in **electrical engineering** (course work and practicals) from 2013-present.
- Worked as **Accommodation Committee Member** for GIAN course on "***Resilient Power Grid Operation Using Synchro Phasor Technology: A Smart Grid Operation Perspective***" from 17th – 21st Dec, 2018 at Delhi Technological University, Delhi, India.
- Worked as **Accommodation Committee Member** for GIAN course on "***Recent trends in Protection of Microgrids with high DER penetration: Issues, Challenges and Mitigation***" from 12th – 16th Feb, 2018 at Delhi Technological University, Delhi, India.
- Worked as **Organizer** in 2nd IEEE ***International Conference on Power Electronics, Intelligent Control and Energy Systems*** (ICPEICES), held at Delhi Technological University, Delhi, India, 2018.
- **Volunteered** in two weeks UGC Sponsored STTP on "***Integrating Renewable Energy Sources into Emerging Electrical Power Systems***" from 8th – 19th, Dec, 2014 at Delhi Technological University, Delhi, India.
- Worked as the ***Technical Co-Head*** of 'GNIX', in academic session 2012-2013 at Greater Noida Institute of Technology, Greater Noida, India.

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A hybrid optimization technique for proficient energy management in smart grid environment

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HIGHLIGHTS

- The article proposes a hybrid MG with renewable energy sources and energy storage systems (battery and fuel cell).
- Develop a novel energy management system using modified grey wolf optimizer (MGWO) with multi objective functions.
- Analyzes the load demand and the cost of electricity from the power grid for effective designing of MG at test locations.
- A significant savings of 30.88% and 49.99% of the rolling cost in comparison with FL and MILP based EMS respectively.

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ABSTRACT

Electrical energy is one of the key components for the development and sustainability of any nation. India is a developing country and blessed with a huge amount of renewable energy resources still there are various remote areas where the grid supply is rarely available. As electrical energy is the basic requirement, therefore it must be taken up on priority to exploit the available renewable energy resources integrated with storage devices like fuel cells and batteries for power generation and help the planners in providing the energy-efficient and alternative solution. This solution will not only meet electricity demand but also helps reduce greenhouse gas emissions as a result the efficient, sustainable and eco-friendly solution can be achieved which would contribute a lot to the smart grid environment. In this paper, a modified grey wolf optimizer approach is utilized to develop a hybrid microgrid based on available renewable energy resources considering modern power grid interactions. The proposed approach would be able to provide a robust and efficient microgrid that utilizes solar photovoltaic technology and wind energy conversion system. This approach integrates renewable resources with the meta-heuristic optimization algorithm for optimal dispatch of energy in grid-connected hybrid microgrid system. The proposed approach is mainly aimed to provide the optimal sizing of renewable energy-based microgrids based on the load profile according to time of use. To validate the proposed approach, a comparative study is also conducted through a case study and shows a significant savings of 30.88% and 49.99% of the rolling cost in comparison with fuzzy logic and mixed integer linear programming-based energy management system respectively.

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A New Approach to Design and Optimize Sizing of Hybrid Microgrids in Deregulated Electricity Environment

Astitva Kumar, Mohammad Rizwan, *Senior Member*, *IEEE*, and Uma Nangia, *Member*, *IEEE*

***Abstract*—The demand for electrical energy in urban and suburban areas is increasing drastically because of various reasons. The electricity bill has increased significantly due to increased comfort levels and uses of modern appliances. Therefore, the demand response along with the power generated from renewable energy resources is playing an important role in reducing electricity bills without compromising any comforts. In this paper, a novel framework is proposed for the selection of renewable energy resources and sizing optimization with reduced costs and increased productivity for the end-users. The simultaneous process of selecting the appropriate renewable energy resources and sizing is covered in three stages: initially, the prediction of power from the renewable energy resources to perform a feasibility analysis is provided. Then, the sizing of the battery energy storage system for a grid integrated system to meet the load profile is performed. Finally, the performance analysis of the proposed microgrid in a deregulated electricity environment is performed. The modeling of the proposed hybrid microgrid considers load flexibility and the stochastic behavior of renewable energy resources. Moreover, the net metering concept (bi-directional energy exchange) is applied. For the developed model, the percentage of annualized return of investment (AROI) is found to be 6.8% with a payback period of 6.67 years.**

***Index Terms*—Hybrid systems, load management, metaheuristic technique, renewable.**

NOMENCLATURE

AROI	Annualized return of investment.
ACI	Annualized cost of investment.
BESS	Battery energy storage system.
BESS_{om}	Operational and maintenance cost for BESS ($/kWh).
BESS_{ii}	Initial investment cost of battery ($/kW).
$C_{\mathrm{p}}(t)$	Cost of purchasing electricity at t ($/kWh).
$C_{\mathrm{s}}(t)$	Cost of selling electricity at t ($/kWh).
DoD	Depth of Discharge of the battery.
$E^{\text{bt}}(t)$	Energy of battery at the beginning of t^{th} hour (kWh).
$E^{\text{bt}}_{\text{tcf}}(t)$	Total capacity fade of battery at the t^{th} hour (kWh).
$G(t)$	Solar irradiance at time t (W/m^2).
Inv_{ii}	Initial investment cost of bidirectional inverters ($/kW).
Inv_{om}	Operation maintenance cost for bidirectional inverters ($/kWh).
L_{cnst}	Constant loads (W).
L_{exl}	External lighting loads (W).
L_{bld}	Building loads (W).
L_{mtr}	Motor loads (W).
LF_{per}	Load Flexibility percentage.
LoB	Life of Battery (years).
N_{pv}	Installed capacity of SPV system.
N_{B}	Installed BESS capacity (kWh).
N_{inv}	Installed capacity of bidirectional inverter (kW).
N_{wt}	Installed capacity of WT system.
$\eta_{\frac{\text{dc}}{\text{ac}}}, \eta_{\frac{\text{ac}}{\text{dc}}}$	Energy conversion efficiency.
$\eta_{\text{C}}(t)$	Charging efficiency of the battery at t.
$\eta_{\text{D}}(t)$	Discharging efficiency of the battery at t.
$P_{\text{pv}}(t)$	SPV Power at time t (kW).
n_{pv}	Efficiency of SPV system **O&M** Operational and Maintenance.
PV_{A}	Total area of SPV system (m^2).
P_{B}	Maximum charge/discharge capacity per hour of the battery (kW).
$P_{\text{wt}}(t)$	Wind Power at hour t (kW).
P_{wtr}	Rated power of WT.
$P^{\text{ac}}_{\text{PG}}(t)$	Purchased grid power for the loads at t (kW).
$P^{\text{dc}}_{\text{PG}}(t)$	Purchased grid power for BESS at t (kW).
$P^{\text{ac}}_{\text{pv}}(t)$	SPV power dispatched to AC side at t (kW).
$P^{\text{dc}}_{\text{pv}}(t)$	SPV power dispatched to BESS at t (kW).
$P^{\text{ac}}_{\text{wt}}(t)$	WT power dispatched to AC side at t (kW).
$P^{\text{dc}}_{\text{wt}}(t)$	WT power dispatched to BESS at t (kW).
$P_{\text{L}}(t)$	Power consumption of the loads at t (kW).
$P_{\text{SG}}(t)$	Power sold to the grid at t (kW).
$P_{\text{D}}(t)$	Battery discharged power at t (kW).
$P_{\text{C}}(t)$	Battery charged power at t (kW).
$\overline{P_{\text{G}}}$	Maximum grid power purchased or sold.
PV_{ii}	Initial investment cost of SPV system ($/kW).
PV_{om}	Operational and maintenance cost for SPV system ($/kWh).
$r_{\text{pso1}}, r_{\text{pso2}}$	Random numbers in PSO.

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RESEARCH ARTICLE - ELECTRICAL ENGINEERING

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A Hybrid Intelligent Approach for Solar Photovoltaic Power Forecasting: Impact of Aerosol Data

Astitva Kumar[1] · M. Rizwan[1] · Uma Nangia[1]

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Abstract
The penetration of solar photovoltaic (PV) power in distributed generating system is increasing rapidly. The increased level of PV penetration causes various issues like grid stability, reliable power generation and power quality; therefore, it becomes utmost important to forecast the PV power using the meteorological parameters. The proposed model is developed on the basis of meteorological data as input parameters, and the impacts of these parameters have been analyzed with respect to forecasted PV power. The main focus of this research is to explore the performance of optimization-based PV power forecasting models with varying aerosol particles and other meteorological parameters. A newly developed intelligent approach based on grey wolf optimization (GWO) using multilayer perceptron (MLP) has been used to forecast the PV power. The performance of the GWO-based MLP model is evaluated on the basis of statistical indicators such as normalized mean bias error (NMBE), normalized mean absolute error (NMAE), normalized root-mean-square error (NRMSE) and training error. The results of the developed model show the values of NMBE, NMAE and NRMSE as 2.267%, 4.681% and 6.67% respectively. To validate the results, a comparison has been made with particle swarm optimization, Levenberg–Marquardt algorithm and adaptive neuro-fuzzy approach. The performance of the model is found better as compared to other intelligent techniques. The obtained results may be used for demand response applications in smart grid environment.

Keywords Grey wolf optimization · Artificial neural network · Solar power forecasting · Solar PV · Distributed power generation

1 Introduction

The demand of electrical energy is increasing drastically because of increasing population, urbanization and increased comfort level. Due to greenhouse gases emission and depleting nature of conventional energy sources, the adoption of renewable energy sources such as solar, wind and biomass has been gaining momentum. Among the renewable energy sources, the adoption of solar photovoltaic is increasing day by day, because of various advantages such as clean, silent, availability and low running cost. However, the rapid development of solar PV system also brings many challenges in operation and control of solar PV-based power systems [1, 2]. Further, the high penetration of solar PV may cause the grid stability and reliability issues in smart grid environment. Therefore, the solar PV power forecasting is one of the key tools for this paradigm and plays a vital role in efficient integration of renewable power generation and reduction in volatility to distributed generation systems. Precise and accurate forecasting of PV power helps massively in planning and scheduling of power demand supply for the consumers as well as various distribution companies (DISCOMs). It further enhances system reliability and power quality issues due to uncertainty in PV power generation.

Further, the forecasting is an important tool for grid operators since they can schedule generation and distribution according to the load profile, and also define generation units to act as operating reserve generators [3, 4]. It is also an essential tool for creating a modern transactive energy framework in a grid-connected microgrid system [5–8]. PV power prediction not only reduces the number of units required in hot standby but also minimizes the operational costs. Therefore, prediction of PV power has become vital and very crucial for grid stability, optimal unit commitment and economical dispatch.

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Novel AI Based Energy Management System for Smart Grid With RES Integration

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[2]Department of Electrical Engineering, College of Engineering, Qassim University, Buraydah, Qassim 52571, Saudi Arabia

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ABSTRACT The different energy assets such as solar panels and batteries help electrical engineers to manage and meet the increasing demand. The amalgamation of renewable energy resources with artificial intelligence is the key focus of providing high energy efficiency with alternative sources. This solution will not only meet electricity demand but also help in reducing greenhouse gas emissions as a result the efficient, sustainable and eco-friendly solution can be achieved which would contribute a lot to the smart grid environment. Here, a modified grey wolf optimizer approach is utilized to develop a novel energy management system for SPV-based microgrid considering modern power grid interactions. The proposed approach aims to provide a proficient microgrid that utilizes solar photovoltaic technology, and energy storage systems using an artificial intelligence algorithm-based microgrid control for optimal dispatch of energy in grid-connected systems. The performance of this novel energy management system is validated under sunny day and cloudy day, to emulate the stochastic nature of solar photovoltaic systems. A comparative study with mixed linear programming is also conducted that indicates towards the savings in 23.34% and 45.55% of the rolling cost for a clear and cloudy day respectively.

INDEX TERMS Smart grid, microgrid, renewable energy resources, optimization technique, artificial intelligence, energy storage system.

I. INTRODUCTION

The generation, transmission, and distribution of electrical energy have entered into technological change and reforms globally. Renewable energy-based technologies particularly solar photovoltaic and wind energy conversion systems are invigorated due to their abundant availability and have the potential to provide an eco-friendly and sustainable solution for future power requirements. To accommodate the fluctuating nature of these resources, the operation of power generating systems should be efficient and responsive, thus the concept of the smart grid is playing a key role in such transitions. However, the major challenge lies in the development of a distributed generating system that can cater to the requirements of remote areas. As per the latest data, about 17% of the world's population does not have the access to electricity [1]. This is an alarming situation for the sustainable growth and development of any nation and a renewable energy-based distributed power generating system would be able to provide an alternative solution for this challenging task. Presently, these areas are catered by diesel-based generating systems which are costly and cause significant pollution in the environment. In such a scenario, a hybrid system consisting of more than one renewable energy resources or the concept of microgrid has a tremendous potential to provide electricity access to the 1.2 billion deserving people, who do not have access to constant electricity.

To meet the overgrowing demands of the rising population and increasing comfort levels, power engineers are exploring the use of renewable energy (RE) resources. In recent years, there has been significant growth in the installed capacity of renewables. RE technology has seen a boom because of the continuous decrease in the price of PV panels, easy availability of solar energy, government subsidies, and innovative models in residential and commercial sectors. The integration of RE with MG offers many benefits, still, the challenge is to maintain a low cost of operation, controlling

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Energy Production Forecasting From Solar Photovoltaic Plants Based on Meteorological Parameters for Qassim Region, Saudi Arabia

MUHANNAD ALARAJ [1], (Member, IEEE), ASTITVA KUMAR [2], IBRAHIM ALSAIDAN [1], (Member, IEEE), MOHAMMAD RIZWAN [1,2], (Senior Member, IEEE), AND MAJID JAMIL [3], (Senior Member, IEEE)

[1]Department of Electrical Engineering, College of Engineering, Qassim University, Buraydah 52571, Saudi Arabia
[2]Department of Electrical Engineering, Delhi Technological University, Delhi 110042, India
[3]Department of Electrical Engineering, Jamia Millia Islamia, Delhi 110025, India

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The authors extend their appreciation to the Deputyship for Research and Innovation, Ministry of Education and, Saudi Arabia for funding this research work through the project number (QU-IF-1-3-3). The authors also thank to the technical support provided by Qassim University.

ABSTRACT Due to the increasing cost of crude oil because of pandemic COVID-19 and global environmental threats, the exploitation of fossil fuels for power generation is discouraged. Further, the demand for electrical power is increasing drastically, and therefore, the exploitation of renewable energy resources, particularly solar photovoltaic-based technology for power generation is invigorated. However, the large-scale penetration of solar photovoltaic is becoming a major challenge in terms of stability, reliability of power when integrated with the grid. Thus, it becomes important to develop a novel approach or strategy which is useful to improve power quality, reliability, and grid stability. Solar photovoltaic power forecasting is a key tool for this new era and becoming the main component for a smart grid environment. Here, in this paper, the ensemble trees approach-based machine learning approach is utilized to forecast the solar photovoltaic power with the help of various meteorological parameters. The high-quality measured data for meteorological parameters for Qassim, Saudi Arabia is used in this research. The performance of the proposed model is evaluated with the help of statistical indices such as Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Square Error (MSE), Mean Absolute Percentage Error (MAPE), Training Time (TT) and found within the desired limits. To validate the obtained results a comparative analysis with other machine learning models is carried out. Moreover, the proposed research may provide the roadmap in achieving the vision 2030 of the government of Saudi Arabia.

INDEX TERMS Ensemble trees approach, machine learning, regression analysis, renewable energy resources, solar photovoltaic plants, solar photovoltaic forecasting.

I. INTRODUCTION

Fossil fuel consumption in the last twenty years has increased exponentially leading to a huge environmental and energy crisis. This rapid depletion of non-renewable energy sources has a drastic impact on the economic policies of governments, climatic conditions, and energy sustainability [1]. Almost two-thirds of CO_2 emissions are from fossil fuel burning which leads to changing weather patterns and environmental deterioration. The uncontrolled burning of fossil fuel to meet the demand of the ever-growing population causes higher global temperatures and increased greenhouse gases (GHG) resulting in the greenhouse effect [2]. Electrical energy is a vital factor for facilitating economic growth, industrialization, urban development and technological advancement. Hence, the whole world has channeled its research resources on the application of renewable energy (RE) resources.

To reduce pollution, GHGs and meet the energy demand of humans for better livelihood, there is an increased interest in the development and harnessing of solar and wind energy. Among RE sources the use of solar photovoltaic (SPV) is gaining more importance because of abundance availability, minimal losses, minimum moving parts, and minimal running costs. The amount of solar radiation incident on the outer

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Grey Wolf Optimizer-Based Array Reconfiguration to Enhance Power Production from Solar Photovoltaic Plants under Different Scenarios

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Abstract: The extraction of maximum power is a big challenge in solar photovoltaic-based power plants due to varying atmospheric and meteorological parameters. The concept of array reconfiguration is applied for the maximum power extraction in solar PV plants. Using this approach, the occurrence of multiple peaks in P-V and I-V characteristics during partial shade can be smoothened and reduced significantly. Partial shading due to the movement of the cloud is considered in the research. The cloud movement mainly because of velocity and wind direction is used for creating various shading conditions. The main focus is to reduce the power losses during partial shading using a nature-inspired optimization approach to reconfigure the array for different types of shading conditions. A grey wolf optimizer-based bridge-linked total cross-tied (GWO-BLTCT) configuration is proposed in this paper. The performance of the proposed topology is compared with standard and hybrid topologies, namely, series-parallel, total cross-tied, BLTCT, and SuDoKu-BLTCT, based on performance indicators such as fill factor, performance ratio, power enhancement, and power loss. The proposed GWO-BLTCT outperforms the remaining topologies due to the least power loss and high fill factor. It also has the highest average power enhancement and performance ratio with 23.75% and 70.02% respectively.

Keywords: array reconfiguration; maximum power point; optimization algorithm; partial shading conditions; solar PV system

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1. Introduction

In this era, comfort level and convenience are the basic requirements of human beings and should not be compromised at any level. It is expected that the existing and new buildings may have such provision by incorporating the energy efficiency concept or providing the energy-efficient material in the newly constructed buildings. The world's 40% basic resources are being utilized at a rapid pace by the worldwide construction sector. The European Commission initiated the Asia-Link program to impart knowledge about sustainability and its correlation with energy. Environmental sustainability, energy security, and equity create a three-dimensional aspect for energy sustainability, this three-dimensional aspect is known as a trilemma. European countries maintain the top rank in the energy sustainability aspect, whereas India ranks 88th globally [1]. The primary goal of sustainable design is the reduction in the depletion of critical resources, minimizing environmental degradation, and promoting a built environment that is safe, efficient, and productive. These sustainable developments are achieved by promoting the use of renewable energy and developing infrastructure for the vertical expansion of the urban landscape.

Renewable energy (RE) presently has an over 26% share of worldwide electricity production. Solar photovoltaic (SPV) has been the main focus of research and application

Development of ANFIS-based algorithm for MPPT controller for standalone photovoltaic system

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Abstract: The maximum power point tracking controller is an integral part for efficient implementation of PV system. In this paper, an adaptive neuro fuzzy inference system (ANFIS)-based new algorithm for maximum power point tracking (MPPT) has been developed and implemented to track maximum power point in the standalone photovoltaic system (PV). The work proposes to control the switching of DC-DC boost converter using ANFIS approach and replace the conventional PI controller to detect the error signal. The results of the proposed approach are compared with incremental conductance approach under constant and varying irradiance and temperature conditions. From the proposed approach, the percentage error, rise time and voltage fluctuations have been improved as compared to the incremental conductance method. Further, the proposed adaptive controller effectively tracks the MPP considering all the major nonlinear variables and it improves the rise time and the steady state characteristics of the PV system.

Keywords: photovoltaic systems; ANFIS; maximum power point tracking; MPPT; control algorithms.