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PV/FC HYBRID GENERATION SCHEME FOR FUEL-CELL POWERED GRID CONNECTED SYSTEM

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ABSTRACT:

High step-up dc–dc converters are widely used in solar power generation, fuel cells, electric vehicles and uninterrupted power supplies. Some of the renewable power sources, such as PV panels and fuel cells, are characterized by low-voltage high current output and have strict current ripple requirement. Fuel cells are considered to be one of the most promising sources of distributed energy because of their high efficiency, low environmental impact and scalability. Consequently, a dc–dc converter with high step-up capability, galvanic isolation, low input current ripple, and high efficiency is required. Resonant techniques promise high-efficiency power conversion while operating at high switching frequency with their instinctive capability of well utilizing the circuit parasitic and achieving zero-voltage switching (ZVS) or zero-current switching (ZCS) for the active switches. In this project a high efficiency dc/dc resonant power converter that utilizes a resistance compression network (RCN) to provide simultaneous zero-voltage switching and near-zero-current switching across a wide range of input voltage, and power levels. the RCN technique was originally proposed and applied for radio-frequency (RF) applications, such as very-high-frequency dc/dc converter systems and RF power amplifiers; here we exploit if for high efficiency power conversion. The function of the RCN is to automatically regulate the converter operating power and waveforms in a desirable manner as the input and output voltages vary. In extension the proposed RCN based DC-DC converter is implemented with fuel cell for power condition of Grid connected systems by using MATLAB/SIMULINK Software.

Index Terms—DC/DC converter, high-efficiency power converter, ON–OFF control, resistance compression network (RCN), resonant converter.

(I) INTRODUCTION

The photovoltaic (PV) module-integrated converter (MIC) system is the key technology for the future distributed production of electricity using solar energy. The PV MIC system offers "plug and play" concept, greatly optimizing the energy yield from the PV module. Each PV module has its own power conversion system, generating the maximum power from the PV module. To make the PV MIC system commercially viable, a low-cost and high-efficiency power conversion scheme should be developed. The PV module voltage has a low-voltage characteristic. In order to deliver electric power into the grid, the low PV module voltage should be converted into a high dc voltage. Thus, a dc–dc converter with a high-voltage gain is needed. The active bridge dc–dc converter has been used for low-voltage PV sources. The power switches at low-voltage side are turned ON at zero voltage. However, the output diode at high voltage side has high switching power losses due to its reverse-recovery current. The half-bridge dc–dc converter has been presented to reduce switching power losses at high voltage side. The output diodes are turned OFF at zero current by using the voltage doublers rectifier. However, an additional half-wave rectifier is needed, which increases switching power losses. Alternatively, the active-clamped dc– dc converter has been used for low-voltage PV sources. It uses the active-clamping circuit and the resonant voltage doubler rectifier. However, the active-clamping circuit increases the voltage stress of power switches at low-voltage side, causing high switching power losses. Additionally, thermal management problems should be considered for a practical design of the PV MIC system.

Considering the dynamic response of the converter, bandwidth limitations of conventional controllers have forced power electronics engineers to increase switching frequency or increase output capacitor. Such hardware modification results in lower efficiency and higher component cost. However, by improving the controller's dynamic response, the transient performance of the converter can be improved. Therefore, it is not only necessary but also practical to improve both power efficiency and dynamic response of the dc–dc converter for low-voltage PV sources. This paper proposes a high-efficiency dc–dc converter with fast dynamic response for low-voltage PV sources. An improved active clamped dc–dc converter is presented by using a dual active clamping circuit. The voltage stress of power switches can be reduced at low-voltage side. Also, a modified proportional and integral (PI) controller is suggested for fast output voltage control. The transient performance of the proposed converter is improved. All control functions are implemented in software with a single-chip microcontroller. The proposed converter is realized with minimal hardware with a low cost. The operation of the proposed converter is described. The control strategy is presented, including the fast output voltage control and its digital implementation. The performance of the proposed converter is verified using a 200-W experimental prototype.

This paper introduces a new high efficiency resonant dc/dc converter topology, the Resistance Compression Network (RCN) converter, which seeks to overcome the abovementioned challenges. This converter operates with simultaneous zero voltage switching (ZVS) and near zero current switching (ZCS) across a wide range of input voltage, output voltage and power levels, resulting in low switching losses.

The RCN (composed of *Ls* and *Cs)* is a special single input, multi output matching network that provides desirable impedance control characteristics in order to automatically regulate the converter operating power and waveforms in a desirable manner as the input and output voltages vary.

A limitation of many high-frequency resonant inverter topologies is their high sensitivity to loading conditions. This project introduces a new class of matching networks that greatly reduces the load sensitivity of resonant inverters and radio frequency (RF) power amplifiers. These networks, which we term resistance compression networks, serve to substantially decrease the variation in effective resistance seen by a tuned RF inverter as loading conditions change. Compression networks ideally act without loss, such that all energy provided at the input port is transformed and transferred to the resistive load. In effect, the load resistance range appears compressed when looking through a resistance compression network. This effect can be used to overcome one of the major deficiencies of tuned RF circuits for power applications and expand the range of applications for which high-frequency resonant power conversion is viable. It can be seen that the RCN is highly effective in suppressing the effects of output voltage variation on the operation (e.g., instantaneous power) of the converter. By using the RCN to greatly limit the effects of output voltage variation. See fig .1

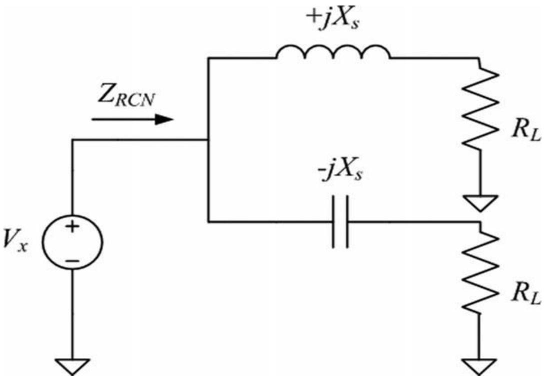


Fig .1 Fundamental frequency model of RCN and the rectifier

(II) Resistance-Compressed Rectifiers

A resistance compression network can be combined with an appropriate set of rectifiers to yield an RF-to-dc converter with narrow-range resistive input characteristics. In order to obtain the desired compression effect, the rectifier circuits must effectively act as a matched pair of resistances when connected to a compression network. Purely resistive input impedance can be achieved with a variety of rectifier structures. For example, in many diode rectifiers the fundamental ac voltage and current at the rectifier input port are in phase, though harmonics may be present. One example of this kind of rectifier structure is an ideal half bridge rectifier driven by a sinusoidal current source of amplitude I_{in} and frequency ω_s, and having a constant output voltage V_{dcout} ,. The voltage at the input terminals of the rectifier will be a square wave having a fundamental component of amplitude $V_{x1} = (2V_{dc,out}/\pi)$ in phase with the input current $i_{in}(t)$ as show $i_{in}(t)$n. The electrical behaviour at the fundamental frequency (neglecting harmonics) can be modelled as a resistor of value $R_{eq} = (2/\pi)(V_{out}/I_{in})$ Similarly, a full wave rectifier with a constant voltage at the output can be modelled at the fundamental frequency as a resistor $R_{eq} = (4/\pi)(V_{dc,out}/I_{in})$ There are many other types of rectifier topologies that present the above mentioned behaviour; another example is the resonant rectifier of [19]. This rectifier also presents a resistive impedance characteristic at the fundamental frequency; furthermore, it requires only a single semiconductor device and incorporates the necessary harmonic filtering as part of its structure. Such a rectifier, when connected to a constant output voltage, presents a resistive equivalent impedance of the same magnitude as that of the full wave rectifier, $R_{eq} = (4/\pi)(V_{dc,out}/I_{in})$ Still another type of rectifier providing this type of behaviour is the resonant rectifier used in the dc–dc converter fig3.2

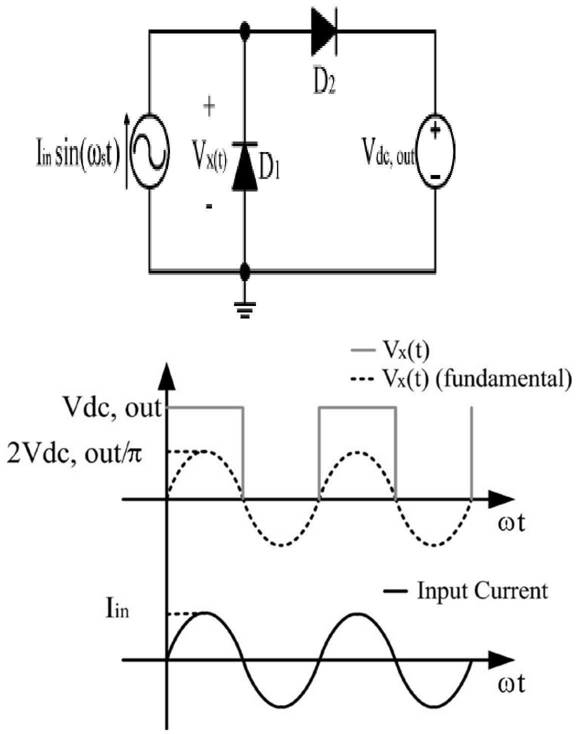


Fig.2 Half wave rectifier

Half-wave rectifier with constant voltage load and driven by a sinusoidal, current source. 2 Characteristic waveforms of the half-wave rectifier .The input current and the fundamental of the input voltage are in phase. Two-element compression network with reactive branches represented by impedances evaluated at the operating frequency.

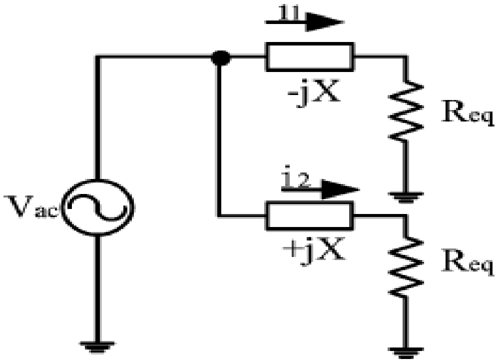


Fig.3 Two element compression network

Driving this type of rectifier with a tuned network suppresses the harmonic content inherent in its operation and results in a resistive impedance characteristic at the desired frequency. This equivalent resistance can be represented by $R_{\mathrm{eq}} = (k_{\mathrm{rect}}/|I_1|)V_{\mathrm{dc,out}}$, where k_{rect} depends on the specific rectifier structure and $|I_1|$ is the fundamental component of the drive current. As shown below, when two identical such rectifiers feed the same dc output and are driven via reactance's with equal impedance magnitudes, they act as matched resistors with values that depend on the dc output. Thus, a pair of such rectifiers can be used with a compression network to build a rectifier system having a resistive ac-side (input) characteristic that varies little as the dc-side operating conditions change. This type of compression network/rectifier combination can be modelled. We can express the magnitude of the current i_1 as

$$|i_1| = \frac{V_{\mathrm{ac}}}{\sqrt{X^2 + R_{eq}^2}}.$$

By replacing R_{eq} with its corresponding value we obtain

$$|i_1| = \frac{V_{\mathrm{ac}}}{\sqrt{X^2 + \frac{k_{\mathrm{rect}}^2}{|i_1|^2} V_{\mathrm{dc,out}}^2}}.$$

Rearranging

$$|i_1|^2 X^2 + k_{\mathrm{rect}}^2 V_{\mathrm{dc,out}}^2 = V_{\mathrm{ac}}^2.$$

Solving for $|I_1|$

$$|i_1| = \sqrt{\frac{V_{\mathrm{ac}}^2 - k_{\mathrm{rect}}^2 V_{\mathrm{dc,out}}^2}{X^2}}.$$

From this expression we can see that the branch current magnitude $|i_1|$ depends on the dc output voltage and the reactance magnitude. The branch carrying $|i_2|$ has the same reactance magnitude and output voltage, so both branches present identical effective load resistances. For all the rectifier structures that can be represented by an equivalent resistance of value $R_{\mathrm{eq}} = (k_{\mathrm{rect}}/|i_1|)V_{\mathrm{dc,out}}$,we can express the equivalent resistances loading each branch as

$$R_{\mathrm{eq}} = \frac{k_{\mathrm{rect}} V_{\mathrm{dc,out}}}{\sqrt{\frac{V_{\mathrm{ac}}^2 - k_{\mathrm{rect}}^2 V_{\mathrm{dc,out}}^2}{X^2}}} = X \sqrt{\frac{1}{\left(\frac{V_{\mathrm{ac}}}{k_{\mathrm{rect}} V_{\mathrm{dc,out}}}\right)^2 - 1}}$$

(III) Design Considerations For Resistance Compression Networks

In designing resistance compression networks and resistance compressed rectifiers there are some subtle considerations that must be taken into account. The first consideration is how the compression network processes frequencies other than the operating frequency. When a compression network is loaded with rectifiers, the rectifiers typically generate voltage and/or current harmonics that are imposed on the compression network. It is often desirable to design the compression network to present high or low impedances to dc and to the harmonics of the operating frequency in order to block or pass them. Moreover, in some cases it may be important for the impedances of the two branches to be similar at harmonic frequencies in order to maintain balanced operation of the rectifiers. To achieve this, it is often expedient to use multiple passive components to realize each of the reactance's in the network. This strategy was employed in the compression network of the system in described in the following section [2] A second design consideration is that of selecting a center impedance for the compression. Typically, one places the center impedance at the geometric mean of the load resistance range to maximize the amount of compression. However, in some cases one might instead choose to offset the center impedance from the middle of the range. This might be done to make the input resistance of the compression network vary in a particular direction as the power level changes. Also, in systems that incorporate impedance or voltage transformation, different placements of the compression network are possible, leading to different possible values of . For example, one might choose to place a transformation stage before the compression network, on each branch after the compression network, or both. The flexibility to choose in such cases can be quite valuable, since centering the compression network at too high or too low an impedance level can lead to component values that are either overly large or so small that they are comparable

to parasitic elements [3]. A third major consideration is circuit quality factor and frequency sensitivity. Since compression networks operate on resonant principles, they tend to be highly frequency selective. This fact requires careful component selection and compensation for circuit parasitics in the design and layout of a compression network. Moreover, as with matching networks that realize large transformation ratios , compression networks realizing large degrees of compression require high quality-factor components. Component losses typically limit the practical load range over which useful compression may be achieved.

(IV) RCN CONVERTER TOPOLOGY AND CONTROL

RCN converter is the new type of converter design to achieve the high efficiency of the converter. This project introduces a new high efficiency resonant dc/dc converter topology, the resistance compression network (RCN) converter, which seeks to overcome the aforementioned challenges. This converter operates with simultaneous ZVS and ear-ZCS across a wide range of input voltage, output voltage, and power levels, resulting in low switching losses. See in fig 4

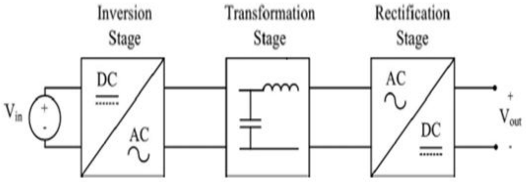


FIG 4. Architecture of The Proposed RCN Converter

Operation: The dc/dc converter proposed here consists of an inversion stage, a transformation stage, and a rectification stage, as shown in The inversion and rectification stages use standard designs. The inversion stage means it converts DC to AC ,this stage is composed with full bridge inverter to achieve the high efficiency and high performance and also provide the voltage gain so that the voltage gain requirement of the transformer and matching network are reduced. The input to this inversion stage is the dc voltage and this dc supply voltage is taken from the photovoltaic system . and now coming to the transformation stage ,it is mainly composed of the three components named as matching network ,transformer and the Resistance Compression Network .and now coming to the rectification stage, this rectification stage is composed of two half bridge rectifiers .the output of the rectification stage is the DC voltage and that DC voltage is fed to the single phase DC series motor and this motor is running at the reference speed .However, the transformation stage and the control of the converter are new. The transformation stage is the new design of our proposed model of converter .the transformer is designed based on the loss considerations, by using computer search routine the design of the transformer is employed for high efficiency.

The topology of the proposed RCN converter as shown is designed to step-up voltage. The transformation stage consists of a matching network, a transformer, and RCN. See in fig 5.

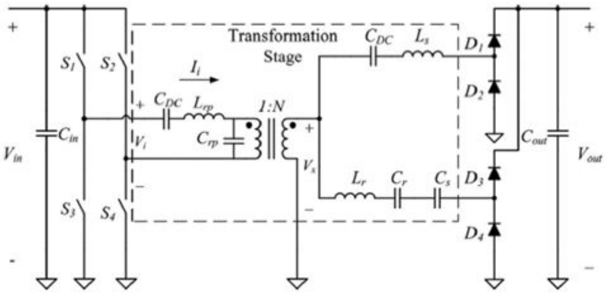


fig 5. Topology of the proposed RCN dc/dc converter

The matching network composed of Lrp and Crp acts as a filter and provides a voltage gain , hence reducing the transformer turns ratio requirement. One issue with high-turns-ratio step-up transformers that exists in many topologies is that the parasitic leakage inductance of the transformer can undesirably ring with its secondary side winding capacitance at the switching transitions. This creates large ringing in the current and voltage waveforms, and high-frequency losses. The matching network also eliminates this ringing by absorbing the transformer parasitic. The 1:N transformer provides additional voltage gain and isolation. The RCN (composed of Ls and Cs) is a special single input, multi output matching network that provides desirable impedance control characteristics. The RCN technique was originally proposed and applied for radio-frequency (RF) applications, such as very-high-frequency dc/dc converter systems and RF power amplifiers here, we exploit if for high efficiency power conversion.[4] The function of the RCN is to automatically regulate the converter operating power and waveforms in a desirable manner as the input and output voltages vary. As applied here, the RCN also includes a series resonant tank (composed of Lr and Cr) . Its purpose is to provide additional filtering. The inverter stage is simply a full-bridge inverter (composed of switches S1 − S4). A full bridge is used instead of a half bridge to reduce the voltage gain requirement from the matching network and the transformer. The rectification stage is composed of two half-bridge rectifiers. The capacitors Cin and Cout are for input and output filtering, respectively, and the two capacitors marked as CDC are for dc blocking purposes. The output power in the proposed converter is regulated using ON– OFF control, also known as burst-mode control or bang–bang control. The power is controlled by gating the converter ON and OFF at a modulation frequency that is much lower than the switching frequency . The advantage of using ON–OFF control is that the magnetic are designed for only a single frequency (a high frequency), while the power is regulated by turning the converter ON and OFF at a lower frequency. Moreover, the power is transferred only in the fraction of the time the converter is ON, which results in high efficiency even at light loads. The output power is controlled by the duty ratio of the ON–OFF modulation. The ON–OFF control can be implemented through hysteretic control, through fixed-period ON–OFF PWM , or other methods. Additional care may be necessary in implementations that allow very short ON or OFF durations to maintain high efficiency and desired operation during ON–OFF transient conditions. The ON–OFF modulation has its own corresponding loss. The higher the modulation frequency the greater the loss. The output capacitance is sized according to the ON–OFF modulation frequency; with a lower modulation frequency, a larger capacitor has to be used. The duty ratio of the modulation also influences the loss. Very small or very large duty ratio results in greater loss as the converter operates in steady state for a shorter time. So, in order to minimize the total loss both the modulation frequency and the duty ratio have to be considered. The ON/OFF modulation frequency for output power control was chosen as 500 Hz. The reason for selecting this low frequency was to achieve a high efficiency under modulation with acceptable capacitance at the input and output. In applications where capacitance reduction is desired, significantly higher modulation frequencies can be realized. . For the transformation stage, the reactive elements values were chosen considering the tradeoffs between the losses in the parasitic of the transformer, the matching network, and the RCN.

(V) Analysis And Design Methodology:

The analysis of the resistance compression network converter can be carried out by using the fundamental frequency analysis. According to the fundamental frequency analysis, at the switching frequency the half-bridge rectifiers can be modeled as resistors, as illustrated see in fig 6

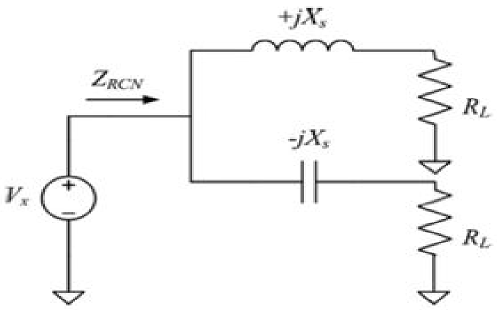


Fig 6. fundamental frequency model of RCN and the rectifiers

The effective resistance of these rectifiers is given by

$$R_L = \frac{4V_{\mathrm{out}}^2}{\pi^2 P_{\mathrm{out}}} \qquad (1)$$

where Vout is the converter output voltage and Pout is the switching-cycle-average output power. one of the branches of the RCN comprises a blocking capacitor CDC and an RCN inductor Ls . The other branch comprises a series LC tank tuned to be net capacitive at the switching frequency (net equivalent capacitance Cs). This branch may be modeled as a series resonant tank (with components Lr and Cr) tuned to the switching frequency for filtering, in series with an additional RCN capacitance Cs . Since the series LC tank appears as a short circuit at the switching frequency, it is treated as such and in the following analysis. Similarly, the dc blocking capacitor CDC of is an effective short at the high switching frequency.[4] Hence, at the switching frequency the input impedance of the RCN looks purely resistive and is given by

$$Z_{\mathrm{RCN}} = \frac{X_s^2 + R_L^2}{2R_L} \qquad (2)$$

where Xs is the magnitude of impedance of the RCN elements (Ls and Cs) at the switching frequency. The use of the RCN reduces the change in impedance seen by the inverter as the effective rectifier resistance (RL) changes due to variations in output voltage and output power . This compression effect can be seen in which shows that the RCN input impedance (ZRCN) varies only by 25%, while the effective rectifier resistance varies by 400%.

This helps achieve ZVS and near-ZCS of the inverter switches across a wide range of output and input voltages. The RCN also serves to limit the instantaneous output power across the full operating range by providing a specified loading characteristic to the inverter. The value of Xs is selected in such a way so as to limit the output power to the maximum value required across the range of output voltages at the minimum input voltage. Since the power delivery capability of the converter increases with input voltage, this ensures that the converter can deliver the maximum required power across ts entire input voltage range. It is also noted that the power characteristic across output voltage is quite flat at the minimum input voltage, owing to the effect of the RCN. The expression for output power (Pout) can be found by neglecting losses and equating input power (Pin = (4 π Vin)2/2ZI , where ZI is the input impedance of the matching network as shown in Fig. 7) to output power (Pout = 4V 2 out/π2RL). The output power of the converter is given by

$$P_{\text{out}} = \frac{4V_{\text{out}}}{X_s \pi^2} \sqrt{4V_{\text{in}}^2 N^2 G^2 - V_{\text{out}}^2}. \qquad (3)$$

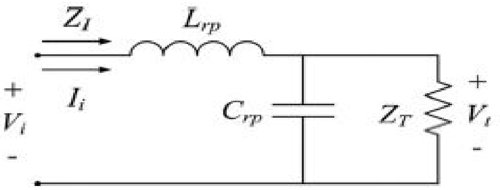


Fig 7: matching network with equivalent impedance

This expression for output power is in terms of input voltage (Vin), output voltage (Vout), the transformer turns ratio (N) and the matching network gain voltage (G). The gain of the matching network can be calculated using the equivalent circuit and is given by

$$G \equiv \frac{V_t}{V_i} = \frac{1}{\sqrt{\left(\frac{\omega L_{rp}}{Z_T}\right)^2 + (1 - \omega^2 L_{rp} C_{rp})^2}} \qquad (4)$$

Where ω is the angular switching frequency. Here, ZT(=ZRCN/N2) is the effective load seen by the matching network. As ZT varies with changes in power, the gain varies. However, due to the RCN, this gain is fairly constant across variation in input and output voltages. The input impedance of the matching network as seen by the inverter is given by

$$Z_I = \frac{j(X_{Lrp} Z_T^2 + X_{Crp}^2 X_{Lrp} - X_{Crp} Z_T^2) + X_{Crp}^2 Z_T}{Z_T^2 + X_{Crp}^2} \quad (5)$$

Where XLrp and XCrp are the magnitude of the impedance of Lrp and Crp , respectively. For ZI to be resistive, XLrp, XCrp, and ZT must satisfy

$$X_{Lrp} = \frac{X_{Crp} Z_T^2}{X_{Crp}^2 + Z_T^2}. \qquad (6)$$

Picking XLrp to be slightly larger than the value given by (6) so that ZI is slightly inductive, ensures that the inverter switches achieve ZVS and near-ZCS. The application of the equations presented previously is illustrated in the design of the prototype converter in the next section we have to seen. . As illustrated earlier, narrow-range frequency operation is used to improve the overall performance of the converter. By adjusting the converter switching frequency over a narrow range from 425 to 500 kHz as input voltage varies, the maximum output power that can be delivered by the converter can be maintained within a narrower range than if strictly fixed frequency operation is used, yielding moderate power variation across variations in input voltage. This helps maintain high efficiency as the input voltage varies. The switching frequency is decreased as the input voltage increased: 500 kHz is used at an input voltage of 25 V and 425 kHz with an input voltage of 40 V.

(VI) Implementation

A prototype of the RCN dc/dc converter of Fig.8 has been designed and built. The designed dc/dc converter is meant for large-step-up applications such as the two-stage photo voltaic to- grid conversion system The

RCN dc/dc converter can be used to convert the low (widely varying) output

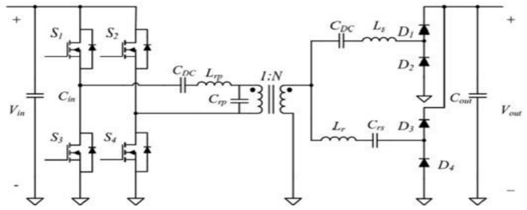


Fig 8: implementation of the proposed RCN dc/dc converter

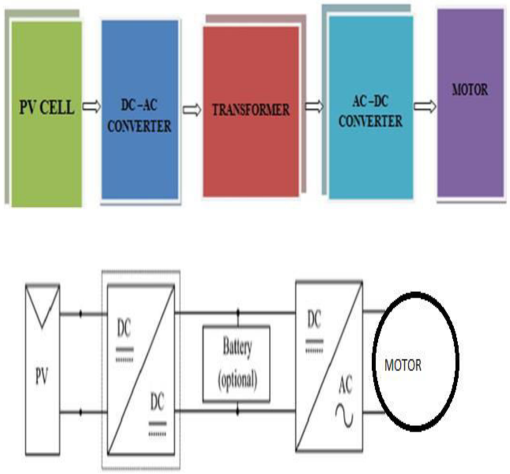


Fig 9: block diagram of PV connected motor

(VII) SIMULATION RESULTS

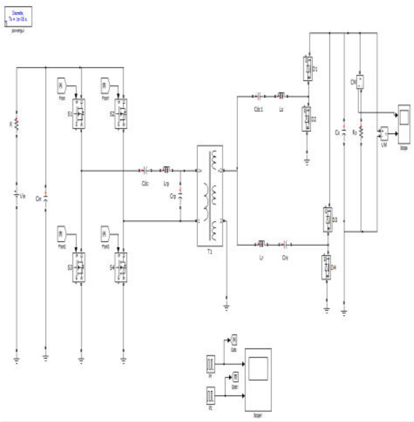


Fig 10 SIMULINK FORMAL CIRCUIT CONFIGURATION

Output:

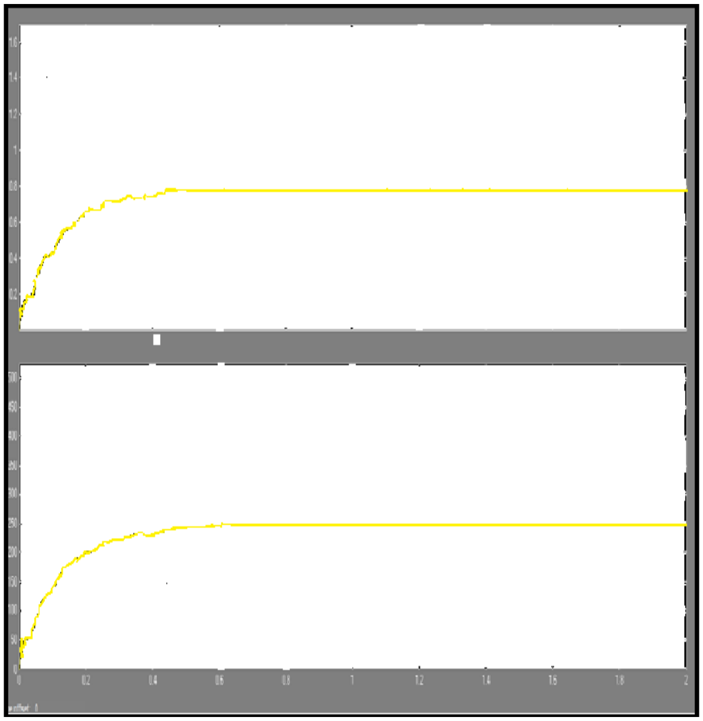
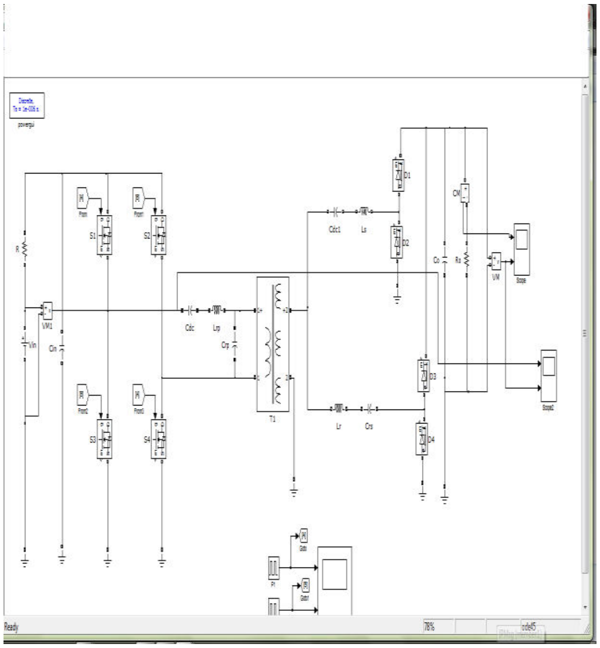


Fig 11 output wave forms

(i) PROPOSAL CONFIGURATION CIRCUITS:



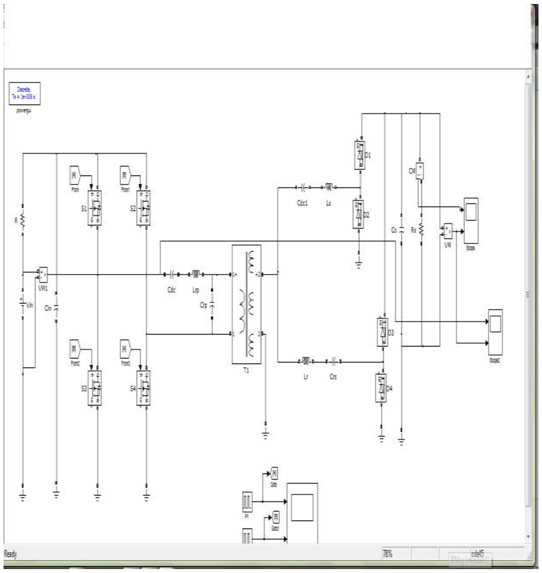


Fig 12 proposed circuit configuration

Output wave forms of proposed circuit configuration

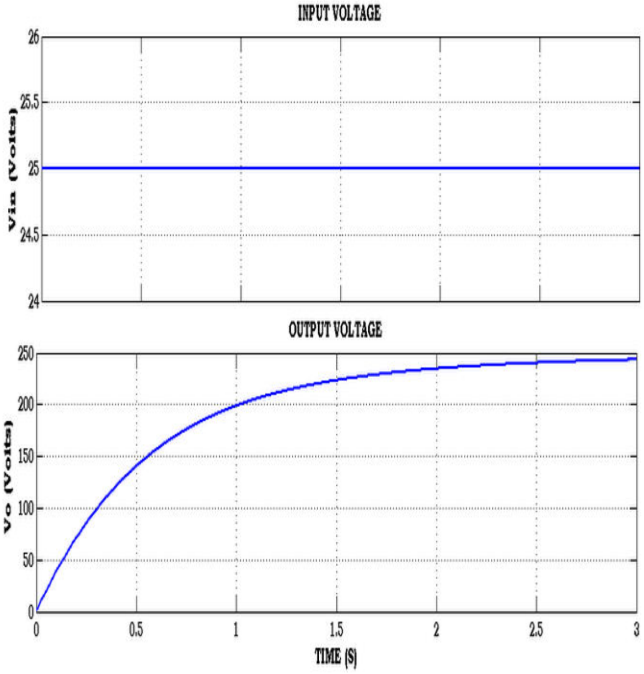


Fig 13 Proposed circuit Input and output wave forms

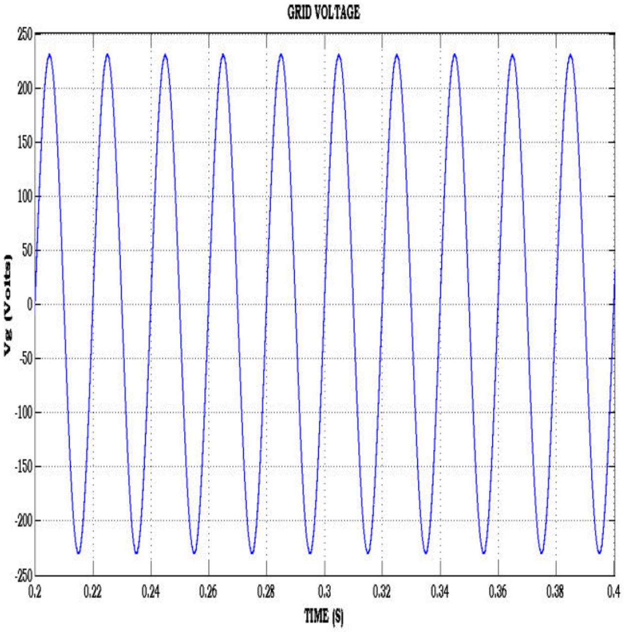


Fig :14 Proposed circuit grid voltage wave form

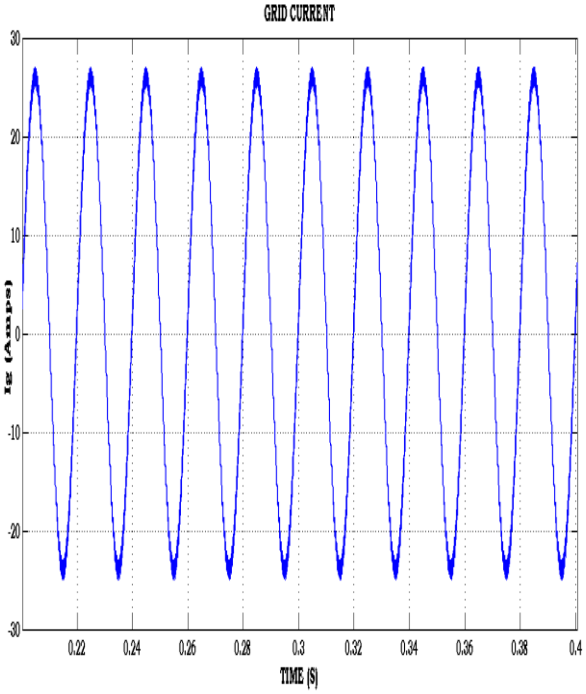


Fig 15 Proposed circuit grid current wave form

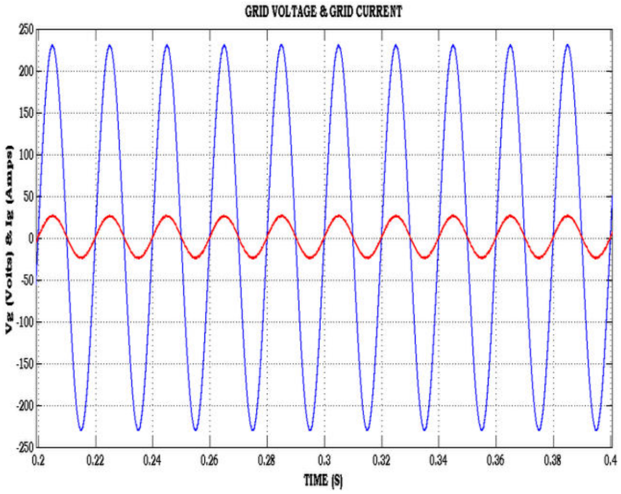


Fig 16 Proposed circuit grid power factor circuit

(ii) PARAMETERS

PV Array:
Number of cells per module 96
Number of series connected modules for string 1
Number of parallel strings 24
Module specifications under STC [V_{OC}, I_{OC}, ,V_{mp}, I_{mp}]=[64.2 5.96 54.7 5.58]
Model parameters per one module
[R_S,Rp,Isat,Iph,Qd]=[0.037998 993.51 1.1753e-08 5.9602 1.3]
Sample time 0.0000001
RCN CONVERTER:
Resistance[R] = 0.01ohms
Input Capacitance [Cin] = 5000e-6 F
Inverter: Mosfet**:** FET resistance Ron = 0.1 ohms
Internal diode resistance Rd= 0.01 ohms
Matching network: capacitance [Cdc] = 10e-3 F
Inductance Lrp = 1e-6 H
Capacitance Crp =60e-9 F
RCN: capacitance [Cdc1] = 10e-3 F
Inductance [Ls] = 78e-6 H
Inductance [Lr] = 101e-6 H
Capacitance [Crs]= 560e-12 F
Rectifier: Diode: resistance Ron = 0.001 ohms
Forward voltage [Vf] =0.8 V
Snubber resistance [Rs] =500 ohms
Snubber capacitance [Cs] =250e-9 F
Output Capacitance [Co] = 20e-3 F

(VIII) CONCLUSION:

Photovoltaic cell fed DC electrical drive configuration is proposed in this project. And the dc series motor operated at the reference speed with the given power electronic configuration. The converter implementation provides galvanic isolation and enables large (greater than 1:10) voltage conversion ratios. The proposed converter achieves very high efficiency by maintaining ZVS and near-ZCS over a wide input voltage, output voltage, and power range. The MATLAB based circuit results for the conventional and the proposed circuit configuration is successfully presented in this project.

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