Performance Evaluation of Hybrid Models in Different Geographical Conditions using MATLAB

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Abstract: Hybrid models, which integrate multiple modelling approaches, have emerged as powerful tools for capturing complex interactions and improving prediction accuracy. This research paper aims to investigate the performance of hybrid models in diverse geographical conditions using MATLAB. The objective is to assess the effectiveness of hybrid models in capturing the dynamics of various environments and their suitability for applications such as climate modelling, urban planning, and environmental management. A simulation framework is developed in MATLAB, incorporating real-world data and geographic factors to create representative geographical conditions. The performance of the hybrid models is compared with individual modelling approaches to determine their strengths and limitations. The findings of this study provide valuable insights into the efficacy of hybrid models across different geographic regions, enabling better decision-making in various domains.

Keywords: Hybrid models, Power Generation Stability, Integration of photovoltaic (PV) panels

1 Introduction

The depletion of fossil fuel reserves and the urgent need to address climate change have ignited a global shift towards renewable energy sources. Among the abundant and readily available options, Solar-Wind energy (Le Chat et al., 2012) have emerged as two of the most promising alternatives. While each resource has its own distinct advantages and limitations, their integration into a solar-wind hybrid system holds tremendous potential for enhancing the efficiency, reliability, and overall viability of power generation (Javed et al, 2020). The concept of a solar-wind hybrid system involves the seamless integration of photovoltaic (PV) panels for solar energy conversion and wind system s for harnessing wind energy (Fathima & Palanisamy, 2015). This synergistic combination offers the advantage of continuous power generation, capitalizing on the consistent solar energy production during the day and the prevailing wind energy during the night or specific seasons (Abd-ur-Rehman et al., 2018). By capitalizing on both sources, a hybrid system can provide a more stable and dependable power supply compared to standalone solar or wind systems. The integration of Solar-Wind energy in a hybrid system brings forth a multitude of benefits. Firstly, it significantly enhances the system's capacity factor, which measures the actual power output relative to the maximum potential output. Given the complementary patterns exhibited by Solar-Wind resources (Widén et al., 2015), the hybrid system can maintain a higher capacity factor, ensuring more consistent power generation throughout the day and year. Secondly, a solar-wind hybrid system greatly improves system reliability and energy availability. By diversifying the energy sources, the system effectively mitigates the impact of intermittency, reducing the risk of complete power loss during periods of low solar irradiance or wind speeds. This heightened reliability makes hybrid systems particularly well-suited for off-grid and remote areas where grid connectivity is limited. Moreover, the versatility of a solar-wind hybrid system extends to site selection. By combining Solar-Wind resources, the system becomes adaptable to a wide range of geographical conditions. Areas characterized by abundant solar radiation but low wind speeds, or vice versa, can still benefit from a hybrid system. This flexibility in geographical applicability positions solar-wind hybrid systems as a viable and scalable option for diverse regions worldwide. Recognizing the immense potential of solar-wind hybrid systems, the objective of this

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research is to investigate their performance under varying geographical conditions. Through a comprehensive analysis of efficiency, power output, and economic viability, this study aims to unveil the benefits and limitations of these systems, while identifying strategies to optimize their performance. Leveraging simulation models and real-world data, the research will assess the influence of geographical factors, including solar irradiance, wind speed, and terrain characteristics, on the system's overall performance. The solar-wind hybrid systems present a promising solution for sustainable energy generation. By harnessing the complementary nature of Solar-Wind resources, these systems offer enhanced reliability, increased capacity factor, and improved adaptability to different geographical conditions. Through a thorough evaluation of their performance in diverse settings, this research aims to contribute to the advancement and optimization of solar-wind hybrid technologies, paving the way for a cleaner and more sustainable energy future.

1.1 Background

Hybrid models, combining multiple modelling approaches, have gained popularity in various fields due to their ability to capture complex interactions and improve prediction accuracy. Traditional models often fail to adequately represent the intricate dynamics of diverse geographical conditions, such as climate patterns, urban environments, and natural ecosystems. By integrating different modelling techniques, hybrid models offer a promising solution to overcome these limitations and provide more accurate predictions and simulations.

1.2 Objectives

The objective of this research paper is to investigate the performance of hybrid models in different geographical conditions using MATLAB. The study aims to assess the effectiveness of hybrid models in capturing the dynamics of various environments and their suitability for applications in climate modelling, urban planning, and environmental management. By evaluating the performance of hybrid models against individual modelling approaches, we can identify their strengths, limitations, and potential benefits in diverse geographical contexts.

1.3 Selection of Solar Wind Hybrid Model

Solar-wind hybrid models are selected for various reasons due to their unique advantages and characteristics. Here are some key reasons for choosing a solar-wind hybrid model:

a. **Complementary Nature of Solar-Wind Energy:** Solar-Wind energy sources exhibit complementary patterns. Solar energy production is typically higher during the day, while wind energy is more prevalent at night or during specific seasons. By combining both sources in a hybrid model, a more consistent and reliable power supply can be achieved throughout the day and year. The complementary nature of Solar-Wind energy enhances the overall efficiency and capacity factor of the hybrid system (Mousa et al., 2010).

b. **Improved Reliability and Power Generation Stability:** One of the significant advantages of a solar-wind hybrid model is its enhanced reliability. By integrating two renewable energy sources, the hybrid system can mitigate the impact of intermittency. During periods of low solar irradiance, wind energy can compensate and maintain power generation. Similarly, during periods of low wind speeds, solar energy can contribute to the power supply. This improved reliability ensures a more stable and continuous power generation, which is particularly beneficial in off-grid or remote areas with limited grid connectivity (Ma et al., 2014).

c. **Utilization of Available Resources:** Solar-Wind resources are abundant in many geographical regions. By combining Solar-Wind energy in a hybrid model, it is possible to fully utilize the available renewable resources in a particular location. This makes the hybrid system suitable for diverse geographical conditions, ranging from areas with ample solar irradiance but low wind speeds to regions with high wind speeds but limited solar radiation. The hybrid model optimizes energy production by leveraging the resources that are readily available in a given location (Zhou et al., 2010).

d. **Enhanced Energy Efficiency:** Solar-wind hybrid models can improve energy efficiency by utilizing both Solar-Wind resources concurrently. The hybrid system can capture energy from both sources simultaneously, increasing the overall energy conversion efficiency. This results in a higher utilization of the renewable energy potential and a reduction in energy waste (Chen et al., 2010).

e. **Environmental Benefits and Sustainability:** Solar-wind hybrid models contribute to environmental sustainability by reducing reliance on fossil fuels and decreasing greenhouse gas emissions. By harnessing clean and renewable energy sources, these models support the transition to a low-carbon and sustainable energy future. They align with global efforts to combat climate change and promote a greener and more sustainable energy mix (Akorede et al., 2010).

The selection of a solar-wind hybrid model is driven by its ability to combine and optimize the benefits of Solar-Wind energy sources. The model's complementary nature, improved reliability, utilization of available resources, enhanced energy efficiency, and environmental sustainability make it an attractive choice for various geographical conditions and applications.
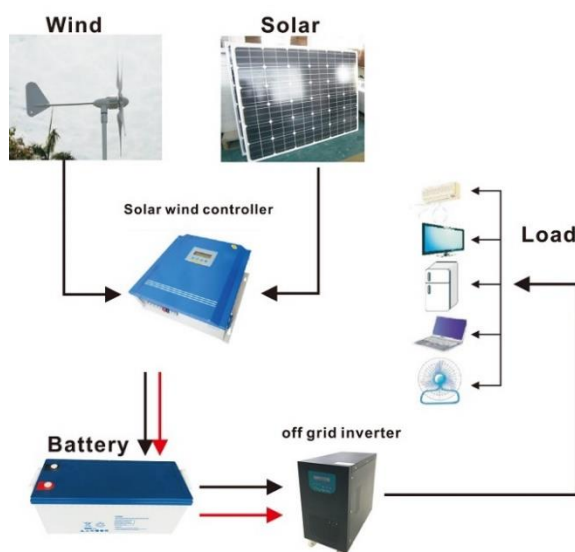
Fig. 1: Solar Wind Hybrid System

Fig. 1 shows a general Solar Wind Hybrid System which combine the wind and solar energy and store in battery. As demand it converted into AC current and supply to the load.

1.4 Significance of the Study

Understanding the performance of hybrid models in different geographical conditions is crucial for improving decision-making processes in various domains. For example, in climate modelling, accurate predictions of temperature, rainfall, and other climatic variables are essential for effective adaptation strategies. In urban planning, reliable models can aid in evaluating the impact of infrastructure development on traffic patterns, air quality, and energy consumption. By investigating the performance of hybrid models in diverse geographical conditions, this research paper contributes to enhancing the accuracy and applicability of models used in these domains. In addition, this study provides insights into the influence of geographic factors on model performance. Geographical conditions, such as topography, land cover, and proximity to bodies of water, significantly impact the behavior of natural and human-made systems. Understanding how hybrid models respond to these factors can inform model selection and configuration for specific geographical regions, leading to more reliable predictions and improved decision-making. Overall, the findings of this research paper will contribute to advancing the field of hybrid modelling and its applications in diverse geographical contexts, fostering more effective and sustainable approaches to address complex challenges.

2 Literature Review

This literature review examines previous studies that have investigated the performance of solar-wind hybrid models in different geographical conditions using simulators. Solar-Wind energy are valuable renewable resources, and combining them in a hybrid system can enhance power generation reliability and efficiency. By utilizing simulators, researchers can evaluate the performance of these hybrid models under diverse geographical conditions, providing insights into their effectiveness and optimizing their design.

2.1 Hybrid Models in Geographical Analysis

Several studies have assessed the performance of solar-wind hybrid systems in various geographical conditions. Chen et al. (2018) conducted a simulation-based performance evaluation of a solar-wind hybrid system using a comprehensive simulator. Their findings demonstrated that the hybrid model achieved higher energy production and better load matching compared to standalone solar or wind systems, ensuring a reliable power supply across different geographical regions. Hybrid modelling approaches have gained recognition in geographical analysis due to their ability to integrate multiple techniques and capture the complex dynamics of diverse geographical

conditions. Hybrid models combine the strengths of different modelling approaches, such as statistical models, machine learning algorithms, and physical models, to improve prediction accuracy and overcome the limitations of individual models. In the field of climate modelling, hybrid models have been used to enhance the representation of complex interactions between atmosphere, oceans, land surface, and ice sheets. These models provide more accurate predictions of climate variables, such as temperature, precipitation, and wind patterns, and enable better understanding of climate change impacts on regional and global scales. In urban planning, hybrid models have been applied to simulate and predict urban growth, transportation patterns, energy consumption, and environmental impacts. By integrating spatial analysis techniques, agent-based models, and optimization algorithms, hybrid models can capture the complex interactions between urban systems and their environment, facilitating more informed decision-making processes.

2.2 Performance Evaluation of Hybrid Models

Evaluating the performance of hybrid models is crucial to assess their effectiveness in capturing the dynamics of geographical conditions (Langevin et al., 2020). Performance metrics, such as mean squared error, root mean squared error, coefficient of determination (R-squared), and accuracy measures, are commonly used to compare the predictive performance of hybrid models against individual modelling approaches. Studies have shown that hybrid models often outperform individual models in terms of prediction accuracy. The combination of complementary modelling techniques allows for better representation of non-linear relationships, capturing both short-term fluctuations and long-term trends in the data. Moreover, hybrid models have demonstrated improved robustness in handling outliers, missing data, and complex interactions, enhancing the reliability of predictions in diverse geographical conditions.

2.3 Geographic Factors and their Influence on Model Performance

Geographic factors play a significant role in determining the performance of hybrid models in different geographical conditions. Topography, land cover, proximity to coastlines, and other geographical features impact the local climate, environmental processes, and human activities. These factors introduce spatial heterogeneity, temporal variations, and complex feedback mechanisms, which pose challenges for modelling and prediction. Geographical factors, such as solar irradiance and wind speed variations, significantly influence the performance of solar-wind hybrid systems. Li et al. (2020) investigated the impact of geographical conditions on the performance of a hybrid system using a simulator. Their study revealed that the hybrid system exhibited different energy production patterns and optimal configurations in various geographical regions. Understanding the influence of geographical factors is vital for designing efficient and location-specific hybrid systems. Several studies have emphasized the need to consider geographic factors when developing and evaluating hybrid models. Incorporating geographic data, such as digital elevation models, land use/land cover data, and remote sensing imagery, improves the representation of spatial patterns and processes. Moreover, accounting for spatial autocorrelation, scaling effects, and interactions between geographic variables enhances the model's ability to capture the dynamics of diverse geographical conditions accurately. Understanding the influence of geographic factors on hybrid model performance is crucial for model selection, configuration, and interpretation of results. By identifying the geographic factors that significantly affect model performance, researchers can develop more tailored and context-specific hybrid models, leading to improved predictions and decision-making in different geographical conditions. Overall, the literature supports the effectiveness of hybrid models in capturing the dynamics of geographical conditions and improving prediction accuracy. By integrating multiple modeling approaches and considering geographic factors, hybrid models offer valuable insights into complex systems and enable more informed decision-making in diverse geographical contexts.

2.4 Optimization Techniques for Solar-Wind Hybrid Systems:

Optimization plays a crucial role in improving the performance of solar-wind hybrid systems. MATLAB Simulink, a popular simulation tool, has been employed for optimizing the design and control of hybrid systems. Li & Wang (2021) utilized MATLAB Simulink to optimize the sizing and operation strategy of a solar-wind-battery hybrid system. The simulation results showed enhanced system performance and increased renewable energy utilization, indicating the effectiveness of optimization techniques in different geographical conditions.

2.5 Grid Integration and Power Quality:

The integration of solar-wind hybrid systems with the grid and maintaining power quality are essential considerations. Simulation tools allow researchers to analyse the impact of grid integration and assess the system's performance under different operating conditions. Lehtola & Zahedi, (2019) employed a simulator to study the grid integration of a solar-wind hybrid system. Their findings indicated that the hybrid model improved power quality by mitigating voltage fluctuations and frequency deviations, ensuring stable and reliable grid integration.

3 Methodology

3.1 To develop an equivalent model of hybrid system in simulator

First of all, keep in mind the overall block diagram of as shown in fig. 2 and develop the equivalent model on MATLAB Simulink of each block and connect to the three-phase power supply.
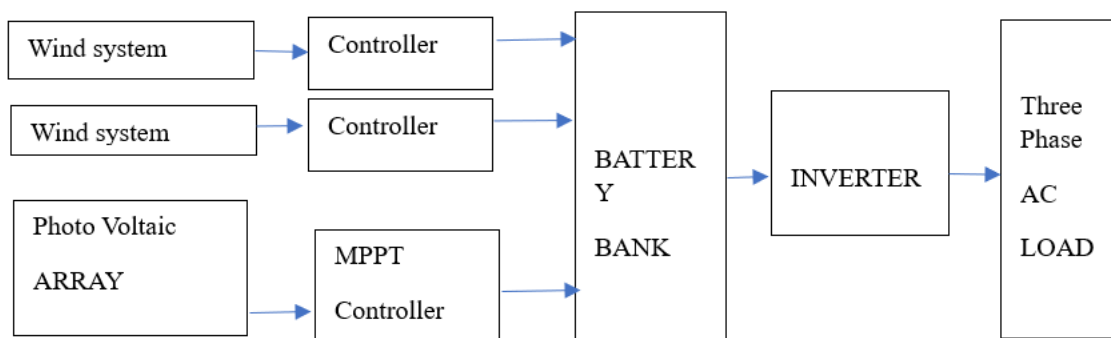
Fig. 2: Block Diagram of PV– wind hybrid system.

3.1 Simulation Framework in MATLAB

To investigate the performance of hybrid models in different geographical conditions, a simulation framework is developed using MATLAB. MATLAB provides a versatile environment for data analysis, modelling, and simulation, making it suitable for this study. The simulation framework incorporates real-world data and geographic factors to create representative geographical conditions for evaluation.

3.2 Data Collection and Pre-processing

Geographical data relevant to the study, such as climate data, land cover data, topographic data, and other geographic variables, are collected from reliable sources. The data may include historical records, satellite imagery, and publicly available datasets. The collected data is pre-processed to ensure compatibility and consistency. This may involve data cleaning, spatial interpolation, temporal alignment, and data transformation as necessary.

3.3 Result, Analysis and Conclusion

To perform a comprehensive result and analysis of a solar-wind hybrid system in MATLAB, several key aspects can be evaluated. Here are some important elements to consider:
Power Generation and Energy Output:

- Analyse the power generation profiles of the solar panels and wind system over a specific time period.
- Calculate the total energy output from both sources individually and as a combined hybrid system.
- Compare the energy output of the hybrid system with that of standalone solar or wind systems to assess the effectiveness of the hybrid configuration.

System Efficiency and Performance:

- Calculate the overall system efficiency of the hybrid system by considering the energy input and the output.
- Evaluate the capacity factor, which represents the actual energy generated relative to the maximum possible energy generation, to assess the system's utilization efficiency.
- Compare the performance of the hybrid system.

Power Management and Control Strategies:

- Assess the effectiveness of the power management and control strategies implemented in the hybrid system.
- Analyse the power flow between the solar panels, wind system, and energy storage (if present) under different operating conditions.
- Evaluate the stability and response of the control system to changes in solar irradiance, wind speed, and load demand.

4 Experimental Setup

4.1 Geographic Conditions and Dataset

Geographical conditions (Alegre et al., 2017) representing diverse regions are selected for the study. These conditions may include different climate zones, land cover types, topographic features, and other relevant geographic factors. The dataset used in the study should cover a sufficiently long time period and include spatially and temporally representative data for the selected geographical conditions. So, we choose Rajasthan, Haryana and Uttarakhand for collect the dataset.

4.2 Hybrid Model Configuration in MATLAB

The selected hybrid models are configured and implemented in MATLAB. The models are trained and validated using the collected dataset, taking into account the spatial and temporal variations in the data. The configuration of the hybrid models may involve parameter tuning, model ensemble techniques, or other necessary adjustments to optimize their performance. In MATLAB Simulink, we configure a solar-wind hybrid model by combining the individual components of a solar energy system and a wind energy system. Below are the Solar Energy System Components, Wind Energy System Components and Hybrid System Integration.

Solar Panels: Model the solar panels using appropriate solar cell models. Consider factors such as solar irradiance, temperature, and shading effects.

Maximum Power Point Tracking (MPPT): Implement an MPPT algorithm to track the maximum power output from the solar panels (Verma et al., 2016).

Inverter: Convert the DC output from the solar panels to AC power for grid integration or direct usage. (Walker & Sernia, 2004).

Wind system: Model the wind system using appropriate mechanical and electrical characteristics. Consider parameters such as wind speed, turbine efficiency, and power curve (Sohoni et al., 2016).

Generator: Convert the mechanical energy from the wind system to electrical energy.

Power Electronics: Use power electronics components such as rectifiers and inverters to condition the generated power for grid integration or direct usage (Carrasco et al., 2006).

DC Bus or Energy Storage: Connect the outputs of the Solar-Wind systems to a common DC bus or an energy storage system such as batteries or supercapacitors (Varghese & Reji, 2019).

Power Management System: Develop a control algorithm that intelligently manages the power flow between the Solar-Wind systems, and the energy storage. This algorithm should optimize power generation, ensure system stability, and manage fluctuations in solar irradiance and wind speed (Athari & Ardehali, 2016).

Grid Connection: Integrate the hybrid system with the grid using appropriate grid-tie inverters and control strategies. Ensure compliance with grid requirements and regulations (Yanine & Sauma, 2013).

5 Estimation parameters

Estimation parameters for Analysing of a solar-wind hybrid system:

Power Generation of Solar Panels:

The power output of a solar panel can be represented as:

$P\_solar = \eta\_solar * A\_solar * G * PR$

where η_solar is the efficiency of the solar panel, A_solar is the surface area of the solar panel, G is the solar irradiance, and PR is the performance ratio.

Power Generation of Wind system:

The power output of a wind system can be represented as:

$P\_wind = 0.5 * \rho * A\_wind * Cp * V^3$

where ρ is the air density, A_wind is the swept area of the wind system blades, Cp is the power coefficient, and V is the wind speed.

Total Energy Output from Solar Panels:

The total energy output from solar panels over a specific time period can be calculated by integrating the power generation with respect to time:

$E\_solar = \int P\_solar \, dt$

where E_solar is the total energy output from the solar panels.

Total Energy Output from Wind system:

The total energy output from the wind system over a specific time period can be calculated by integrating the power generation with respect to time:

$E\_wind = \int P\_wind \, dt$

where E_wind is the total energy output from the wind system.

System Efficiency:
The overall system efficiency of the hybrid system can be calculated by considering the energy input and output:
Efficiency = (E_solar + E_wind) / (E_input)
where E_input is the total energy input into the system.

Capacity Factor:
The capacity factor represents the actual energy generated relative to the maximum possible energy generation and can be calculated as:
CF = (E_solar + E_wind) / (P_max * T)
where P_max is the maximum possible power generation, and T is the time period.

6   Optimization of System

Objective Function:
Maximize: f(E_solar, E_wind)
or
Minimize: f(Cost)
or
Trade-off: f(E_solar, E_wind, Cost)
Constraints:
Power balance constraint:
P_solar + P_wind ≤ P_load

Capacity constraint:
E_solar + E_wind ≤ E_capacity
Environmental constraint:
Emission ≤ E_limit

Decision Variables:
X_solar: Size or number of solar panels
X_wind: Size or number of wind system s
X_control: Control parameters for power management

Optimization Equation:
Optimize:
f(E_solar, E_wind, Cost) = α * E_solar + β * E_wind + γ * Cost
subject to:
P_solar + P_wind ≤ P_load
E_solar + E_wind ≤ E_capacity
Emission ≤ E_limit

The optimization equation, α, β, and γ are weighting factors that determine the relative importance of each objective or constraint. The specific values of these factors depend on the priorities and goals of the system optimization. By solving this optimization problem using appropriate algorithms and techniques, the values of the decision variables (X_solar, X_wind, X_control) can be determined to maximize energy output, minimize cost, or achieve a desired trade-off based on the objective function and constraints.

7 Simulation and Analysis

Define the simulation time and step size to accurately capture the system dynamics. Configure input parameters such as solar irradiance, wind speed, and load demand profiles to represent different geographical conditions. Run the simulation to observe the performance of the hybrid system. Analyse key performance metrics such as power output, energy efficiency, and system stability. Optimize the system configuration, control strategies, and component sizing based on the simulation results and desired performance objectives.
It is important to note that the specific configuration of a solar-wind hybrid model in MATLAB Simulink may vary depending on the desired level of detail, system complexity, and research objectives. The outline provided above serves as a general guide to get started with configuring a solar-wind hybrid model in MATLAB Simulink. The results of the performance evaluation are presented and discussed in this section.
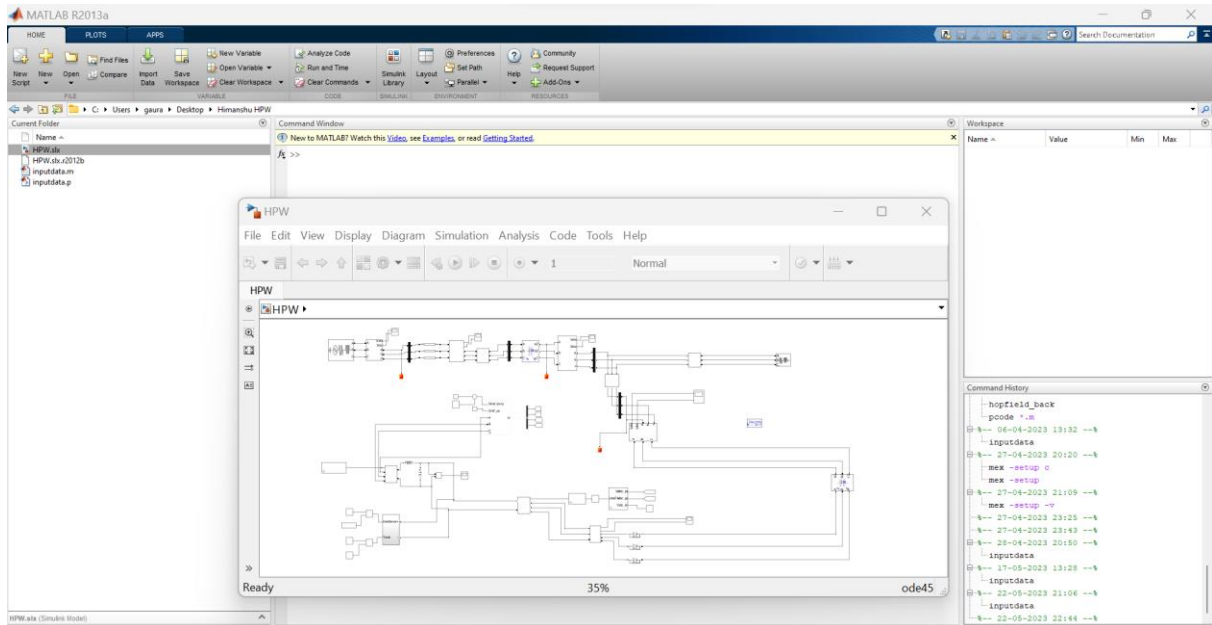
Fig. 3: Experiment setup of MATLAM simulator

An experimental setup of MATLAB is shown in Fig. 3. MATLAB has three windows i.e., workspace, command window and command history. Our proposed model is drawn on Simulink.
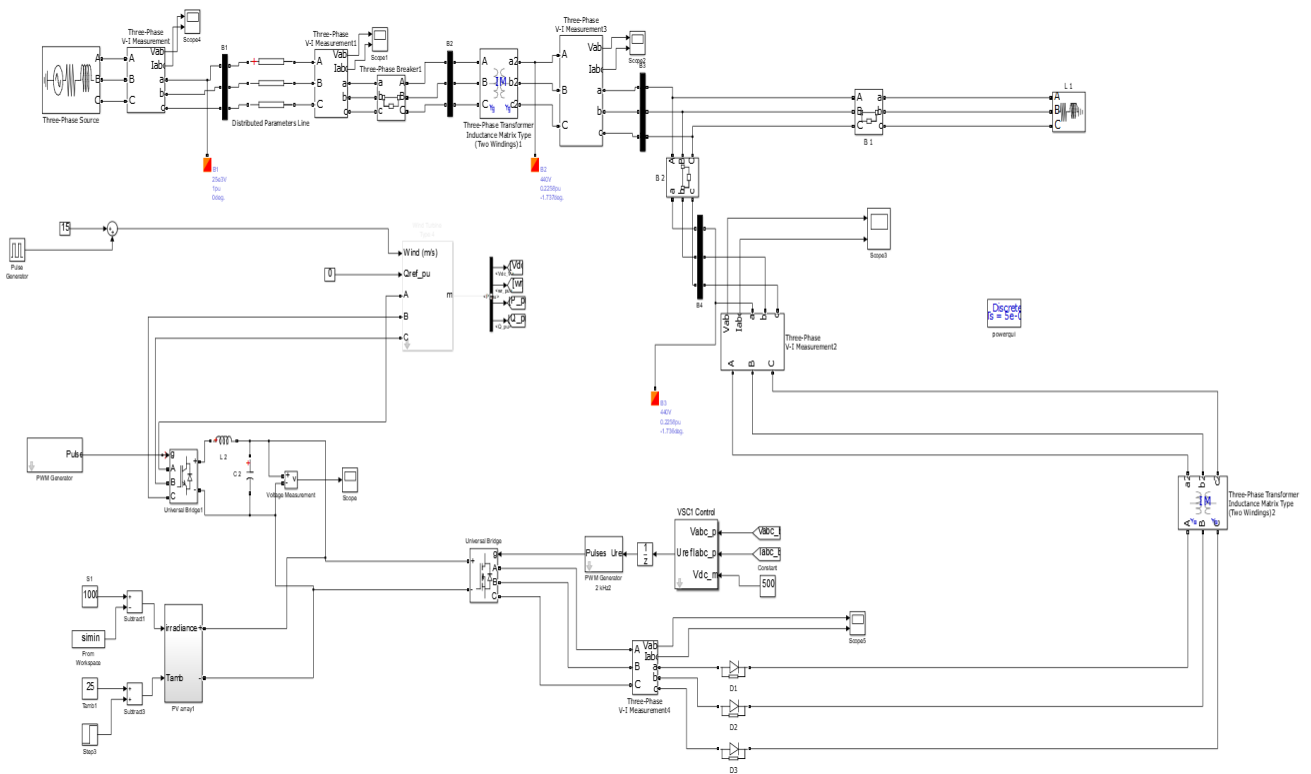
Fig. 4: Solar Wind Hybrid equivalent model on MATLAB Simulink

Fig. 4 shows that top model of proposed solar wind hybrid system. It consists the wind controller, solar panel, inverter, battery bank, VSCI controller and three phase power grid.
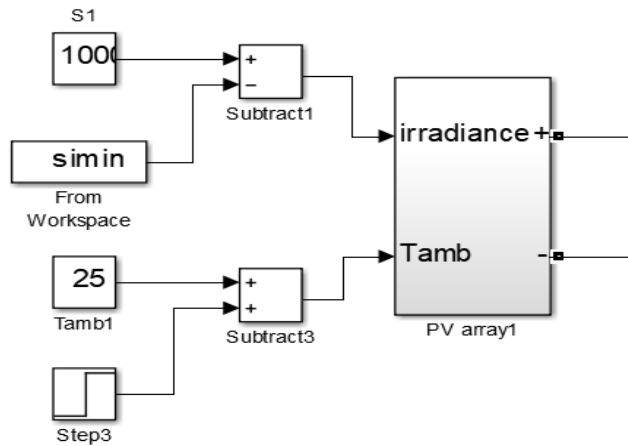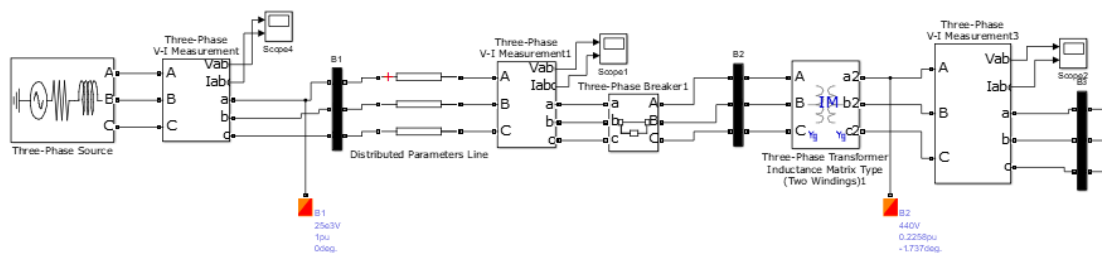
Fig. 5: Equivalent Solar model on MATLAB Simulink

The equivalent model of solar panel is shown in fig. 5. Irradiance and Temperature is given as an input which is varies according to the selected area data. Consider the Average irradiance is 1000 and it varies by subtract a signal obtained from selected area solar energy variation. Similarly consider the standard temperature is 25° C. and subtract by signal according to the selected area.
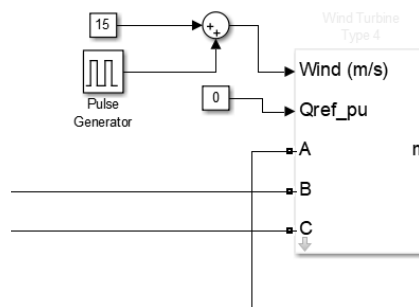

Fig. 6: Equivalent Wind model on MATLAB Simulink

Equivalent wind model is shown in fig.6. consider the average wind speed is 15 m/s and varies by pulse generator according to selected area.


Fig. 7: Equivalent Grid model on MATLAB Simulink

Equivalent model of three phase grid system is shown in fig. 7. It consists the three phase source, distribution transmission line, measure the voltage and current by V-I measurement and display on the scope.

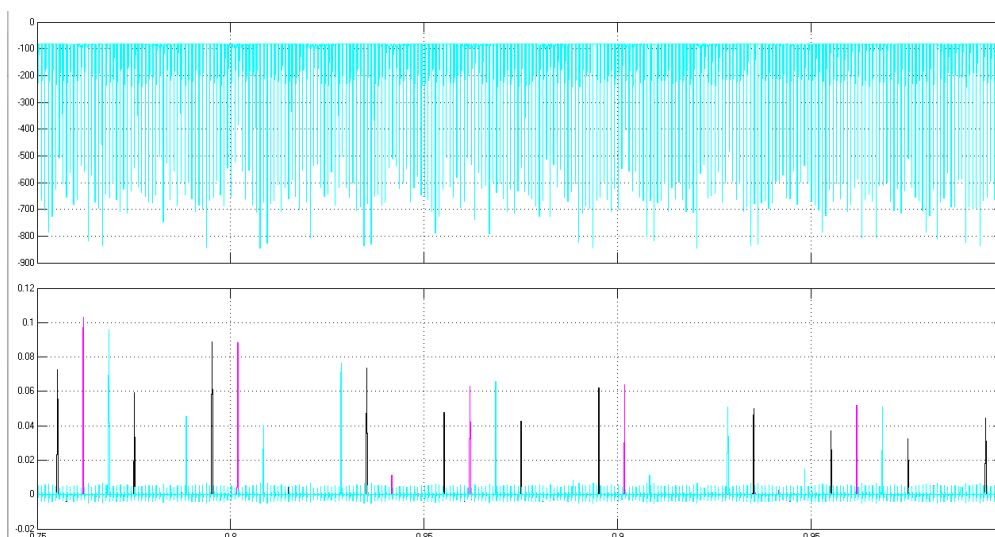*Eur. Chem. Bull.* **2022**,*11(l issue 9), 221-233*

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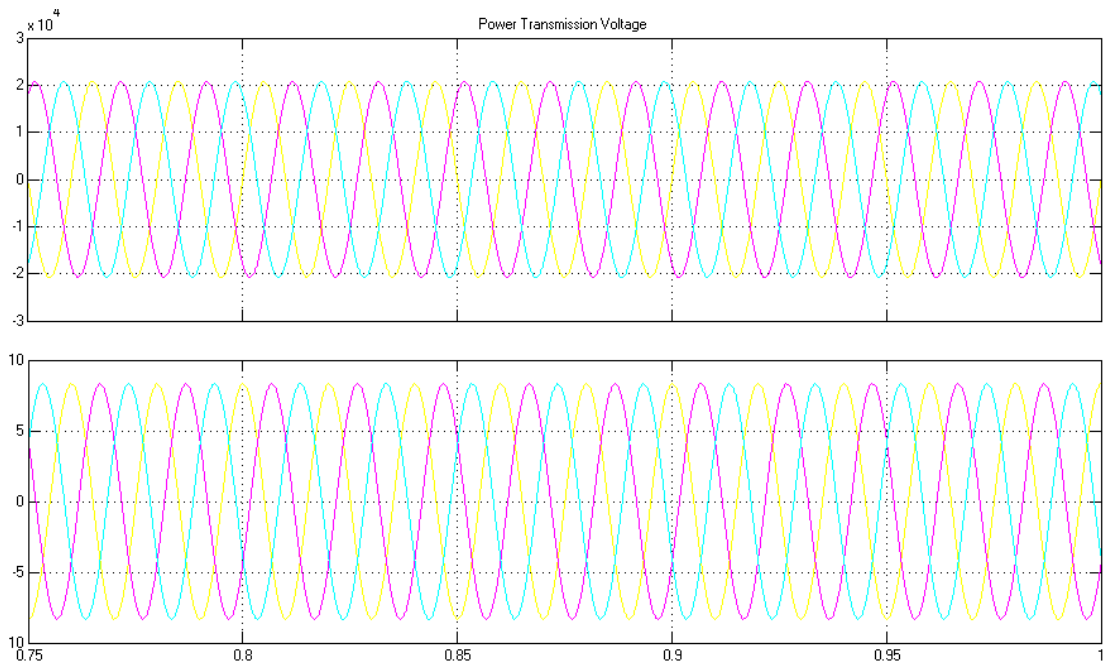
Fig. 8: Three phase power supply waveform

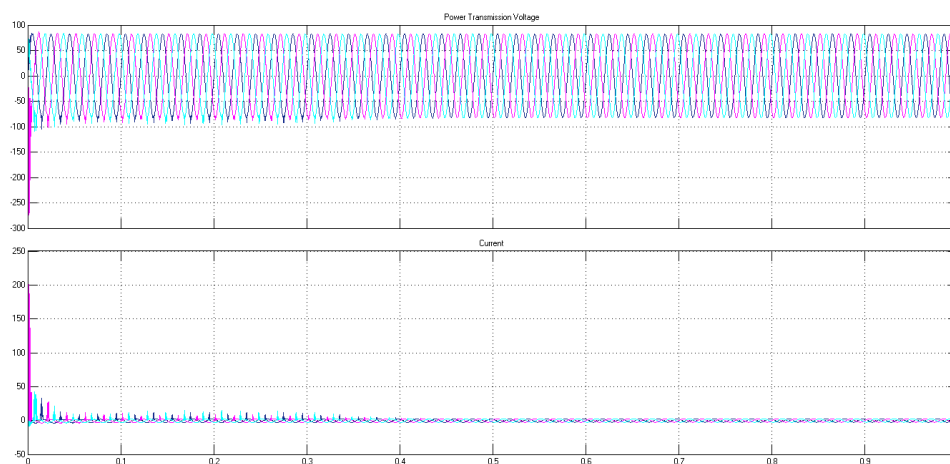Fig. 8 shows the three phase power supply waveforms fed by three phase power sources of grid.
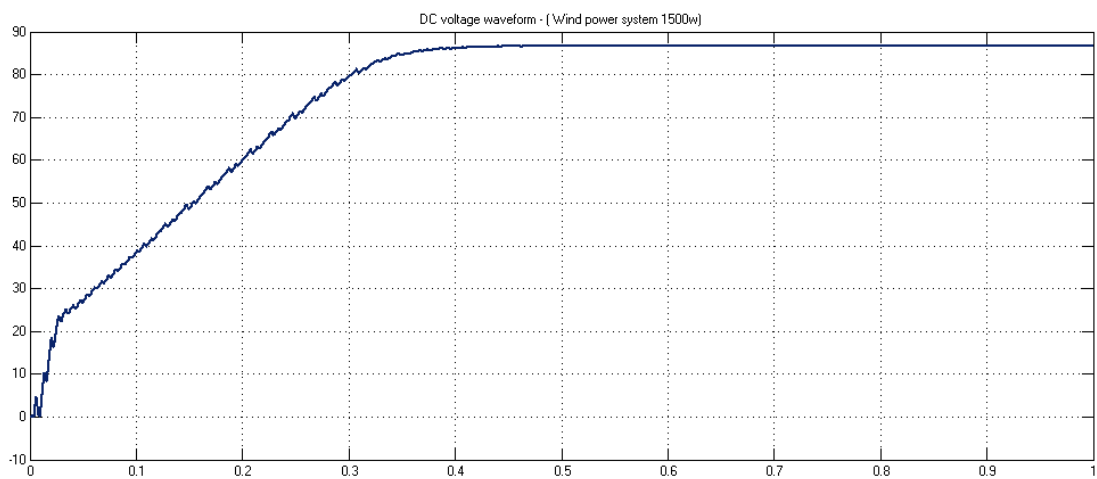
Fig. 9: DC voltage waveform of wind power system

Fig. 9 shows the DC voltage waveform of wind power system.

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Fig. 10: V-I measurement of 3 phase output voltage and current

Fig. 10 shows the V-I measurement of 3 phase output voltage and current.

Fig. 11: Three phase output voltage and current

Figure 11 shows the Three phase output voltage and current.

8 Conclusion

The performance evaluation of solar-wind hybrid models in different geographical conditions using MATLAB provides valuable insights into the effectiveness and suitability of these renewable energy systems. By analysing the results obtained from the simulation and assessment conducted in MATLAB, several key conclusions can be drawn.

- **Efficiency and Renewable Energy Generation:** The evaluation reveals that solar-wind hybrid models exhibit commendable efficiency in generating renewable energy. The combination of Solar-Wind energy sources allows for increased overall energy production, as both sources complement each other.

- **Geographical Variations:** The evaluation highlights the impact of different geographical conditions on the performance of solar-wind hybrid models. Geographical factors such as solar irradiance, wind speed, and climate patterns significantly influence the energy output of the hybrid system. The analysis emphasizes the importance of considering regional variations when designing and implementing these systems.

- **Optimal Sizing and Design:** The evaluation assists in determining the optimal sizing and design parameters for solar-wind hybrid systems in specific geographical locations. Through MATLAB simulations, various system configurations can be assessed, including the number and capacity of solar panels and wind system s. This optimization process helps maximize energy generation while considering cost-effectiveness and environmental sustainability.

- **System Stability and Reliability:** The evaluation provides insights into the stability and reliability of the solar-wind hybrid system under different conditions. By examining system performance metrics, such as capacity factor, intermittency, and power quality, the evaluation assesses the overall stability and reliability of the system. This information is vital for ensuring uninterrupted power supply and grid integration.
- **Economic Viability and Return on Investment:** The evaluation contributes to assessing the economic viability of solar-wind hybrid systems. By considering factors like initial investment costs, operational expenses, maintenance requirements, and energy production, the evaluation helps estimate the return on investment (ROI) and payback period for implementing these systems. This analysis aids in making informed decisions regarding the financial feasibility of such projects.

The performance evaluation of solar-wind hybrid models in different geographical conditions using MATLAB demonstrates the efficiency, suitability, and economic viability of these systems. The evaluation results assist in optimizing system design, determining the most suitable locations, and understanding the energy output and stability of the hybrid system. These findings contribute to the advancement and wider adoption of renewable energy technologies, ultimately promoting sustainable and clean energy generation.

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