A MULTIPHASE INTERLEAVED BOOST CONVERTER WITH HIGH VOLTAGE GAIN FOR EV APPLICATIONS

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ABSTRACT: For use in electric vehicle (EV) applications, the article suggests a soft switching interleaved boost converter (SS-IBC) with an auxiliary resonant circuit. A multiphase interleaved boost converter, which functions similarly to a single-phase boost converter, can be made by connecting the converter in multiple phases. The converter offers an affordable solution for grid-integrated battery charging applications. Each phase is controlled by a PWM control technique with equal switching frequency and duty cycle. The suggested converter can use a variety of energy systems, including renewable ones like photovoltaic (PV), wind, or fuel cell systems, to supply consistent electrical power to the demand. The study offers a suitable design example and analyses of design circuit parameters and component sizes. The analysis, design, and simulation of the converter provided in this research were verified using the MATLAB simulation tool. An extensive output power converter range from rated power to a minimum power of 460 W with complete soft switching operation on an 8.2 kW setup system with a conversion rate of more than 97%.

Key terms: Fuel cell, Electric Vehicle, interleaved boost converter, soft switching.

I. INTRODUCTION:

Increasing energy demand, the depletion of fossil fuels, and ICE (internal combustion engine) cars are posing environmental issues that have sparked interest in renewable energy, integrated distributed generation, and electric propulsion [1]. These figures show how the market is growing more concerned about electric and hybrid vehicles (EVs) [2]. In 2050, there won't be any ICE cars on the road, and plug-in hybrid electric (PHEV) automobiles would make up the bulk of vehicles, according to the data presented [2]. Consequently, EVs are a fantastic choice for transportation, even though some technological challenges remain [2]. One-fourth of the greenhouse gas emissions in the European Union are attributed to the transport sector, which overtakes the energy sector as the second greatest emitter of gases. As a result, the Europe Union has implemented a number of policies to reduce greenhouse gas emissions, including a goal of having ICE vehicles make up only half of urban transport by 2030 and being completely removed by 2050 [3].The market for electric vehicles is progressively seeking a variety of more potent powertrains to approach increased drivability in a way that is superior to or at least comparable to conventional combustion engines. In order to start the engine using the inverter in EVs, battery EVs (BEVs), fuel cell EVs (FCEVs), hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicles (PHEVs), a secondary high voltage battery pack must be fitted. The high voltage battery pack, which is composed of several lithium-ion cells, stores the energy required to power the car. Low current, high power density and high torque are produced while conduction losses are decreased when a high voltage battery pack is used [4]. However, it increases the system's overall cost, weight, and size. However, the boost converter is a separate system element that reduces the system's power conversion efficiency by raising conduction and switching losses, particularly at high power ratings. The schematic representation of a typical BEV powertrain is shown in Fig. 1. It includes an electric motor, a boost converter, an elevated volt cell package, an onboard battery charger, and a power control and management system.

Additionally, EVs still need to overcome certain significant obstacles before they can be widely adopted, including as additional costs, battery life, a lack of infrastructure for charging, and problems with battery chargers. Since electric vehicles (EVs) need electrical power from chargers rather than gasoline, a further significant challenge is the significant harmonics that EV chargers produce, which have a negative impact on distribution systems [6].

Many automobile owners discover that charging an electric vehicle (EV) at home is more convenient than frequently visiting a petrol station, saving time, effort, and money. However, because of the EV market's explosive expansion, public charging stations for EVs are also becoming more commonplace. This move makes it necessary to design EV chargers that are more effective, durable, accessible, reliable, and affordable. A level 1 electric vehicle (EV) charger is an example of an on-board charger provided by a single phase or a three-phase power source in Fig. 2 [7]. An example of an on-board power converter's construction includes an EMI filter, an AC-DC conversion stage, a stage for power factor correction, and a stage for DC-DC boost conversion. In the past ten years, numerous researchers have put forth a variety of converters for reducing current ripple and novel DC-DC converter topologies, such as interlaced boost converters (IBC) [8], [9], [10], [11]. Interfacing renewable energy sources like fuel cells, solar panels, and the direct current (DC) connection of inverters with IBCs is a promising development. IBCs exhibit decreased current and voltage ripple on the supply and load side, respectively, as a result of the interleaving process [12]. A correction for component size, conversion efficiency, current ripple, switch count, and expenditure is used to validate the three-phase IBC [10]. When it comes to power density, conversion efficiency, and current ripple, FCEV applications present intriguing challenges that may be addressed thanks to the IBC. In order to solve the issue of current ripple, reduce element size, boost power rating, improve dynamic reaction, and attain high conversion efficiency, interleaving topologies are frequently used in applications requiring considerable power [24][29].

These novel architectures make excellent candidates for highly efficient vehicle chargers and powertrains. However, there is still a lot of room for and promise in further developments that will lead to better results. This research presents a new soft switching multiphase interleaved boost converter for EV applications that uses an auxiliary resonant circuit.

The proposed interleaved converter offers the following key benefits: 1) a broad soft switching power control range; 2) a reduction in ripple currents through an interleaved operation; 3) a reduction in conduction power loss through discontinuous current operation in the input side; and 4) a high voltage conversion ratio. Due to these characteristics, the proposed converter is particularly practical for high voltage batteries in electric vehicle applications as well as low voltage sources like solar panels and fuel cell systems that need the ability to convert high voltage. The following is how the paper is set up: Section II provides a description of the suggested soft switching interleaved boost converter (SS-IBC) topology, including its configuration, performance, and analysis. In section III, thorough steady-state analyses, performance equations, and the modes of operation with their corresponding circuits and voltage and current waveforms throughout one switching cycle are carried out. Considering the design Section IV deals with fuel cells. In sections V, simulation results are presented.

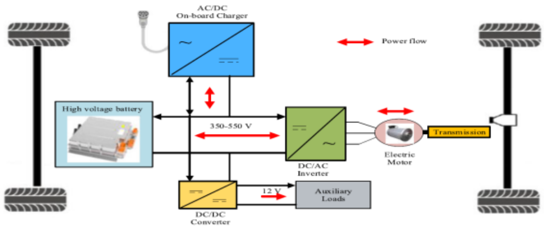

FIGURE 1. Block diagram of the battery electric vehicle powertrain.

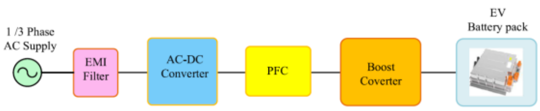

FIGURE 2. Level 1 on-board EV charger.

II. DESIGN of SOFT SWITCHING INTERLEAVED BOOST CONVERTER

A.Circuit Description: The circuit configuration of a typical EV charger is shown in Fig. 3 along with the suggested SS-IBC's use of an auxiliary resonant circuit. The suggested soft switching interleaved boost converter's single phase is seen in Fig. 4. To the traditional soft switching boost converter, two diodes (D1 and D2), one auxiliary active switch (S2), and one resonant capacitor (Cr) are added. If active switches are used in place of the output diodes Do and D2, the suggested IBC can be used as a bidirectional converter. The suggested converter's crucial feature, in addition to its simplicity, is the reduced current and voltage stress it places on the active and auxiliary switch. Switches and diodes can operate at zero voltage thanks to the proposed resonance circuit's use. Consequently, increased conversion efficiency is achieved. To create a multiphase interleaved boost converter, the suggested converter's phases can be connected in parallel. The suggested multiphase interleaved converter's functionality is comparable to that of a single-phase boost converter. The PWM control technique with the equal switching frequency and duty cycle regulates all phases, which are ideally identical with shifting control signals. The PWM switching function has a phase shift of 360/N degrees for all phases, where N is the number of phases. The proposed converter can be viewed as an affordable upgrade to the current boost converters. It provides a reliable high-voltage direct current power supply for the load from renewable resources like PV, FC, or wind systems in addition to conventional energy storage systems like batteries or utility grids. MATLAB/SIMULINK software is used for the proposed converter's analysis, design, and simulation.

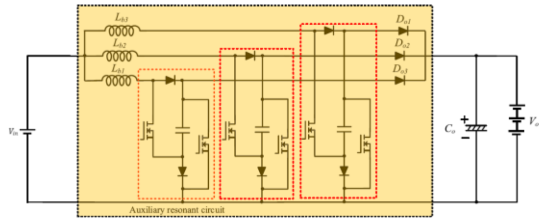

Fig 3 Proposed Circuit

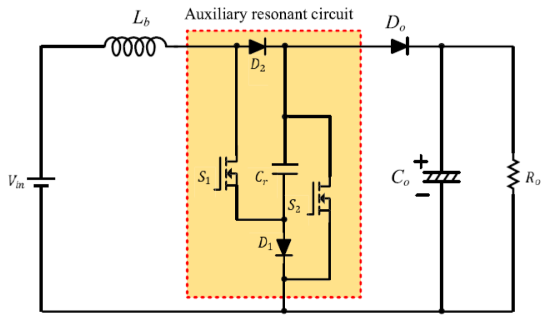

Fig 4 One phase of proposed SS-IBC.

III. OPERATION PRINCIPLES AND OPERATION MODES

Under steady state operation conditions, a discontinuous conduction mode (DCM) study is performed on the converter in detail. All power switches and passive components are presumptively perfect in order to simplify the analysis. Inductor and capacitor internal resistance and switching loss are regarded as insignificant. During each switching cycle, the operation modes are split into five operation modes. The corresponding circuit is shown, along with the current routes for each mode.

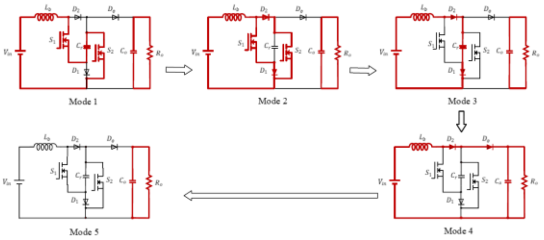

Fig5 Modes of Operation

Mode1: The boost inductor current iLb is zero prior to the commencement of mode 1 and the resonant capacitor Cr is initially charged up to the output voltage V0. When both the primary active switch S1 and the secondary active switch S2 are turned on at the same time, at time D to, mode 1 is initiated. The capacitor starts to gradually discharge from V0 to zero as the boost inductor current iLb and the switches currents is1; is2 start to gradually grow from zero initial value. Therefore, at zero current switching (ZCS) conditions, both active switches S1 and S2 are turned on. The resonant capacitor voltage, the boost inductor voltage, and the switches currents can be given by supposing the time origin to= 0 for simplicity.

$$Vcr(t) = (Vin + Vo)Cos(wrt) - Vin(1)$$

$$Vlb(t) = (Vin + Vo)\cos(wrt)\ (2)$$

$$ilb(t) = Is1(t) = Is2(t) = (Vin + Vo)\sqrt{\left(\frac{Cr}{Lb}\right)}\sin(wrt)\ (3)$$

When the resonant capacitor is completely drained to zero at time t1 and the boost inductor current reaches the value ILb1 at the conclusion of this mode, mode 1 is complete.

Mode 2: The voltage across the resonant capacitor drops to zero at time t1, which initiates the boost inductor energy charging mode. Auxiliary diodes D1 and D2 start to conduct once the resonant capacitor is fully depleted at time t1, which causes them to become forward biassed. The resonant capacitor voltage is held at zero volts, the boost inductor voltage is equal to the supply voltage, and the boost inductor current is evenly distributed among the parallel routes. The Equations can be represented as

$$Vcr(t) = 0\ (4)$$

$$Vlb(t) = Vin\ (5)$$

$$Ilb(t) = \frac{Vin}{Lb}(t - t1) + \sqrt{}((vo^2 + 2VoVin) * \frac{\sqrt{Cr}}{Lb}\ (6)$$

$$Is1(t) = Is2(t) = \frac{iLb(t)}{2}\ (7)$$

When the main switch S1 and the auxiliary switch S2 are simultaneously turned off at time t2, this mode is ended.

Mode 3: At time t2, when both the main switch S1 and the auxiliary switch S2 are simultaneously disabled, this mode starts. At this point, the loop's input voltage Vin, boost inductor Lb, diode D2, resonant capacitor Cr, and diode D1 begin to resonate. Due to the resonant capacitor Cr's presence, the voltage across the main switch S1 and the auxiliary switch S2 progressively increases from zero.

As a result, at zero voltage switching (ZVS), both the main and the auxiliary switches S1S2 are turned off. Additionally, because there is no voltage applied across the auxiliary diodes D1 and D2, they are both turned on at ZVS.

$$v_{Lb}(t) = V_{in}\cos\omega_r(t - t_2) - \sqrt{\frac{L_b}{C_r}} I_{lb2}\sin\omega_r(t - t_2) \quad (8)$$

$$v_{cr}(t) = -V_{in}(1 - \cos\omega_r(t - t_2)) + \sqrt{\frac{L_b}{C_r}} I_{lb2}\sin\omega_r(t - t_2) \quad (9)$$

$$i_{Lb}(t) = \sqrt{\frac{C_r}{L_b}} V_{in}\sin\omega_r(t - t_2) + I_{lb2}\cos\omega_r(t - t_2) \quad (10)$$

The boost inductor current reaches its greatest magnitude in this mode. Mode 3 is when the resonance capacitor voltage gradually climbs from zero and remains in this mode until the output voltage V0 is reached by the resonance capacitor voltage vcr (t) and the boost inductor voltage reaches a negative voltage equal to (Vin-Vo) at time t3.

Mode 4: This phase, known as the energy discharge mode, starts when the output voltage V0 at time t3 is reached by the resonance capacitor voltage vcr (t). Diodes D1 and D2 are currently no longer conducting and have been turned off at ZVS. The boost inductor's collected energy is delivered to the load via the output diode Do while the main and auxiliary switches are in the off position. The boost inductor current steadily drops off in mode 4 and finally hits zero at time t4. The boost inductor and resonance capacitor voltages are maintained at V0 and (Vin-Vo), respectively.

$$
\begin{aligned}
v_{cr}(t) &= V_o \\
v_{Lb}(t) &= V_{in} - V_o \\
i_{Lb}(t) &= \frac{V_{in} \vdash V_o}{L_b}(t - t_3) + I_{Lb3} \\
t_4 &= t_3 + \frac{L_b I_{Lb3}}{V_o - V_{in}}
\end{aligned}
\quad (11,12,13,14)
$$

Mode 5: In mode 5, the output current travels via the output capacitor Co while the boost inductor current is 0. Until the start of the subsequent switching cycle, when the switches S1 and S2 are tuned-on once more at the t5, the boost inductor current remains at zero.

$Vcr(t) = v0$ (15)

$Vlb(t) = 0$ (16)

$ilb(t) = 0$ (17)

The volts balance equation of the boost inductor voltage during one whole switching period can be used to determine the voltage gain (Vo/Vin) of the proposed converter. The mean value of the boost inductor voltage Vlb,dc during one switching period should be zero according to the volt-second balance equation.

IV Fuel Cell

The job of the fuel cell is to convert the chemical energy of the fuel, in this case hydrogen, into an electrical energy form that is better suited to power other devices. Fuel cells are becoming a more and more attractive alternative to combustion engines powered by fossil fuels because to their high efficiency, low emissions, and great adaptability. The four core components of every fuel cell—the anode, the cathode, the electrolyte, and an external circuit connecting the anode and the cathode—are present in all fuel cells, regardless of the variety. Two reactions form the foundation for the generation of electric energy.

The fuel is oxidised on the anode side, where it transforms into an ion with a positive charge and an electron with a negative charge. If hydrogen is the fuel, we get the following reaction:

$$2H_2 \longrightarrow 4H^+ + 4e^- \quad (18)$$

The compounds are transported from the anode of the battery to the cathode in a variety of methods. Ions go through the electrolyte that separates the electrode from the cathode, and electrons move through an external circuit to produce electrical current. Ions and electrons combine in the cathode, where they react with oxygen to form water.

$$O_2 + 4e^- + 4H^+ \longrightarrow 2H_2O \quad (19)$$

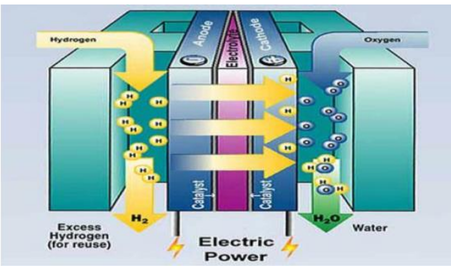

Fig6: Fuel Cell

Due to their efficient and clean energy qualities, fuel cells are seen as a potential source of energy for the future. In addition, they provide low-varying dc voltage in the range of 26 to 42 V for domestic power applications. To acquire isolated high voltage and link commercial ac voltage.

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Here in this Report FC is used as source alternative to the Conventional source (Battery).Schematic Diagram of FC with proposed Converter is Shows in Fig 7

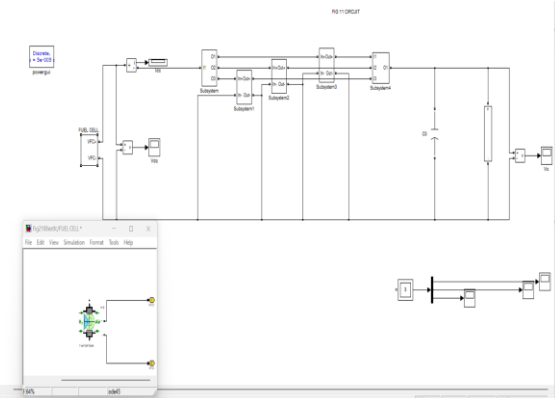

Fig7: Proposed Converter with Fuel Cell

V SIMULATION

The circuit parameters and simulation specifications listed in the table below were used to simulate the proposed soft switching boost converter and its multiphase interleaved converter using MATLAB software. Simulation is Carried out Using Basic input source and Proposed source Fuel Cell.

In this section, the simulation results using the voltage and current waveforms are provided and thoroughly analysed. Figs. 8 to 11 depict the simulated voltage and current waveforms for a single switching cycle at a 40 kHz switching frequency. The representative results of the voltage and current waveforms are in perfect agreement, as can be seen from the acquired voltage and current waveforms. By adjusting the duty cycle, the suggested converter's output power can be managed.

Parameter	Symbol	Value
Rated power	P_0	8.2 kW
DC input voltage	V_i	200 V
Output voltage	V_0	600 V
Boost inductor	L_b	50 uH
Resonant capacitor	C_r	32 nF
Output capacitor	C_0	1200 uF
Load resistance (Ω)	R_0	100 Ω
Switching frequency	f_s	40 kHz

TABLE 1. Simulation constants and circuit parameters.

The suggested one phase converter is used in circuit configuration of the proposed three phases SS-IBC. The input current waveforms and the gating signal of the active switches for various duty cycles of 0.40 and 0.61, respectively, are shown in Figs. 11 and 12. All phases have equal duty cycles, and the PWM switching function is shifted by 120.

It is plain to see that as the number of interleaved phases raises, the ripple factor significantly improves. The one-phase, two-phase, and three-phase interleaved converters, respectively, have ripple factors at rated power of 1.65, 0.39, and 0.29, as opposed to 2.33 for conventional hard switching converters. It should be mentioned that the proposed converter outperforms the competition in terms of efficiency throughout a broad range of output power.

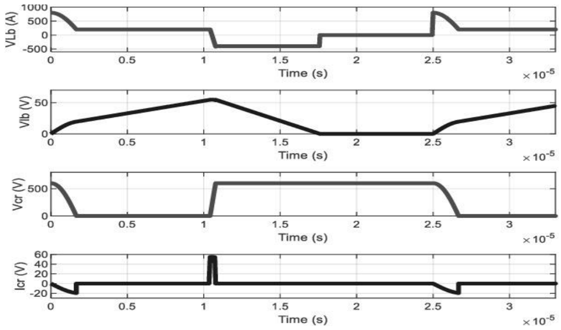

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Fig. 8 shows the computational results for the voltage and current waveforms of Lb &Cr.

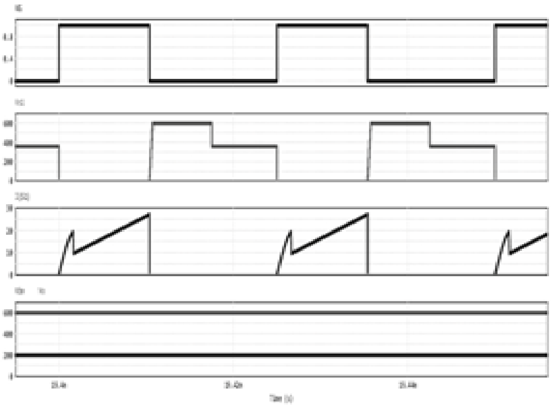

Fig9 Voltage &Current Wave forms gating signal, Active switch Voltage, Current, Input & Output voltages

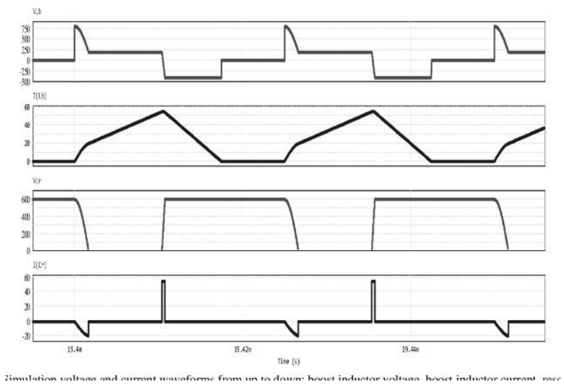

Fig10 Boost Inductor Voltage and Current, Resonant capacitor Voltage & Current

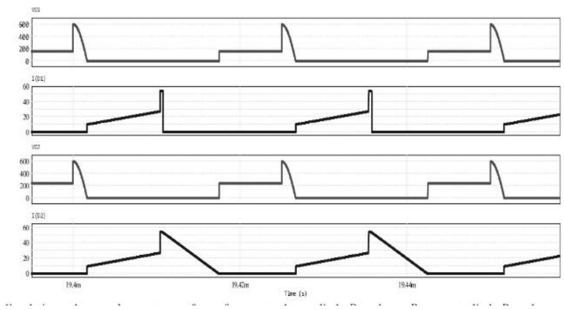

Fig 11 Diodes Voltages and Currents

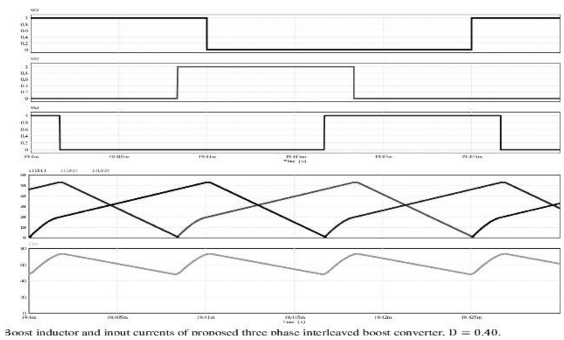

Fig12 Boost Inductor and Input Current of Proposed Converter when D=0.40

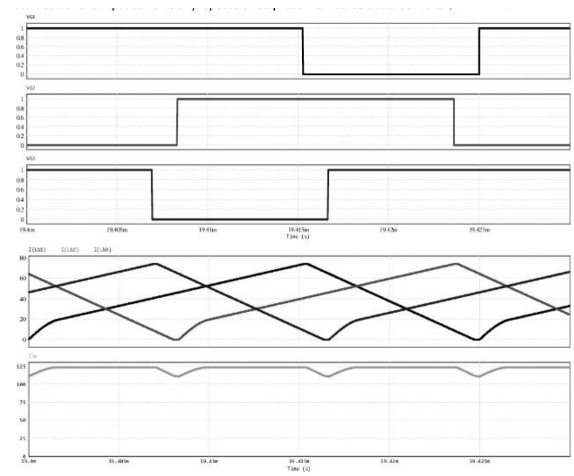

Fig13 Boost Inductor and Input Current of Proposed Converter when D=0.61

VI CONCLUSION

This research presents a soft switching multiphase SS-IBC for EV applications that operates in discontinuous current mode with excellent voltage gain. Through the use of simulation results, operation principles, in-depth analysis, voltage and current waveforms, and performance evaluation have all been examined. Due to the input current being evenly split into two parallel phases, the controlled switches' current stress and conduction losses are significantly decreased. Switches can be turned on and off at ZCS and ZVS, respectively, and the suggested converter's overall efficiency has increased. In comparison to the conventional hard switching boost converter, the suggested converter has lower switching losses and subsequently higher conversion efficiency thanks to the soft switching operation of the main and auxiliary switches over a wide output power control range. In simulation, a high conversion efficiency of more than 97% was attained for a large output power range of 8.2 kW to minimum power of 460. Further paper Can be Implemented either with Wind, Super Capacitors, PV system.

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