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High Voltage DC – DC Converter for Line Type Modulator used in Radar Transmitters

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Abstract: This paper proposes a high voltage power supply for line type modulator using forward converter. Modulator is the important part of radar transmitter and it requires a high voltage power supply. A DC- DC converter is designed to drive the modulator. Forward converter topology is used to convert a 28V input to 175V output. The proposed topology is more advantageous compared to other simple converter topologies.

Keywords**:** DC power conversion, Forward converter, Line type modulator, switched mode power supply, PFN.

I. INTRODUCTION

In today's modern society power electronics can be found everywhere and the quantity is increasing day by day. This is due to their ability to control electrical energy that is voltage, current and frequency in an everyday increasing span. This paper deals with the design of a switched mode power supply [1][3] for line type modulators used in radar applications.

Radar is actually an object detection device that uses radio waves to determine the range of an object, altitude reached, direction and speed of object [4]. It can be used to track aircrafts, spacecrafts, missile etc. Transponder is a combination of transmitter and receiver used to wirelessly receive and transmit electric signals using a common antenna. Transponder is derived from the words transmitter and responder. It was developed to be attached to an object that is to be located and is still used in this manner even today. Transponder functions by the reception of a signal and this signal is called an interrogator because it is always asking for information and will automatically convey a radio wave at a predetermined frequency. For broadcasting a signal with a different frequency than the one received a frequency converter is used. Receiving and transmitting with different frequencies can detect the two signals simultaneously. The most important part of transponder is a line type modulator which comprises of dc-dc converter, pulse forming network and pulse transformer.

The dc-dc converter [3] proposed in this paper is a forward converter to boost the 28V input to a range of about 175V. The input voltage range specified is usually the standard for space applications. Several topologies are proposed for this application but the forward converter topology is adopted because of its advantages over other converter topology [1].

Boost converter is a simple converter topology that can be used for boosting the voltage to the specified range but this converter topology does not provide any isolations. Likewise fly back converter can also be adopted for this purpose but they are less energy efficient compared to the forward converter. The forward converter offers various advantages ahead of the above topologies, such as easy implementation of transformer isolation, high energy efficiency, and simple design.

II. PRACTICAL FORWARD CONVERTER

Forward converter [1][2] is a popular switched mode power supply circuit that is used for producing isolated and controlled dc voltage from the unregulated dc input supply. Forward converter consist of a fast switching device along with its control circuitry, a transformer with its primary winding connected in series with switch to the input supply and a rectification and filtering circuit for the transformer secondary winding. The load is connected across the rectified output of transformer secondary.

The circuit is basically a dc-dc converter with a transformer for output voltage isolation and scaling. A practical forward converter will take care of the non ideal nature of practical transformer. Other non idealities of the circuit elements are taken care of by modifying the system parameters chosen on the basis of ideal circuit assumption. The most common consequence of the non ideal nature of the circuit elements are increase in losses and hence reduction in efficiency of the power supply.

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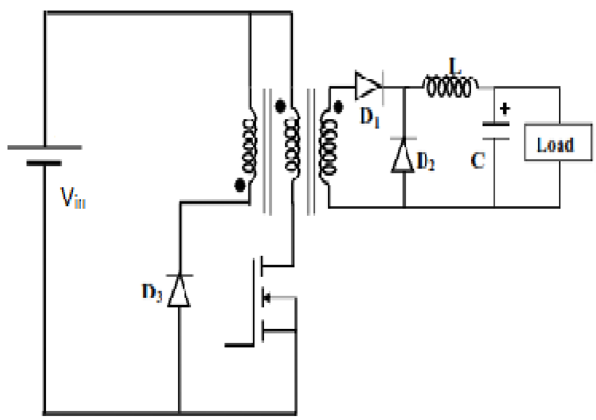

Fig (1): Forward converter

The non ideality of the transformer however cannot simply be overcome by changing the circuit parameters. A practical transformer will have finite magnetizing current and finite energy associated with this magnetizing current. The effect of magnetizing current is to be taken cared else it will case destructive effect. For this reason the practical forward converter uses an extra tertiary winding with a series diode. The primary winding and tertiary winding turns are wound together to provide better magnetic coupling. These types of windings are known as bifilar windings.

Mode 1: The switch is turned on, the input voltage V_{in} appear across primary winding. The primary and secondary winding starts conducting when the switch is turned on. A scaled voltage appears across the secondary winding. The diode D_1 is forward biased and D_2 is reverse biased, the voltage across secondary winding flows to the load through the L-C filter circuit. This mode of operation is known as powering mode and during this mode of operation input power is transferred to the load.

Mode 2: this mode starts when the switch is turned off. As the switch is turned off both the primary and secondary winding currents of the transformer suddenly fall to zero. But the secondary side filter inductor will maintain a continuous current through the freewheeling diode D_2 which is forward biased. Diode D_1 is reverse biased during this mode and the output section of the circuit is isolated from the transformer and supply. There is no power flow from source to load during this mode of operation but the load voltage is maintained almost constant by the large value output capacitor used. The charged capacitor and the inductor maintain continuity in the load. This mode is known as the freewheeling mode

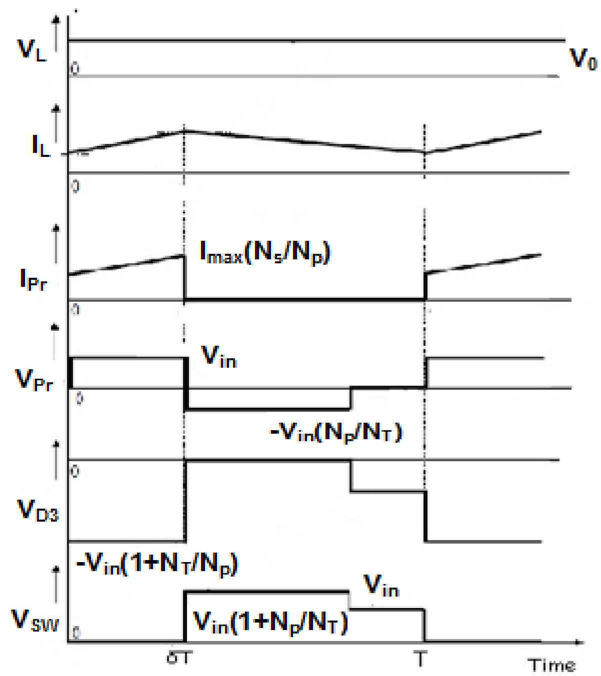

Fig (2): Practical Forward converter waveforms

III. DESIGN OF THE CONVERTER

The design [2] of the converter is based on certain mathematical assumptions. The converter is assumed to be operating in continuous conduction mode. The relation between input and output voltage is given by

$$V_0 = \delta \frac{N_s}{N_p} V_{in} \quad (1)$$

where δ is the duty ratio, N_s / N_p denotes turns ratio and V_{in} is the input voltage. The selection of the transformer turns ratio is a crucial factor and depends on the type of core and also the duty ratio. For maximum efficiency the duty ratio must ≤ 0.5.

The transformers secondary is rectified and filtered by the rectifier and filter components to get the desired output voltage waveform. The filter inductor and capacitor values are to be chosen appropriately to obtain a cost effective and less bulky power supply. The inductor value is given by

$$I_{Load} = 0.5(I_{min} + I_{max}) = 0.5 I_{max} = 0.1 I_{rated} \quad (2)$$

$$I_{max} - I_{min} = \delta T \left[\left({N_s}/{N_p} \right) V_{in} - V_0 \right] \quad (3)$$

Thus for $I_{min} = 0$ and $I_{max} = 0.2\ I_{rated}$

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$$L = \frac{\delta T\left[\left({N_s}/{N_p}\right)V_{in} - V_0\right]}{0.2\times I_{rated}} \qquad (4)$$

Even though the output capacitor voltage has been assumed constant, there will be a minor ripple in capacitor voltage which will have only negligible effect on the analysis. For the worst case, peak to peak ripple in capacitor voltage is given by

$$V_{0,p-p} = {I_{rated}}/{20\ c\ f_{sw}} \qquad (5)$$

‘C’ is the output capacitance in farad. Capacitance value is selected based on the above equation.

IV. PROPOSED SYSTEM WITH LINE MODULATOR

The proposed forward converter will be a dual output converter in which one of the outputs is fed back to the controller for the switching purpose hence the isolation effect is maintained. The forward converter with line modulator as load is shown in the fig 3. The sub assemblies of line modulator are charging choke, blocking diode, Pulse forming network and a pulse transformer[4][5]. The dc input to the modulator is obtained from the forward converter and his voltage is stepped up to a high voltage pulse in the range of about 3kv to generate microwaves (5660 MHz) for radar applications. Pulse forming network comprises of inductors and capacitors arranged in any of the different possible combinations so as to obtain the required pulse.

A. Dual Output Forward Converter

The forward converter is designed as explained above and its switching is controlled by a dedicated PWM controller IC UC1825. Line modulator is connected as a load to the first output and voltage divider is connected to the second output. The PWM controller IC operates with a voltage of about 5V hence the second output of the converter is reduced to the required voltage level using the voltage divider resistors. The resistor values are selected by

$$V_{ref} = {(V_0 \times R_2)}/{(R_1 + R_2)} \qquad (6)$$

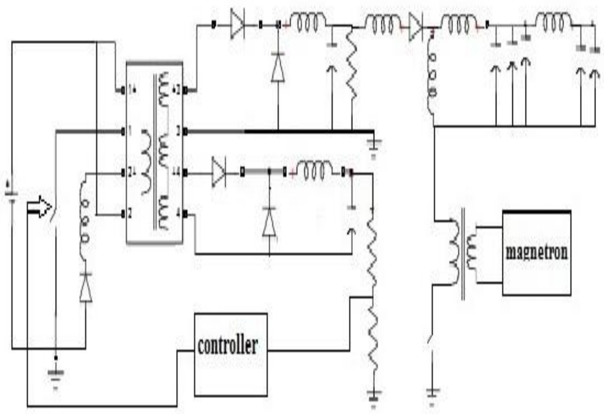

Fig (3): Proposed system

B. Line Modulator

It consists of charging choke, blocking diode, PFN and pulse transformer.

1. Charging choke: It is a protection element and should be inserted in series between the power supply and the pulse forming network. It will limit the current flowing through the circuit during the charging process. The charging inductance value is given by

$$L = (3.2 \times N^2 \times A \times 10^{-8})/(a + l/\mu) \qquad (7)$$

where L inductance in Henry, N no. of turns, a length of air gap, A area of core, μ permeability, l length of magnetic path of core.

2. Blocking diode: the diode maintains the modulator charged with the highest voltage reached during the charging process.

3. Pulse forming network: PFN consist of a set of inductors and capacitors which may put together in any one of the possible number of configurations. The values of these elements can be calculated to give an arbitrary pulse shape when the PFN configuration, pulse duration, impedance level and load characteristics are specified.

$$Z_0 = \sqrt{L_n/C_n} \qquad (8)$$

$$C_n = {pulse\ width}/{2 \times Z_0} \qquad (9)$$

$$L_n = (pulse\ width \times z_0)/2 \qquad (10)$$

L_n total network inductance, C_n total network capacitance, Z_0 characteristic impedance.

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4. Pulse Transformer: The pulse transformer [6] is the most critical element of modulator. A pulse transformer is capable of to supply different voltage levels to load to effect dc isolation between the source and the load.

V. SIMULATIONS OF THE PROPOSED SYSTEM

The proposed system is evaluated and tested in a MATLAB Simulink environment.

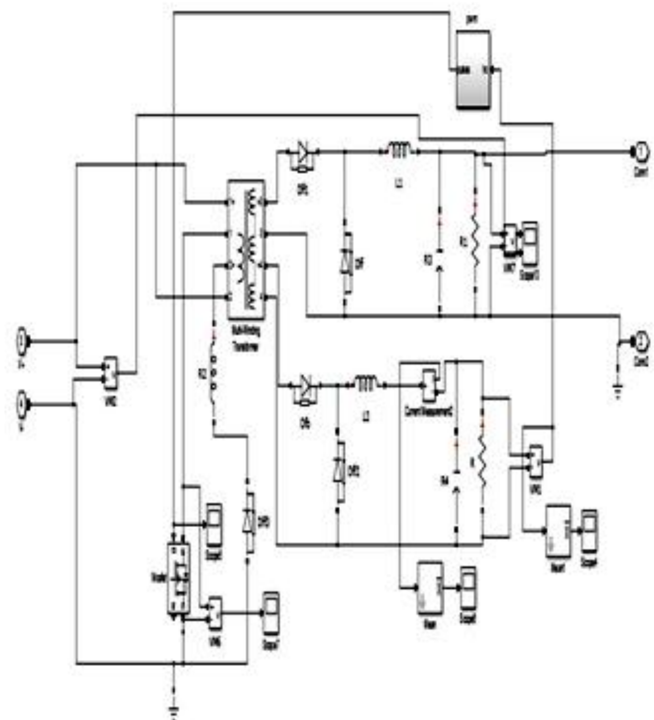

Fig (4): Simulation diagram of forward converter

The schematic diagram of forward converter is shown in Fig 4. The simulated output of forward converter is shown below. The requirement is to generate a voltage between 150V – 175V. The simulated result has an output voltage of 160V.

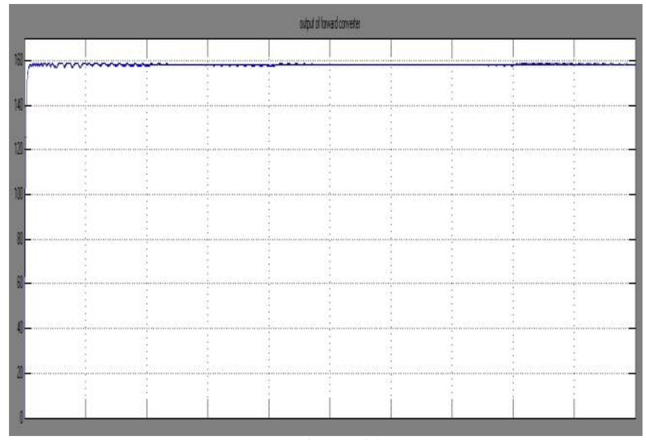

Fig (5): Output waveform of forward converter

The forward converter, which is a switched mode converter topology with isolation, generates this output dc voltage. The generated output voltage will supply the line modulator section.

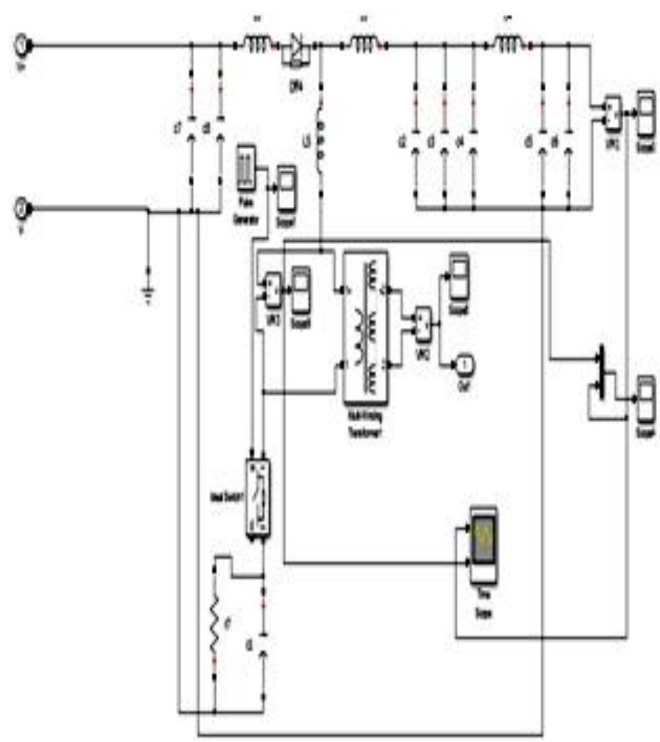

Fig (6): Simulation diagram of Line Modulator

Fig 6 shows the schematic diagram of line modulator. Line modulator generates an output of 2.5 – 3KV used for the operation of magnetrons used in radars. The simulated result is shown in the figure below.

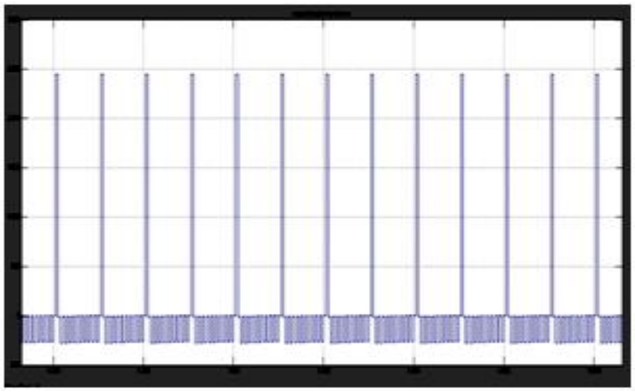

Fig (7): output of line modulator

Fig 7 shows the output of the modulator which is a pulsed waveform of magnitude 2.5 KV. The simulation results show that all the required specifications are satisfied. The output pulses are having a magnitude of 2.5 KV with pulse width of 1µs and having a pulse repeating frequency of 2 KHz.

VI. CONCLUSION

An efficient forward converter based switched mode power supply is designed for the line modulators used in radar applications. The circuit is verified using the MATLAB simulink environment. Simulations of both the forward converter and line modulator are evaluated and the required result is obtained.

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BIOGRAPHY

Amal M R was born in Kerala, India in 1989. He received the B Tech degree from Cochin University of Science and Technology, Kerala in 2011. He is currently pursuing his Masters degree in Power electronics from Cochin University of science and technology, Kerala. His area of interest includes power electronics, switched mode power supplies, high voltage dc, and electrical machines.