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Design of T Source inverter for DBD Applications

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ABSTRACT

Dielectric barrier discharge (DBD) is a high voltage discharge phenomenon. A high voltage and high frequency excitation is applied to a metal electrode which is separated from a grounded plane by an air gap and a dielectric barrier. Thus a steady alternative discharge is formed to generate low temperature plasma. To obtain this dielectric discharge a high voltage transformer is required which is obtained by using T source inverter. The design of a T source inverter used in dielectric barrier discharge (DBD) field is needed and designed. This paper deals with performance of T source inverter which is used in conversion of DC-AC voltage and also for boost operation. Two inductors in T source network act as high voltage transformer to produce high temperature plasma. Self-sustained oscillation controller is adopted to get the phase angle between voltage and current to zero. By this ZVS operation is done and high power transfer is realized. The simulation of this model is done in MATLAB and results are shown.

Keywords: T source inverter, Dielectric barrier discharge, Low temperature Plasma, High voltage transformer.

INTRODUCTION

Dielectric barrier discharge (DBD) is a high voltage discharge phenomenon, and its basic configuration can be illustrated by Fig. 1.Various configurations of DBDs are available in which the configuration showed in fig.1 is used in our system. A high voltage and high frequency excitation is applied to a metal electrode which is separated from a grounded plane by an air gap and a dielectric barrier. Thus a steady alternative discharge is formed to generate low temperature plasma. Due to its unique characteristics, DBD is widely employed in areas such as decontamination, semiconductor fabrication, lighting and surface treatment. There are several equivalent circuit models that can be used to simulate the electrical characteristics of the DBD load in power supply design is presented in.

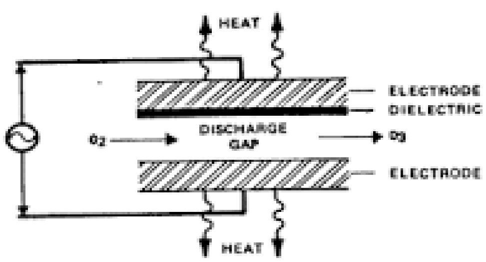

Fig.1.DBD equivalent circuit

The DBD load usually requires a peak voltage of several kilovolts to initiate the discharge is mentioned in, thus the high voltage boost ability is essential for the power supply. This necessitates the use of a high voltage transformer which is obtained by using two inductors in T topology.

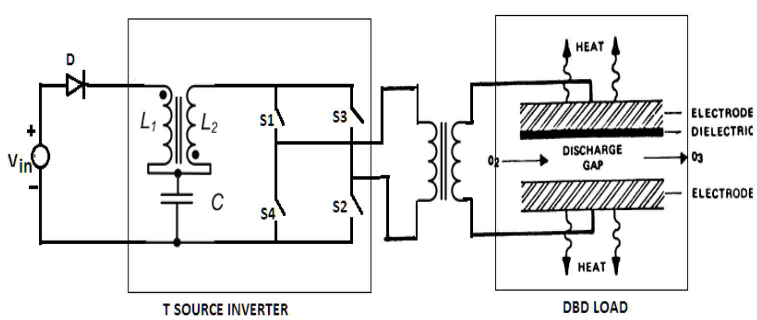

Fig.2.T source inverter with DBD load

Traditional voltage source inverters are well studied and widely utilized in industrial applications for their simple topology and flexible control schemes but it doesn't give more efficiency and more reliability. Hence Z source inverter was used which in turn has some disadvantages. It is sensitive to parasitic inductance of galvanic connections and capacitors of LC network. Thus modified Z source inverter with use of two inductors and one capacitor which in form of alphabet T is designed. This is named as T source inverter which has many advantages than conventional inverters. The diode across supply prevents leakage of current in reverse direction. For instance, in the surface treatment application where short circuit on the DBD load happens from time to time, the anti-short circuit ability, in which T source inverters are extremely strong, is essential in protecting both the switches and the system from breaking down. Furthermore, the ability of flexible flux balance for the transformer is quite welcomed in the applications where a transformer is implemented.

The T source inverter analyzed in this paper is shown in Fig. 2. The use of a diode at its DC input brings the anti-short circuit nature. The active switches S1S2 and S3S4 commutate complementally and the output current of the inverter, i_p, is an alternative current. Self-sustained oscillation controller is adopted to get the phase angle between $i_p$and $v_C$to zero by regulating the switching frequency, f_o. In simple terms, the input of the self-sustained controller, γ, maintains 0 in any case, and f_o follows the resonant frequency automatically. Since ip and v_C are in phase, ZVS operation and high efficiency power transfer are realized, which can lower the electrical stresses of the active switches.

T source inverter has fewer components. It utilizes a unique impedance network that links the inverter circuit and the DC source. The two inductors are built together to form couple inductors and it has low leakage impedance. Two capacitors used in Z source inverter is reduced to one capacitor in T source. TSI requires low leakage inductance HF transformer that should be made with high precision. TSI has a feature of common dc rail used between source and inverter. The use of HF transformer with transformer ratio n:1 higher than one allows for the extension of voltage range with same shoot through duty cycle or allows small time period of short circuit current flow with voltage gain than conventional ZSI. The output of impedance network is supplied to four switches which helps in inversion operation. Boosting operation is done through shoot mode operation of inverter. This inverter is very suitable for the DBD applications.

During shoot through mode the energy is transferred from capacitor to inductor. At this stage voltage boosting capability is obtained. The DC voltage is fed as input to the impedance network of T network which helps in buck and boost operation. Capacitors get charged to voltages higher than supply voltage, the diode D helps in discharge of capacitors through the source.

In recent years, a lot of analytical methods for voltage source and Z source inverters have been proposed. These methods can be good references for the analysis of the T source inverter. Traditional Fundamental Harmonic Approximation (FHA) was first proposed in reference where the output rectifier and the load are substituted by a linear resistor and only the fundamental harmonic is considered. FHA simplifies the analysis of resonant converter and is widely employed. However, FHA is not desirable as the DBD load is capacitive.

By assuming that the current is sinusoidal, reference introduced an Extended FHA. The load is an equivalent RC load which makes the FHA more adaptive. But the Extended FHA is not an accurate analysis and does not cover all the circuit parameters and load conditions. Time domain method which is very adaptive and has accurate analytical results. But the proposed method does not link the characteristic parameters with circuit parameters tightly, which makes the analysis and design complex.

In this paper, mathematical analysis is performed in different circuit modes and the expressions that can accurately describe the behavior of the T source inverter in the entire load range are obtained. To demonstrate the advantage of the proposed method, the conventional simulation results of the voltage source inverter which uses only switches is also shown and discussed.

Principle of t source inverter: The T source inverter works in two modes of operation. It works in same principle of conventional Z source inverter. TSI can handle shoot-through states when two switches in same phase leg conduct. T network is used instead of LC network for boosting operation by inserting shoot through states in PWM. TSI operates in two modes. A) Shoot through mode B) Non-Soot through mode.

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Shoot Through Mode: Fig.3 shows the equivalent circuit of shoot through mode of operation of TSI. This shoot through zero is prohibited in traditional voltage source inverter. It can be obtained in three different ways such as shoot through in one leg phase or through combination of two leg phase. At this stage diode D is reverse biased separating DC link from AC line. Both the capacitor voltage and output voltage are the functions of shoot through coefficient $D=T_0/T_s$ where T_s is switching time period. The equation in shoot through mode is given by

$V_c/V_{in} = T1/ (T_1\text{-}n.T_0) = 1\text{-}D/(1\text{-}(n+1).D)$ Where D satisfies the condition $D<1/ (n+1)$.

Thus the desired voltage can be obtained by controlling the interval of shoot through mode. TSI improves the reliability of system since it allows across any phase leg and prevents switches from damages.

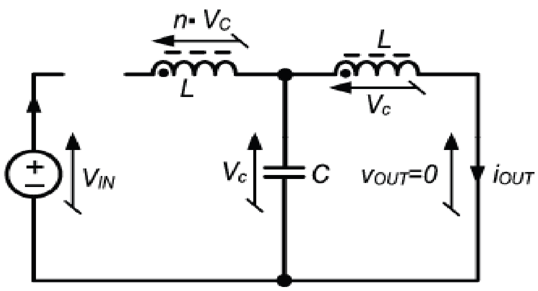

Fig.3.Shoot-through mode

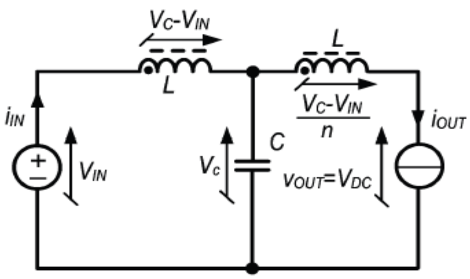

Fig.4.Non-Shoot through mode

Non-Shoot through Mode: Fig.4 shows the equivalent circuit of Non-shoot through mode of TSI. In this mode, the inverter bridge works in one of the traditional active states, thus act as current source. The diode D is forward biased and hence conducts. It carries the current difference between inductor current and input DC current. As two inductors are coupled both inductors has same current.

The output voltage at the load is given by,

$V_{dc}= (V_c\text{-}V_{in})/ n + V_c$

As the secondary side inductance of the transformer is not paralleled by any capacitor during non-shoot through mode, the impact of leakage impedance is significant when compared to conventional voltage inverters.

Simulation of TSI with DBD load: The simulation of T source inverter is done using Matlab. The simulation diagram and simulated output is shown below. It shows that the output obtained in T source inverter has high voltage compared to conventional inverter.

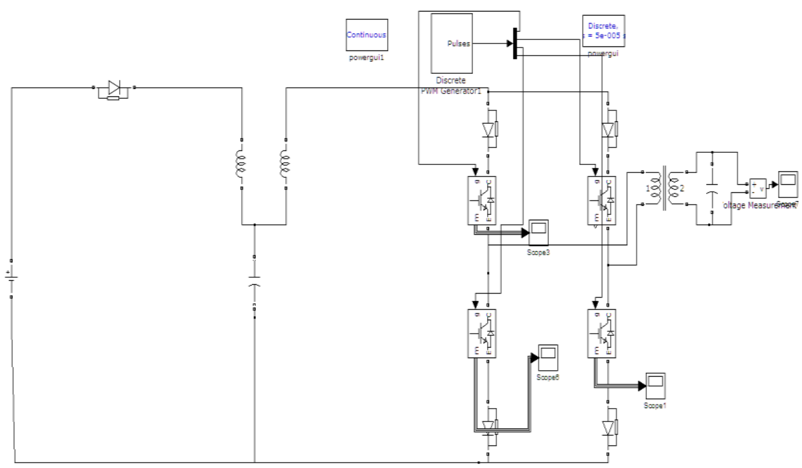

Fig.5.Simulation diagram of TSI with DBD load

Here the input voltage used is dc 220 V and the output voltage is 1MV ac voltage. High voltage transformer is used which is needed for DBD application.

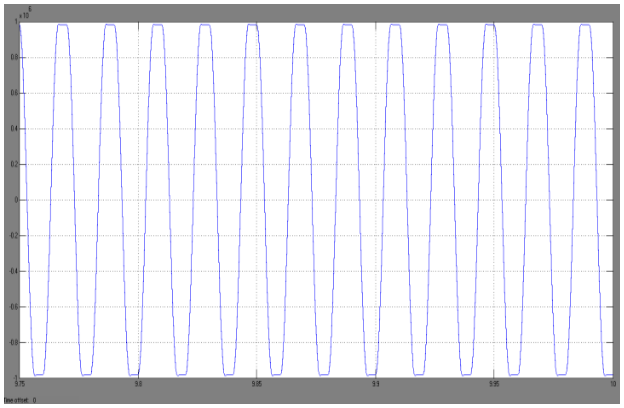

Fig.6.Simulated output voltage At DBD load

Application of DBDs: DBDs can be used to generate radiation by the relaxation of excited heat in the plasma. The main application here is the UV-radiation generation. These excimer UV lamps can produce light with short wavelength which produce ozone in industrial scales. Ozone is used extensively in industrial air and water treatment. An excimer lamp is one of the application of UV radiation. The lamp relies on a dielectric barrier discharge in an atmosphere of xenon and other gases to produce the plasma. The plasma itself is used to treat or clean (plasma cleaning) surfaces of materials (e.g. polymers, semiconductor surfaces), that act as dielectric barrier, or to modify gases applied in "soft" plasma to clean and increase adhesion of surfaces prepared for coating or gluing.

Other modern applications include semiconductor manufacturing, polymer surface treatment, high-power CO_2 lasers used for welding and metal cutting, germicidal processes, pollution control and plasma displays panels. The relatively lower temperature of DBDs makes it an easy method of generating plasma at atmospheric pressure.

Dielectric barrier discharges are used to inactivate bacteria. This eventually led to the development of the biomedical applications of plasmas. This field is now known as plasma medicine. An additional process is by using chlorine gas for removal of bacteria and organic contaminates in drinking water supplies. Public swimming baths, aquariums and fish ponds treatment involves the use of ultraviolet radiation produced when a dielectric mixture of xenon gas and glass are used.

A dielectric barrier discharge plasma treatment is used in textiles at atmospheric pressure and room temperature. The treatment can be used to modify the surface properties of the textile to improve the absorption of dyes and adhesion, improve wet ability and for sterilization. DBD plasma also provides a dry treatment that doesn't generate waste water or require drying of the fabric after treatment. A DBD system requires a few kilovolts of ac voltage, at between 1 and 100 kilohertz for textile applications. Voltage is applied to insulated electrodes with a millimeter -size gap through which the textile passes.

CONCLUSION

The mathematical analysis and optimal design for a T source inverter used in dielectric barrier discharge (DBD) field is presented. The expressions that can accurately describe the behavior of the inverter in any load conditions are obtained. The simulation and experimental results verifies the analysis and design of the optimal design, and proved the advantages of T source inverter than other inverter for DBD applications. In future work the DC source can be replaced by using solar power which is obtained by using PV panels.

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