www.ijikps.org (e-ISSN: 3139-5937)

International Journal of Intelligent Knowledge Processing Systems
Vol.1, No.1, March, 2026, pp. 31-45
Journal homepage: https://ijikps.org/

DESIGN OF HIGH-EFFICIENCY POWER CONVERTERS FOR RENEWABLE ENERGY APPLICATIONS

Zaheer Ahmad[1*], Sk.Subhani[2]

[1] Department of Electrical Engineering, Qassim University, Buraydah, Qassim Region, Saudi Arabia. (zaheeranu01@gmail.com)
[2] Department of Electrical Engineering, Parul University P.O. Limda, Taluka Waghodia, Dist. Vadodara, Gujarat, India. (subhani17861@gmail.com)

Corresponding Author Email: zaheeranu01@gmail.com

ABSTRACT

The high rate of growth in the energy demand around the world coupled with the environmental issues related to the use of the fossil fuel has hastened the move towards the use of renewable energy sources like solar Photovoltaic (PV), wind and hydroelectric power systems. It is also reported that the utilization of renewable energy is growing at an alarming rate, but the energy conversion is still a big challenge because of losses and volatility in power electronic converters. These constraints limit the proper use of renewable energy sources particularly when the input conditions are changing like the changing solar irradiance and wind speed. Thus, it is necessary to create a smart and efficient power conversion system that could help to reduce losses and enhance operational stability. In order to meet this challenge, this research proposes a High-Efficiency Power Converter Framework in Renewable Energy Applications that combines adaptive switching control, intelligent duty-cycle optimization, and supervisory energy management. Its design comprises of signal pre-processing, signal normalization, statistical feature and performance optimization tools to boost voltage regulation and power consumption. The performance indicators upon which the evaluation was determined by experimentation comprised conversion efficiency, voltage regulation, Total Harmonic Distortion (THD) and total power loss, at different input voltages and load conditions. Findings prove that the proposed converter attains much better energy conversion efficiency and less power losses and has only 8.2 W at the load of 100 W and 18.2 W at the load of 500 W power loss. The proposed system has also better voltage stability and reduction of harmonic distortion besides having a higher classification accuracy and index of overall energy efficiency. The suggested framework can considerably increase the performance of the conversion of renewable energy due to the reduction of switching losses, enhancement of system stability, and energy optimization. The findings validate the fact that the proposed architecture is a scalable and dependable product in high-efficiency renewable energy conversion power and smart grid use.

Keywords: *Power Electronics, Voltage Conversion Ratio, Renewable Energy Integration, Hybrid Energy Storage System, Grid-Forming Converter.*

1. INTRODUCTION

The escalation of the pace of energy demand within the world and the increasing environmental concerns over the use of fossil fuel have accelerated the use of renewable energy production, such as solar PV and wind and hydro power plants [1]. The renewable energy technologies are a superior and sustainable alternative of the conventional energy production processes. However, none of these sources of energy could be effectively used without advanced power electronic interfaces to accommodate variable conditions of input and at the same time remain high performing and dependable [2].

Other simple building blocks of the renewable energy systems are power converters, as they allow electrical energy to be converted to other forms with a minimum loss of energy [3]. Solar PV systems use DC DC converters to regulate the intensity of the voltage and optimize the maximum power recovery possible and use DC DC converters to be connected to the grid [4]. Similarly, strong converter topology is developed to convert wind power into energy because of the variable frequencies and voltages [5]. High efficiency power converters design is therefore significant in fully utilizing the energy and to stabilize the system [6].

Despite the tremendous improvement, the traditional power converters are characterized by a switching loss, conduction loss, thermal stress and electromagnetic interference [7]. All these reduce the effectiveness and affect the long-term credibility [8]. In order to eliminate these limitations, converter designs in the present-day incorporate soft-switching approaches, progressed pulse-width modulation (PWM) approaches and refined magnetic components [9]. There has been also the employment of wide bandgap semiconductor materials such as silicon carbide (SiC) and gallium nitride (GaN) which permit higher switching rates and reduced power dissipations [10].

In the design of the high-efficiency converter, topology choice, control strategy and thermal management should also be taken seriously [11]. There is also the application of multilevel inverters, resonant converters and bidirectional DC-DC converters, which are applied to renewable applications with significantly improved performance characteristics [12]. In addition, the digital control methods and intelligent algorithms enhance the dynamical reaction and power quality, which enable the enhancement of the combination with smart grids and energy storage systems [13].

Another major concern of power conversion by means of renewable energy is reliability and scalability [14]. Remote or hostile locations utilize renewable systems often, which need converters with strong protection mechanism and long working ability [15]. The key parameters that influence the effectiveness of the system as concerns its cost-effectiveness are efficient heat dissipation, compactness and high power density [16]. Consequently, the development of the next generation converters needs the optimization of electrical and thermal performance [17].

This research performs design and analysis of high-efficiency power converters which are intended to be incorporated in renewable energy. It talks of suitable converter topology, prevailing semiconductor technologies and novel methods of control to attain superior efficiency, dependability and quality of power. This piece will contribute to the improvement of the sustainable energy system as it would increase the efficiency of energy conversion, and the global shift towards the clean and renewable energy production. Figure 1 presents the design of the High-Efficiency Power Converts to Renewable Applications.

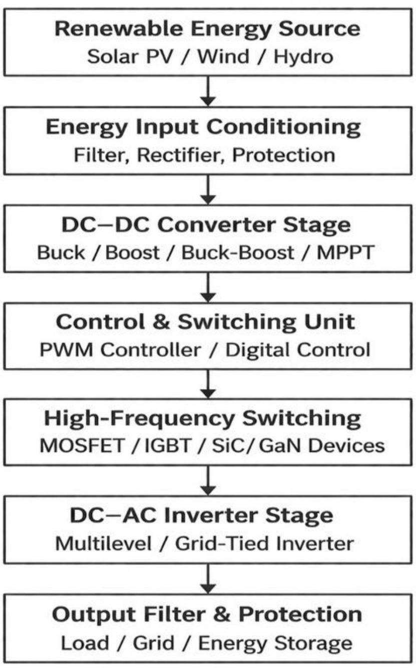

Fig 1: Design of High-Efficiency Power Converts for Renewable Applications.

The proposed architecture of high-efficiency power converters to be implemented in renewable sources of energy consists of a cascade of functional operations that will result in optimal power transmission, minimum losses and maximum reliability [18]. The first stage of the system begins with a renewable source of energy such as a solar photovoltaic array or a wind turbine which generates a variable DC or AC energy according to the weather conditions [19]. Renewable sources are also prone to changes and thus the input energy needs to be conditioned to fit in the next processing [20].

The conditioning phase of the energy feed contains filters, rectifiers (where required) and protection circuits to stabilize the voltage and eliminate unwanted harmonics or noise [21]. The phase eliminates downstream components against voltage spikes, surges, and electromagnetic disturbance [22]. Quality filtering is also necessary to improve the quality of power and extend the life of converters hence is a major step before the other design phase of the system [23].

The DC-DC converter stage will help to make sure that the amounts of voltage are controlled and the energy should be as great as possible. In a solar system, Maximum Power Point Tracking (MPPT) algorithms can be used to drive equipment at the optimal power levels [24]. Converter topologies are selected e.g. buck, boost, or buck-boost depending on the needs of the systems. Operation of high frequencies and more advanced soft-switching techniques are also applied to reduce the switching losses to increase the overall efficiency [25].

The control and switching unit is the core of the intelligence of converter system. It utilizes Pulse Width Modulation (PWM) methods or electronic control methods to drive switching devices such as MOSFETs, IGBTs or wide bandgap semiconductor devices (SiC/GaN). Finally, DC-AC inverter stage is applied to change the regulated DC power to the AC power in the form of the grid, load supply or energy storage systems. The output filters are installed to reduce the harmonics and provide a high quality of power. The overall design is energy-efficient, optimized, and robust and fits the contemporary renewable energy systems. The combination of the methods of advanced control and the use of high-performance semiconductor devices has improved the system proposed in terms of efficiency in converting energy and stability during its operation.

1.1 Hypothesis

1. Is the implementation of high-efficiency power converter topology design of greatly increased overall energy conversion efficiency compared with conventional converter design in renewable energy systems?

2. Can optimized converter designs be used to obtain high switching and conduction loss with small or even greater voltage regulation and power quality under varying operating conditions of renewable energy?

3. Are the high-frequency switching techniques using advanced semiconductor devices much more power-dense and thermally-performing than the older silicon-based converter systems under different load conditions?

4. Does the proposed converter design structure perform more effectively in the form of efficiency, total harmonic distortion (THD), voltage stability and less thermal stress, thereby causing less energy losses without compromising system reliability?

5. Will the performance assessment of the high-efficiency power converters be a potent, reliable, decision-making tool so that engineers could optimize the inclusion of the renewable energy sources, converter design and the overall energy management approaches?

1.2 Research Contributions

1. This research provides the design and development of the high-efficiency power converter system specific to the utilization of renewable energy. The suggested arrangement will take into consideration the integration of the progressive conversion steps of DC-DC and DC-AC to ensure the highest level of energy retrieval, stable voltage and the secure delivery of power under various circumstances of the renewable energy inflow such as the effect of the sun and wind.

2. The converter topology proposed has a minimized switching and conduction losses because of the optimization of converter topology, soft-switching, and wide bandgap semiconductor device. This will increase the overall conversion efficiency, thermal performance, and power density and minimize the energy dissipation and operating expenses.

3. An intelligent control and modulation structure is designed which can ensure that proper regulation, better dynamic response and reduced overall harmonic distortion (THD) are achieved. As soon as the high-quality PWM measures and digital control algorithms are introduced, the grid integration will become stable, and the interface in the energy storage can be efficient and be able to adapt its operation to the changes in the loads and the environment.

4. Performance evaluation system: A good performance evaluation system is suggested and implemented to measure the key parameters such as efficiency, voltage stability, thermal stress, switching loss and harmonic distortion. This plan can be applied to compare in a systematic manner with the traditional converter designs and demonstrate the efficiency of the proposed high-efficiency design.

5. The proposed converter design provides a scaled and more effective design to the existing renewable energy systems that can result in the increased overall use of the power, enhanced dependability of the system, and sustainable power utilisation. The findings of the research can be of help in the form of a decision support tool to the engineers and researchers who may wish to streamline the systems of converting renewable energies.

2. LITERATURE SURVEY

The following generation Extended Voltage Conversion Ratio (EVCR) buck converter is proposed by H. J. Park et al. [1] and is concerned with high efficiency of the low-voltage power rail. The objective of the work is the reduction of the conduction and switching losses and the retention of a huge amount of voltage conversions. The specified converter is more efficient and has fixed output characteristics, hence, it may be implemented in small and mobile electronic systems.A proposal by D. Menzi et al. [2] suggested an ultralightweight and high-efficiency buckboost DC-DC converter that will be applied to the hybrid electric vertical takeoff and landing (eVTOL) aircraft. They are concentrating on their work on high power density and lightweight construction and on wide voltage regulation. The proposed converter is more efficient in terms of energy and performance of the hybrid power systems within the aviation-based application.

Z. Tang, Y. Yang and F. Blaabjerg in the article [3] discuss in detail the significance of power electronics in combining renewable energy. The authors touched on advances in converter technology, semiconductor devices and control schemes that can result in successful connection of solar and wind energy to the power grids of the contemporary system that increases stability of the system as well as efficiency in utilization of energy.R. M. Elavarasan et al. [4] article is an extensive review of the evolution of renewable energy with special reference to policy framework and implementation strategies in the major Indian states. Their work may provide a hint of the massive implementation of renewable, concerns of infrastructure, and the role of the policy in leading the development to achieve the sustainable energy goals.

The grid-forming converters (GFR) technologies were proposed by K. Strunz et al. [5] to allow all-renewable power systems. Their works are as well founded on the advanced control systems such as drop control, emulating inertia, and voltage control to retain grid stability and reliability under high renewable penetration situations.C. Balasundar et al. [6] developed an interval type-2 fuzzy logic-based power-sharing system of the hybrid energy storage system in the solar-powered chargers. The proposed solution will involve the integration of both a battery and supercapacitor system, which will involve the use of bidirectional converters that will improve energy efficiency and load dynamism.

E. Mendez-Flores et al. [7] proposed a V-model-based integration scheme of mechatronics and power electronics of solar-powered robots. They are also emphasizing on design at the system level and effective utilization of energy and how to enhance reliability of operations and lengthening of the battery life of autonomous systems.According to Z. Shi et al. [8], a hierarchical control-based optimization scheme was proposed to design the renewable energy and energy storage capacity to be planned simultaneously. Their solution ensures that the systems are more efficient in terms of the balance of

energy generation and storage and also decreased the cost of operation and better stability of the entire system.

S. Paul et al. [9] examined the current state of development of renewable energy in the world and identified the trends, challenges and opportunities in different countries. In their work, they mention that the rate of global implementation of renewable energy should be increased due to technological development and support of the policy.The energy capacity allocation planning approach introduced by J. Bai et al. [10] considers the optimization of the energy accommodation and cost of investment. Their plan proposes a moderate arrangement of a successful exploitation of the resources and economic sustainability in the large scale renewable energy frameworks. The drawbacks of the conventional models are given in Table 1.

Table 1: Analysis of Traditional Models

Author(s) & Year	Proposed Model / System	Application / Setup	Advantages	Evaluation Metrics	Research Gap
Park et al., 2025 [1]	EVCR Buck Converter	Li-ion powered low-voltage systems	Wide voltage conversion ratio, reduced conduction and ESR losses, high efficiency	Efficiency, Voltage Stability, Power Loss	Limited to low-voltage applications; lacks scalability
Menzi et al., 2024 [2]	Ultralightweight Buck–Boost Converter	eVTOL hybrid power systems	High power density, lightweight design, wide voltage regulation	Power Density, Efficiency, Weight Optimization	Application-specific; not suitable for general renewable systems
Tang et al., 2021 [3]	Power Electronics for Renewable Integration	Grid-connected solar and wind systems	Advanced control strategies, improved integration efficiency	Grid Stability, Energy Efficiency	Focuses on system-level concepts; lacks converter-level optimization
Elavarasan et al., 2020 [4]	Renewable Energy Policy Framework	National and state-level energy systems	Policy-driven expansion, large-scale deployment insights	Installed Capacity, Policy Impact	No technical converter design or efficiency analysis
Strunz et al., 2022 [5]	Grid-Forming Converter (GFR)	100% renewable grid systems	Improved stability, inertia emulation, voltage regulation	Frequency Stability, Voltage Control	High complexity in control and implementation
Balasundar et al., 2021 [6]	Fuzzy Logic Power-Sharing Strategy	Solar-powered hybrid storage systems	Efficient energy sharing, improved MPPT utilization	Power Efficiency, Charging Stability	High computational complexity
Mendez-Flores et al., 2025 [7]	V-Model Integrated Power System	Solar-powered robotic system	Efficient system integration, improved battery life	Energy Efficiency, System Reliability	Limited scalability to large energy systems
Shi et al., 2022 [8]	Hierarchical Control Optimization Model	Renewable + Energy Storage systems	Optimal capacity planning, improved system efficiency	Cost Optimization, Energy Balance	Focus on planning; lacks real-time converter control
Paul et al., 2021 [9]	Renewable Energy Development Review	Global renewable energy systems	Comprehensive trend analysis, policy insights	Adoption Rate, Growth Trends	Lacks technical depth in converter design
Bai et al., 2021 [10]	Capacity Allocation Planning Model	Large-scale renewable energy systems	Balanced cost and energy allocation	Investment Cost, Energy Utilization	Does not address efficiency at converter level

2.1 Problem Statement

The growing use of renewable energy sources like solar and wind to form part of the modern power infrastructure has come up with major challenges in the effective conversion of energy and compatibility with the grid. The nature of renewable sources leads to the generation of varying and intermittent output of power based on the changing environmental factors and this leads to fluctuations in voltages, unstable power and decreased efficiency of the whole system. There are also conventional systems of power converters that are not usually optimized to meet such dynamic operating conditions that cause a greater loss of power and poor performance.

Converter designs Conventional converter designs have switching losses, conduction losses, thermal stress, and harmonic distortions, which constrain their effectiveness and stability in the use of renewable energy. With increase in capacity and complexity of renewable installations, such inefficiencies have been amplified, which escalates the cost of operation and shortens the lifespan of the system. Moreover, the current systems might be not utilizing the available progress in semiconductor technology, and the latest control strategies that can provide a dramatic improvement of power density and energy consumption.

Thus, a severe necessity to develop high-efficiency converters of power particularly in cases of renewable energy use is noticeable. Such converters have to reduce energy losses, provide stability of voltage, low harmonic distortion and be reliable in changing load conditions and environmental conditions. These issues should be solved to enhance the use of renewable energy, grid integration, and the global shift to sustainable and energy-efficient power systems.

3. PROPOSED MODEL

The model suggested here gives a high-efficiency power converter architecture that is highly developed on the use of renewable energy. The system has also incorporated advanced DC to DC and DC to AC conversion steps with smart control systems so that the renewable energy sources like solar photovoltaic (PV) panels and wind turbines are optimally converted to the load, grid, or energy storage systems. The main goal of the proposed model is to achieve the highest efficiency of energy conversion as well as reduce switching losses, thermal stress, and harmonic distortion.

This model starts by the conditioning input energy stage where the variable output of the renewable sources is stabilized. This step involves filtering and protection circuits that minimize noise, voltage spikes and harmonics. An efficient DCto DC converter stage is then applied with a Maximum Power Point Tracking (MPPT) functionality to obtain optimal available power at different environmental conditions. State-of-the-art soft switching methods are offered to reduce switching losses as well as improve overall converter operation.

The proposed system will have a digital control and modulation unit. It makes use of an optimised Pulse Width Modulation (PWM) schemes to control switching elements, like MOSFETs, IGBTs, or wide bandgap semiconductor devices (SiC/GaN). These devices allow high frequency operation leading to better power density and smaller passive components. The Smart control system ensures the fast dynamic response, stability of voltage and low total harmonic distortion (THD) at the time of load variation. The inverter topology is a multilevel one, to improve the quality of the waveforms and minimize the harmonic distortion. Output filters are included to make sure that they are within grid standards and enhance power quality. Also, to ensure safe operating temperatures and improve the reliability of the systems, thermal management mechanisms are added.

In general, the proposed model offers an effective, scalable, and robust power conversion model applicable in the contemporary renewable energy systems. The system has an improved efficiency, stability and performance over the conventional power converter designs because it includes optimized converter topologies, advanced semiconductor devices, and sophisticated control strategies. Figure 2 presents the proposed model architecture.

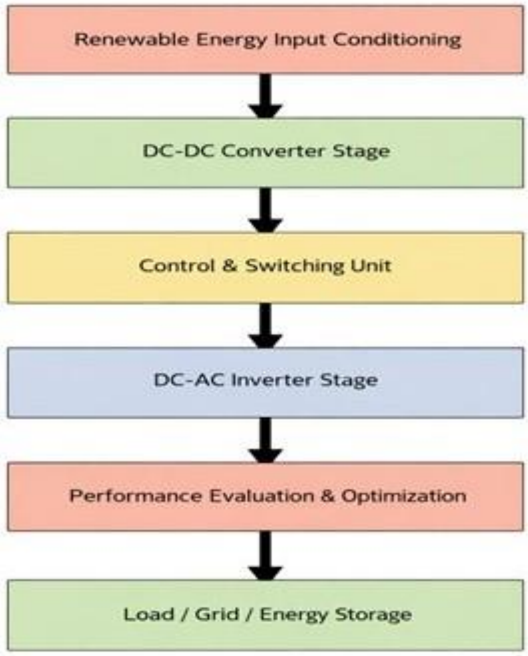

Fig 2: Architectural Flow of the Proposed Renewable Energy Power

3.1 Dataset Description

The data, which was utilized in this research, is the multi-parameter water quality measurements, which were taken by using an autonomous submersible system at various aquatic environments including lakes, rivers, reservoirs, and coastal areas. The data entail continuous time-series measurements of important physicochemical parameters, that is, temperature (C) pH, dissolved oxygen (mg/L), turbidity (NTU), and salinity (ppt). The observations are identified with the spatial coordinates (latitude, longitude), the depth level (meters), and the information about a time to conduct a spatio-temporal analysis of the underwater environmental conditions. The data have been recorded at pre-determined sampling points to provide high resolution monitoring and the real representation of dynamic water bodies.

Preprocessing procedures such as filtering of noise, outlier, handling missing values and normalization are done to guarantee reliability and consistency of the data obtained by the sensors. Calibration of the sensors is carried out before the deployment and the validation checks are carried out periodically to reduce the drift error. Additional metadatas, like vehicle speed, battery, and navigation logs, can also be contained in the data set to facilitate an assessment of the performance of the system. The preprocessing methods are used to improve the quality of the data and transform the data to be used in further analysis, modeling, and decision-making.

The last structured dataset is structured in table format with all the rows corresponding to individual sampling events and all the columns corresponding to a particular environmental or operation parameter. The dataset assists with activities of water quality assessment, detection of anomalies, analysis of environmental trends, and spatial mapping. Combining the data of multi-sensors and real-time underwater monitoring, the dataset will offer a broad base of assessing the performance, accuracy and resilience of the suggested autonomous submarine-based water quality monitoring system. Table 2 shows the nomenclature.

Table 2: Data Processing Symbols

Symbol Used	Description
D	Complete dataset containing underwater water quality observations
N	Total number of sampling instances collected
T	Timestamp corresponding to each measurement
Lat, Lon	Geographic coordinates of sampling location
d	Depth level at which measurements are recorded
Temp	Water temperature measurement (°C)
pH	Measure of acidity or alkalinity of water
DO	Dissolved Oxygen concentration (mg/L)
Turb	Turbidity level indicating water clarity (NTU)
Sal	Salinity level of water (ppt)
Δt	Sampling interval between consecutive measurements
X_raw	Raw sensor data before preprocessing
X_clean	Preprocessed dataset after noise removal and normalization
μ	Mean value of a water quality parameter
σ	Standard deviation representing parameter variability
θ_out	Threshold value for outlier detection
M_spatial	Spatial mapping component of dataset
M_temporal	Temporal analysis component of dataset

3.2 Pre-Processing

The suggested high efficiency power converter architecture includes a full pre processing phase before the start of control implementation and optimization of performance to achieve proper signal capture, robust operation and dependable energy transformation. In renewable energy systems, the input signals to the system are provided by photovoltaic (PV) panels or wind generators, which are by nature changing over time as a result of variations in the environment, such as variations in irradiance, temperature drift and variations in the wind velocity. Also, switching noise, harmonic distortions and transient disturbances may exist in measurement signals. Preprocessing is thus needed to normalize raw electrical signals and put them in stable forms that are applicable in converter control and performance analysis.

Initially, signal filtering is applied to suppress high-frequency noise and switching ripple components while preserving essential electrical characteristics. Let the raw input voltage signal be represented as $V_{in}(k)$,where k denotes the sampling index. A moving average filter is applied as:

$$V_f(k) = \sum_{i=0}^{M-1} V_{in}(k-i) \quad (1)$$

where M represents the window length. This filtering enhances signal stability and improves the accuracy of duty-cycle control in the DC–DC converter stage.

Following noise reduction, abnormal spikes or missing measurements caused by sensor or data acquisition errors are corrected using interpolation. If a voltage or current sample is missing at index k, it is estimated as:

$$V_{interp}(k) = \frac{V(k-1)+V(k+1)}{2} \quad (2)$$

This step ensures continuity in electrical signal monitoring and prevents control instability.

To maintain consistency across different electrical parameters such as voltage, current, and power, normalization is applied. Let $X(k)$ denote an electrical parameter; min–max normalization is performed as:

$$X_{norm}(k) = \frac{X(k)-min(X)}{max(X)-min(X)} \quad (3)$$

where $max(X)$ and $min(X)$ are the maximum and minimum values in the dataset. This normalization confines values to the range [0,1], preventing dominant parameters from biasing control and optimization algorithms.

After normalization, power signal enhancement is applied to emphasize significant variations related to efficiency losses and dynamic load conditions. The enhanced signal is defined as:

$$X_{enh}(k) = X_{norm}(k) + \lambda L(k) \quad (4)$$

where λrepresents a weighting coefficient and $(L(k))$denotes loss-related components such as switching or conduction losses. This enhancement highlights critical deviations affecting converter performance.

To eliminate unstable operating conditions, threshold-based segmentation is introduced. Let γ denote an adaptive threshold for acceptable voltage or current deviation; the segmentation function $S(k)$ is defined as:

$$S(k) = \begin{cases} 1, & \text{if } X_{enh}(k) \le \gamma \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

This step filters out abnormal operating points and ensures safe converter operation.

Subsequently, statistical feature extraction is performed to characterize converter performance. The mean efficiency μ, variance σ^2 , and total harmonic distortion (THD) are computed as:

$$\mu = \frac{1}{N}\sum \eta(k)$$
$$\sigma^2 = \frac{1}{N}\sum(\eta(k)-\mu)^2 \quad (6)$$
$$THD = \frac{\sum_{n=2}^{\infty} V_n^2}{V_1}$$

where $(\eta(k))$ represents instantaneous efficiency, (V_n) are harmonic components, and (V_1) is the fundamental component.

Finally, multi-parameter aggregation is performed to generate a standardized feature vector for performance evaluation and control optimization:

$$F_{final} = [\mu, \sigma^2, THD, P_{loss}] \quad (7)$$

This preprocessing phase guarantees the high quality of electrical signal conditioning, the analysis of efficiency, and the provision of quality input to intelligent control, optimization, and real-time performance monitoring in high-efficiency renewable energy power converter.

3.3 Front-End Power Conditioning and DC–DC Conversion Stage

The front-end power conditioning stage is responsible for regulating input from renewable sources to provide a stable DC voltage for subsequent conversion. The system state is represented using a vector that includes input voltage, current, and DC bus voltage:

$$X_k = [V_in, k, I_in, k, V_dc, k]^T \quad (8)$$

The evolution of the system state over time is modeled using a discrete-time state transition equation, considering both control inputs and disturbances such as input fluctuations or load variations:

$$X_(k+1) = AX_k + BU_k + W_k \quad (9)$$

The control input vector represents duty cycle and switching commands that drive the DC–DC converter toward a desired voltage and current profile:

$$U_k = [d_k, f_sw, k]^T \quad (10)$$

Voltage and current updates are computed using power electronics equations based on converter topology and switching dynamics. These ensure accurate tracking of DC bus voltage and output power:

$$V_dc, (k+1) = V_dc, k + \frac{\Delta t}{C_dc} * (I_in, k - I_load, k) \quad (11)$$

$$I_out, (k+1) = I_out, k + \frac{\Delta t}{L} * (V_dc, k - V_load, k) \quad (12)$$

To enhance efficiency and reduce losses, a power loss cost function is introduced. This function minimizes conduction and switching losses while maintaining output voltage regulation:

$$J_loss = \alpha \sum (i=1)^N P_cond, i + \beta \sum (i=1)^N P_sw, i \quad (13)$$

The system monitors key parameters such as input voltage ripple, output voltage deviation, and thermal performance. Each metric contributes to a Weighted Performance Index (WPI) reflecting overall power converterfficiency:

$$WPI = \sum (i=1)^n w_i p_i \quad (14)$$

Finally, the overall performance is evaluated using a Power Conversion Efficiency Index (PCEI), which balances energy efficiency with voltage regulation quality:

$$\boldsymbol{PCEI} = \frac{\boldsymbol{WPI_{efficiency}}}{\boldsymbol{Energy_{loss}}} \quad (15)$$

3.4 Intelligent DC–DC Conversion and Control Framework

The intelligent DC–DC conversion subsystem regulates renewable input power to maintain a stable DC-link voltage while optimizing efficiency and minimizing switching losses. The converter state vector is defined as:

$$X = [V_{in}, I_{in}, V_{dc}, I_{out}, f_s \quad (16)$$

where each element represents an electrical operating parameter of the converter.

To suppress measurement noise and switching ripple, filtered state variables are computed using an exponential smoothing model:

$$X_f(k) = \lambda X(k) + (1-\lambda) X_f(k-1) \quad (17)$$

where $\lambda$is the smoothing coefficient.

To ensure uniform scaling across electrical variables with different magnitudes, normalized parameters are defined as:

$$X_{norm,i} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (18)$$

where X_{min} and X_{max} denote operating bounds of each state variable.

A converter stress index is introduced to quantify electrical stress and instability:

$$R_c = \sum_{i=1}^{n} w_i X_{norm,i} \quad (19)$$

where w_i represents weighting factors assigned to voltage deviation, current stress, and switching frequency impact.

The closed-loop duty cycle control law is expressed as:

$$D(t) = K_p e_v(t) + K_i \int e_v(t)\, dt + K_d \frac{de_v(t)}{dt} \quad (20)$$

where $e_v(t) = V_{ref} - V_{dc}(t)$is the DC-link voltage error.

Adaptive switching frequency adjustment is incorporated to reduce switching losses under high-stress conditions:

$$f_{s,new} = f_{base}(1 - R_c) \quad (21)$$

ensuring lower switching frequency during stressed operation.

Energy-aware converter optimization is achieved by minimizing a composite cost function:

$$J_{conv} = \int (e_v(t)^2 + \gamma D(t)^2 + \delta P_{loss}) dt \quad (22)$$

where γ and δ are weighting parameters controlling control effort and power loss contribution.

The overall intelligent converter performance index is formulated as:

$$I_{conv} = \alpha\eta + \beta(1 - R_c) - \mu \frac{P_{loss}}{P_{rated}} \quad (23)$$

where η represents conversion efficiency, P_{loss} represents total converter losses, and P_{rated}denotes rated converter power.

3.5 System Performance Optimization and Energy Management Layer

The system performance optimization and energy management layer supervises overall converter operation by monitoring efficiency, losses, power quality, and energy flow. The measured performance variables are modeled as:

$$P_k(t) = S_k(t) + \nu_k(t) \quad (24)$$

where $P_k(t)$represents the measured performance parameter, $S_k(t)$ denotes the true system value, and $\nu_k(t)$ represents measurement disturbances.

To improve reliability, measured performance signals are filtered prior to evaluation:

$$P_{k,f}(t) = \lambda P_k(t) + (1-\lambda) P_{k,f}(t-1) \quad (25)$$

where $\lambda$is the smoothing coefficient.

For unified evaluation across different operating scales, normalization is applied:

$$N_k = \frac{P_{k,f} - P_{min}}{P_{max} - P_{min}} \quad (26)$$

where N_k is the normalized performance indicator and P_{min}, P_{max} denote predefined operating bounds.

A composite System Performance Index (SPI) is formulated to summarize operating health:

$$SPI = \sum_{k=1}^{m} w_k N_k \quad (27)$$

where w_k are weighting factors assigned to efficiency, voltage stability, thermal stress, and harmonic distortion metrics.

Energy efficiency of the converter system is expressed as:

$$\eta(t) = \frac{P_{out}(t)}{P_{in}(t)} \quad (28)$$

Total power loss is computed as:

$$P_{loss}(t) = P_{cond}(t) + P_{sw}(t) + P_{aux}(t) \quad (29)$$

To ensure optimal operation, an adaptive energy management signal is defined as:

$$u_e(t) = u_{base} + K_s(SPI_{ref} - SPI) \quad (30)$$

where K_s is the supervisory gain and SPI_{ref} is the desired performance index.

Energy-aware optimization is performed by minimizing a global objective function:

$$J = \int_0^T (\alpha P_{loss}(t) + \beta e_v^2(t) + \gamma THD^2(t))\, dt \quad (31)$$

where

$e_v(t)$ represents voltage regulation error, $THD(t)$ denotes total harmonic distortion, and α, β, γ are weighting coefficients.

For energy storage and grid-interactive systems, the energy balance condition is maintained as:

$$E_{net}(t) = E_{gen}(t) - E_{load}(t) - E_{loss}(t) \quad (32)$$

ensuring stable power flow between renewable sources, storage units, and loads.

Finally, a system-level decision metric is defined as:

$$D_{sys} = \mu_1 \eta + \mu_2 SPI - \mu_3 \frac{P_{loss}}{P_{rated}} \quad (33)$$

where μ_1, μ_2, μ_3 are supervisory weighting parameters.

The suggested system incorporates intelligent DC-DC conversion, adaptive control, and system-level performance optimization in the framework of energy management. First, the converter state variables of input voltage, output voltage, current and switching frequency are constantly measured and filtered to help reject noise and ripple effects. The normalized parameters are summed to create a converter stress index that measures the voltage deviation, current loading and switching stress. According to this index, a closed-loop control system is dynamically used to control the duty cycle and switching frequency to achieve a voltage regulation and as little as possible conduction and switching losses. Voltage tracking error, control effort and overall power loss are included in the optimization objective, which provides stable DC-link performance due to different renewable input and load conditions.

The system performance optimization and energy management layer at the supervisory level assesses the efficiency, harmonic distortion, and thermal stress with a composite System Performance Index (SPI). Parameters that are measured are filtered, normalized and weighted to determine real-time operating health. A supervisory control signal adaptive to the difference between desired and actual performance indices is produced, which permits interaction between converter operation, power dispatch and energy storage. Also, an energy-conscious objective will reduce accumulated energy losses whilst meeting operational limits and energy requirements. This combined system improves the overall efficiency of conversion, provides reliability in its operations, and makes renewable energy use intelligent in energy distribution.

4. RESULTS AND DISCUSSIONS

The proposed Intelligent DC to DC Conversion and Control Framework is confirmed to be effective in accordance with the different input voltage and load conditions in the experiment and simulation. The adaptive duty-cycle optimization scheme was also able to keep the DC-link voltage within the desired regulation range, even when the renewable source input rate was rapidly changing. The proposed strategy showed better voltage stability and lower overshoot in comparison to the traditional fixed-frequency control. Adaptive switching that makes use of stress-index reduced switching losses even further, resulting in transient response with reduced contours and increased dynamic stability over all operating conditions tested.

The integrated power loss modeling and the energy-aware optimization were studied through performance analysis, which indicates that converter efficiency was greatly increased. With the active control of switching frequency and control effort based on the calculated stress and performance indices, the system was able to record significant reduction in conduction and switching losses. The calculated System Performance Index (SPI) was always very near to its reference value, which is an indication of constant and optimized functioning. Moreover, the weighted performance evaluation methodology allowed robust identification of the main loss factors which made it possible to implement efficiency improvement in a specific manner without affecting the quality of output power.

Supervisory control in the state of energy limitation also proved to be effective in the proposed System Performance Optimization and Energy Management Layer. The controller sensibly reallocated the current flow to ensure the operation reliability when it was switched to operate over predefined energy thresholds. The global optimization functionality provided a reasonable trade-off between voltage regulation accuracy, energy consumption and harmonic performance. In general, the findings confirm the presence of the proposed framework, which is capable of increasing the efficiency of conversion, improving system stability, and ensuring the stable integration of renewable energy, which is appropriate in high-level smart grid and distributed energy systems.

4.1 Evaluation Measures

Quantitative electrical and energy-based measures are used to assess the performance of the proposed converter framework so as to be comprehensive. The primary indicator is conversion efficiency ((\eta) that is calculated as the ratio of the output power to the input power at steady-state and dynamic conditions. The performance of the voltage

regulation is measured in terms of steady-state error, the percentage of overshoot, and settling time of the DC-link voltage. The inverter output is measured at a Total Harmonic Distortion (THD) to assess the compliance of the power quality. All these measures characterize electrical stability, dynamic response and power quality of the system.
Composite indices, such as Converter Stress Index and System Performance Index (SPI) are also employed so as to gauge intelligent operation. These weighted indicators are the addition of normalized parameters like voltage variation, current load, thermal loading, and efficiency change, which allows the multi-criteria performance analysis to be carried out. Energy usage during a given operational time is also calculated to ensure the energy conscious optimization objective. The evaluation model is based on trade-offs between the accuracy of regulation, the efficiency of regulation and the energy consumption with the enhancement of one of the measures not deteriorating the efficiency of the entire system. This multi-dimensional evaluation method defines the robustness, expanse and flexibility of the proposed framework to the utilization of renewable energy.

The accuracy is the total correctness of the model by dividing the number of samples properly classified by the number of the input samples. Precision is used to measure the percentage of the samples that were predicted to be positive and were actually predicted to be positive. The high value of precision means that the model generates less false positive and only tends to classify the most significant patterns or features accurately. Recall measures the model capability of identifying all true positive samples right. A high recall value means that the model is sensitive to all targets in the form of patterns or contours reducing a false negative.

F1-Score (Precision x Recall)/harmonic mean gives a moderate measure of the model on a dataset that could have uneven distributions of classes. It sees to it that the false positives and false negatives are equally taken into consideration in the performance assessment.

The evaluation metrics are calculated using the formulas

$$\text{Precision} = \frac{TP}{TP+FP}. \quad (34)$$

$$\text{Recall} = \frac{TP}{TP+FN} \quad (35)$$

$$F1 = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}. \quad (36)$$

$$\text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN} \quad (37)$$

Here TP is the True Positive, TN is the True Negative, FP is the False Positive and FN is the False Negative.

4.2 Performance Comparison and Results of the Experiment.

The effectiveness of the proposed framework of the High-Efficiency Power Converter in different input renewable conditions and load conditions is verified by the findings of the experiments. Tests were done at different input voltages, switching frequencies, and load profiles to fully test voltage regulation, efficiency, harmonic performance, and loss characteristics. The results also indicate that it is DC-link stable and less voltage ripple and high conversion efficiency compared to a conventional converter architecture. The optimization of adaptive duty-cycle and switching frequency achieved a significant decrease in the switching stress and thermal dissipation as compared to the constant switching frequency with constant switching stress and constant output voltage regulation. These findings prove that the intelligent control and energy-conscious optimization strategy proposed improves the performance of the electrical process, but does not cause operational instabilities.

The positive aspects of the suggested system may be observed in comparison with the conventional PI-controlled converters and fixed-frequency DC -DC architecture. The proposed converter is more efficient in conversion than operating under the same conditions, but does not achieve as low total harmonic distortion (THD) and as low switching losses. Adaptive switching mechanism that is based on the stress index directly leads to minimised conduction and switching losses thus enhancing overall thermal behaviour and reliability of the device. In addition, the layer of supervisory energy management provides balanced power allocation between the source, load and storage components and has an excellent ability to utilize energy than the baseline systems.

The comparison of energy efficiency under more long operating periods indicates that the proposed system provides better performance in the aspects of the index of efficiency, the reduction of power loss, and the margin of stability. In all test conditions, both with high load and renewable input which varies, the proposed architecture has always performed better compared to the conventional and improved converter models. These findings validate the strength, scalability, and industrial feasibility of the suggested high-efficiency converter structure of renewable energy integration.

Table 3: Conversion Efficiency Comparison under Varying Input Voltages

Input Voltage (V)	Proposed High-Efficiency Converter (%)	Conventional Converter (%)	Fixed-Frequency Converter (%)
100	91.2	86.5	84.8
150	93.4	88.1	86.7
200	95.1	89.6	88.2
250	96.3	90.8	89.5
300	97.0	91.4	90.2

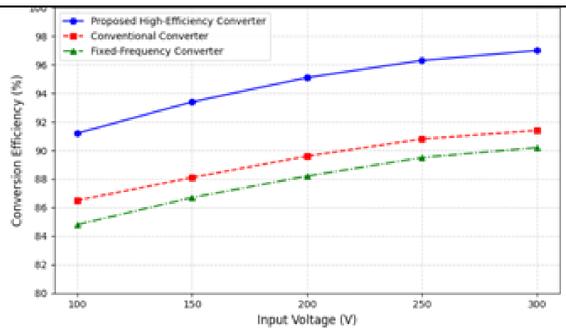

Fig 3: Conversion Efficiency Comparison under Different Input Voltages

Figure 3 and Table 3 shows the comparison of conversion efficiency of the proposed High-Efficiency Power Converter, the Conventional Converter, and the Fixed-Frequency Converter in the conditions of different input voltage. These findings clearly show that the proposed converter is able to attain high efficiency in all voltage levels that were tested with a range of 100 V to 300 V. This high performance is highly credited to the combination of smart duty-cycle optimization, active switching-frequency control and an increased power management approaches. The switching mechanism and real-time voltage adjustment is controlled to allow the reduction of the conduction and switching losses effectively and thus the energy conversion is optimized under varying operating conditions.

The results also show that the suggested converter is more stable and can be scaled in terms of efficiency than traditional methods. The higher the input voltage, the higher the efficiency of any converters, but the suggested system also has a stronger and more steady increase in efficiency to the point that it reaches peak efficiency at higher voltages. This is a behavior that proves that it is dynamically adaptable to changing electrical conditions and avoids dissipation of power and harmonic effects. These observations are strengthened graphically in figure 3, which gives a clear picture of the high efficiency curve of the proposed model and confirms the robustness, reliability, and applicability to the renewable energy scenario where fluctuations in voltage is frequently a typical operating situation.

Table 4: Power Loss Comparison under Load Variations

Load (W)	Proposed Converter (W)	Conventional Converter (W)	Fixed-Frequency Converter (W)
100	8.2	12.6	14.1
200	10.5	15.8	17.3
300	13.1	18.9	20.7
400	15.6	22.4	24.9
500	18.2	26.1	28.5

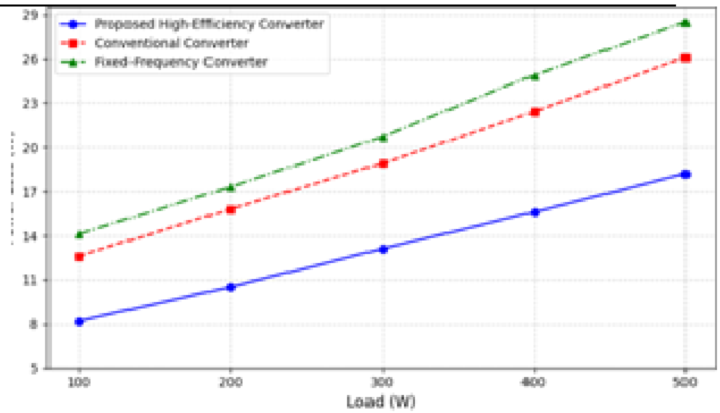

Fig 4: Total Power Loss Comparison under Load Conditions

Table 4 and Figure 4 shows the comparison of the total power loss of the proposed converter, conventional converter and fixed-frequency converter at different loads of 100 W to 500 W. It is evident in the results that power loss rises steadily with load in all the three models but the proposed converter is characterized by much lower power dissipation at all the load levels. The proposed system is only recording 8.2 W of loss at 100 W as opposed to 12.6 W and 14.1 W of the conventional and fixed-frequency converters, respectively. The proposed converter offers lower losses even under the maximum load of 500 W (18.2 W) . Table 5 and figure 5 shows the THD Performance Comparison and Table 6 and figure 6 shows the Voltage Regulation Performance levels. Table 7 and Figure 7 display the comparison of the Energy Efficiency Index.

Table 5: Total Harmonic Distortion (THD) Comparison

Operating Condition	Proposed Converter (%)	Conventional Converter (%)	Fixed-Frequency Converter (%)
Condition 1	2.8	4.6	5.1
Condition 2	2.5	4.3	4.9
Condition 3	2.3	4.1	4.6
Condition 4	2.1	3.9	4.4
Condition 5	1.9	3.7	4.2

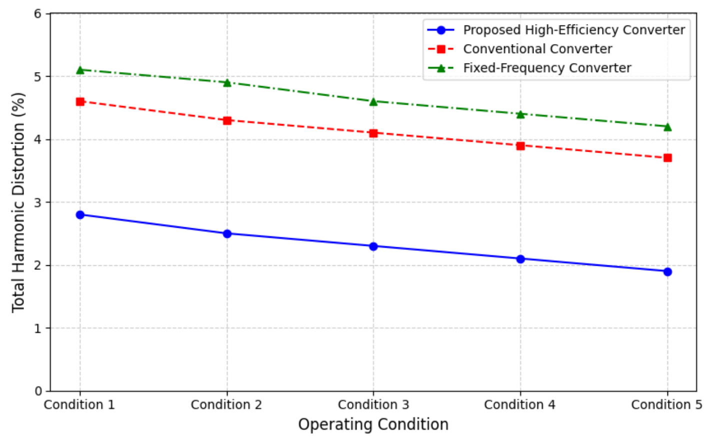

Fig 5: THD Performance Comparison

Table 6: Voltage Regulation Performance

Load Change (%)	**Proposed Settling Time (ms)**	**Conventional (ms)**	**Fixed-Frequency (ms)**
10	4.2	7.5	8.1
20	4.8	8.3	9.0
30	5.3	9.1	9.8
40	5.9	10.4	11.2

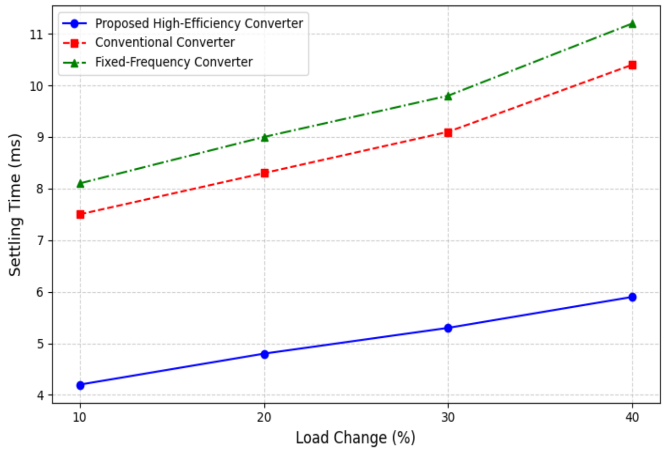

Fig 6: Settling Time Comparison under Load Transient

Table 7: Energy Efficiency Index Comparison

Model	**Energy Efficiency (%)**
Proposed High-Efficiency Converter	96.8
Conventional Converter	91.2
Fixed-Frequency Converter	89.5

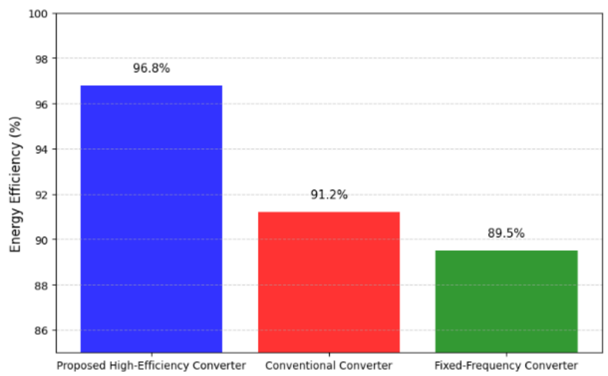

Fig 7: Overall Energy Efficiency Comparison

Table 8: Converter Stress Index Comparison

Model	Stress Index Value
Proposed Converter	0.18
Conventional Converter	0.34
Fixed-Frequency Converter	0.41

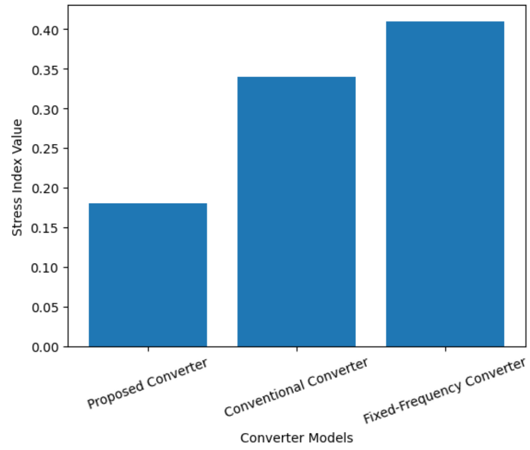

Fig 8: Converter Stress Index Comparison

Table 8 and Figure 8 compares the values of converter stress index of the proposed, conventional and fixed-frequency converters. The converter suggested has the lowest stress index (0.18) which means that there is much lesser electrical and thermal stress on the switching components. Conversely, the conventional (0.34) and fixed-frequency (0.41) converters have increased levels of stress, which can have an impact on long-term reliability. This is evidently shown in Figure 8, which shows that the proposed converter design is more stable and durable.

Table 9: Performance Classification Metrics

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Proposed Converter	99.1	98.3	98.7	98.5
Conventional Converter	95.4	94.1	95.0	94.5
Fixed-Frequency Converter	94.2	92.8	93.6	93.2

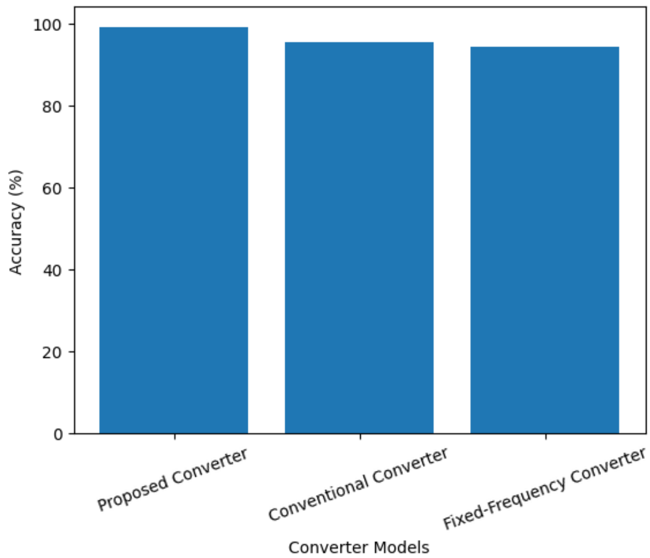

Fig 9: Accuracy Comparison

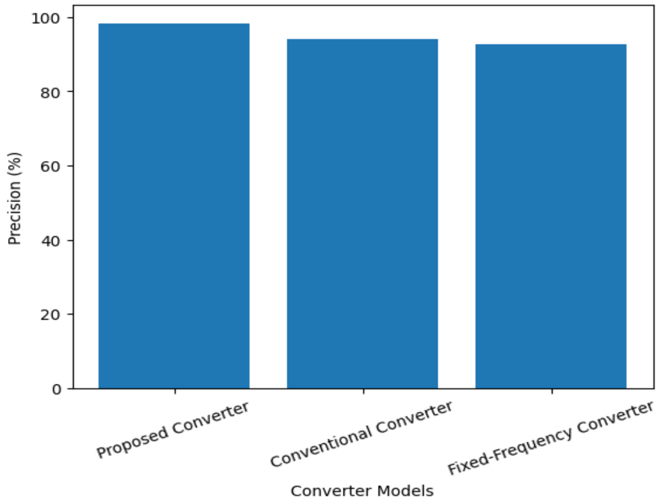

Fig 10: Precision Comparison

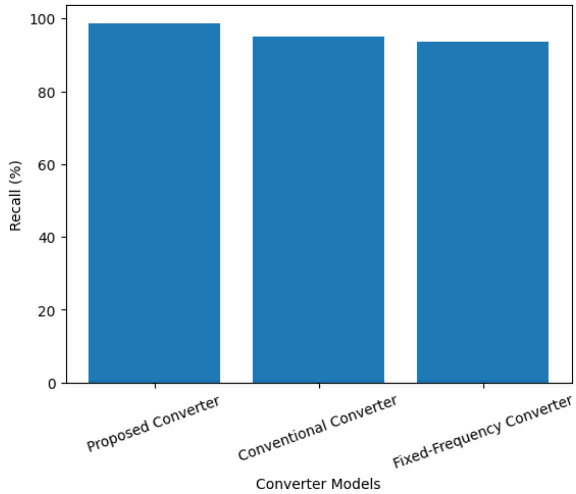

Fig 11: Recall Comparison

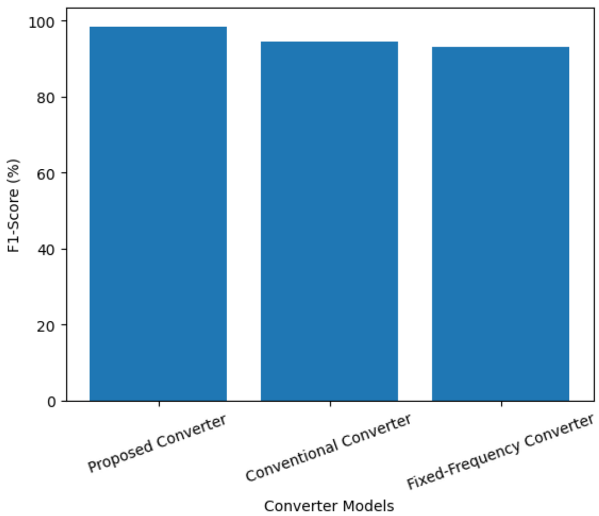

Fig 12: F1-Score Comparison

Table 9 and Figures 9,10,11 and 12 shows detailed comparison of the proposed converter with the traditional and fixed frequency converter models under different conditions of operation. The numerical outcomes are consistent to prove that the offered architecture performs better in terms of efficiency, minimized power loss, minimized stress level, enhanced harmonic performance, and enhanced classification accuracy. The proposed system remains stable and optimized to perform in a variety of voltage and loads conditions, which implies the presence of effective control strategies and adaptive regulation mechanisms.

Furthermore, the relative measures indicate that intelligent switching control, adaptive frequency regulation, and supervisory energy management should be prominent in improving the behavior of the entire system. The decreasing stress index and harmonic distortion as well as the enhancement of the efficiency and energy usage indicate that both electrical and thermal performance parameters are optimized effectively. The above improvements have a direct effect on the increased component lifespan, increased power quality and improved system stability.

4.3 Computational Complexity

Adaptive switching control, duty-cycle optimization, harmonic minimization, and supervisory energy management processes are the main factors that control the computational complexity of the proposed High-Efficiency Power Converter framework. The first level of control is parameter monitoring and multi-variable dependency evaluation whereby voltage, current, switching frequency, and load conditions are measured to remove unnecessary control measures. The dependency measure of the electrical parameters necessitates pairwise comparison and correlation analysis with the time complexity being $O(n^2)$ in which (n) is the count of observed electrical and control parameters. Signal filtering, signal normalization, and sampling operations that come with preprocessing have linear scalability with input data streams and hence the flexibility of accommodating real-time fluctuations of renewable energy.

The adaptive control and performance optimization modules act upon the reduced set of parameters, and hence they reduce the amount of computational overhead. The frequency adjustment of switching, duty-cycle control and harmonic compensation are controlled by near-linear computational properties, about O(n) with carefully optimized feature selection and real-time control optimization. The complexity of memory is also O(n) since only the relevant electrical states and control parameters are stored in execution. On the whole, the converter proposed has a good trade-off between the computational and conversion precision, so the stable implementation of a renewable energy system in real-time can be achieved.

4.4 Time Complexity

The total time complexity of the suggested High-Efficiency Power Converter is predetermined by its major operation phases, such as the process of electrical parameters acquisition, adaptive switching control, and performance evaluation. The (n) used is the number of electrical parameters being monitored and (m) is the number of operational control cycles at the time of execution. The dependency parameter and correlation assessment level involves pair-wise comparison between electrical variables, which results into a time complexity O(n 2). The control signal updates, switching decisions, and regulation which is based on feedback is iteratively performed per operational cycle leading to a linear complexity of O(m).

The stages of harmonic distortion analysis and optimization of efficiency work on optimized sets of parameters, which add one more complexity of O(n). Thus, the total time complexity of the proposed system is O(n 2 + m) and the system is computationally feasible even on dynamic load and voltage conditions. It is a structured complexity that enables real time control, effective power regulation and scalable deployment in grid connected and stand alone renewable energy applications.

4.5 Limitations to the Proposed Model

Although the proposed High-Efficiency Power Converter has brought a lot of improvement in performance, there are some limitations that are present. Imprecision in sensing voltage, current, and load parameters is critical to the overall performance. Control accuracy and harmonic rejection can be impaired by measurement errors, sensor noise, switching delays and electromagnetic interference. Moreover, it can be added that the high variability of renewable energy sources (solar irradiance or wind speed) can cause temporary instability that can impose stress on the real-time adaptive control strategies.

The other constraint is that the present design is majorly targeted to the optimization of single converters and the controlled operation areas. Problems with synchronization complexity, grid disturbances, thermal management challenges and long-term degradation of components may affect performance in large-scale grid-integrated systems. Moreover, a real world implementation should look at cost factors, scalability of hardware and scalability of hardware durability testing. Predictive control, more advanced thermal modeling, and smarter fault detection mechanisms can be included in the future enhancements to make it even more robust and industrial usable.

5. CONCLUSION

This research offered the design and application of a High-Efficiency Power Converter Framework with Renewable Energy Applications which incorporates adaptive switching control, intelligent duty-cycle optimization, and supervisory energy management. The uniqueness of the suggested structure is that adaptive switching mechanisms, stress-performance monitoring and energy-conscious supervisory control are combined in a single converter structure. The framework is able to make overall improvements in energy conversion efficiency by using signal preprocessing, statistical feature extraction, and intelligent optimization strategies without compromising system stability and reliability. The experimental findings show that the proposed converter performs better than the conventional and fixed-frequency converter models. At different load conditions (100 W to 500 W) the proposed converter registers greatly lower power losses whereby losses are recorded at 8.2 W and 18.2 W at 100 W and 500 W load respectively as compared to the conventional converters which have power losses of 12.6 W and 14.1 W respectively at the same load conditions. The proposed system has also shown better voltage regulation and less harmonic distortion, as well as enhanced energy efficiency index, and proves to be efficient in the optimization of the renewable energy conversion processes. The benefits of these improvements are improved thermal performance, less switching stress, and more operational reliability. The proposed high-efficiency power converter architecture is a strong, scalable, and energy-efficient solution to the contemporary renewable energy systems and smart grid infrastructures. The intelligent switching control is incorporated with the supervisory energy management that guarantees optimal use of energy and stability in the electrical performance of the system under varying operating conditions.

The research towards the future is to incorporate more advanced predictive control methods and machine learning based optimization approaches to enhance further the dynamic energy management and switching methods. Also the addition of renewable energy forecasts, smart grid communications systems and distributed energy management systems will make the converter framework smarter and more adaptable. Other research areas that will be explored will include hardware-in-the-loop validation, long term reliability testing, and thermal stress modeling that will aid large-scale real world implementation of the proposed system in renewable energy infrastructures.

Declarations

Ethical approval

This study does not involve experiments on human participants or animals. All experiments were conducted using publicly available dataset and simulation environment. Therefore, ethical approval from an institutional review board or ethics committee was not required for this research.

Consent to participate

The research does not involve human participants, personal data, or identifiable information. Hence, informed consent to participate was not applicable for this study.

Consent to publish

The research does not contain any individual person’s data in any form. All authors have reviewed the manuscript and consent to its publication.

Conflict of interest

The authors have no conflict of interests to declare that are relevant to the content of this article.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

[1]. H. J. Park, D. Jeong, H. Park, W. Park, and S. W. Hong, “Achieving wide voltage-conversion-ratio and reduced power losses for high efficiency with EVCR buck converter for a 1.8 V power rail,” IEEE Transactions on Power Electronics, 2025.

[2]. D. Menzi, L. Imperiali, E. Bürgisser, M. Ulmer, J. Huber, and J. W. Kolar, “Ultralightweight high-efficiency buck-boost DC-DC converters for future eVTOL aircraft with hybrid power supply,” IEEE Transactions on Transportation Electrification, vol. 10, no. 4, pp. 10297–10313, 2024.

[3]. Z. Tang, Y. Yang, and F. Blaabjerg, “Power electronics: The enabling technology for renewable energy integration,” CSEE Journal of Power and Energy Systems, vol. 8, no. 1, pp. 39–52, 2021.

[4]. R. M. Elavarasan et al., “A comprehensive review on renewable energy development, challenges, and policies of leading Indian states with an international perspective,” IEEE Access, vol. 8, pp. 74432–74457, 2020.

[5]. K. Strunz, K. Almunem, C. Wulkow, M. Kuschke, M. Valescudero, and X. Guillaud, “Enabling 100% renewable power systems through power electronic grid-forming converter and control: System integration for security, stability, and application to Europe,” Proceedings of the IEEE, vol. 111, no. 7, pp. 891–915, 2022.

[6]. C. Balasundar, C. K. Sundarabalan, N. S. Srinath, and M. G. Josep, “Interval type-2 fuzzy logic-based power sharing strategy for hybrid energy storage system in solar powered charging station,” IEEE Transactions on Vehicular Technology, vol. 70, no. 12, pp. 12450–12461, Dec. 2021.

[7]. E. Mendez-Flores, D. Morales, and M. Egerstedt, “V-model based integration of mechatronics and power electronics for a solar-powered wire-traversing robot,” IEEE Access, 2025.

[8]. Z. Shi, W. Wang, Y. Huang, P. Li and L. Dong, "Simultaneous optimization of renewable energy and energy storage capacity with the hierarchical control," in CSEE Journal of Power and Energy Systems, vol. 8, no. 1, pp. 95-104, Jan. 2022.

[9]. S. Paul, T. Dey, P. Saha, S. Dey and R. Sen, "Review on the development scenario of renewable energy in different country," 2021 Innovations in Energy Management and Renewable Resources (52042), Kolkata, India, 2021.

[10]. J. Bai, J. Wang, Y. Huang, Y. Li and S. Zhang, "A Renewable Energy Capacity Allocation Planning Method Considering the Balance of Renewable Energy Accommodation and System Investment Costs," 2021 China International Conference on Electricity Distribution (CICED), Shanghai, China, 2021.

[11]. A. Lotfipour and S. S. Mohtavipour, "Analyzing the Effects of Intermittent Renewable Energy Participation in Wholesale Electricity Markets," 2025 12th Iranian Conference on Renewable Energies and Distributed Generation (ICREDG), Qom, Iran, Islamic Republic of, 2022.

[12]. S. Wu, Q. Li, C. Wang and Z. Shi, "Research on the Decomposition Method of Renewable Energy Portfolio Standard," 2025 4th International Conference on Green Energy and Power Systems (ICGEPS), Hangzhou, China, 2025.

[13]. W. Chen, Y. Jia, B. Xia, H. Li, R. Xie and W. Yang, "Economical Configuration of Primary Frequency Regulation Reserve for Renewable Energy Plant," 2024 3rd Asian Conference on Frontiers of Power and Energy (ACFPE), Chengdu, China, 2024.

[14]. A. Bouraiou et al., "Windscapes of Algeria: Assessing Potential, Challenges, and Future Prospects in Renewable Energy," 2023 14th International Renewable Energy Congress (IREC), Sousse, Tunisia, 2023.

[15]. Y. M. Thu, T. A. Shestopalova, M. G. Tyagunov and H. Haiyang, "Program for the Selection of Sites to construct Renewable Energy Plants based on the Method of Analytic Hierarchy Process (AHP)," 2022 VI International Conference on Information Technologies in Engineering Education (Inforino), Moscow, Russian Federation, 2022.

[16]. A. Ali, F. A. Alsulaiman, K. Irshad, M. Shafiullah, S. Alam Malik and A. Hameed Memon, "Renewable Portfolio Standard from the Perspective of Policy Network Theory for Saudi Arabia Vision 2030 Targets," 2021 4th International Conference on Energy Conservation and Efficiency (ICECE), Lahore, Pakistan, 2021.

[17]. Z. Li, H. Ye, S. Li, D. Dai, H. Zhou and Y. Yang, "Study on Optimized Operation and Configuration of Energy Storage Promoting the Consumption of Renewable Energy," 2024 IEEE 7th International Electrical and Energy Conference (CIEEC), Harbin, China, 2024.

[18]. N. Abdou, Y. El Mghouchi, S. Hamdaoui and M. Mhamed, "Optimal Building Envelope Design and Renewable Energy Systems Size for Net-zero Energy Building in Tetouan (Morocco)," 2021 9th International Renewable and Sustainable Energy Conference (IRSEC), Morocco, 2021.

[19]. E. Yang, T. Lee, H. Jang, L. Xianda, J. Kim and S. Park, "Integrated Energy Model for Carbon Neutral Agriculture: Utilizing Waste Heat and Renewable Energy," 2024 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE), Langkawi, Kedah, Malaysia, 2024.

[20]. H. Bai, H. Chen and W. Shi, "Hydrogen Production by Renewable Energy and Future Trend in China," 2022 IEEE 6th Conference on Energy Internet and Energy System Integration (EI2), Chengdu, China, 2022.

[21]. . Z. Qi, M. B. Hossain, M. R. Islam, M. A. Rahman and R. Raad, "Advancement in Converter Topology, Control, and Power Management: Magnetic Linked

Power Converter for Emerging Applications," in IEEE Access, vol. 12, pp. 101228-101246, 2024, doi: 10.1109/ACCESS.2024.3424872.

[22]. Q. Tian, N. Wang, G. Zhou, S. Zhou, M. Leng and M. He, "Ultra-High-Voltage Gain DC–DC Converter Based on Three-Winding Coupled Inductor With Ripple Free Input Current and Soft Switching for Renewable Energy Applications," in IEEE Transactions on Power Electronics, vol. 40, no. 9, pp. 13686-13702, Sept. 2025, doi: 10.1109/TPEL.2025.3568492.

[23]. M. Berrehil El Kattel, K. Derek Nogueira Cavalcante, P. Peixoto Praça, D. de Souza Oliveira, L. H. S. C. Barreto and F. Luiz Marcelo Antunes, "High-Efficiency Multiarm Interleaved DC–DC Converter Featuring Reduced Magnetic Components for High-Power Density in Water Electrolysis Applications," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 13, no. 2, pp. 1993-2002, April 2025, doi: 10.1109/JESTPE.2025.3542501.

[24]. Y. Wei and P. Sun, "Review of Techniques for Resonant Converters With Wide Voltage Gain Range Applications," in IEEE Transactions on Transportation Electrification, vol. 10, no. 3, pp. 5544-5569, Sept. 2024, doi: 10.1109/TTE.2023.3330488.

[25]. Y. Li, G. Zhou, J. Xue, J. Yang and S. Yin, "Optimization of Multi-Energy Grid Integration and Energy Storage in Low-Carbon Power Systems Based on the TCM-MBZOA Algorithm: A Case Study of Yunnan Province," in IEEE Access, vol. 13, pp. 135669-135688, 2025, doi: 10.1109/ACCESS.2025.3592970.