Simulation of a Cascaded High Voltage Converter with Improved Power Factor for Biofuel Extraction

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***Abstract*— Crude oil is used for fuel needs in cars, trucks, heavy machineries, ships etc. Jet fuel is needed to power aircraft for commercial transport. This fuel form is extensively used for defense applications also. Existing global fossil fuel reserves are rapidly depleting. As resource decreases and consumption increases prices will continue to rise. The alternative solution for fuel needs in industrial scale can be obtained using algae. Selected algae can produce 50% oil and 50% biomass which can be converted into fuel products and this in turn makes algae, a valuable, sustainable and renewable fuel resources. This paper presents the simulation results of a cascaded high voltage converter for a system voltage of 230V ac used for algae lysing using pulsed electric field technology. Lysing is the process of breaking down the cell wall in order to isolate the lysate or cellular components necessary to produce biofuel. The proposed system is distinct from other known systems because of its ability to adjust peak voltage, pulse width and frequency of the output waveform independently. The converter is able to provide a range of output voltage from 10V-80V peak, 60Hz-100 KHz frequency and 20 to 80 % duty cycle.**

***Index Terms*— Pulsed electric field; Lysing; Biofuel; Cascaded high voltage converter.**

I. INTRODUCTION

All Food, fuel and energy prices rise when there is scarcity of natural resources. An increase in population means an increase in demand for resources. If demand rises too quickly, it results in resource scarcity and causes prices to rise for several reasons. Nonrenewable resources, including fossil fuels, cannot be replaced, so prices increase when supply diminishes gradually in size. The only logical solution is vigorous management of human consumption of natural resources. Fossil fuels, as the name suggests, are very old. Fossil fuels are an incredibly dense form of energy, and they took millions of years to become so and because of that it traps carbon dioxide. So there should be a step through towards green diesel or biodiesel in the future in order for a sustainable development. Therein lies the answer for future energy; Algae biofuel. Algae exist in many forms and they extract energy during photosynthesis and store it in the form of oil. This oil can be directly converted into fuel for useful applications. The fuel that obtained matches with the performances of gasoline. Algae could be ten or more times productive than other forms of energy and it removes carbon dioxide from air during photosynthesis, thus rule over fossil fuels as a readily available renewable source of energy. The initial products of biofuels came in the form of sugars, starches, and vegetables. These compounds are used as vehicle fuels after undergoing through various processing stages such as fermentation, distillation, dehydration, and evaporation. The resulting products bioethanol, biodiesel, green diesel, and vegetable oil obtained are viable substitutes to fossil fuels. So to preserve fossil fuels and to increase energy security, biofuels can be used as an alternative solution to help meet the increasing demand of energy in the future also. In 2010, global production of biofuels increased 17 percent and constituted 2.8% of the world fuels for road transport [1]. In 2007, Continental airline's "The Boeing 737-800" burned a green fuel derived partially from genetically modified algae produced oil and became the first US commercial flight fueled by algae based biofuel [2]. Seeing no modification to the jet engine is necessary, airline companies started investing in commercially produced algae biofuel [3].

Algae are a great source for biofuel since it is both a renewable and sustainable source of energy. Defining the term renewable is in theory very simple. Merriam-Webster's online dictionary does so as, "capable of being replaced by natural ecological cycles or sound management practices." Algae grow naturally in the water making it a renewable source. Algae can be harvested in the sea and in a cultivated environment making growing a mass amount of algae possible. According to Brundtland commission sustainable means "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [5]. Algae can be grown infinitely. After being harvested, it goes to a bio-refinery process that transforms the oil contained in it to biofuel, which can be used to power vehicle, and excretes bio-waste. The bio-waste is put into an anaerobic digester that converts the waste into natural gas and residue taken as fertilizer for plants. It is clear that biofuel is needed in the future as an important resource to fuel our energy needs.

II. ALGAE TO BIOFUEL CONVERSION

The first technique for producing high voltage pulsed electric field for lysing was adopted from food pasteurization systems consisting of RC and RLC circuits [6]. And the five most common power electronic topologies that are used to create pulsed electric field are flyback, forward, push-pull, half-bridge, and full bridge topologies [7]. Flyback and forward are usually used for low power applications (5-150 W), the push-pull is usually used for medium power (300 W), and the bridges are used for high power applications (>500W) [8]. Capacitor discharge circuit [9][10], square wave pulse generators[11][12], modular square wave pulse generators [13], analog generators [14] and blumlein generators [15][16] are some other existing systems for high voltage pulse generation. The aim of this work is to develop a power converter that provides a variable pulse output voltage and pulse width (f, D). The adjustment of the maximum output voltage and the pulse width (f, D) can be performed independently. Therefore, this can provide flexibility in locating the optimal conditions beneath which algae lysing or cellular disruption arise. For algae lysing, the three foremost variables which will be investigated are amplitude of output voltage, frequency, and pulse width. The system uses 230V rms ac voltage waveform that allows the user to connect the whole system to a wall outlet and operate the system anywhere a grid connection is available. The output voltage is a square wave pulse having amplitude A, period T, and the pulse width D*T, where D is duty cycle of the waveform. The three variables will be adjustable using control signals that the user inputs to the system. The most challenging aspect of the work is setting design parameters because algae lysing is a new technology; therefore there is no value range or conditions that best lyse algae, so the objective is to create a system to find the unknown variables to lyse algae, and not to create the optimum solution for lysing algae. In addition, the system must be withstandable to different loads due to testing on different algae strains as selected algae will be of different type. Therefore, the best approach is to set realistic ranges of each variable and then design accordingly. An output voltage range of 10V-80V will allow the user to adjust the electric field strength across the load. Variable voltage indicates that, at what electric field strength cell disruption occurs without damaging the cellular components that is, the potential across cell membrane. The target frequency range of the output square wave is from 60Hz to 100 KHz which corresponds to periods of approximately 17ms down to 10µs. This variable voltage parameter indicates how often the output voltage must be applied to the load to rupture the algal cell membrane. The duty cycle is varied from 20% to 80% in order to determine what duration of the period the voltage should be applied. Further, the user will be able to adjust each variable individually while keeping the others constant; by varying output voltage and frequency for a fixed duty cycle and vice versa .So in order to give a robust solution, the whole system is designed as serially connected subsystems to yield accurate controllability for the user. By connecting different power electronic topologies in series, the system will be able to meet the required design parameters. A detailed block diagram is shown in figure 1.

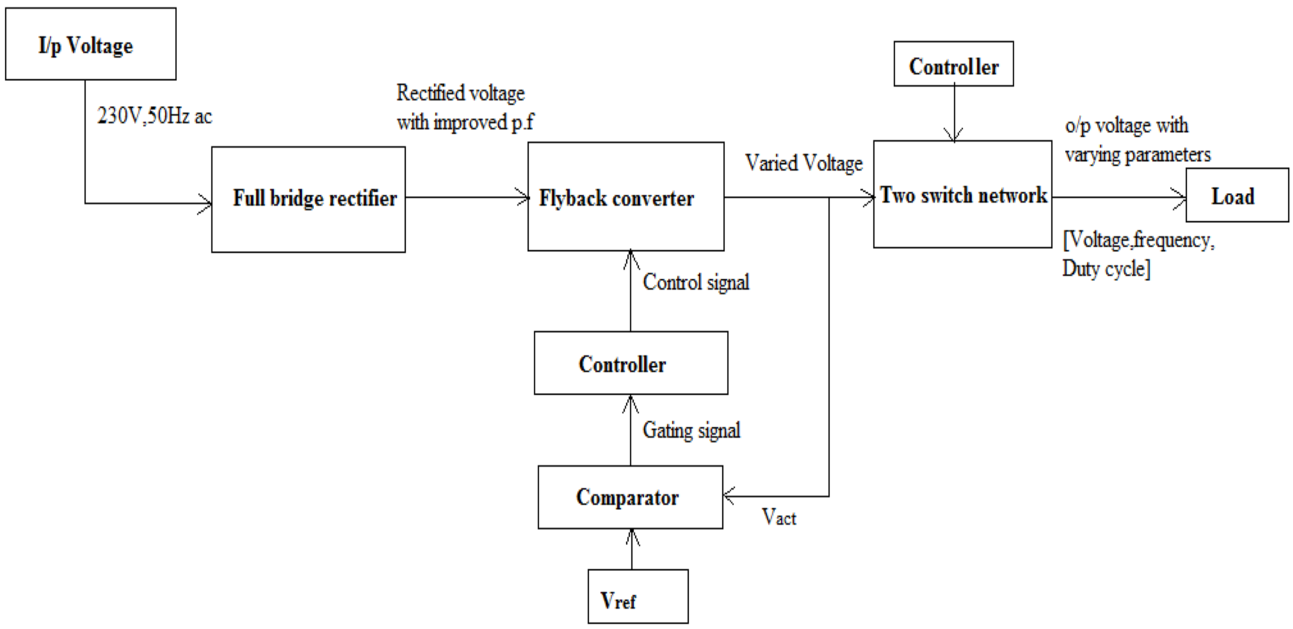

Figure 1: Block Diagram of the Proposed System

III. CIRCUIT SIMULATION

The simulation model of a biofuel extraction converter is constructed using MATLAB/Simulink is as shown. The circuit simulation consists of an input stage rectifier with capacitor filter, flyback converter and a two port switch as important components. The full wave rectifier shown in figure 2 is the basic circuitry needed for rectification from ac input to a dc output voltage. It consists of four diodes connected as shown in figure. The ac input voltage of 230Vrms is stepped down to a lower voltage using a suitable step down transformer. In this case the turns ratio is set as 2:1.

The selection of transformer plays a big role in improvement of input power factor of the system. Also the closed loop control of flyback converter is responsible for the improvement of power factor at the input. Basic DC-DC converters, when operating in the discontinuous conduction mode, have the property of self-PFC[17]. If these converters are connected to the rectified AC line, they have the capability of giving higher a power factor by the very nature of their topologies. The nominal power is selected as 1.5kVA for 50 Hz frequency. Thus simulating, the power factor of the system is obtained as .99 which is very near to the ideal value. In order to eliminate the voltage ripples at the output, a filter capacitor is designed considering maximum ripple voltage of 5%. The power factor measurement block constructed using simulink is as shown in figure 3.

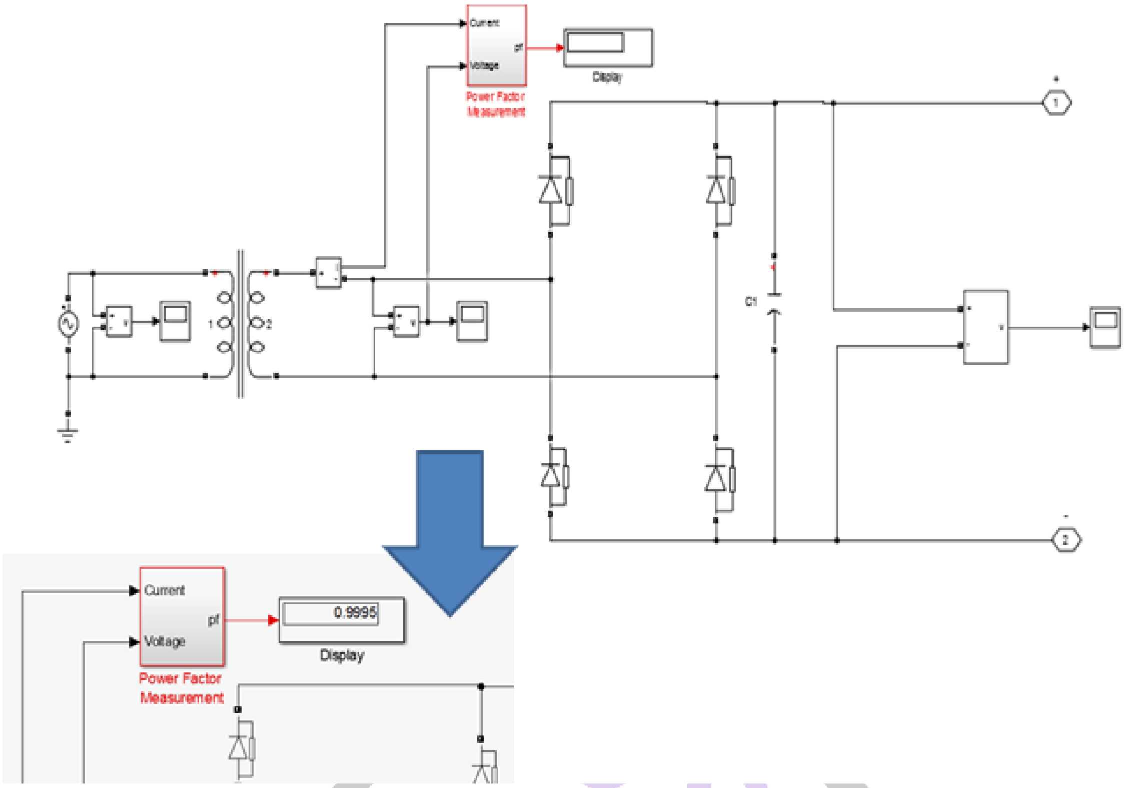

Figure 2: Main Unit

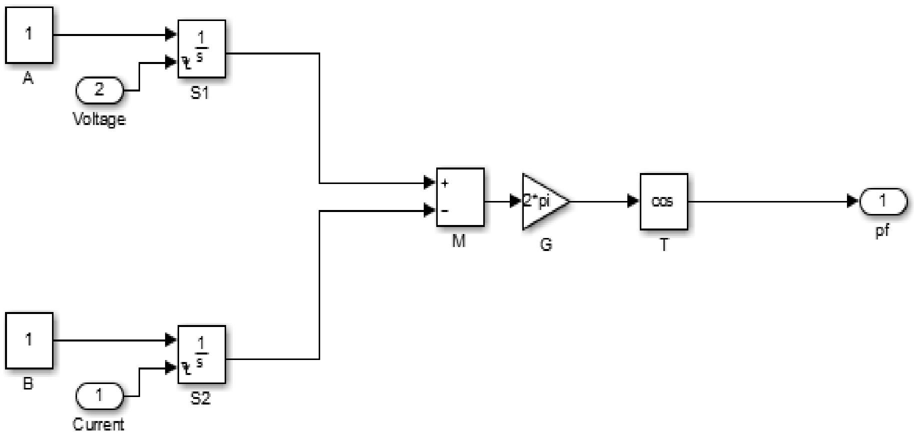

Figure 3: Power factor Measurement Block

The next stage is a dc-dc converter responsible for providing a dc output voltage with varying magnitude. The flyback topology was selected for the dc-dc converter as the second stage of the proposed system. The flyback is an isolated topology because of the transformer's ability to electrically isolate the output from the input, which is critical because the system is connected to the grid. The flyback is capable of producing large ranges of output power and more importantly, high output voltages at low power. Also the regulator establishes and maintains a constant dc voltage throughout the system regardless of the load. For flyback converter the selection of transformer plays an important role in output voltage waveform. For obtaining multiple output voltage range, closed loop control is given using suitable PI controller, where gain of the controller is adjusted so as to obtain a voltage range of 10-80V. The controller gain is set using trial and error method. A two switch network is implemented into the system in order to take a dc voltage and convert the signal into a periodic square wave. The main responsibility of the two switch network is to easily adjust the period and pulse width of the output voltage. In addition, each parameter should be able to be changed individually and the variables should be independent of each other; which means changing one variable should not affect the other variables. To verify this, voltage was maintained at 40V and frequency was fixed at 5 KHz. The system requires a minimum of 20% duty cycle and a maximum of 80%. Therefore the simulations have duty cycles (D) of 20%, 50%, and 80%. The system is simulated both in open loop and closed loop for a detailed comparison and the simulation circuit is shown in figure 4 and figure 5.

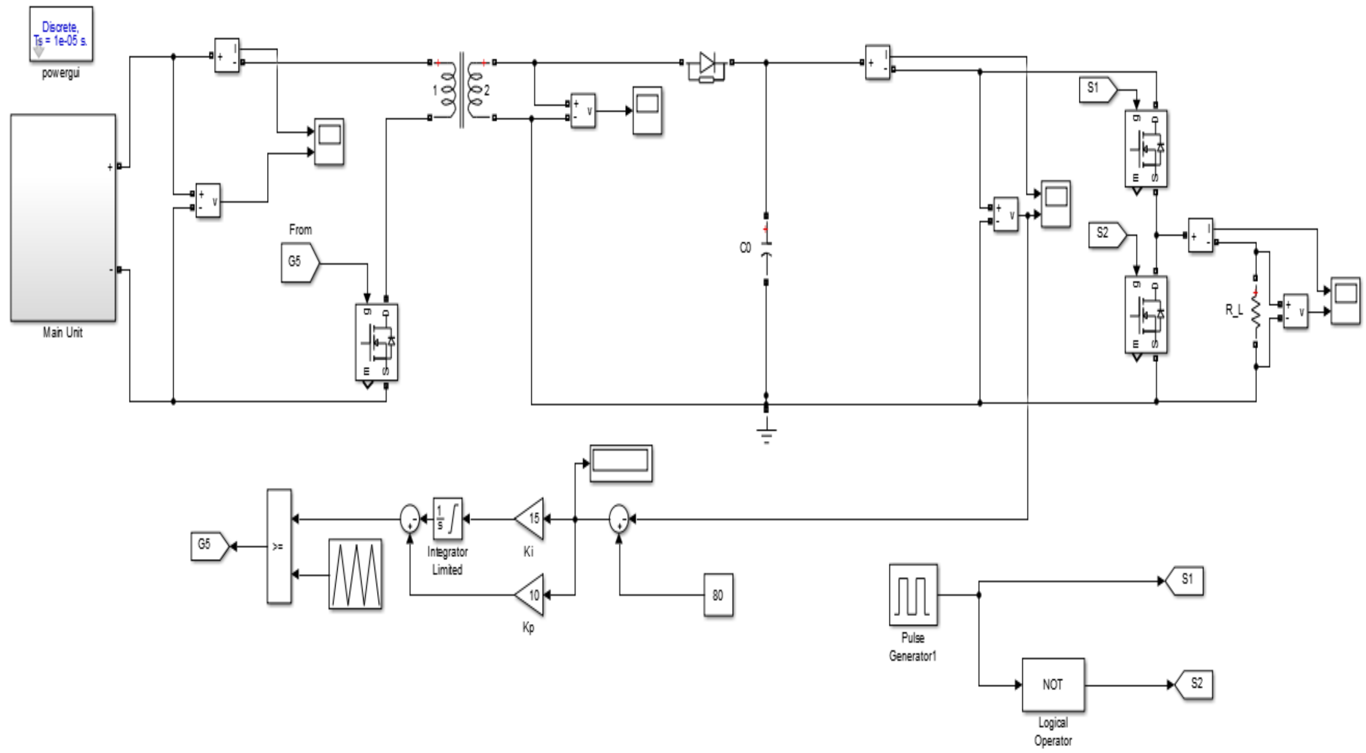

Figure 4: Simulation Diagram of the Open Loop System

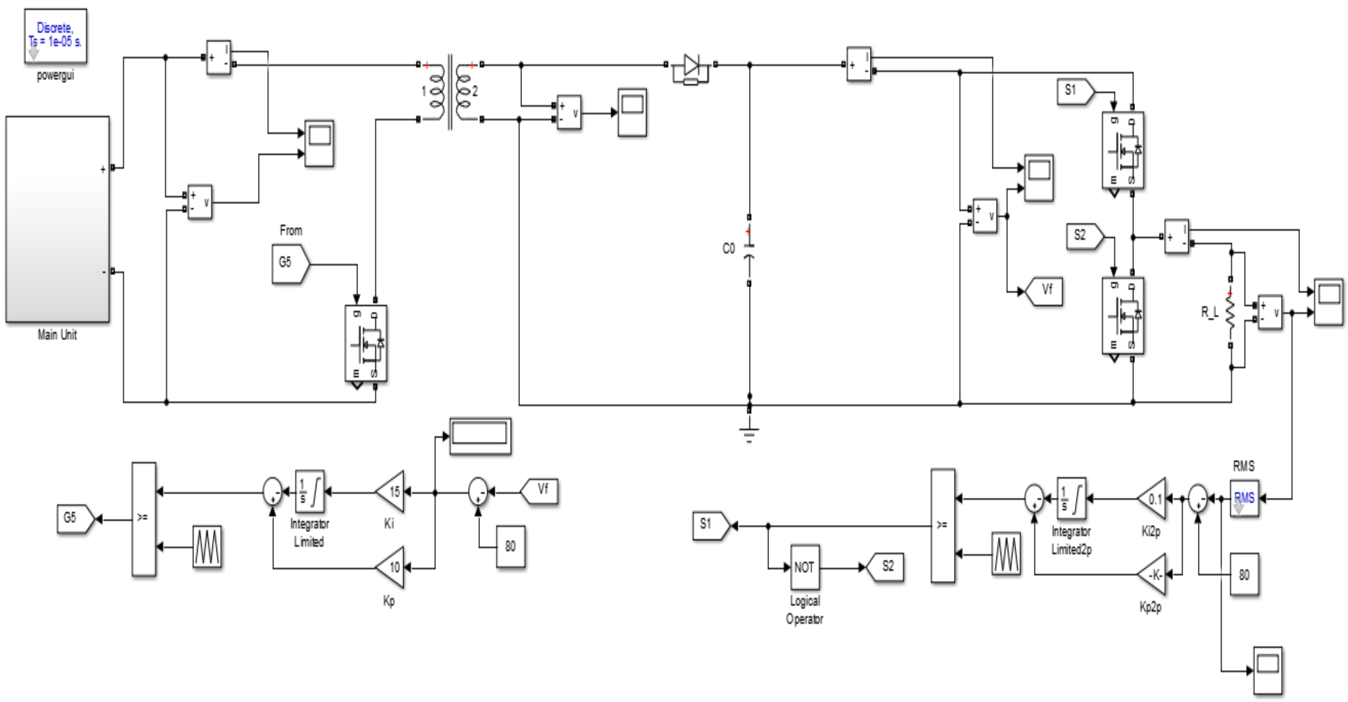

Figure 5: Simulation Diagram of the Closed Loop System

IV. SIMULATION RESULS AND ANALYSIS

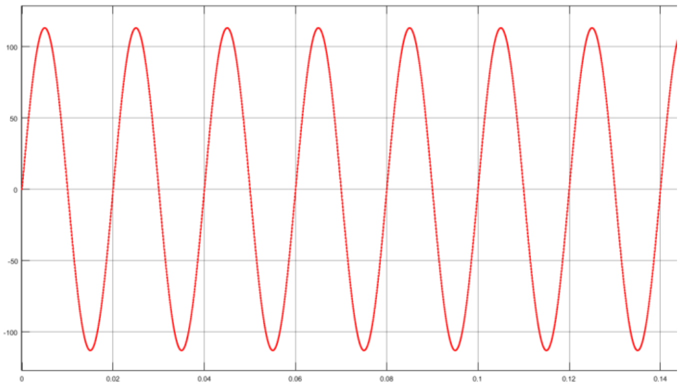

Figure 6: Rectifier stage input

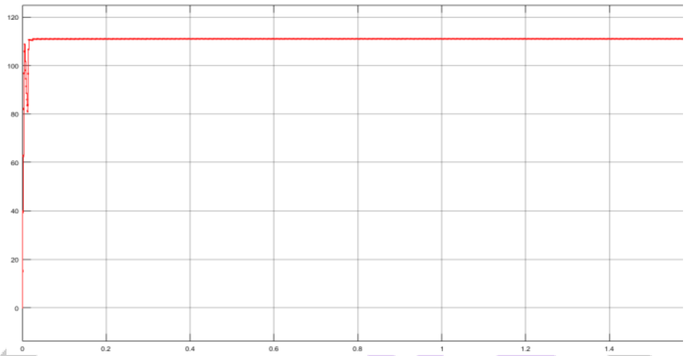

Figure 7: Rectifier stage output

The input and output waveforms observed from rectifier stage is shown in the figure 6 and figure 7. Figure 8 shows the output voltage with D=20% in open loop system. The corresponding pulse width is 40µs which is exactly 20% of 200µs. 200µs is the time period of a 5 KHz frequency signal thus showing the system responds correctly to the control signals. The same is true for figure 9 and 10. Open loop results show a slight variation in expected output voltage range which is termed as voltage tracking error in open loop configuration. The same is obtained with closed loop system with a difference that output voltage doesn't shows any tracking error and it follows the exact expected voltage value. Also any set of voltage between (10-80) V can be obtained in both open loop and closed loop.

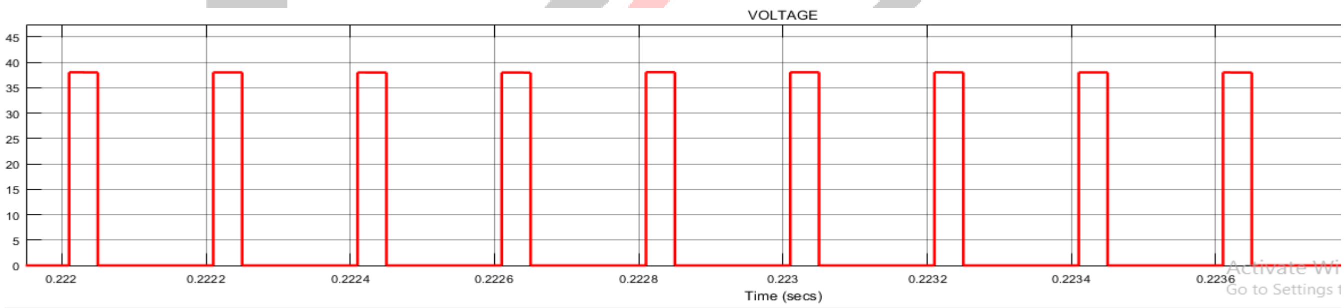

Figure 8: Open Loop System for a 40V, 5 KHz, 20% Duty cycle

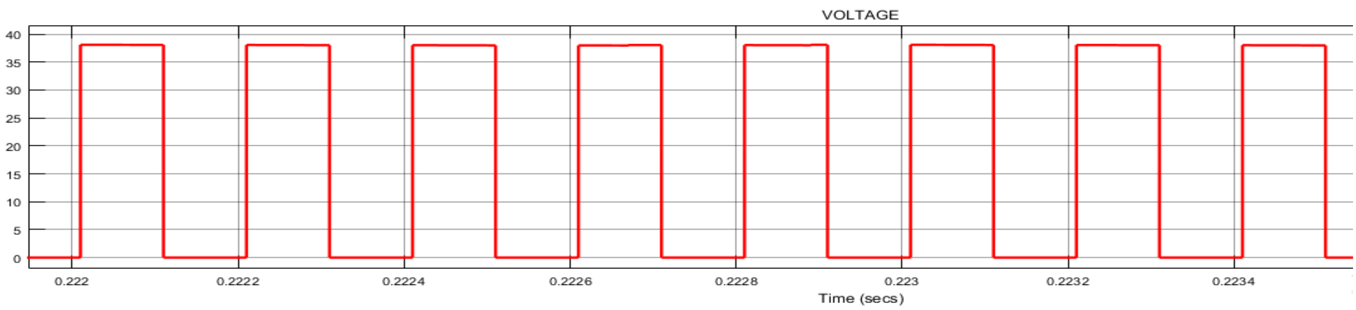

Figure 9: Open Loop System for a 40V, 5 KHz, 50% Duty cycle

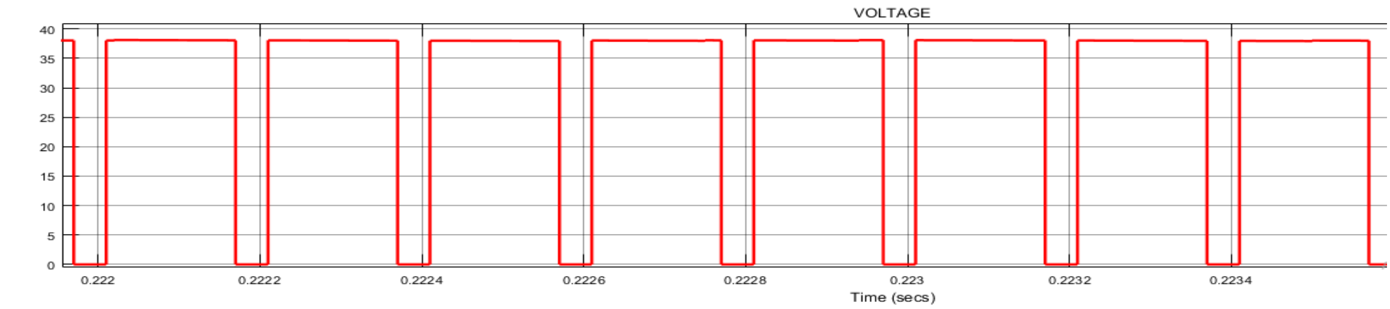

Figure 10: Open Loop System for a 40V, 5 KHz, 80% Duty cycle

The next thing to analyze is how well the network achieves the desired frequency. For these simulations, the voltage, 40V, and the duty cycle, 50%, were held constant while changing the frequency from 60 Hz (f_{min}) to 100 KHz (f_{max}). A middle range frequency, 5 KHz, is also simulated for comparison. The results are shown in figure 11, 12 and 13 respectively. Each frequency was regulated producing the desired signal. The small delay occurs at the beginning of the waveform. This delay is probably due to the rise time and the high set frequency of 100 KHz. Besides this small delay, each frequency is accurate. The load current seems to have no effect on the integrity of the signal.

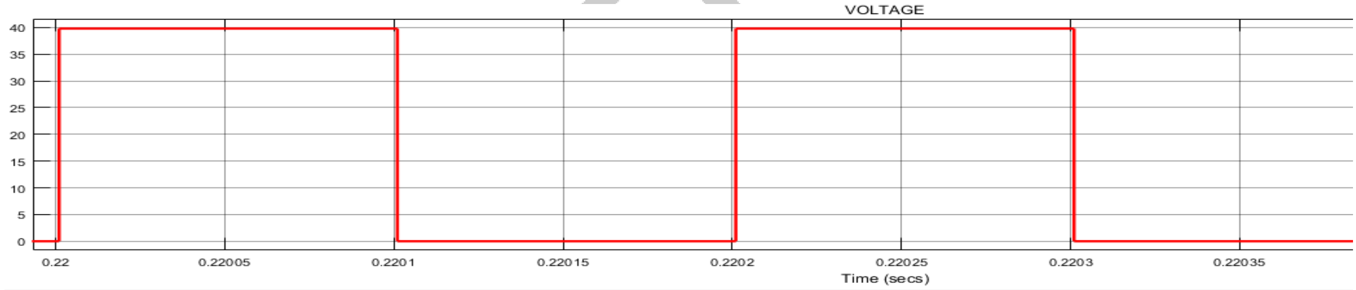

Figure 11: Output Waveform for 40V, 50 % Duty cycle, 5 KHz Frequency

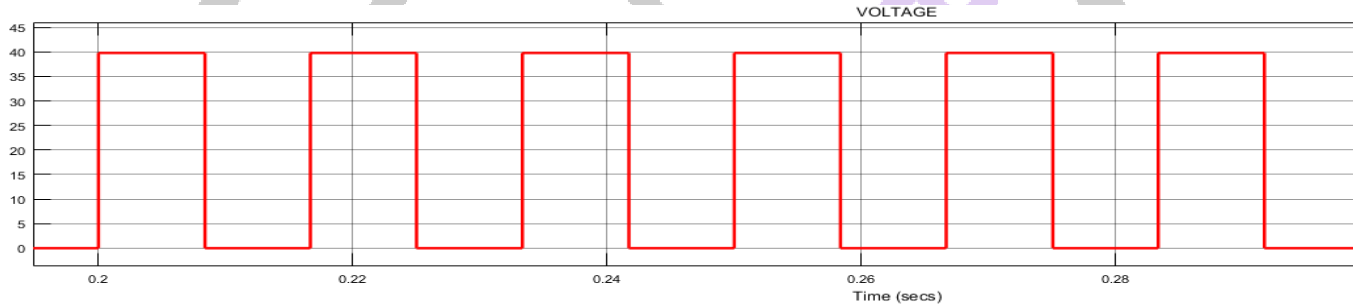

Figure 12: Output Waveform for 40V, 50 % Duty cycle, 60Hz Frequency

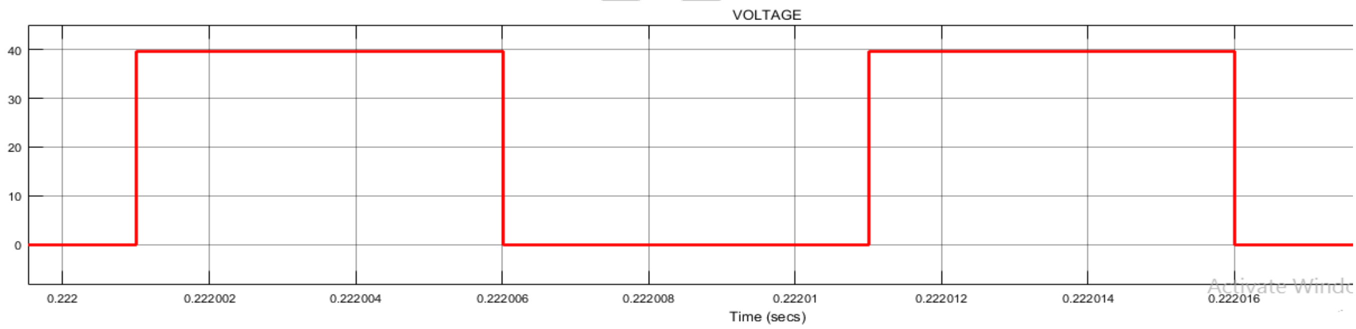

Figure 13: Output Waveform for 40V, 50 % Duty cycle, 100 KHz Frequency

For selecting each set of values, a multiport switch can be used. By inputting the port number, it is able to select the desired set of frequency and duty cycle for the range of output voltages obtained. Figure 14 shows the simulink model of multiport switch used in system simulation and this in turn is used for switch selection in open loop system.

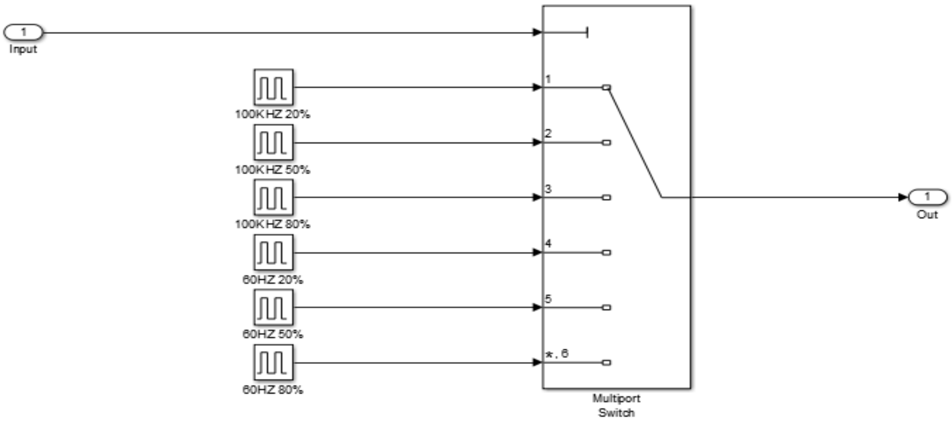

Figure 14: Simulink Model of a Multiport Switch

V. RESULTS AND DISCUSSION

The objective of this work was to develop a system that provides stretchability in finding the favorable operating conditions for algae lysis. The system consists of power electronic converters that are able to provide a pulse output voltage in order to create a pulsed electric field to lyse algae. The proposed system is distinct from any other known pulsed electric field systems because it provides the ability to solitarily alter peak value of output voltage, frequency and pulse width. This in turn provides great mouldability in determining optimum pulse voltage at various operating conditions for lysing algae. Due to the fact that algae lysing is a new and emerging technology, the ability of each variable to accomplish a wide range is necessary and therein lies the most difficult aspect that the design has no set values to base a design on as said earlier. However, to demonstrate that the proposed system provides a solution for obtaining green fuel using algae lysing technology, certain design parameters were set. When matched against these previously set design parameters, the proposed system was able to meet most of the requirements. Overall, the simulation results demonstrate that the proposed new system can indeed produce pulse output voltages with adjustable voltage, pulse width and frequency.

VI. CONCLUSION

Designing a cascaded system and a system solution to a real world problem made the design very challenging. Some of the issues encountered in the work involved tuning of PI controller so as to meet the wide range of output conditions.

A major improvement is that the entire system operates from a single input voltage rather than using multiple dc power supplies. Creating controller circuits to provide the power requirements from the input voltage would make the system less complicated and easier to use. Another idea for improvement is to implement a microprocessor for the control signal which may further enable users to interface the proposed system with a computer. The simulation results of the proposed system successfully demonstrate that the proposed topology works and is able to adjust each variable individually and independently. As a further improvisation of the work, the system is planned to build as a prototype in PCB board to examine how close the real time system meets the user requirement. Although the proposed system using flyback converter offers great flexibility as well as isolation, it has some major drawbacks. One common issue with flyback converter is that it is prone to leakage spike which may cause voltage across the main mosfet to exceed above its theoretical value. Also any small difference in the inductance turns may result in change in output values. One suggestion for future improvement would be to use a different topology that is immune to leakage spike. One good example is the double-ended forward converter.

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