An Adaptive Control Technique Based Grid Connected Hybrid System Using High Gain Sepic Converter

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Abstract - For grid-connected hybrid systems, effective power conversion and clever control techniques are essential due to the growing use of renewable energy sources. In order to improve voltage regulation and power quality, this work offers a grid-connected hybrid energy system based on adaptive control techniques that uses a high-gain Single-Ended Primary Inductor Converter (SEPIC). The suggested hybrid system combines a number of renewable energy sources, including solar photovoltaic (PV) and battery energy storage, to provide dependable and continuous power delivery in a range of load and environmental circumstances. Wide voltage conversion ratios are achieved with less switching stress and more efficiency by using the high-gain SEPIC converter. In order to account for system uncertainties, renewable intermittency, and grid disruptions, an adaptive control technique dynamically modifies converter and inverter settings. During grid synchronisation, this control strategy guarantees steady DC-link voltage, efficient power sharing, and unity power factor operation. MATLAB/Simulink is used to model and simulate the system, and its performance is assessed under various operating conditions, such as variations in load, changes in irradiation, and grid failures. In comparison to traditional control techniques, simulation findings show increased grid compliance, lower harmonic distortion, quicker dynamic response, and greater voltage gain. Therefore, for contemporary grid-connected renewable energy applications, the suggested adaptive control-based hybrid system with a high-gain SEPIC converter provides an effective and dependable solution.

1. INTRODUCTION

The rapid growth in global energy demand and increasing environmental concerns have accelerated the adoption of renewable energy sources (RES) such as solar photovoltaic (PV) and wind energy. Grid-connected hybrid renewable energy systems are gaining significant attention due to their ability to improve power reliability, reduce dependence on fossil fuels, and enhance system efficiency. However, the intermittent nature of renewable sources and fluctuations in load demand pose major challenges in maintaining voltage stability, power quality, and grid synchronization [1]. DC–DC power converters are essential for conditioning renewable energy sources' output before connecting them to the grid in order to overcome these difficulties. The Single-Ended Primary Inductor Converter (SEPIC), which can function in both step-up and step-down modes with non-inverted output voltage, is one of the most used converter topologies. However, when utilised in low-voltage renewable applications like solar PV systems, traditional SEPIC converters have a restricted voltage gain [2]. By adding linked inductors, switching capacitors, or voltage multiplier cells, high-gain SEPIC converters have been created to get around this restriction and enable greater voltage conversion with less component stress and increased efficiency [3].

Effective control techniques are crucial for grid-connected hybrid systems in order to maintain stable DC-link voltage, control power flow, and adhere to grid rules. Conventional linear controllers, like PI controllers, perform poorly under dynamic operating situations, nonlinearities, and parameter fluctuations. Consequently, by automatically modifying control parameters in response to system uncertainties and external disturbances, adaptive control techniques have become a viable way to improve system robustness [4]. Even in the face of variable renewable output and grid disruptions, adaptive control-based grid-connected systems enhance dynamic responsiveness, reduce total harmonic distortion (THD), and preserve unity power factor functioning [5]. Voltage regulation, power quality, and energy consumption may all be greatly improved by combining an adaptive control technique with a high-gain SEPIC converter.

In order to achieve effective power conversion, dependable grid integration, and enhanced dynamic performance appropriate for contemporary smart grid applications, this study focusses on the design and analysis of an adaptive control technique-based grid-connected hybrid system employing a high-gain SEPIC converter.

1.1 Literature Review - Related Papers

The creation of grid-connected hybrid renewable energy systems has been thoroughly researched as a solution to the problems with power quality, voltage instability, and intermittent renewable energy. To improve system performance, a number of academics have suggested various converter topologies and control schemes.

In their discussion of distributed renewable generating integration with the utility grid, Blaabjerg et al. [1] highlighted the significance of sophisticated power electronic converters and intelligent control strategies for grid compliance. The research emphasised problems with grid-connected systems, including synchronisation problems, voltage fluctuations, and harmonic distortion. A thorough examination of DC–DC converter topologies utilised in renewable energy applications was given by Rashid [2]. Because of its non-inverting output and capacity to function in both buck and boost modes, the SEPIC converter was determined to be an appropriate option. However, the traditional SEPIC converter is less appropriate for low-voltage renewable sources due to its limited voltage gain.

Siwakoti et al. [3] suggested high-gain DC–DC converter designs utilising linked inductors and switching capacitors to get around this restriction. Their research showed that high-gain SEPIC-based converters are appropriate for grid-connected renewable applications as they can achieve high voltage conversion ratios with less switch stress and increased efficiency.

Under nonlinear and dynamic operating conditions, Guerrero et al. [4] examined control techniques for distributed generation systems and emphasised the shortcomings of traditional PI controllers. The authors showed how adaptive and intelligent control strategies greatly enhance grid synchronisation performance, power sharing accuracy, and dynamic reaction.

A basic work on adaptive control theory was provided by Åström and Wittenmark [5], who highlighted the theory's capacity to manage parameter uncertainty and external disruptions. Their work established the foundation for the use of adaptive control techniques in power electronic systems, especially in the integration of renewable energy.

Neural network-based controllers for grid-connected converters, fuzzy adaptive control, and model reference adaptive control (MRAC) are examples of adaptive and intelligent control techniques that have been the subject of more recent research. In comparison to traditional controllers, these methods have demonstrated better DC-link voltage regulation, lower total harmonic distortion (THD), and increased resilience [6], [7]. The research currently in publication indicates a gap in the integrated use of adaptive control techniques and high-gain SEPIC converters in grid-connected hybrid systems, despite notable progress. The majority of research either concentrate on control strategies or converter design independently. An integrated strategy that concurrently improves voltage gain, system stability, and power quality is therefore required.

2. Proposed Block diagram

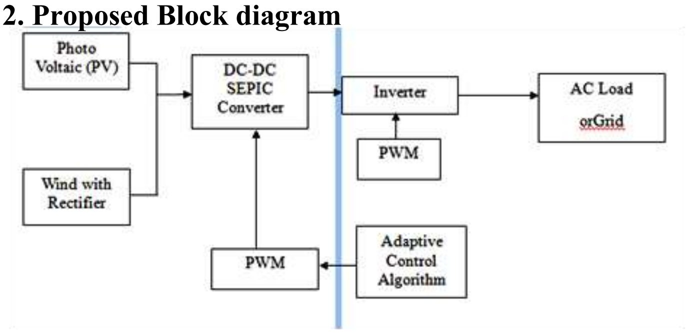

Figure:1 Adaptive control of Solar and Wind Hybrid System

In order to provide reliable and high-quality AC power to the load or utility grid, the suggested system functions as a grid-connected hybrid renewable energy system that integrates solar photovoltaic (PV) and wind energy sources utilising a high-gain SEPIC converter and an adaptive control approach. Solar energy is transformed into DC electricity by the solar PV panel. Concurrently, the wind energy system produces AC electricity, which a rectifier transforms into DC. The output voltages of both sources are constantly fluctuating due to their intermittent and variable character. A hybrid DC input is created by combining the DC outputs from the PV and rectified wind systems. Improved dependability and a steady power supply are guaranteed by this hybridization, even in the event that one source is poor or unavailable. The high-gain SEPIC converter receives the hybrid DC voltage and uses it to boost and control the low and fluctuating input voltage to a higher and steady DC level. Because it can operate in both step-up and step-down modes and generates a non-inverted output, the SEPIC converter is suitable for renewable energy applications.The steady DC-link voltage needed for inverter operation is formed by the SEPIC converter's output.A Pulse Width Modulation (PWM) signal is used to regulate the SEPIC converter's switching function. The converter output voltage is controlled by varying the duty cycle. To react to variations in source voltage and load demand, the PWM signals are updated continually.System variables including DC-link voltage, grid voltage, and load circumstances are tracked by the adaptive control algorithm. It dynamically adjusts the PWM duty cycles and control gains of the inverter and SEPIC converter based on these inputsA voltage source inverter (VSI) transforms the regulated DC-link voltage into AC power. The inverter generates a sinusoidal AC output that may be used for freestanding AC loads or synchronised with the grid. PWM signals, which are produced by comparing reference and feedback signals, are used to regulate the inverter.

Ultimately, the AC load or utility grid receives the conditioned AC electricity. While shortages are made up for by the grid, any extra electricity produced by the renewable sources can be exported. A high-gain SEPIC converter stabilises the fluctuating power supplied by the hybrid renewable sources. To guarantee steady DC-link voltage and excellent AC output, an adaptive control technique continually modifies system parameters. With enhanced performance and fewer harmonics, the inverter provides dependable and effective power to the load or grid.

3. SIMULATION OUTPUT

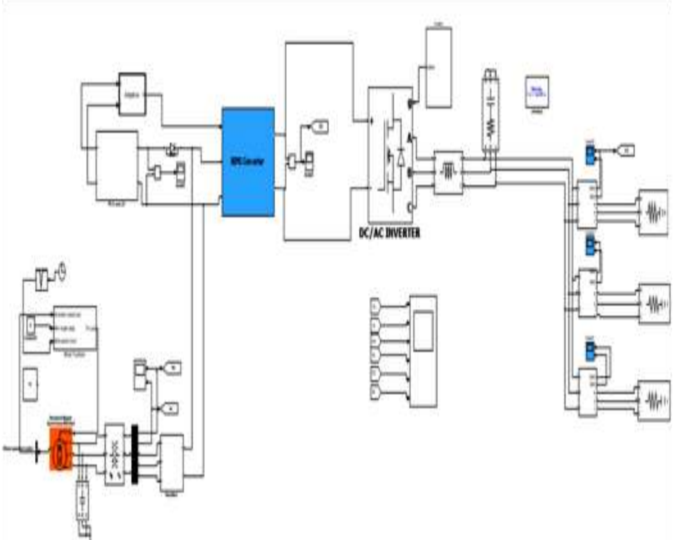

Figure:2 Overall Simulation Diagram

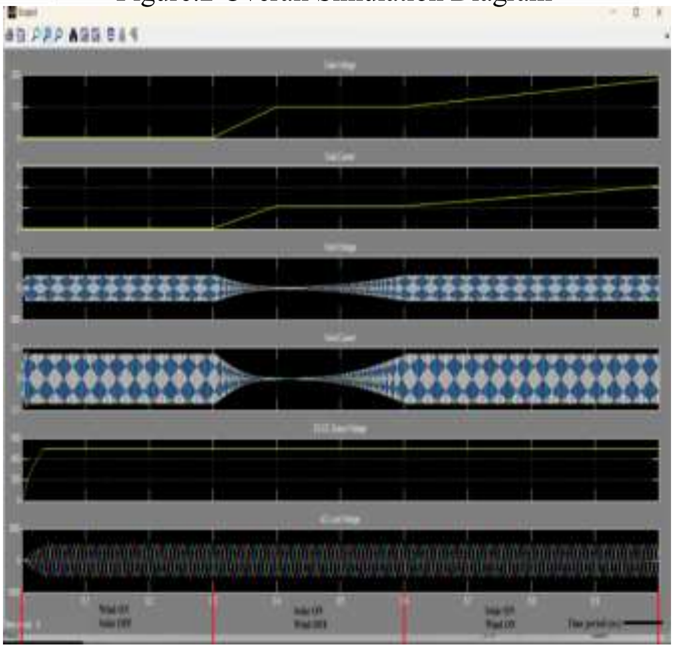

Figure:3 Output of Hybrid System using SEPIC Converter

TABLE: 1 OUTPUT VOLTAGE OF SOLAR AND WIND AT DIFFERENT TIME PERIOD

S.NO	TIME PERIOD (sec)	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	LOAD OUTPUT VOLTAGE (V)
1.	0-0.3s	0	250	500
2.	0.3-0.6s	100	0	500
3.	0.6-1.0s	185	250	500

3.1 Solar panel Output

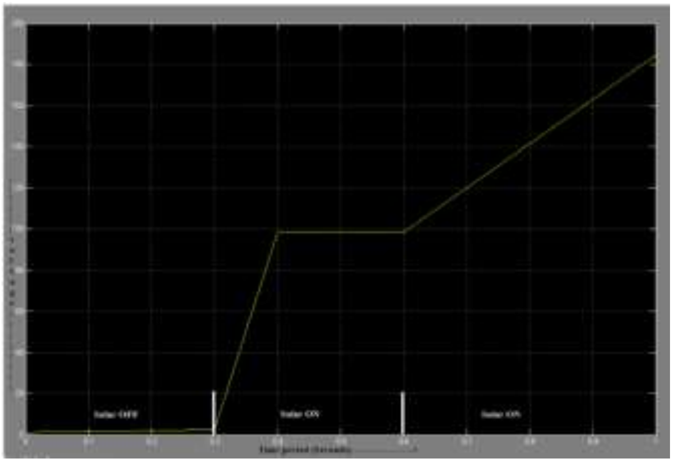

Figure: 4 Response of Solar System

Figure 10.2 shows the solar panel output waveform at time period of 0-0.3 seconds and Solar ON in both the time period of 0.3-0.6 seconds and 0.6-1.0 seconds.

TABLE:10.2 SOLAR PANEL OUTPUT RESULT

S.NO	TIME PERIOD (sec)	IRRADIATION	SOLARVOLTAGE (V)
1.	0-0.3s	0	0
2.	0.3-0.6s	80	100
3.	0.6-1.0s	150	185

3.2 Wind energy Output

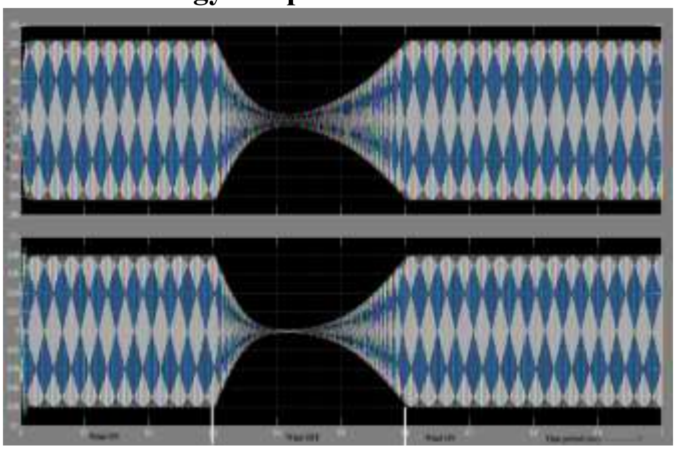

Figure:5 Responseof Wind System.

Figure 10.3 shows the Wind output waveform of Wind ON in time period of 0-0.3 seconds and 0.6-1.0 seconds.Wind OFF in time period of 0.3-0.6 seconds.

TABLE: 10.3 WIND OUTPUT RESULT

S.NO	TIME PERIOD (sec)	SPEED (m/s)	WIND VOLTAGE (V)
1.	0-0.3s	15	250
2.	0.3-0.6s	1	0
3.	0.6-1.0s	15	250

3.3 Converter Output

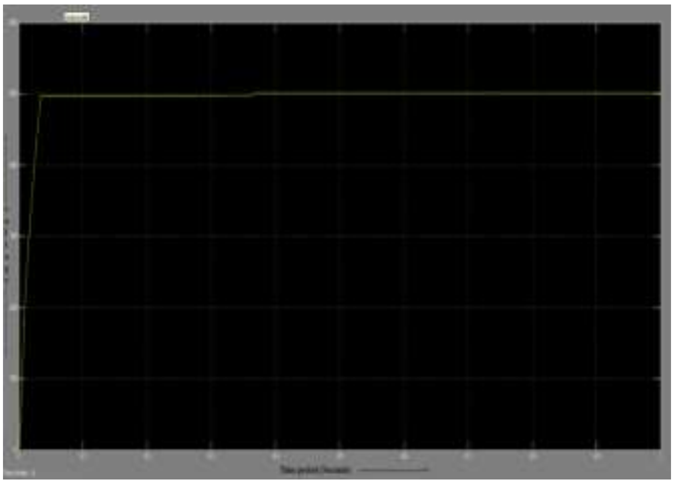

Figure: 6 Performance of SEPIC Converter

hFigure 10.4 shows the converter output waveform of conversion of low level input voltage to high level output voltage.

TABLE 10.4: CONVERTER OUTPUT RESULT

S.NO	TIME PERIOD (S)	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE (V)
1.	0-0.3s	0	250	500
2.	0.3-0.6s	100	0	500
3.	0.6-1.0s	185	250	500

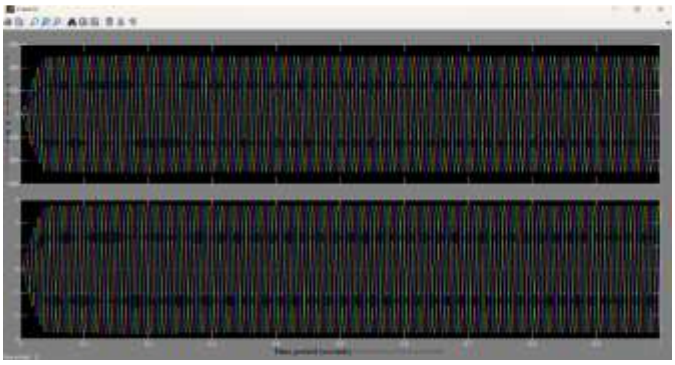

Figure: 7 Responseof Load Grid

Figure 10.5 shows the converter output waveform of conversion of low level input voltage to high level output voltage.

TABLE 10.5: GRID OUTPUT RESULT

S.NO	TIME PERIOD (S)	GRID VOLTAGE (V)
1.	0-0.3s	500
2.	0.3-0.6s	500
3.	0.6-1.0s	500

4 Hardware performance

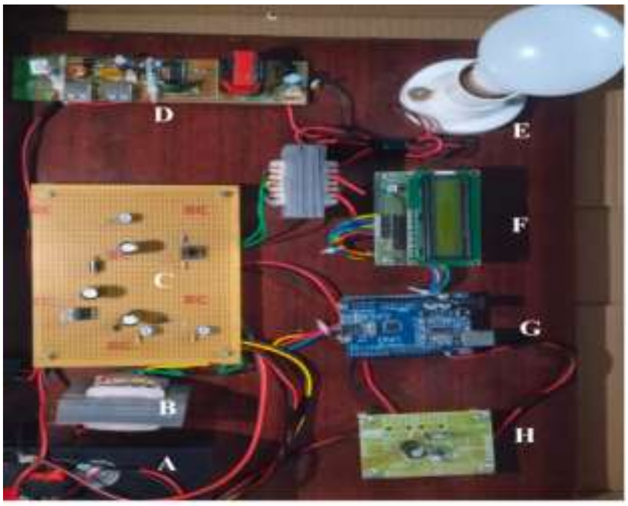

Figure: 7 Hardware of Hybrid system

SPECIFICATIONS

A - Battery
B - Inductor
C - DC to DC converter
D - Inverter
E - LED
F - Display
G - Arduino
H - Regulator module

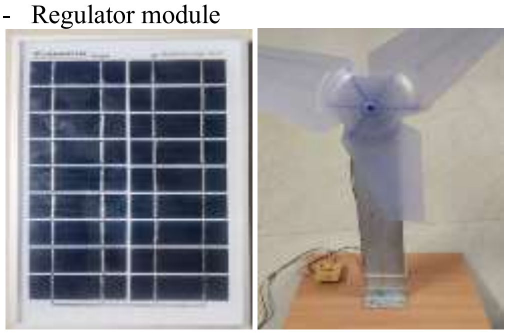

Figure: 8 Solar & Wind Mill

In this project, the 12V windmill serves as one of the energy source, converting kinetic energy into electrical power. Output depends on wind speed, blade size, and turbine efficiency. A small wind turbine can generate 12V to 48V DC, suitable for charging batteries or powering remote systems.

4.41PERFORMANCE OF HYBRID SYSTEM

Figure: 9Performanceof Hybrid System using SEPIC Converter

Figure 9 shows the overall output of Adaptive control of both Solar and Windenergy in various ON and OFF conditions.

TABLE 10.6HARDWARE OUTPUT RESULT

S.NO	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	LOAD OUTPUT VOLTAGE (V)
1.	0	6	12
2.	7	0	12
3.	6	6	12

4.2 PERFORMANCE OF SOLAR SYSTEM

Figure: 10Performanceof Solar System

Figure10 shows the overall output of Adaptive control of Solar energy in ON and Wind energy in OFF conditions.

TABLE:10.7 SOLAR PANEL OUTPUT RESULT

S.NO	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	OUTPUT VOLTAGE (V)
1.	4	0	12
2.	6	0	12
3.	7	0	12
4.	8	0	12

4.3 PERFORMANCE OF WIND SYSTEM

Figure: 11Performanceof Wind System

Figure .11 shows the overall output of Adaptive control of Wind energy in ON and Solar energy in OFF conditions.

TABLE: 10.8WIND OUTPUT RESULT

S.NO	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	OUTPUT VOLTAGE (V)
1.	0	3	12
2.	0	4	12
3.	0	5	12
4.	0	6	12

5.COMPARISION OF HARDWARE AND SIMULATION RESULT

TABLE: 12 COMPARISON OF HARDWARE AND STIMULATION RESULT

S. NO	STIMULATION OVERALL OUTPUT RESULT			HARDWARE OUTPUT RESULT		
	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	LOAD OUTPUT VOLTAGE (V)	SOLAR VOLTAGE (V)	WIND VOLTAGE (V)	LOAD OUTPUT VOLTAGE (V)
1.	0	250	500	0	6	12
2.	100	0	500	7	0	12
3.	185	250	500	6	6	12

Table12 shows the comparison of output voltage between the stimulation overall output result and hardware output result. The maximum converter voltage is 500v in stimulation and maximum hardware output voltage is 12v.

6. CONCLUSION

Micro grids have become more popular as a result of the smart grid's debut and the quick installation of variable renewable energy. A framework for voltage control in autonomous micro grids that can function in a variety of operating modes and situations has been created by this research. The micro grid's solar PV and wind turbine positions and sizes were predetermined, while the energy storage's location and size were chosen using an optimisation technique. When compared to each solar PV/wind turbine operating independently, the hybrid solar PV/wind production offered the micro grid system more efficient voltage management. Additionally, the hybrid PV/wind energy system's coordination with energy storage—a characteristic of the smart micro grid—was likely to bring the voltage back within legal bounds when the voltage fluctuation exceeded the hybrid system's capabilities. This enhances the quality of the voltage profile and gives the distribution system active power adjustment capability. Further research on the effectiveness of real-time pricing demand response tools in shaping load demand is recommended in order to significantly reduce both peak load and load demand variance.

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