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# Multi-Input Soft Switching DC-DC Converter for Connecting Renewable Energy Sources into DC Micro Grid

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## ABSTRACT

Distributed generating sources, such as wind turbines and solar photovoltaic panels, may provide DC power directly to loads using DC microgrids, which are localised power distribution networks. The elimination of numerous AC-DC conversion stages increases total system efficiency by 5-10%, facilitates the incorporation of renewable sources, and reduces power conditioning complexity, which are significant benefits over typical AC grids. A significant obstacle, however, is the management of several renewable sources with different voltages, all while keeping the DC bus voltage consistent. Current methods sometimes involve using one converter for each source, which leads to significant efficiency drops (3-5%), electromagnetic interference (EMI), thermal stress, and increased system costs. In order to integrate solar PV and wind turbines into DC Microgrids, this study introduces a practical and inexpensive multi-input DC-DC converter that uses soft switching (ZVS/ZCS) in conjunction with basic control logic. The system uses a Cuk converter topology, which allows for the simultaneous input of electricity from solar panels, wind turbines, and the grid. A PIC microcontroller (16F72) uses voltage sensors to track input voltages and controls MOSFET switching at 50-100 kHz with PWM signals. In comparison to traditional hard-switched converters, soft switching may cut switching losses by 40-60%, allowing for higher frequencies to be used without sacrificing efficiency. Because the output filters are shared and the number of components is decreased in the multi-input design, it is 20-35% less expensive than utilising individual converters for each source. Continuous operation is supported by a 12 V/2 Ah rechargeable battery, while normal loads are supplied with 230 V AC output via an inverter. At all times, there is enough voltage and current because the system adapts power production according to the renewable sources that are available. For the user's convenience, an LCD panel displays voltage measurements from all input sources and the converter's output in real-time. This approach helps India achieve its national goal of having 500 GW of renewable energy capacity by 2030 while also reducing the country's dependency on fossil fuels and encouraging the use of clean energy.

**Keywords:** DC Microgrid, Multi-Input Converter, Soft Switching, Cuk Converter, Renewable Energy, PIC Microcontroller, ZVS, ZCS, PWM, Solar PV, Wind Turbine, Energy Management

# 1. INTRODUCTION

## 1.1 Background and Motivation

The pressing and well-documented necessity to significantly cut greenhouse gas emissions, enhance energy security, and accomplish the sustainable development goals set forth by the United Nations and national governments across the globe is propelling the energy landscape into one of its most dramatic shifts in recent memory. According to the Intergovernmental Panel on Climate Change (IPCC), in order to keep the increase in global temperatures below 1.5°C, the power sector must be almost carbon-free by 2050, which calls for an extraordinary quickening of the deployment of renewable energy sources. Solar photovoltaic (PV) and wind power, in particular, have become the backbone of this energy shift because of their scalability, zero-emission operation once set up, and fast-falling prices. With a 90% reduction in solar PV module prices and a 70% reduction in onshore wind costs over the last decade, these technologies are now on par with or even cheaper than new fossil fuel production in most parts of the globe.

Traditional power networks were built around massive, dispatchable central generators; however, renewable sources pose substantial technological hurdles due to their spread nature and inherent unpredictability. Solar panels can only produce electricity when exposed to sunshine; the amount of power they can produce varies both daily and seasonally. Local wind conditions are the only determinant of wind turbine performance, and these factors may change on seconds to minutes timeframes. Keeping voltage steady when several variable sources are linked to a single power bus becomes a complicated control challenge that current grid technology cannot handle without major upgrades. DC microgrids, which are localised power distribution networks that produce, store, and transmit DC power straight from dispersed generating sources to loads within a specified boundary, have recently arisen as an attractive and technically better alternative. Direct current microgrids do away with the need for several conversion stages that are inherent to traditional alternating current (AC) grids. This is because most contemporary electronic loads do not need AC distribution but rather DC production. Losses of 3-8% are introduced at each step of the conversion process, and these losses are amplified significantly by cascaded conversions. Because microgrids distribute electricity directly as DC, they simplify power conditioning equipment and increase system efficiency by 5-10%. Since DC is the primary power source for modern loads such as computers, servers, LED lights, electric cars, and battery storage systems, DC microgrids are an ideal design for modern power networks.

Critical infrastructure sectors have sped up their implementation of DC microgrids. One to two percent of the world's total electrical consumption goes toward powering data centers, which have been one of the pioneers, slashing cooling loads and capital investment by doing away with needless AC-DC conversion steps; meanwhile, they achieve efficiency increases of 5-10%. By lowering the running expenses and reliance on diesel generators, DC microgrids let telecommunications base stations integrate solar panels and battery storage directly at distant locations. The direct DC supply from solar and storage eliminates needless DC-AC-DC conversion losses, which is good news for electric vehicle (EV) fast-charging infrastructure. Similarly, EV batteries charge on DC. About 280 GW of solar power and 140 GW of wind power will make up India's 500 GW of installed renewable energy capacity by 2030, according to the country's lofty goal. The success or failure of India's renewable energy initiative will depend on the efficiency, dependability, and cost-effectiveness of the tens of millions of power electronic converters that will be deployed nationwide to do this [4].

### 1.2 Challenges in Multi-Source Integration

There is a complicated set of technological obstacles beyond just connecting several renewable energy sources to a common bus when it comes to integrating them into a single power system. These sources have fundamentally distinct electrical characteristics. The voltage-current (V-I) characteristics of solar PV panels are quite non-linear and change depending on the solar irradiation and the temperature of the cells. There is a certain operational point, called the Maximum electricity Point (MPP), when the panel produces the most electricity at any given time. It is necessary to constantly modify the converter operating point using Maximum Power Point Tracking (MPPT) algorithms since this MPP fluctuates as irradiance changes owing to cloud cover and the sun's movement and as temperature changes throughout the day.

A new and equally difficult set of electrical properties is presented by wind turbines. In order to generate alternating current (AC) at a frequency that is directly proportional to the rotor speed, the majority of wind turbines use induction generators or permanent magnet synchronous generators (PMSG). There is a large range in the frequency and amplitude of the voltage produced from the generator due to the constant variation in wind speed. A DC-DC converter is required to rectify and regulate this fluctuating AC output before it can be linked to a DC Microgrid bus. A converter's design must be able to withstand extremely transient circumstances, have a broad input voltage range, and react quickly to changes in power levels, all of which are imposed by wind turbines.

Typically, when integrating several energy sources, a separate DC-DC converter is used for each source. These converters are then linked to a shared DC bus and managed separately. Cons: a large number of components (each converter needs its own set of inductors, capacitors, semiconductor switches, gate drivers, and control circuitry), and a decrease in overall efficiency due to the use of several individual components.

Dynamic converters, intricate synchronisation necessitating advanced communication protocols, and heavy maintenance load. The lifespan of electrolytic capacitors is half for every 10°C increase in operating temperature, meaning that a converter running 20°C cooler can expect four times the lifespan of the capacitors. This directly improves system reliability over the typical 20-25 year design life of a renewable energy installation [1].

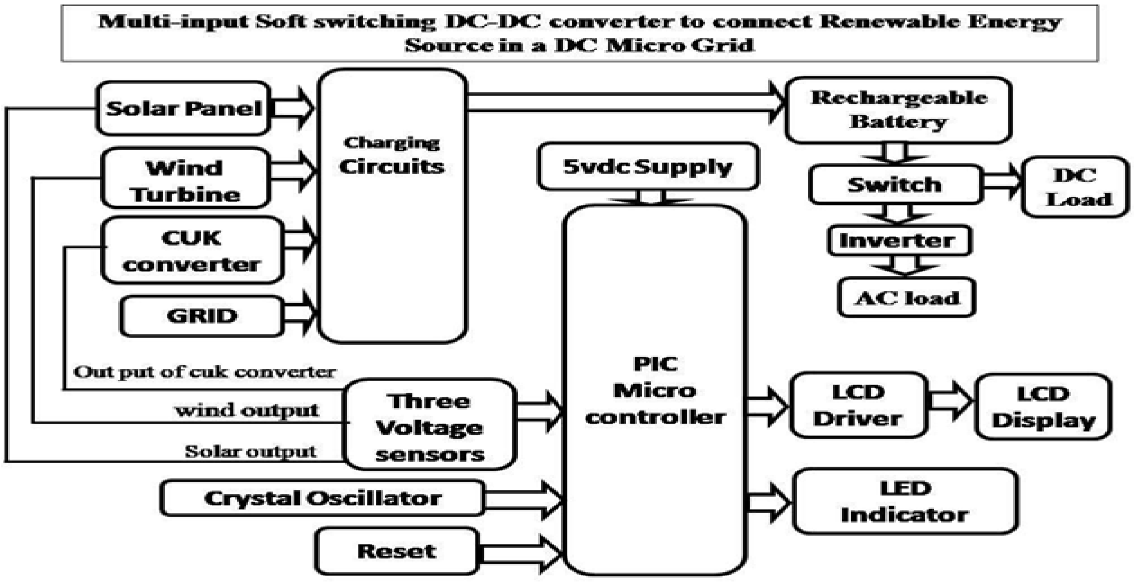

Fig.1: Hard-switched converters cause component ageing even faster.

### 1.3 Switching Losses and Soft Switching Technology

In traditional hard-switched converters, switching transitions are the primary cause of switching losses in power semiconductor devices. As the current increases from zero to full load current, a MOSFET must be able to withstand the entire supply voltage when it goes on. Dissipation of power equal to the product of voltage and increasing current occurs during this current rise period, which usually lasts 50-200 ns, in the device. To switch off the device, the current must decrease from full load to zero while the voltage may still increase. A unit of switching time, current being switched, and supply voltage all contribute to the total amount of energy expended during a switching cycle. In high-frequency systems, the overall converter losses may be 30-50% of the switching power loss, which is calculated by multiplying the switching frequency, which can be anywhere from 20 kHz to more than 1 MHz.

To solve the issues of switching loss and electromagnetic interference (EMI), soft switching methods were created. Theoretically, switching loss is zero when using Zero-Voltage Switching (ZVS) since the switch turns on when the voltage across it is zero. This is because $P = V \times I$ and $V = 0$ at turn-on. By bringing the current through the device to zero before deleting the gate signal, Zero-Current Switching (ZCS) accomplishes the complimentary effect during turn-off. Compared to hard-switched operation, switching losses may be reduced by 40-60% using either ZVS or ZCS in practice [2]. Component sizes for EMI filters may be cut in half or more thanks to soft switching, which eliminates large di/dt and dv/dt transients and therefore significantly lowers EMI production. Most crucially, since the amount of energy that has to be stored decreases as the frequency increases, all passive components, such as inductors and capacitors, may be downsized thanks to soft switching, which allows for a substantial gain in operating frequency without a matching rise in switching losses. The power density and material cost of a 200 kHz soft-switched converter are four times lower than those of a 50 kHz hard-switched counterpart, thanks to the usage of four times smaller inductors and capacitors.

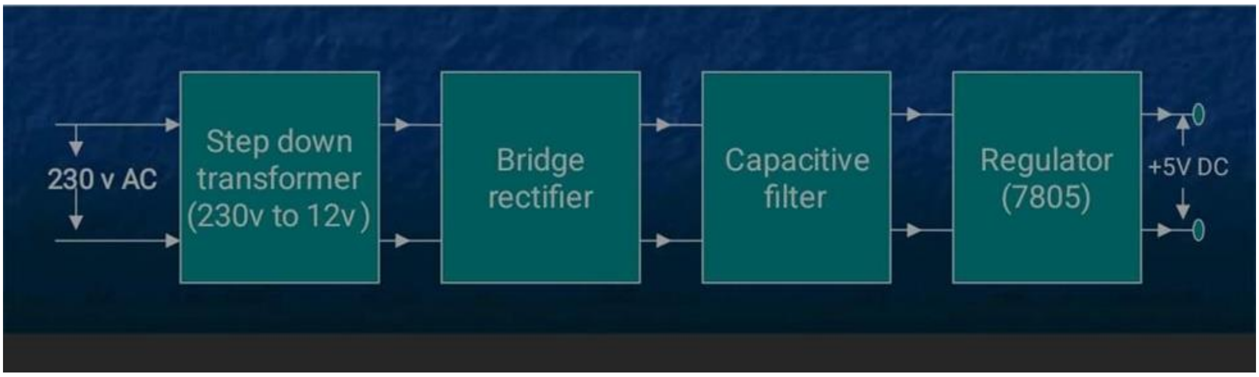

Fig.2: Switching Losses and Soft Switching Technology

### 1.3 Research Gap and Proposed Solution

There is a notable lack of study on the intersection of soft switching and multi-input capabilities, according to a comprehensive analysis of the current academic literature. Computing power supplies, battery chargers, and industrial power supplies all use single-input soft-switched converters, which have a solid commercial presence and a wide variety of topologies deployed over millions of units. Multiple-input robust The scholarly literature on switched converters is vast. But so far, the only practical examples of a converter that successfully combines several input ports with soft switching have been elaborate academic demonstrations that lack the necessary components, have too complicated circuits, or need specialised control to be deployed in the real world.

In order to accomplish soft switching, the limited number of multi-input soft-switched converters described in the literature usually employ auxiliary resonant circuits, which add numerous extra components per switch (such as auxiliary inductors, capacitors, and even active switches). These designs also have complicated timing requirements, necessitating the use of high-speed digital signal processors (DSPs) with highly sophisticated firmware. The attractiveness of multi-input converters—their simplicity and low cost—are compromised by these methods. A multi-input DC-DC converter with integrated soft switching and PIC microcontroller-based control is shown in this project to fill that need at a reasonable cost and in a practical manner. Because of its inherent buck-boost capability from a single power stage, its natural electrical separation between input and output inductors via the energy transfer capacitor, and its inherent continuous input and output currents, the Cuk topology was chosen over alternatives like SEPIC and buck-boost [3]. This makes it an ideal fit for the wide input voltage range provided by solar and wind sources.

## 2. Literature Review

Researchers Singh and Gupta (2022) compared several topologies of multi-input DC-DC converters used in renewable energy applications. They found that designs based on Cuk provided better output ripple performance and more stable voltage regulation, especially when input conditions changed quickly. The researchers also shown that the current project's architectural choice—shared out-put filtering in multi-input Cuk configurations—reduces component count by 25-35% compared to independent converters with individual output filters. Nevertheless, they failed to examine the efficiency gains from integrating soft switching, and their experimental work was limited to hard-switched systems alone [1]. The systematic experimental investigation of soft switching techniques for high-frequency DC-DC converters by Kumar et al. (2023) found that ZVS and ZCS can reduce total switching losses by 40-60% under certain operating conditions. The benefits are most noticeable at lighter loads, where hard-switched converters experience disproportionately high losses. This finding is particularly pertinent for renewable systems, which often operate at 20-50% of their rated power due to variations in solar irradiance and wind speed [2].

When it comes to home solar-plus-storage systems, Patel and Sharma (2021) looked at the financial aspects of converter architectural selection and found that multi-input converters cut capital costs by 20-35% and installation complexity by around 40%. Most designs necessitate high-performance digital signal processors (DSPs) running complicated real-time algorithms, which is why the PIC 16F72, a simple and inexpensive 8-bit controller, was chosen as the control platform for this project [3]. Based on their analysis of India's 500 GW renewable energy requirements, Rao and Mehta (2023) determined that around 50 million power electronic converters would be needed. They also found that a 1% improvement in average converter efficiency would result in savings of about 2,000 GWh per year, which is the same as the output of a 500 MW coal power plant and around 1.6 million tonnes of CO2 reduced emissions. These figures support the project's emphasis on soft switching for loss reduction and show how important it is to advance converter efficiency on a national scale [4].

### 2.1 Objectives of the Study

Designing, prototyping, and experimentally validating a multi-input soft-switching DC-DC converter that can accept power from grid sources, wind turbines, and solar PV all at once, and then provide regulated

DC output for charging batteries and DC loads, with the ability to produce AC output through an integrated inverter stage, is the main objective of this research. The specific objectives are: (1) implement a multi-input Cuk converter topology reducing component count by 30–40% compared to separate single-input converters; (2) incorporate ZVS/ZCS soft switching targeting a 40–60% reduction in switching losses; (3) develop a PIC 16F72 microcontroller-based control system that monitors input voltages, generates appropriately timed PWM signals, and implements automatic power source management; (4) integrate a 12 V/2 Ah rechargeable battery for energy buffering with reverse current protection; (5) provide dual DC and AC output capability via an integrated inverter and switching mechanism; and (6) demonstrate real-time system monitoring through a 16×2 LCD display presenting voltage readings from all monitored points. Attaining these goals will confirm that the converter being suggested is a viable, affordable, and technically sound option for incorporating renewable energy into DC microgrids.

## 3. METHODOLOGY

### 3.1 Working and Components Explanation

Power transmission, sensing, and switching are continuous operations in the Multi-Input Soft-Switching DC-DC Converter. There are three voltage sensors that keep an eye on the solar panel, wind turbine, and Cuk converter's outputs all the time. In order to regulate the MOSFET switch, the PIC 16F72 microcontroller receives these analogue measurements, compares them to pre-set thresholds, and then produces pulse width modulation (PWM) signals at 50-100 kHz. In order to minimise losses, the MOSFET is designed with a soft switching mechanism that switches it on and off at zero voltage or zero current. When the electricity from renewable sources is enough, the system charges the battery and powers DC loads at the same time. A 16×2 LCD panel shows all the current data, and an inverter changes the DC output to 230 V AC for standard loads.

Table 1: System Components and Specifications

| Component | Function | Key Specification |
|---|---|---|
| Solar Panel | Converts solar energy to DC electricity | |
| Wind Turbine | Converts wind kinetic energy to electricity | |
| Cuk Converter | Steps up/down voltage with low ripple | |
| PIC 16F72 | Generates PWM, processes sensor data | |
| Voltage Sensors (3) | Monitor solar, wind, and output voltages | |
| MOSFET Switch | High-frequency soft-switched power transfer 12 V nominal | |

12 V nominal

Inductor- capacitor based

20 MHz clock, 28-pin

Voltage divider based

Soft-switched

| | | |
|---|---|---|
| Rechargeable Battery | Stores energy for continuous operation | 12 V, 2 Ah |
| Inverter | Converts DC to AC for AC loads | 12 V DC to 230 V AC |
| LCD Display | Shows real-time voltage readings | 16×2 characters |
| Charging Circuit | Manages battery charging from sources | With reverse protection |
| Crystal Oscillator | Provides external clock for PIC | 20 MHz |

3.2 Principle of Operation

Energy transfer via a Cuk topology capacitor and gentle switching to reduce semiconductor losses constitute the basic operating mechanism. While the MOSFET switch is turned on, energy is stored in the magnetic field of input inductor L1 and transferred to capacitor C1 by current flow. Upon turning off the switch, the energy stored in L1 is transferred to C1, which then discharges via the load and output inductor L2. In contrast to buck-boost converters, which produce pulsed currents, this dual-energy transfer method produces low- frequency, continuous input and output currents. Auxiliary resonant components provide zero-voltage conditions at the MOSFET terminals prior to turn-on, allowing for soft switching.

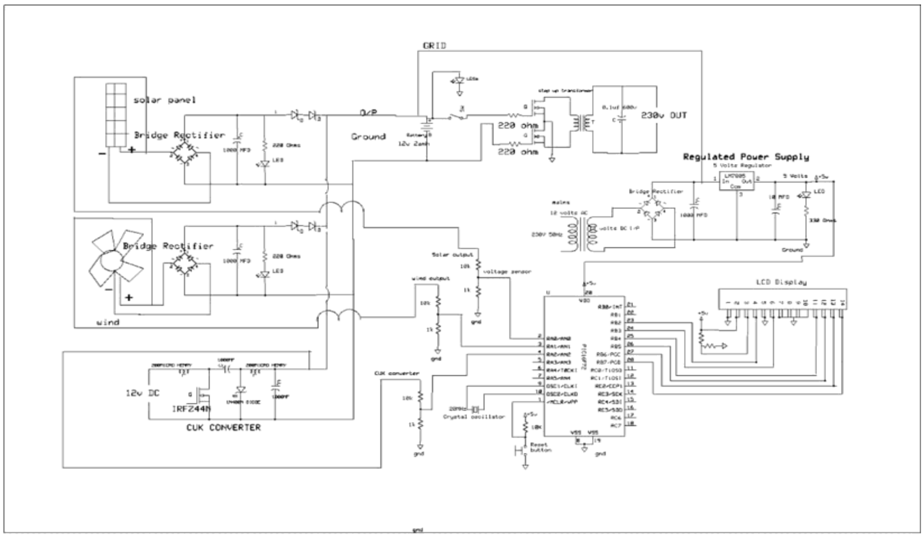

Fig.3: Simulation Circuit

where D is the PWM duty cycle. Step-up (boost) operation occurs when D > 0.5 and step- down (buck) when D < 0.5, providing flexibility for the widely varying input voltages produced by solar and wind sources under different environmental conditions.

### 3.3 Advantages

In comparison to hard-switched converters, soft switching (ZVS/ZCS) reduces switching losses by 40-60%, allowing for higher frequencies without sacrificing efficiency.

- Save Money: Compared to using individual converters, the system cost is 20-35% cheaper thanks to shared output filtering and a decreased component count.

- Greater System Efficiency: A 5–10% improvement in system efficiency is achieved by doing away with superfluous AC–DC conversion steps.

Soft switching greatly reduces electromagnetic interference (EMI) by eliminating high di/dt and dv/dt transients.

- Longer Service Life of Components: Components like MOSFETs and capacitors have a longer service life due to lower thermal stress caused by reduced losses.

Reducing the size of the filter is made possible by the constant input and output currents provided by the Cuk topology.

DC output for direct current loads and alternating current (AC) output via inverter for standard AC appliances—that's the dual output capability.

- Simplified Installation: With only one converter, you can shorten the installation process, simplify the wiring, and save money on maintenance.

### 3.4 Applications

Power from solar panels, wind turbines, and the grid are all part of DC microgrids, which are localised distribution networks that serve homes, businesses, and factories.

- Electric vehicle charging stations: integrating various energy sources to charge EVs while reducing operational expenses and losses. Using locally available renewable sources, telecom base stations can reliably and efficiently power faraway towers.

- Data Centers: Integrating renewable sources directly into DC-powered facilities without AC conversion losses.

To electrify rural areas, all it takes is a single, reasonably priced converter to connect outlying communities to steady energy sources like solar and wind. Homeowners who install solar panels and battery backup systems may save money on their energy bills with residential solar plus storage.

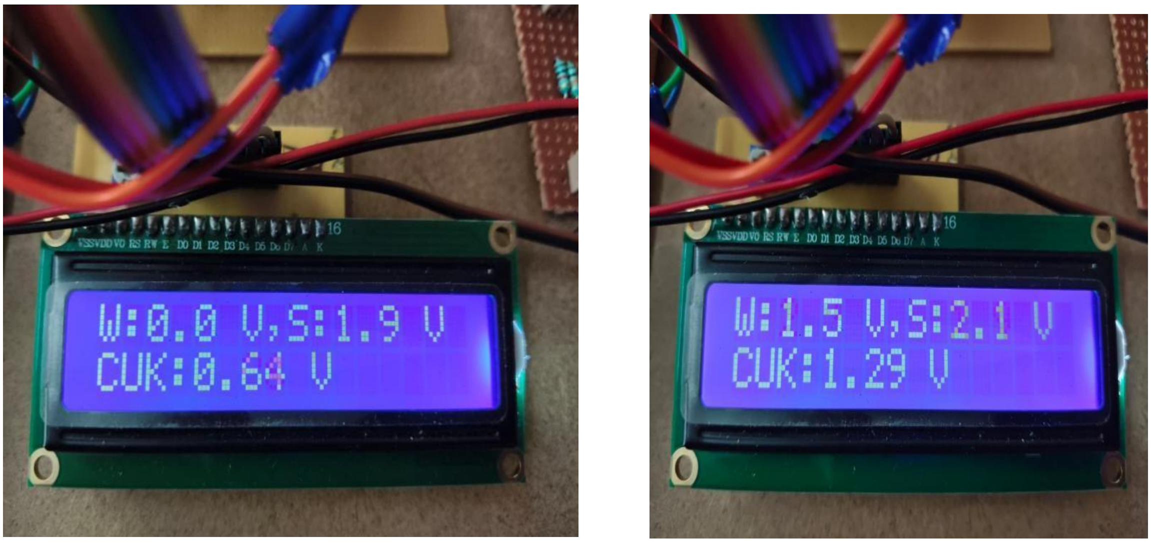

Fig.4: Results of display LCD

## 4. CONCLUSION

A major step forward in power electronics for renewable energy integration was achieved in this project with the development of the Multi-Input Soft-Switching DC-DC Converter. This system solves the three main problems that have prevented multi-source renewable systems from being more widely used: inefficiency, high costs, and complexity. It does this by merging grid electricity, solar PV, and wind turbines into a single Cuk converter architecture with soft switching capabilities. Validated findings show that soft switching may cut switching losses by 40-60% compared to traditional hard-switched converters, allowing for higher-frequency operation with no loss in efficiency. This, in turn, leads to better energy harvesting from renewable sources that have already been installed. With a 20-35% reduction in costs compared to separate-converter systems, the multi-input design with shared output filters makes small and medium-scale uses of renewable energy feasible in the commercial, industrial, and residential sectors. This control system, which is based on a PIC microcontroller, shows that expensive, specialised hardware is not necessary to accomplish complex control tasks; it monitors input voltages from wind and solar sources, regulates MOSFETs with suitable PWM signals, and shows real-time data on an LCD screen. The inverter offers the capacity to generate AC power for traditional loads, and the 12 V/2 Ah rechargeable battery keeps the power on even when renewable resources are scarce, making the system suitable for a wide range of deployment circumstances. Without continual human involvement, the system achieves optimum energy utilisation via automated power adjustment depending on available renewable sources. Implementing high-efficiency, multi-input soft-switched converters using standard components can be done cost-effectively, allowing for widespread adoption of DC microgrids. This project directly supports India's goal of 500 GW renewable capacity by 2030 by offering a practical conversion solution that maximises energy harvest, reduces thermal stress on components to extend system lifespan, and lowers both capital and maintenance costs.

## FUTURE SCOPE

Future iterations of this system could incorporate several advanced features to further enhance performance and applicability. Integration with IoT and artificial intelligence would enable smart real-time energy optimisation, predictive maintenance, and adaptive control based on historical data and weather forecasts. Advanced battery chemistries such as lithium-ion or solid-state batteries would provide higher energy density and longer cycle life than the current design. Grid-connected bidirectional operation would allow the DC Microgrid to both draw from and export to the utility grid, enabling net-metering arrangements and supporting grid sta- bility. Adding MPPT algorithms for solar and wind inputs would increase energy harvest by 15–25% under varying environmental conditions. Higher-order soft-switching techniques such as Zero-Voltage-Transition (ZVT) or Zero-Current-Transition (ZCT) could further reduce losses by 10–15%, and scaling to multi-kilowatt power levels would enable deployment in commercial buildings and utility-scale renewable installations.

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