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Simulation of an Integrated PWM Resonant Converter for Photovoltaic Applications

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Abstract:

This project presents implementation of an Integrated Resonant Converter (IBR) incorporated with Hybrid Frequency Modulation for photovoltaic applications. Integrated Boost Resonant Converter employs a unique modulation method for extending the input range of Pulse-Width Modulation, low component count, galvanic isolation, simple control and high efficiency across a wide input and load range. The modulation technique includes primarily the hybridizing of constant-on, constant-off, and fixed-frequency control depending only on the required duty cycle. The modulation scheme reduces core loss and conduction loss dramatically by decreasing the applied volt-seconds at the transformer and improving the switching period utilization. It also allows for a predictable voltage gain, dependent only on duty cycle and transformer turns ratio. Effective Photovoltaic power conditioning requires efficient power conversion and accurate power point tracking to counteract the effects of panel mismatch, shading and general variance in power output during a daily cycle.

Index Terms: DC–DC modulation, integrated boost resonant (IBR) converter.

Introduction:

Power conversion for photovoltaic (PV) applications, as opposed to more conventional dc–dc converter configurations, requires an adaptable system that is capable of responding to a wide range of input voltage and current conditions. PV voltage varies significantly with panel construction and operating temperature, while the PV current changes largely due to solar irradiance and shading conditions.

If a converter is designed only for high peak efficiency, oftentimes the range of conditions common to many PV installations will force the converter into another operating region where it is much less efficient. Whether the input source is dynamic or the application calls for a universal input, the ability to maintain high-efficiency energy conversion over a wide range of conditions is a continual challenge. In many cases, extending the input range of a converter requires sacrificing conversion efficiency, or else adding a significant number of additional components. In photovoltaic (PV) applications, efficient, low-cost enhancements to improve converter efficiency are desirable. One such method of enhancing converter operation is the selection of an appropriate modulation scheme. In this paper, a unique dc–dc converter modulation scheme is proposed for a class of converters that integrate PWM stages into unregulated resonant converters. The resonant stage provides galvanic isolation with high efficiency, while the PWM stage provides the necessary regulation. Though the efficiency is good with a narrow input range and fixed-frequency PWM, it is still possible to extend the operating range while maintaining high efficiency. This new method, a hybrid between constant-on, constant-off and fixed-frequency modulation, optimizes the converter efficiency at the nominal line input while allowing an extended input range. In the distributed PV PCS, the isolated dc–dc stage must operate efficiently at full power, while maintaining high performance at light load, across a range of PV voltages. In order to maintain high efficiency under low-power conditions, it is necessary to minimize the amount of circulating energy in the system. One popular option for the dc–dc conversion stage is a simple continuous-conduction-mode flyback converter, It has the benefit of simple construction and low circulating energy. However, the switching loss for both the primary switch and the diode can be quite large, and the overall system efficiency is typically low.

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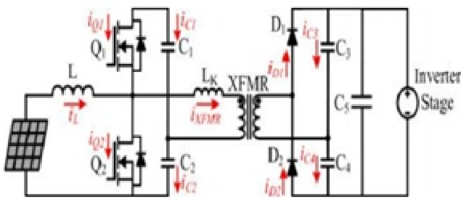

Fig 1: Circuit diagram of the IBR Converter.

Another option is the series-resonant converter, and more recently the LLC resonant converter, both of which operates on a similar principle and, typically, use a variable frequency control to adjust the output voltage. When the series resonant, or LLC converter, is operated near the resonant frequency of the tank circuit, the converter achieves nearly ZVS and zero-current switching (ZCS) with very low circulating energy, giving it high peak efficiency. However, as the operating frequency diverges from the resonant frequency, the amount of circulating energy increases. Unfortunately, the normal conditions for PV conversion will often push the converter significantly away from the optimum switching frequency, causing the CEC efficiency to suffer. Several authors have proposed methods to extend the line and load range of the LLC, once again complicating the circuit topology and control. The method proposed in this paper integrates a traditional boost converter element into the DCX with only the addition of a single inductor. The overall design is straightforward and may be controlled Hybrid frequency PWM with only the need to observe limitations on the maximum and minimum duty cycle. For PV applications, this circuit satisfies the need for galvanic isolation, low switching loss, minimal circulating energy, as well as simple gate drive and control.

Overview of a photovoltaic (PV) module:

To understand the PV module characteristics it is necessary to study about PV cell at first. A PV cell is the basic structural unit of the PV module that generates current carriers when sunlight falls on it. The power generated by these PV cell is very small. To increase the output power the PV cells are connected in series or parallel to form PV module. The electrical equivalent circuit of the PV cell is shown in Fig

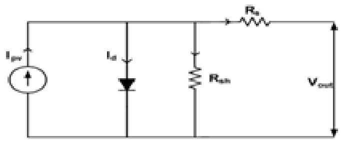

Fig 2: Electrical equivalent circuit diagram of PV cell

The main characteristics equation of the PV module is given by

$$I = I_{pv} - I_o\left[\exp\left(\frac{q(V+IR_S)}{\alpha KT}\right) - 1\right] - \frac{V+IR_S}{R_{sh}}$$

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{\alpha K}\right]\left(\frac{1}{T_n} - \frac{1}{T}\right)$$

$$I_{pv} = [I_{sc} + K_i(T - T_n)]\frac{G}{G_n}$$

Where,

I and V - cell output current and voltage;
Io - cell reverse saturation current;
T - Cell temperature in Celsius;
K - Boltzmann's constant;
q - Electronic charge;
Ki- short circuit current/temperature coefficient;
G - Solar radiation in W/m2;
Gn- nominal solar radiation in W/m2;
Eg - energy gap of silicon;
Io,n - nominal saturation current;
Rs - Series resistance;
Rsh - shunt resistance;

The I-V characteristic of a PV module is highly non-linear in nature. This characteristics drastically changes with respect to changes in the solar radiation and cell temperature..Whereas the solar radiation mainly affects the output current, the temperature affects the terminal voltage. Fig.2 shows the I-V characteristic of the PV module under varying solar radiations at constant cell temperature (T = 25 ºC).

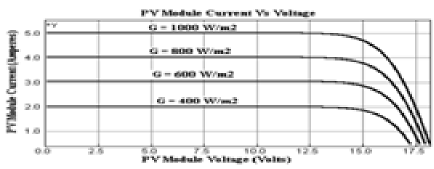

Fig 3: Current versus voltage at constant cell temperature T = 25 ºC.

Fig.3 shows the I-V characteristics of the PV module under varying cell temperature at constant solar radiation (1000 W/m2).

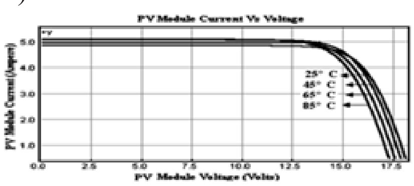

Fig 4: Current versus voltage at constant solar radiation G = 1000 W/m

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Maximum Power Point Algorithm to improve the efficiency of the solar panel MPPT is used. According to maximum power point theorem, output power of any circuit can be maximize by adjusting source impedance equal to the load impedance, so the MPPT algorithm is equivalent to the problem of impedance matching. In present work, the resonant Converter is used as impedance matching device between input and output by changing the duty cycle of the converter circuit. A major advantage of resonant converter is that high or low voltage obtained from the available voltage according to the application. Output voltage of the converter is depend on the duty cycle, so MPPT is used to calculate the duty cycle for obtain the maximum output voltage because if output voltage increases than power also increases. In this paper Perturb and Observe (P&O) and constant duty cycle techniques are used, because these require less hardware complexity and low-cost implementations.

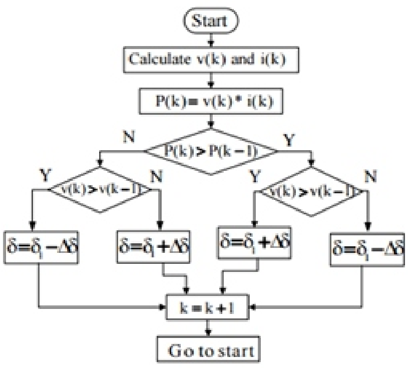

Fig 5: Flow Chart of P&O MPPT.

It is the simplest method of MPPT to implement. In this method only voltage is sensed, so it is easy to implement. In this method power output of system is checked by varying the supplied voltage. If on increasing the voltage, power is also increases then further 'δ' is increased otherwise start decreasing the 'δ'. Similarly, while decreasing voltage if power increases the duty cycle is decreased. These steps continue till maximum power point is reached. The corresponding voltage at which MPP is reached is known as reference point (Vref). The entire process P&O algorithm is shown in Fig.5.

PROPOSED CONVERTER OPERATION AND CONTROL SCHEME:

The proposed modulation scheme is developed primarily for circuits that employ this integration of PWM and resonant conversion.

One such circuit is the integrated boost resonant (IBR) converter, which is shown in Fig. 1. Though this topology appears similar to both the boost half bridge (BHB) and the circuit, the operational characteristics are quite different. The circuit is unidirectional and can be operated under strictly PWM, unlike. Unlike the BHB, the IBR's rectifier capacitors, C1–C4, are sized appropriately so that they resonate fully with the transformer leakage inductance during each half of the switching cycle. This resonant action occurs simultaneously with a synchronous boost circuit formed by the input inductor and the two MOSFETs Q1 and Q2. The two MOSFETs are switched complementary to one another in the proceeding analysis, with the duty cycle D defined for the lower switch Q2. Thus, the boost action is said to be integrated into the resonant converter. Allowing this resonant action to complete fully adds four primary benefits:

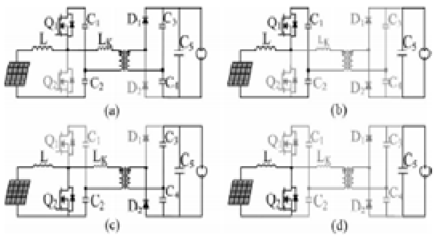

Fig 6: Operating modes of the IBR converter.

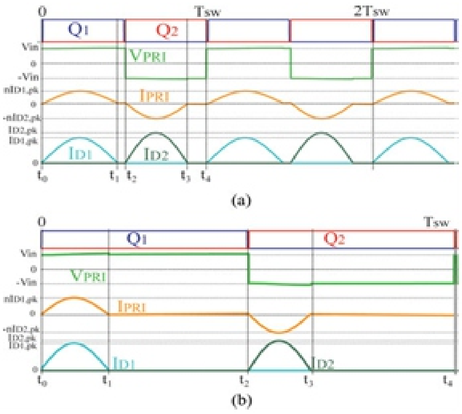

Fig 7: IBR operation at 50% duty with (a) optimized switching frequency and (b) fixed frequency (4:1 input ratio).

1) The output diodes D1 and D2 achieve zero current switching (ZCS);
2) Switching loss in the primary-side MOSFETs is equal to a normal synchronous boost;
3) The transformer has zero circulating energy;
4) The resonant stage gain is fixed and equal to the transformer turns ratio (1:n).

The operating modes for the IBR converter are given in Fig. 4(a)–(d), corresponding to the theoretical waveforms shown in Fig. 7. Because Q1 and Q2 are both MOSFETs and are switched complementary to one another, the input inductor L operates in the continuous conduction mode (CCM) and never becomes discontinuous. The inductor current increases linearly during modes 3 and 4, and decreases linearly during modes 1 and 2. The energy transfer between the combinations of C1 , C2 and C3 , C4 is resonant, occurring only during modes 1 and 3. Though the boost converter is integrated into the resonant circuit, the two elements are effectively decoupled as long as the resonant modes are allowed to fully complete. Thus, the resulting voltage gain is simply the product of a boost converter voltage gain and the gain of the resonant stage. Since the boost converter always operates under CCM, its gain is affected only by the duty cycle of Q2. Second, because the resonant modes are allowed to fully complete and the transformer magnetizing current is negligible, the average secondary current is equal to the average of the primary-side current. The resonant stage gain is, therefore, equal to the turns ratio n and is independent of duty cycle, switching frequency, and power level.

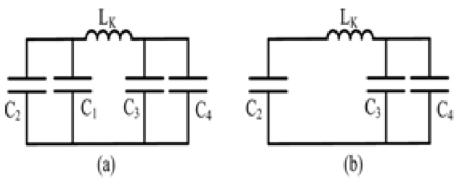

Fig 8: AC-equivalent circuits in (a) Mode 1 and (b) Mode 3.

However, because the resonant action must be allowed to complete during each half-cycle, the maximum and minimum duty ratios for Q2 under traditional PWM control are limited by the length of each resonant period, as shown in (2) and (3). The length of each resonant period (Tres1 and Tres2) can be determined from the ac-equivalent circuits during modes 1 and 3, shown in Fig. 8. The difference between the equivalent circuit is that during mode 1, the upper capacitor C1 is connected through Q1 to the switch node, allowing both primary-side capacitors to participate in the resonant energy transfer. In mode 3, however, the blocking upper switch Q1 isolates C1 from the resonant loop, allowing only C2 to resonate. This creates a shorter resonant period in mode 3, Tres2 , than in mode 1, Tres1 , equations for which are given in (4) and (5). In order to accommodate a larger duty cycle range, the resonant period length must be reduced with respect to the overall switching period.

With a reduced resonant period, and less of the conduction period utilized, the peak amplitude of the resonant current must increase in orde to transfer the same amount of power to the output. This results in an increase in the rms current through all of the devices involved in the resonant operation, and thus an increase in overall conduction loss. Therefore, having the resonant periods equal to the switch-on and -off times would result in the lowest rms current. The waveforms in Fig. 8(a) show the resonant operation of the IBR converter operating at 50% duty cycle with an optimized switching frequency. Under this condition, the resonant action occupies the majority of the switching period, and the peak currents are reduced. Alternatively, Fig. 7(b) shows the converter operating under the fixed-frequency condition with a wide-input range. The resonant action occupies very little of the switching period, and the peak currents increase by 150% of their optimized value. is the management of the core loss in the transformer. In order to accommodate a wide duty cycle range, the switching frequency must be reduced much below optimum, which increases the applied volt-seconds, and therefore the ac flux Fig. Example control system block diagram (MPPT dc–dc converter). density, at the transformer. Because the applied volt-second product is increased at 50% duty cycle, the ac flux density is also increased at the middle of the input voltage range. For a fixed switching frequency, the peak in ac flux density would coincide with a peak in the transformer core loss

$$D_{\max} = 1 - \frac{T_{\text{res1}}}{T_{\text{sw}}}$$

$$D_{\min} = \frac{T_{\text{res2}}}{T_{\text{sw}}}$$

$$T_{\text{res1}} = \pi\sqrt{L_k\left[\frac{n^2(C_1+C_2)(C_3+C_4)}{C_1+C_2+n^2(C_3+C_4)}\right]}$$

$$T_{\text{res2}} = \pi\sqrt{\frac{L_k C_2 n^2(C_3+C_4)}{C_2+n^2(C_3+C_4)}}.$$

In order to overcome the drawbacks of traditional PWM, other modulation methods have been proposed, three of the most popular being constant-on, constant-off, and hysteretic control. For the IBR, constant-on modulation provides a selectable minimum on-time that can ensure ZCS during at least one-half cycle. There is no controllable off-time, however; therefore, ZCS is only guaranteed for the output diode for duty cycles greater than 50%. Also, constant-on control requires an extremely wide frequency range, with the maximum frequency occurring only at the minimum input voltage. Similarly, constant-off control provides only a selectable off-time, guaranteed ZCS for only duty cycles less than 50%, with the maximum frequency occurring at the maximum input voltage.

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With hysteretic control, there is no minimum on- or off-time and no guarantee of ZCS.In order to improve the utilization and efficiency of the IBR converter under a wide load range, the designed modulation scheme needs to have a selectable minimum on- and off time, guaranteed ZCS across the operating range, narrow operating frequency band, and maximum frequency occurring at 50% duty cycle so as to minimize the transformer core loss. The modulation scheme would also need to be compatible with traditional PWM techniques so that traditional voltage and/or current control could be utilized. Fig shows an example control loop block diagram for a PV dc-dc power conditioning system with the hybrid-frequency modulator inserted. The input voltage reference is generated by the maximum-power-point tracking (MPPT) loop, passing a reference to the input voltage control loop. The normal output of the digital compensator is the only required input to the hybrid-frequency modulator, and the output works naturally with a PWM comparator that requires both a switching period length and a value for the main switch on-time.

SIMULATION RESULTS:

The below figure shows the simulation circuit diagram of a proposed system and following shows the waveforms getting from the simulation diagram.

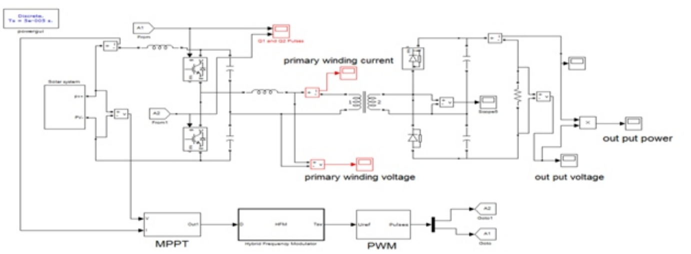

Fig 9: Simulation circuit diagram of a proposed converter system

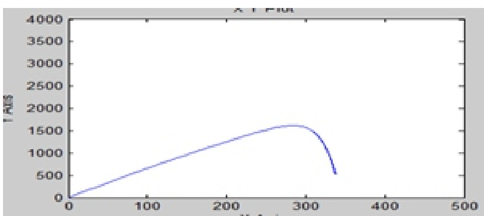

Fig 10: Waveform of PV characteristics of solar array

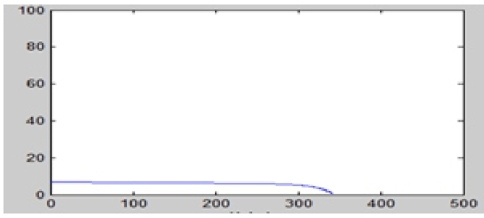

Fig 11: Waveform of IV characteristics of Solar array

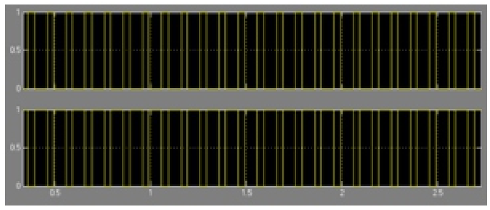

Fig 12: Waveforms of Q1 And Q2 switches pulses

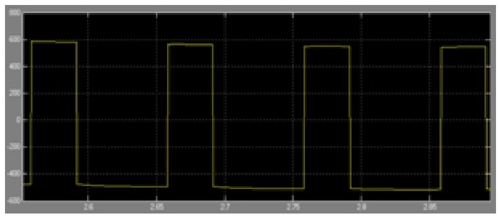

Fig 13: Waveform of a Primary winding voltage

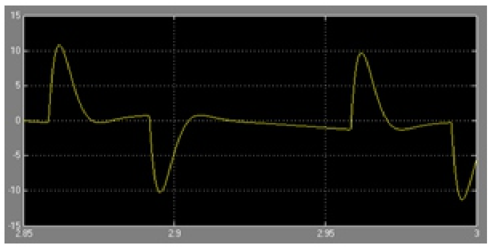

Fig 14: Waveform of a Primary winding current

CONCLUSION:

Distributed PV conversion, an isolated boost resonant converter has been proposed. The system is a hybrid between a traditional CCM boost converter and a series-resonant half bridge, employing only two active switches. The synthesis of the converter was described along with the circuit operating modes and key waveforms In order to extend the line range of the IBR converter while maintaining high weighted efficiency, a special hybrid frequency modulation scheme is proposed.The scheme reduces core and conduction loss dramatically by decreasing the applied volt-seconds at the transformer and improving the switching period utilization. With hybrid-frequency control, the circuit also maintains ZCS for the output diodes, minimizes switching loss,

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and eliminates circulating energy at the transformer across the entire operating range. It also allows for a predictable voltage gain, dependent only on duty cycle and transformer turns ratio. The algorithm uses fixed-frequency, constant-on, and constant off techniques depending only on the required duty cycle. At extremely high or low duty cycles, the converter operates under fixed-frequency control to limit the maximum switching period and prevent magnetic saturation. Simulation results are implemented by using MALAB/Simulink software.

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