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Design and Development of High-Efficiency Power Converters for Renewable Energy Systems

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Abstract

Throughout the late 1960s and early 1970s, industrialization accelerated globally. Mass consumption and rising middle-class affordability of commodities, particularly in developing nations, were major contributors to economic expansion. An indicator of economic growth is the global total energy consumption. Climate change and global warming are the two main environmental effects of energy production and use. Greenhouse gasses are released by all fossil fuels. Deforestation for the purpose of extracting fossil fuels is combined with this. On the other hand, greenhouse gasses are also produced by the energy used in industries. Therefore, a total reliance on fossil fuels will make the issues of climate change and global warming worse. Properly combining the capacity of individual systems, such as wind generators and photovoltaics, is crucial to the hybrid power system's performance. Both wind speed and instantaneous sun irradiation affect power generation. However, the overall generation is also impacted by changes in the load requirements. Studying the total yearly power generation for different PV-wind capacity combinations under various load scenarios is therefore required. Additionally, a highly efficient power converter with a closed loop controller that can accept numerous renewable energy inputs needs to be developed. In order to determine the viability of a PV-wind hybrid system, a detailed model of the system's annual power generation and water production under specific site conditions must be created.

Keywords: Energy Consumption, Power Converters, Pv-Wind Capacities, Total Energy.

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Introduction

With rising living standards and a growing global population, energy consumption continues to rise. The demand has gone up despite advancements in energy efficiency. Both now and in the future, there will be a need to generate electrical power. Due to its limited supply, fossil fuel prices must inevitably rise, forcing policymakers to search for alternative sustainable energy sources (Coelho et al., 2025). In addition to the historically used hydroelectric power sources, the most promising renewable energy sources are wind and solar photovoltaic. Water is a vital resource, and a prerequisite for a nation's sustained growth is water security. The demand for fresh water and its supply is far apart. One way to bridge the gap between the supply and demand of fresh water is to desalinate salty groundwater or seawater. Numerous desalination techniques have been created. An enormous quantity of energy is required for each of these operations. Many regions of the nation lack access to traditional power sources, and expanding the electrical infrastructure to these areas would be extremely expensive (Bughneda et al., 2022). Thankfully, there are regions of the nation with water scarcity that also have renewable energy sources that can be exploited to power desalination operations. Renewable energy systems provide energy from freely accessible local sources. A feasible solution to the water shortage in isolated areas and islands that are typified by a lack of both access to traditional energy sources like the grid for electricity and heating and a lack of sufficient potable water is to produce fresh water at the source using desalination technologies powered by renewable energy systems. Intermittency, uncertainty, and limited availability are inherent issues with renewable energy sources that increase the unreliability of the power supply (Salim et al., 2022). Large energy storage devices, such as batteries, will be used to boost the supply of. While dark days and nights are more likely to have heavy winds, sunny days typically have extremely low wind, making photovoltaic (PV) and wind power complimentary. As a result, hybrid PV-Wind systems may be more dependable and available than those that rely only on wind or PV power (Islam et al., 2014). Thus, the focus of our research is on hybrid PV-Wind systems that are appropriate for small-scale desalination facilities. The issue of intermittent and variable renewable energy can be successfully addressed by the desalination plant, which can function as a variable load.

Related Works

The process of desalination uses a lot of energy. The majority of energy comes from fossil fuels, which make them extremely susceptible to shifts in the world economy as well as the logistical challenges of delivering goods to isolated locations and island communities. Therefore, the fact that they are not sustainable is evident. As of right now, the majority of desalination facilities are situated in areas with abundant energy supplies and affordable energy prices. Currently, solar, wind, biomass, and other comparable new energy sources power over 1% of the water produced by diverse technologies (Feng et al., 2014). The cost of these energy sources is anticipated to decrease in the near future as a result of the widespread adoption of renewable energy in many applications, which has made it a regular energy source. This increases the viability of renewable energy. Desalination systems fueled by renewable energy have a lot of potential worldwide, and the need for desalinated water is rising along with economies and energy-importing nations like China, India, and other small islands. The many desalination technology possibilities must be taken into account by designers, who will base their choices on the renewable energy sources that are available at a particular location. Thermal desalination, for instance, is a practical choice with significant solar energy potential. Using solar photovoltaic panels to generate power is another option for membrane desalination (Lin et al., 2024). For dry areas with significant solar energy potential, this is a suitable option. For membrane desalination projects, wind energy might be taken into consideration in areas with strong wind potential and along coastlines or islands.

Therefore, a map of a nation's water requirements and possible renewable energy sources must be created. For making policy decisions on the closure of desalination facilities fueled by renewable energy sources in the upcoming years, this mapping offers a clear road map. A self-sustaining model of development for segments of society that primarily view desalination systems as the primary source for potable and practical applications would be made possible by such mapping and the planning that follows (Arévalo et al., 2024). Desalination fueled by renewable energy can facilitate ongoing and sustained growth, especially in nations that rely on desalinated water for irrigation and other beneficial applications like sustaining local populations. Overall, this approach can be seen as a self-sustaining investment strategy that reduces a number of expenses, including those linked to operations and the environment. The above choice will also be taken into account by government planners, who will evaluate the whole life-cycle costs of the many technologies available at the time of designing their capacity, associated infrastructure, and water supply needs in a sustainable manner.

Proposed Methodology

The utilization of hybrid wind-solar systems to power a desalination unit is a potential alternative because of the complementing qualities of solar and wind resources which is shown in Fig 1. Typically, when the sun isn't shining, the wind is stronger, and vice versa. However, it should be mentioned that there will be instances in which neither wind nor solar energy is accessible. This suggests that, absent a storage mechanism, the load only partially functions when energy is available. One such storage device is a battery, but they are typically costly. The wind turbine and the photovoltaic system are the fundamental parts of the hybrid system. Others are supplementary or auxiliary elements that support the hybrid system's continuous operation.

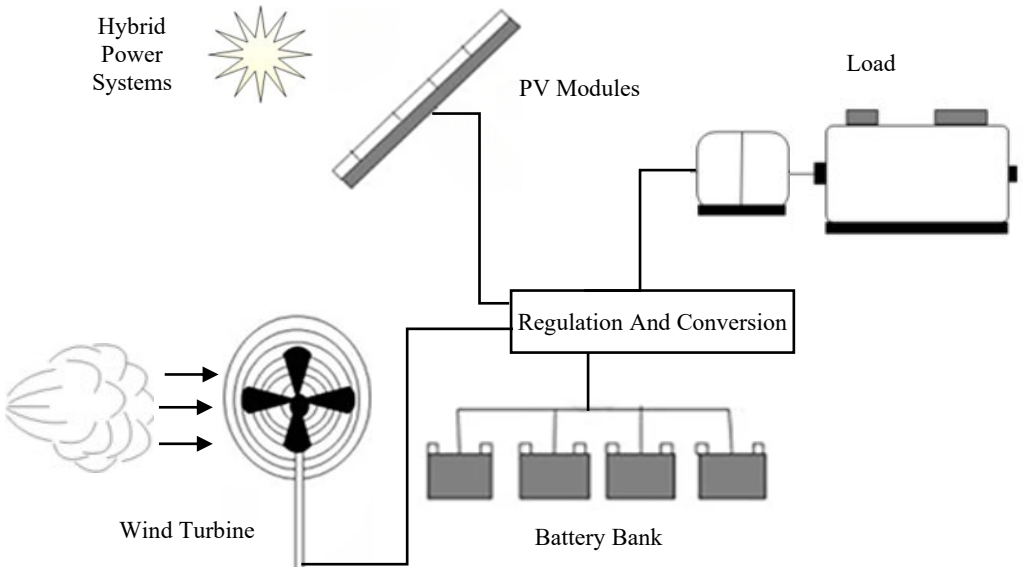


Fig. 1: Block Diagram for the Proposed Framework

The capital cost per kW capacity is taken into consideration when developing the cost model of the different energy sources. The capital recovery factor, which is computed by accounting for interest rates and system longevity, is used to determine the annualized capital costs. The model also accounts for operating and maintenance expenses. The sum of the individual expenses is used to determine the hybrid power system's annual total cost for a specific combination of solar PV, wind, and battery capacities.

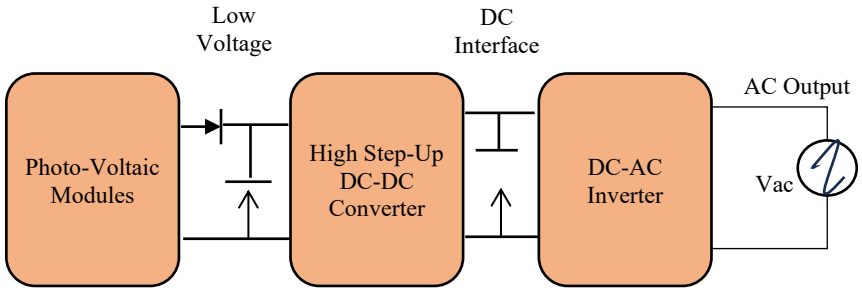


Fig. 2: Schematic of Renewables-Based Generation System with a High Step-Up Converter

Fig 2 depicts the general schematic of a power generation system with a high step-up converter. The input power source is the solar PV or another sustainable energy source. The high step-up converter is then linked to this source in order to generate an adequate DC voltage. An inverter circuit receives the DC voltage and converts it into an AC output voltage that can be connected to the load. The inverter is not required for DC loads.

The total power generated in a given year, the system's construction cost, and its operating and maintenance expenses are all significantly impacted by the capacities of the solar PV, wind generator, and battery. The cost of energy per unit of power generated (COE) and the load's power availability are directly impacted by this. The % availability is the amount of time during the year when the hybrid power system's instantaneous power production is adequate to run the RO plant. A specific combination of solar PV, wind generator, and battery capacity can be used to build a hybrid

power system. The capacity of any given renewable energy resource-based system may result in component oversizing and needless operating and lifetime expenses because renewable sources are intermittent. Additionally, there may be a decrease in the overall amount of power produced, which would decrease availability and raise the cost of energy production per unit. Therefore, attaining the necessary goal requires a suitable mix of solar PV, wind, and battery capabilities.

Simulation Results and Discussion

To calculate the annual kWh production for a specific set of solar PV, wind generator, and storage battery capacities (in kW), a neural network model is suggested. An input layer, a hidden layer, and an output layer are the three layers of a back propagation network that is suggested. The hyperbolic tangent sigmoid transfer function serves as the activation function for the five nodes that make up the hidden layer. The needed output, or the predicted total kWh produced in a year for a specific set of capabilities as input, is represented by the single node that makes up the output layer. The target value, or the power generated value in the training data set, is compared to the expected output. The error is the discrepancy between the needed target value and the projected value. The output is anticipated after the error value is utilized to modify the bias values (b1 and b2) and the weight matrices (IW and LW).

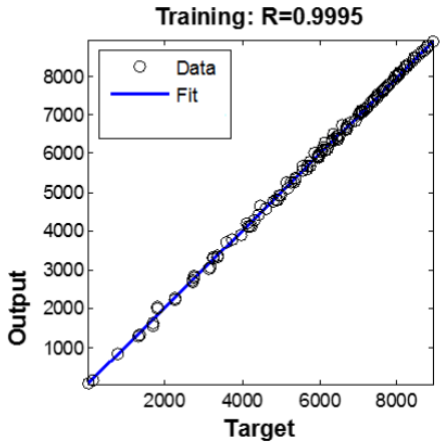


Fig. 3: Regression Plots of Neural Network Model for Training Datasets

The network generalization is measured using the validation data set. We can use this to determine when to stop the training. For the model's validation, 60 samples, or 15% of the total data, are selected at random. In order to compute the outcome, this data was supplied as inputs to the neural network model. To determine the prediction error, the actual value of the output is compared to the expected value. The model is further trained if the error is high which is depicted in Fig 3.

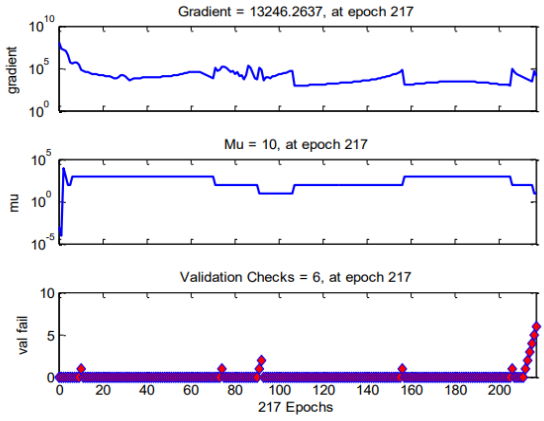


Fig. 4: Validation Checking of The Neural Network Model

The validation performance parameters are displayed in Fig 4. Prior to computing the necessary update for the weight matrices, the gradient refers to the derivative from each data set. The graphic displays the gradient in different training cycles, or epochs. The training gain in each training cycle that aids in the convergence of the error is known as the momentum update (mu) value. This fig also displays the mu values during the course of the training cycle. To make sure the neural network isn't overtrained, a validation fail check is performed. Six validation check failures result in the training being terminated.

Conclusion

To get the best configuration, a methodology for choosing the capabilities of the hybrid power system's several power sources is described. One special benefit of using hybrid PV-wind systems for desalination is that they require less energy storage battery capacity, which increases the amount of electricity produced and lowers costs. The yearly power generated by a specific hybrid power configuration is estimated by a neural network model of renewable energy-based desalination systems that use solar photovoltaic and wind turbines. A power converter prototype that can be used with hybrid renewable energy sources that combine solar and wind power is created for desalination applications. With a variable input voltage in the range of 15 V to 40 V, the converter's closed-loop architecture produces an output voltage of about 200 V. It also has a high step-up ratio.

References

Coelho, S., Monteiro, V., & Afonso, J. L. (2025). Topological advances in isolated DC–DC converters: high-efficiency design for renewable energy integration. *Sustainability*, *17*(6), 2336. https://doi.org/10.3390/su17062336

Bughneda, A., Salem, M., Alhuyi Nazari, M., Ishak, D., Kamarol, M., & Alatai, S. (2022). Resonant power converters for renewable energy applications: A comprehensive review. *Frontiers in Energy Research*, *10*, 846067. https://doi.org/10.3389/fenrg.2022.846067

Feng, W., Qi, B., Wang, Y., & Liu, H. (2014, August). High power DC-DC converter for renewable energy power system. In *2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific)* (pp. 1-4). IEEE. https://doi.org/10.1109/ITEC-AP.2014.6940974

Salim, K., Asif, M., Ali, F., Armghan, A., Ullah, N., Mohammad, A. S., & Al Ahmadi, A. A. (2022). Low-stress and optimum design of boost converter for renewable energy systems. *Micromachines*, *13*(7), 1085. https://doi.org/10.3390/mi13071085

Lin, C. H., Khan, M. S., Ahmad, J., Liu, H. D., & Hsiao, T. C. (2024). Design and analysis of novel high-gain boost converter for renewable energy systems (RES). *IEEE access*, *12*, 24262-24273. https://doi.org/10.1109/ACCESS.2024.3365705

Arévalo, P., Ochoa-Correa, D., & Villa-Ávila, E. (2024). Towards energy efficiency: innovations in high-frequency converters for renewable energy systems and electric vehicles. *Vehicles*, *7*(1), 1. https://doi.org/10.3390/vehicles7010001

Islam, M. R., Lei, G., Guo, Y., & Zhu, J. (2014). Optimal design of high-frequency magnetic links for power converters used in grid-connected renewable energy systems. *IEEE Transactions on Magnetics*, *50*(11), 1-4. https://doi.org/10.1109/TMAG.2014.2329939