iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** I **Month of publication:** January 2015

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Closed Loop control of Hybrid Frequency Modulation of Integrated Boost Resonant Converter

S .Tara Kalyani[1], Supreeth Reddy[2]
[1]Professor & Head, [2]PG scholar, Department of EEE, JNTU College of Engineering, Kukatpally, Hyderabad.

***Abstract*— The paper deals with a unique modulation method for extending the input range of pulse-width modulation (PWM)-integrated resonant converters, such as the isolated boost resonant converter, while maintaining high conversion efficiency. The technique includes primarily the hybridizing of constant-on, constant- off, and fixed frequency control depending only on the required duty cycle. With hybrid-frequency control, the circuital maintains zero currents switching for the output diodes, minimizes witching loss, 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.**
***Keywords*— CCM, DLF, IBR, MPPT, NOCT**

I. INTRODUCTION

Nowadays there is a huge requirement of DC/DC converters. High power density, high efficiency and high power are the major driving force for this application. Hold up time requirement poses big penalty to the system performance. Range winding solution could improve the performance at high input voltage significantly, but with extra devices, windings and control circuit. Asymmetrical winding solution provides a simpler solution, but could only apply to asymmetrical half bridge topology. Also it introduced other problems like discontinuous output current and unbalanced stress. To catch up with and move ahead of the trend, higher switching frequency, higher efficiency and advanced packaging are the paths we are taking now. Within all these issues, a topology capable of higher switching frequency with higher efficiency is the key to achieve the goal. With the techniques proposed, the performance of normal operation could be improved. But none of these methods dealt with the switching loss problem of PWM converter. Even with Zero Voltage Switching technique, the turn on loss could be minimized; turn off loss still limits the capability of the converter to operate at higher switching frequency. Resonant converter ,can achieve very low switching loss thus enable resonant topologies to operate at high switching frequency. In resonant topologies, Series Resonant Converter (SRC), Parallel Resonant Converter (PRC) and Series Parallel Resonant Converter (SPRC, also called LCC resonant converter) are the three most popular topologies. This paper introduces new resonance dc-dc topology called the Integrated Boost Resonant (IBR) converter, born out of the natural design requirements for the micro-converter, such as high CEC efficiency, simple structure, and inherent galvanic isolation. The circuit is a combination of a traditional PWM boost converter and a discontinuous conduction mode (DCM), series resonant circuit. And operation of the circuit with Maximum Power Point Tracking (MPPT) Algorithm and Hybrid frequency modulation principles. In this paper, the integrated boost resonance converter is introduced. Using the minimum number of component, maximum boost up the input voltages, increase switching frequency as well as increase the converter efficiency.In the Integrated boost resonance converter, the resonant circuit is available. In the resonant period, the converter operates Zero Voltage Switching or Zero Current Switching. The usage of this resonant converter, in a converter circuit, the voltage flow through it and or current across it is zero. At that instant the switching operation it here. So the converter efficiency is increased, as well switching loss is low. This paper utilizes Maximum Power Point Tracking (MPPT) Algorithm which tracks maximum voltage corresponding to maximum power available from photo voltaic panel. This project also introduces to the new optimized modulation scheme. This improves the power stage efficiency at nominal input and enhances the available operating range called hybrid-frequency modulation which utilizes areas where the modulator operates in constant-on, constant-off, and fixed-frequency conditions depending on duty cycle, the resonant period length, and the desired input range.

II. INTEGRATED BOOST CONVERTER

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.2.1. Though this topology appears similar to both the boost half bridge (BHB) 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, *C*1–*C*4, are sized

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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 *Q*1 and *Q*2. The two MOSFETs are switched complementary to one another in the proceeding analysis, with the duty cycle *D* defined for the lower switch *Q*2. Thus, the boost action is said to be integrated into the resonant converter. Allowing this resonant action to complete fully adds four primary benefits.

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

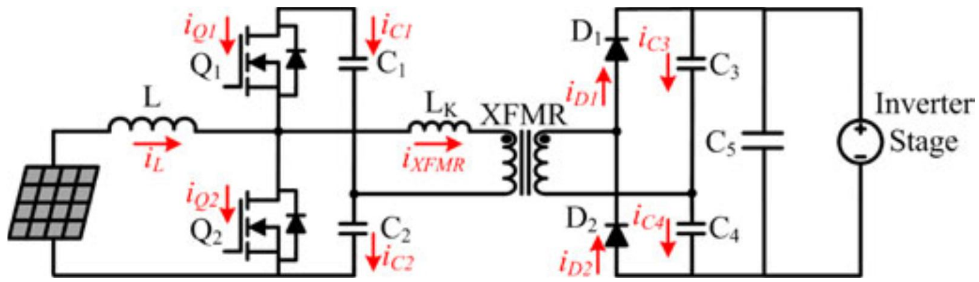

Fig 2.1 Integrated Boost Resonant Converter

The operating modes for the IBR converter are given in Fig. 2.2, Because *Q*1 and *Q*2 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 *C*1, *C*2 and *C*3, *C*4 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 *Q*2. 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. The total voltage gain of the circuit is given in

$$\frac{V_{out}}{V_{in}} = \frac{n}{1-D}$$

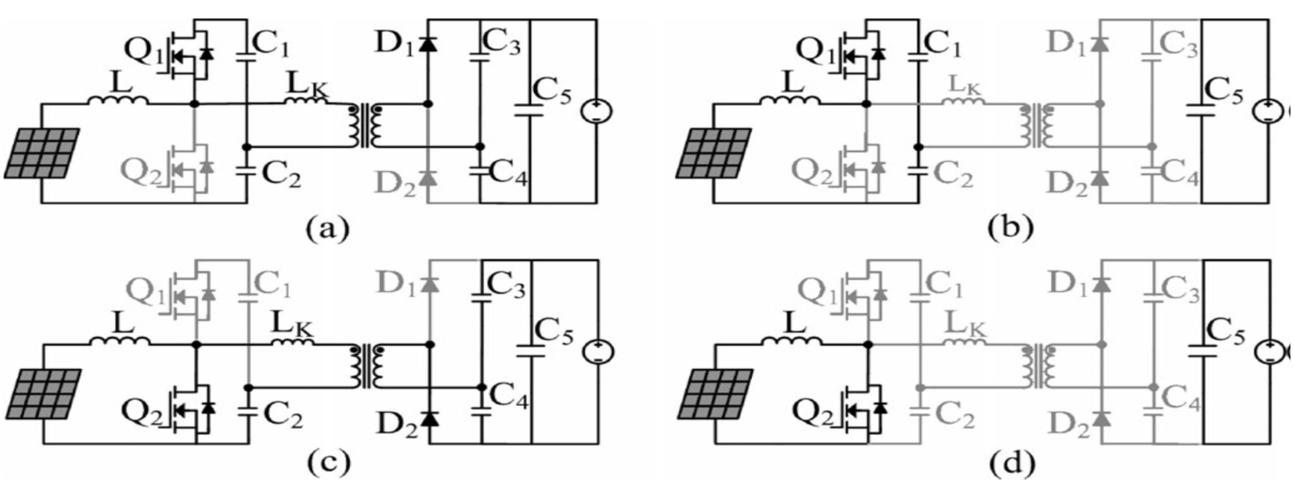

Fig 2.2(a-d)Modes of operation of Integrated Boost Resonant Converter

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III. HYBRID-FREQUENCY MODULATION,PULSE WIDTH MODULATION AND MPPT

The operating modes for the IBR converter are given in chapter 2. Because *Q*1 and *Q*2 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 *C*1, *C*2 and *C*3, *C*4 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 *Q*2. 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. However, because the resonant action must be allowed to complete during each half-cycle, the maximum and minimum duty ratios for *Q*2 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 (*T*res1 and *T*res2) can be determined from the ac-equivalent circuits during modes 1 and 3, shown in Fig. 4. The difference between the equivalent circuits is that during mode 1, the upper capacitor *C*1 is connected through *Q*1 to the switch node, allowing both primary-side capacitors
to participate in the resonant energy transfer. In mode 3, however, the blocking upper switch *Q*1 isolates *C*1 from the resonant loop, allowing only *C*2 to resonate. This creates a shorter resonant period in mode 3, *T*res2 , than in mode 1, *T*res1 , 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 order 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. 2(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. 2(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.

A. Pulse-Width Modulation

Pulse-width modulation (PWM) is the basis for control in power electronics. The theoretically zero rise and fall time of an ideal PWM waveform represents a preferred way of driving modern semiconductor power devices. With the exception of some resonant converters, the vast majority of power electronic circuits are controlled by PWM signals of various forms. Pulse-width modulation can take different forms. The pulse frequency is one of the most important parameters when defining a PWM method and can be either constant or variable. Three common variations of PWM are: (a) constant OFF time, variable ON-time; (b) constant ON-time, variable OFF-time; and (c) hysteretic control .A constant-frequency PWM signal can be produced simply by comparing a reference signal, *r(t)*, with a carrier signal, *c(t)* constant OFF-time, variable ON-time PWM Figure3. Depicts constant OFF-time, variable ON-time PWM using a sawtooth-like carrier signal. The switch is turned on after a fixed OFF-time, *T*off, at which point the sawtooth signal also starts to rise at a constant rate. The switch is turned off again when the sawtooth signal intersects with the reference, at which point the carrier signal is reset to zero. The switch is then kept OFF for a fixed time (*T*off) again before the next switching cycle starts. As can be seen, the ON-time changes with the reference and the switching frequency increases with the decrease in the reference level, resulting in a variable frequency operation when the reference varies.

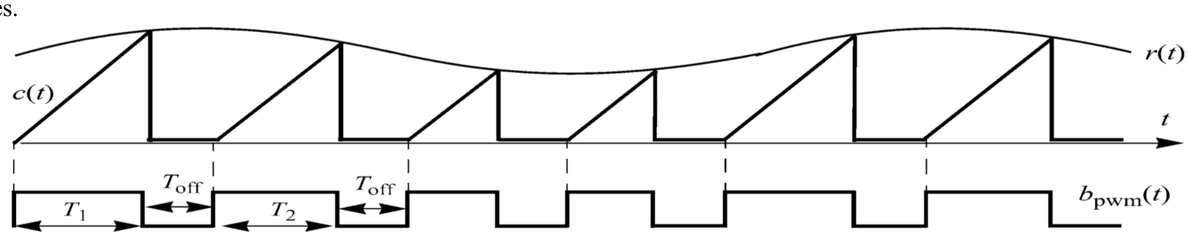

Figure 3.1 Constant ON-time ModulationConstant ON-time, variable OFF-time can be implemented in a similar manner

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B. Maximum Power Point Tracking Algorithm

Photovoltaic System

Photovoltaic (PV) cell is a semiconductor device which directly converts the light energy into electrical energy. A PV system consists of a multiple component, including the modules, mechanical connection, electrical interconnections, and mounting for other components. Photovoltaic cells are made of several types of semiconductors using different manufacturing process. Typically, photovoltaic (PV) cell generates a voltage around 0.5 to 0.8 volts depending upon semiconductor and the built-up technology. The numbers of PV cells are connected in series and parallel to get more amounts of voltage and current known as PV module and if many such modules are connected for any application to get desired amount of current and voltage then it is called as PV array.

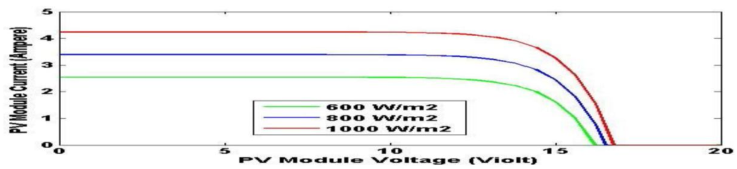

Fig 3.2: i-v Curve Different Solar Irradiance.

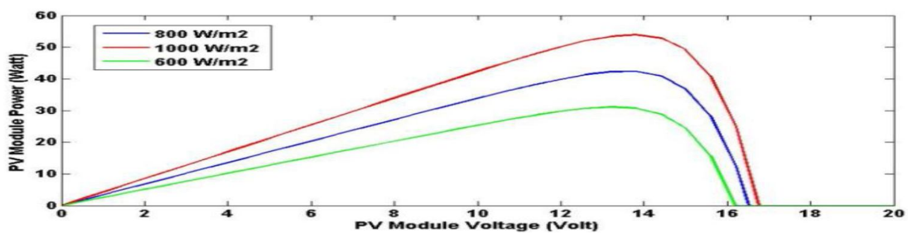

Fig 3.3: p-v Curve for Different Solar Irradiance.

A. MPPT

Among the renewable energy resources, the energy through the solar photovoltaic effect can be considered the most necessary and prerequisite sustainable resource because of the ubiquity, large quantity, and sustainability of solar energy. The output characteristics of PV module depends on the solar irradiance, cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it and simulate for Maximum Power Point Tracking (MPPT) of PV system applications. PV energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions.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, IBR converter is used as impedance matching device between input and output by changing the duty cycle of the converter circuit. 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 project Perturb and Observe (P&O) and constant duty cycle techniques are used, because these require less hardware complexity and low-cost.

B. Perturb & Observe MPPT Algorithm

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 ‘dd’ is increased otherwise start decreasing the ‘dd'. 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).

IV. SIMULATION RESULTS

With reference to the design, the Integrated Boost Resonance converter with MPPT and Hybrid modulation scheme in closed loop is simulated. Simulated models along with results are detailed here below.The figure 4.1 which is shown in below resembles overall control structure of Hybrid Frequency modulation for PWM-Integrated Resonance Converter.

ISSN: 2321-9653
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Table 4.1 Element values for IBR.

Element	Value
L	10uH
C_1, C_2	10mF
$C_3, C_4,$	2.5uF
L_k	10uH
N_p	200 turns
N_s	400 turns
Q_1,Q_2	N/A
D_1, D_2	N/A

A. Simulation Results With out MPPT

Simulating the Integrated Boost Resonance converter with out MPPT and Hybrid modulation scheme. Simulated models along with results are detailed here below.

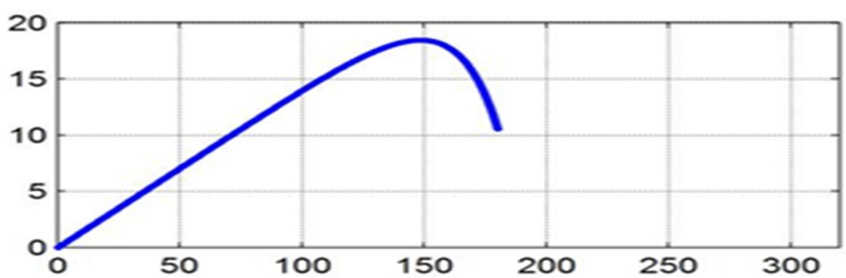

Figure 4.3 PV Curve with Maximum Voltage at 148

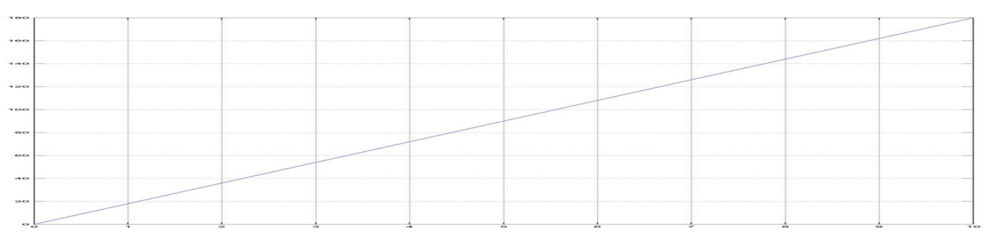

Figure 4.4 Output Voltage curve corresponding to PV curve

B. Simulation Results With MPPT

Figure 4.6 Input Voltage curve corresponding to PV curve using MPPT

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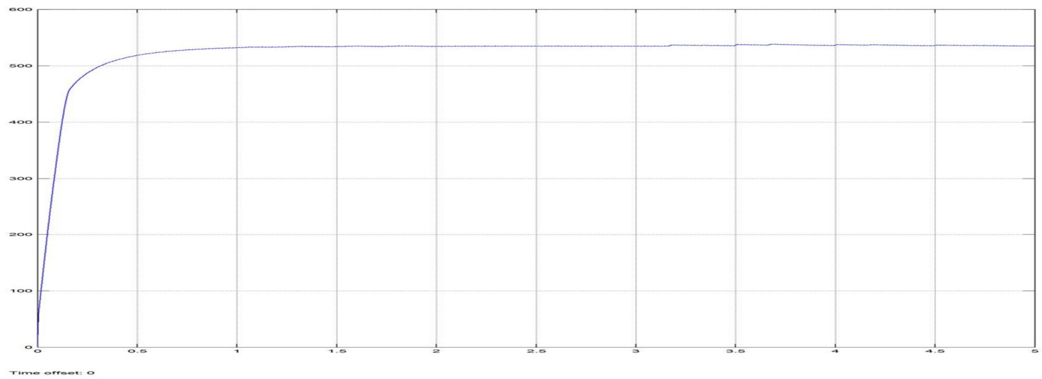

Figure 4.7 Output Voltage curve corresponding to Input Voltage.

C. *Simulation Results With Different Turns Ratio*

Simulating the Integrated Boost Resonance converter with MPPT and Hybrid modulation scheme in closed loop with different Turns Ratio .simulink results are detailed here below.Changing the turns ratio (n) and keeping the duty cycle constant (D=0.5),

Table4.2 Output voltages for different turns ratio.

Sl.No	Turns Ratio	Input voltage(Volts)	Output voltage(Volts)
1.	2	148	592
2.	3	148	888
3.	4	148	1184
4.	5	148	1480
5.	6	148	1776

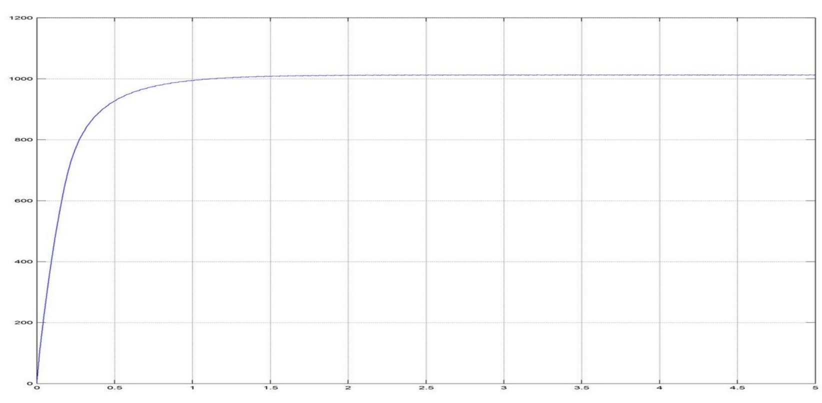

Figure 4.8 Output Voltage curve with turns ratio of 4

D. *Simulation Results With Different duty Cycle*

Simulating the Integrated Boost Resonance converter with MPPT and Hybrid modulation scheme in closed loop with different Duty cycle .simulink results are detailed here below.Changing the duty cycle and keeping turns ratio (n=2) constant,

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Table4.3 Output voltages for different duty cycles

Sl.no	Duty cycle	Gain	Input voltage	Output Voltage
1	0.2	2.5	148	370
2	0.3	2.85	148	421
3	0.4	3.33	148	492
4	0.5	4	148	592
5	0.6	5	148	740
6	0.7	6.66	148	976
7	0.8	10	148	1480

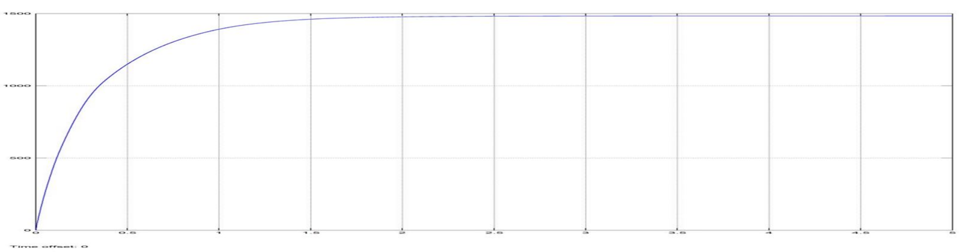

Figure 4.9 Output Voltage curve with duty cycle of 0.8

E. Simulating with Different PV Curves

Simulating the Integrated Boost Resonance converter with MPPT and Hybrid modulation scheme in closed loop with different PV curves .simulink results are detailed here below

Table 4.4 Output voltages for input voltages.

Sl.No	I/P Voltage(MaxVoltage)(volts)	Gain	Output Voltage(Volts)
1	37.25	4	149
2	74.5	4	300
3	90	4	360
4	100	4	400
5	120	4	480

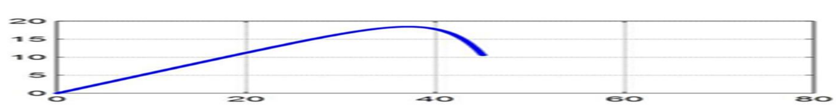

Figure 4.10 PV curve with different voltage level.

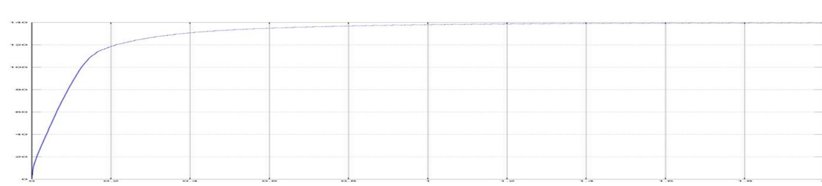

Figure 4.11 Output voltage

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V. CONCLUSION

In this proposed system the isolated boost resonant converter purposeis for more efficient and distributed PV conversion. The system is a hybrid between a traditional CCM boost converter and a series-resonant half-bridge. The design process was then defined, with a focus on the unique combined resonant and PWM behavior. In this, system consist of only two active switches. The results were a simple process, requiring only consideration of the resonant period length in selecting a valid converter duty cycle range. The principle advantages are low circulating energy and reduced switching loss with resonant energy transfer and output diode ZCS and converter efficiency is high, minimum number of active devices and a small overall component count, Galvanic isolation allows for the use of high efficiency inverter stages without additional concern over ground leakage current, Reduced control complexity provides lower auxiliary power loss and simpler controller IC configurations and The efficiency improvements are also possible.

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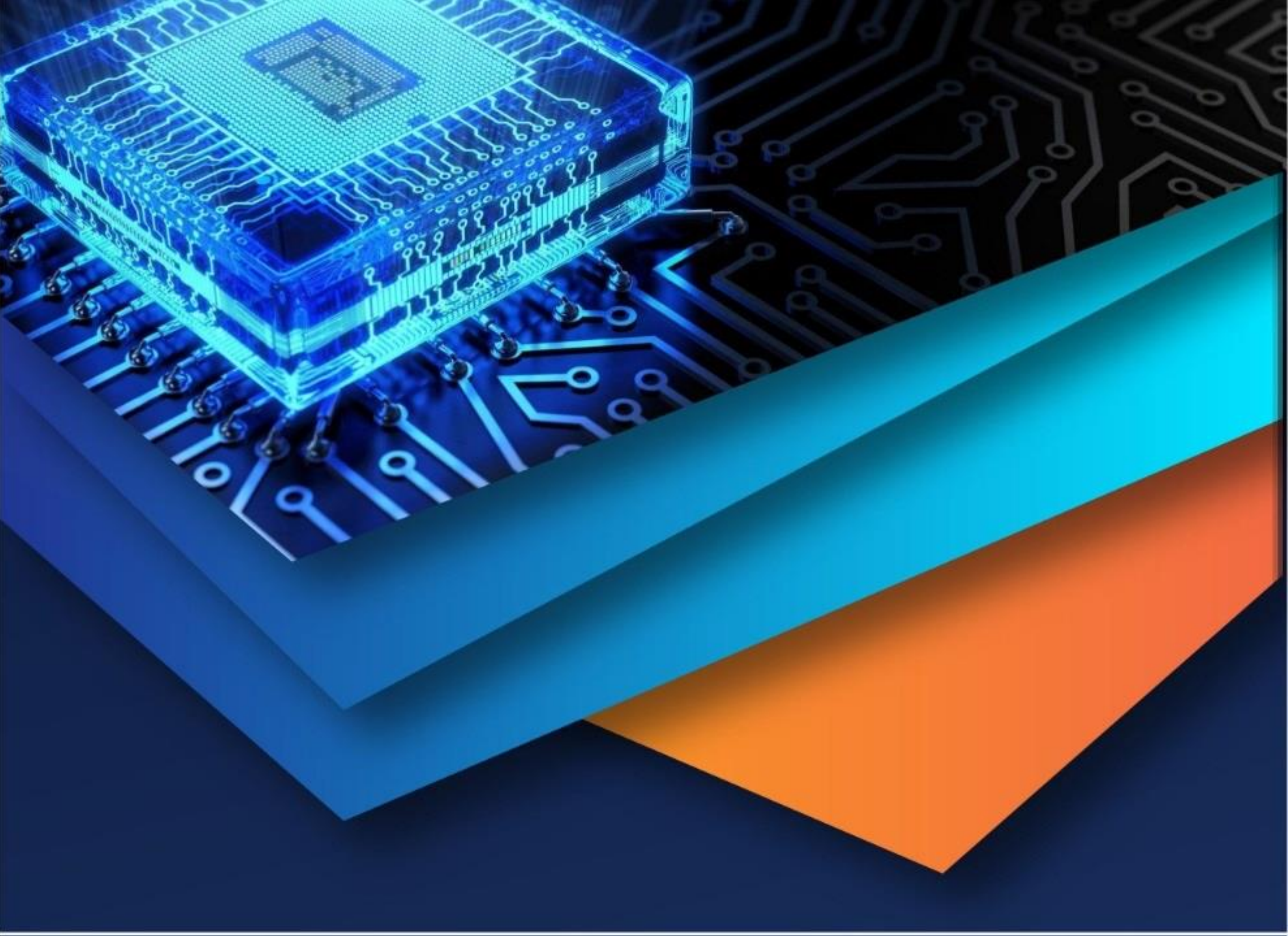

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