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PV Based Power Electronic Converters for High Voltage DC Applications

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Abstract*: In this article, we introduced solar based H-Bridge inverter and high frequency transformer-rectifier for high voltage DC Applications. High Voltage Bridge Rectifier circuit is designed by series connection of large number of 1N4007 diodes. High Frequency transformer is made up E-Type ferrite core and Litz wire. The modeling of PV module and power supply to the electrostatic precipitator was simulated using MATLAB/SIMULINK and its results were validated with experimental results of portable "needle-plate" type ESP. This prototype was developed to optimize the collection efficiency according to the different applied voltage and to determine the optimum voltage to be applied without risk of breakdown. The objective of this paper is design and develops the solar powered cost effective needle-plate type electrostatic precipitator, including a high voltage power supply made-up of a power electronic converters and ferrite core transformer.

Index Terms*: Electrostatic Precipitator (ESP), Medical Wastes Incinerator, Ferrite Core Transformer, Corona Discharge, Photo Voltaic (PV).

I. INTRODUCTION

Renewable energy sources are abundant and best alternate for energy produced from fossil fuels. Among the renewable energy sources, solar energy has identified as favorite due to inexhaustibility, non-polluting nature, and maintenance free [1]. Most solar cells are manufactured using crystalline silicon, it can be able to convert 13-20% of sunlight into electricity. Single solar cell capable to produce tiny amount of voltage which is in the range of 0.5-0.6V. Hence solar cells are grouped together in series and parallel to augment the power. The direct current (DC) output from the panel or array is directly fed into the load or power electronic converters are exercising the output from PV array when it is feed into the sophisticated applications. The accurate modeling of solar cells is needed prior to the installation part. The worldwide researchers found that MATLAB and PSPICE is appropriate software for solar cell modeling. Solar panel manufactures have given limited model parameters such as open circuit voltage(Voc), short circuit current (Isc), voltage at maximum power point(Vmp), and current at maximum power point(Imp), Current temperature coefficient, Voltage temperature coefficient. For modeling the solar panel using single diode model, the model parameters such as shunt resistance (Rsh), series resistance(Rs), ideality factor (a), diode saturation current (I_0), Photo generated current(Iph) are mandatory, however these parameters are not given in manufactures datasheets. The calculation of precise values of model parameters is crucial owing to nonlinearity in the PV characteristics [2]-[5]. Recently Solar energy based system proved to be a most favorable alternative source owing to the conventional fossil fuels degradation. Dastagiri et al. have investigated the S3 inverter which is used to convert dc power obtained from the PV array into ac power, and it consists of dc to dc conversion stage is coupled with push-pull configuration with a center tapped transformer and operating at fundamental frequency. The voltage produced from S3 inverter is function of input voltage and duty cycle. High frequency transformer is used for stepping up the ac voltage [6]. Electrostatic precipitator is one of the device requires high DC voltage and it is widely used to remove the flue gases in thermal power plant and other industries. The collection efficiency can be improved by applying high frequency and high voltage to the electrostatic precipitator.

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II. RELATED STUDY

In past decades, it uses thyristor control and single phase rectifier for achieving high reliability. The particle emission is shrinked by the implementation of High Frequency (HF) ESP power supply. Now the amount of steel used will be minimized by using HF supply [7]. In majority of the Electrostatic Precipitator power supply, the high voltage rectifier circuit is submerged in oil and it utilize hundreds of series connected diodes. For Consistent operation of rectifier circuit, well controlled dv/dt stress and uniform voltage sharing also needed [8]-[9]. A newfangled combination of highly efficient, high voltage and high frequency prototype transformer is designed. This type of transformer is used for high power switch mode power supply to operate the electrostatic precipitators [10]-[11]. Further, the switching frequency is increased to reduce the transformer size. However, it increases the frequency related losses and elevates dv/dt stress in the high voltage circuits. The resonant converter topologies are the best solution for power losses reduction at high frequencies [12]-[15]. The major hurdle to implement filtration system is design a high voltage power supply to the electrostatic precipitator with less cost and size. The aim of this paper is to design a cost efficient power supply for Electrostatic Precipitator. The proposed work utilizes renewable energy such as solar panel as source. High Voltage DC power supply consists of static power converters with ferrite core transformer.

III. MATERIALS AND METHODOLOGY

The high voltage power supply composed of two stages (i) control circuit (ii) power circuit. The control circuit consists of dsPIC microcontroller, TLP250 driver circuit, step down transformer, and voltage regulator. The control circuit delivers the high frequency (20 kHz) square pulse to the semiconductor switches in the proposed power circuit. The power circuit consists of four 250Wp solar modules, DC-DC Boost Converter, High frequency Voltage source inverter, ferrite core transformer and bridge rectifier.Four 250Wp polycrystalline solar module has connected in 2S-2P configuration to obtain 1000W power with voltage and current rating of 74.3V and 13.46 A. The PV system is connected with DC-DC boost converter to consume maximum power. MOSFET IRFP460 is used in the boost converter and it is operated with 20 kHz frequency. The inductor and capacitor of this converter is selected based on the texas instruments application report. Switch is operated in 73% duty cycle to produce 230V voltage.

The FGA25N120AN IGBT switch has utilized in full bridge inverter circuit to convert DC link voltage into high frequency AC with the switching time of 50 micro seconds. High Frequency square wave AC is given as input to the ferrite core transformer which has 1:44 ratio. It steps up the 230V AC into 10kV AC. Bridge rectifier converts square wave AC into DC.

Negative terminal of the rectifier circuit is connected to discharge of the electrostatic precipitator and positive terminal is connected to the collecting plate and it is grounded.

IV. SIMULATION RESULTS AND ITS DISCUSSION

The high voltage power supply to the needle-plate electrostatic precipitator is designed using MATLAB/SIMULINK environment. The electrical circuits containing linear and non-linear elements are simulated using simscape power systems specialized technology and simulink toolboxes. A variable step ode45 solver (Dormand-Prince) has computed the states of the model in different time intervals.

The modeling of solar module is done based on the output current equation of that module [16]-[19].

$$I = I_{PV} - I_0\left[\exp\left(\frac{V + R_S I}{V_t\, a}\right) - 1\right] - (V + R_S I)/R_P$$

Where I-output current of the solar module, Where I_{PV} is the Photo generated current, Where I_0 is the diode saturation current, V_t is the thermal voltage, shunt resistance (*Rp*), series resistance (*Rs*), ideality factor (*a*). The output of the PV module is based on the temperature and irradiance. For accurate modeling, the unknown parameters in the manufacturer's datasheet are calculated by a optimization algorithm called jaya algorithm. The DC-DC Boost converter has regulated the PV voltage by varying the pulse width of the gate signal applied to MOSFET IRFP460 in the circuit. Duty cycle of the switch is varied based on the PV module voltage and current. The H-Bridge inverter is designed using four IGBTS which is switched with the frequency of 20 kHz. The 4µs dead band has been applied to each pulse signal in order to avoid shoot through effect. High frequency square wave AC is given as input to the proposed ferrite core transformer which is new in its fusion of high voltage (10 kV) and high frequency (20 kHz). Bridge rectifier converts the high step up AC voltage into DC.The Figure 1 represents the simulink diagram of high voltage power supply to the electrostatic precipitator.

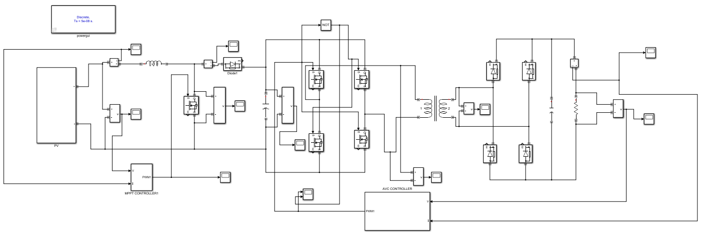

Fig.1. Simulink Diagram of High voltage power supply to ESP

At standard test condition, the output voltage of the PV module is shown in the figure 2.

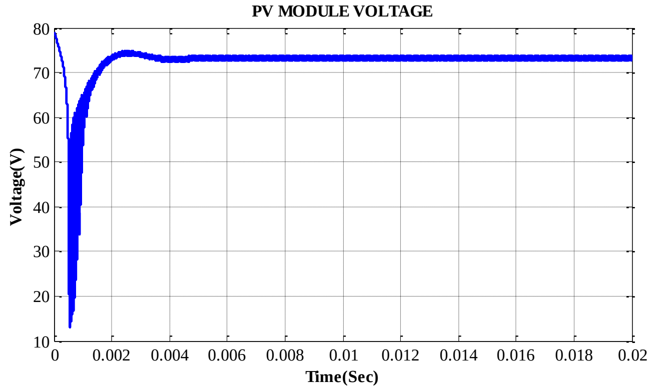

Fig.2. PV Module Voltage

The gate signal for the MOSFET in the DC-DC boost converter is represented in the figure 3.

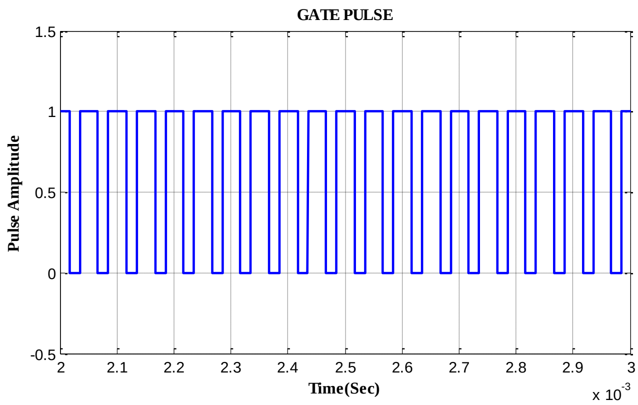

Fig.3. 20 kHz Gate Pulses to MOSFET

The output voltage of the boost converter is shown in the figure 4.

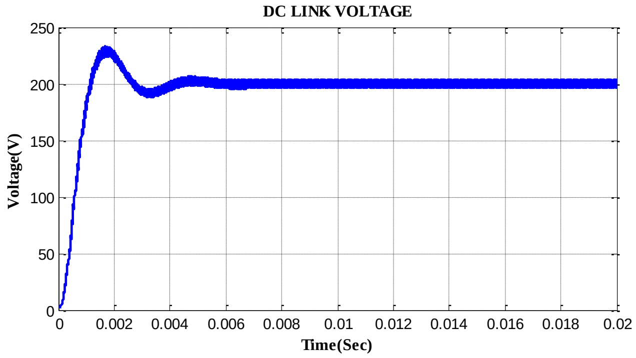

Fig.4. Boost Converter Voltage to the inverter

The high frequency square wave output of the inverter is shown in the figure 5.

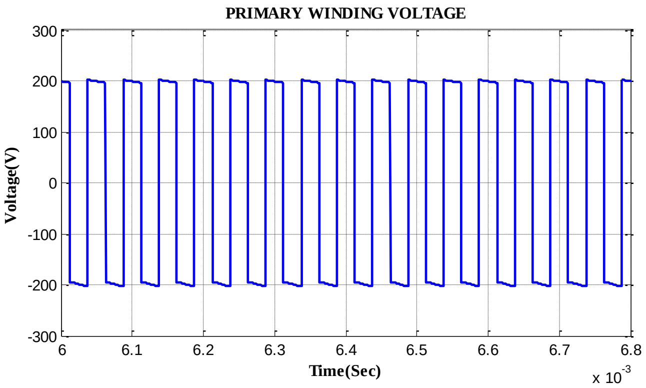

Fig.5. HF Transformer Primary Winding Voltage

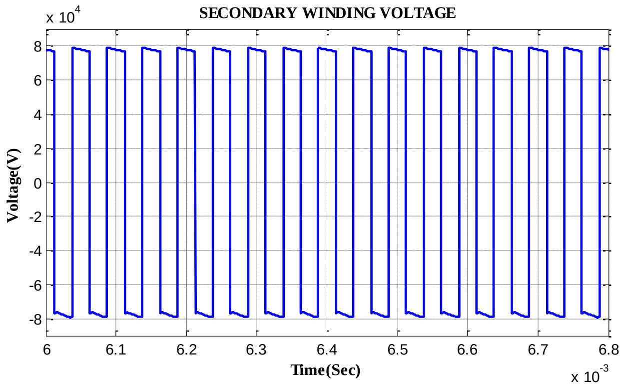

Fig.6. HF Transformer Secondary Winding Voltage

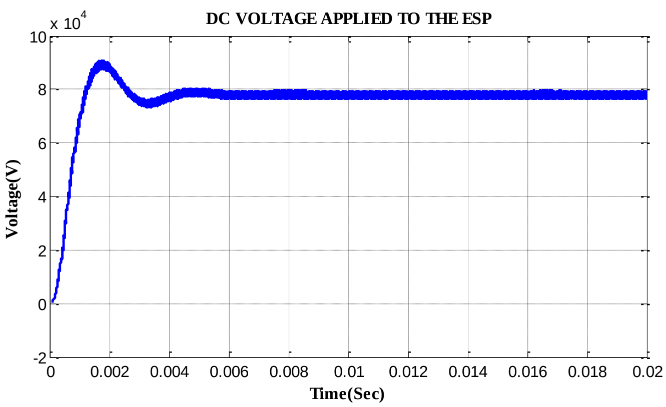

Fig.7. High Voltage DC to the ESP

V. EXPERIMENTAL WORK AND DISCUSSION

Four 250Wp polycrystalline solar module has connected in 2S-2P configuration to obtain 1000W power with voltage and current rating of 74.3V and 13.46 A. The PV system is connected with DC-DC boost converter to consume maximum power. MOSFET IRFP460 is used in the boost converter and it is operated with 20 kHz frequency. The inductor and capacitor of this converter is selected based on the texas instruments application report. Switch is operated in 73% duty cycle to produce 230V voltage.

The FGA25N120AN IGBT switch has utilized in full bridge inverter circuit to convert DC link voltage into high frequency AC with the switching time of 50 micro seconds. The required pulse signals for transistor switches are produced from MATLAB/ SIMULINK models using Auto code generation and it is feed into the dsPIC microcontroller 33FJ64MC802 using MPLAB IDE. The pulse signals are amplified using TLP250 driver circuit.

High Frequency square wave AC is given as input to the ferrite core transformer which has 1:44 ratio. It steps up the 230V AC into 10kV AC. Bridge rectifier converts square wave AC into DC. Negative terminal of the rectifier circuit is connected to discharge of the electrostatic precipitator and positive terminal is connected to the collecting plate and it is grounded.

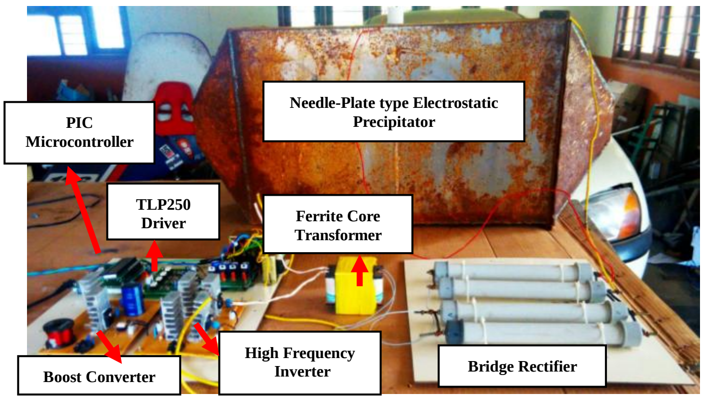

Fig.8. Experimental setup of the proposed system

In PV module, the light energy is converted into electrical energy using photo-voltaic effect. The magnitude of PV voltage depends on the solar irradiance and environmental temperature. Figure 9 depicts the output voltage of the PV module.

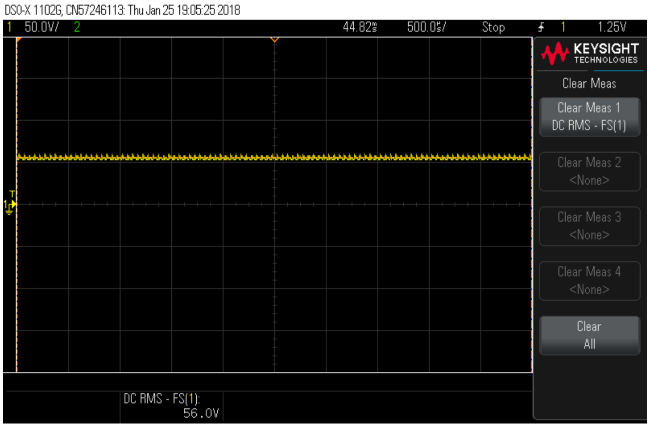

Fig.9.Solar Panel DC Voltage

The 20 kHz Gate pulse signal to the MOSFET switch is shown in the figure 10.

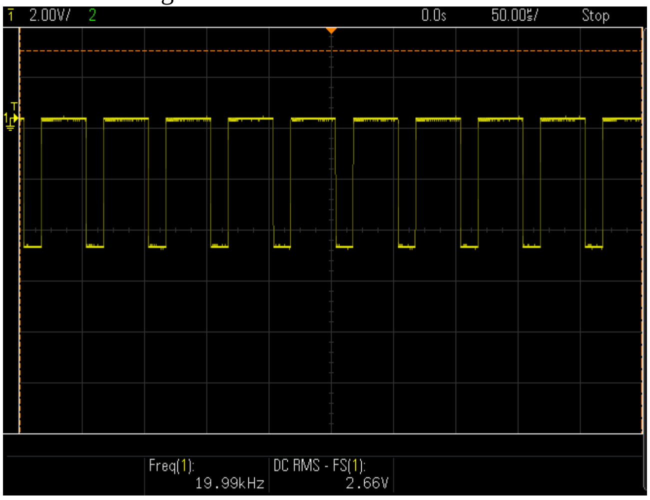

Fig.10. Pulse signal to the semiconductor switch in the Boost Converter

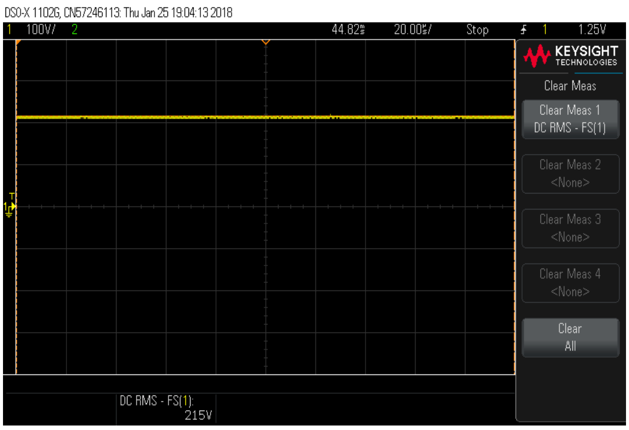

Fig.11.Output Voltage of the Boost Converter

Figure 11, Figure 12, Figure 13 shows the obtained output of the Boost converter, Gate Pulse Signal to the Inverter and Peak to Peak output voltage of the inverter.

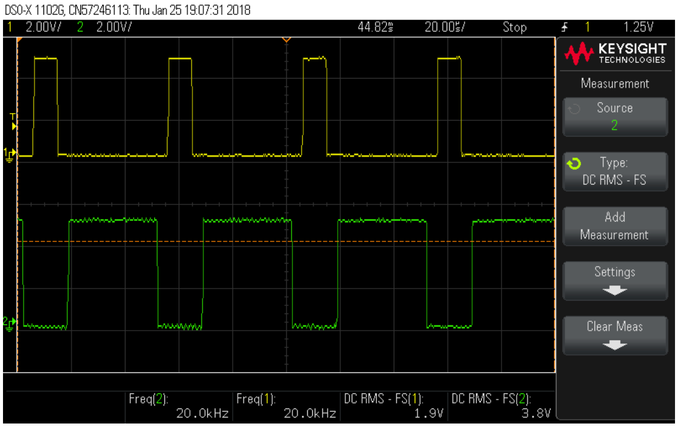

Fig.12.Gate Pulse Signal to the Inverter

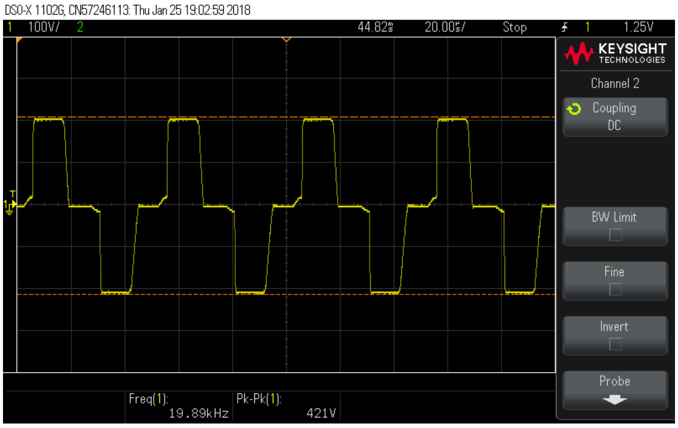

Fig.13.Peak to Peak output voltage of the inverter

VI. CONCLUSION

This article has shown the potential to design cost effective needle-plate type electrostatic precipitator for medical waste incinerators. The ESP is energized by abundant solar energy with power electronic converters and ferrite core transformer. A homemade electrostatic precipitator was fabricated and collection efficiency has measured for different applied voltage.

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