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Research Article

A power circuit design for the poloidal field coils in a torus shaped plasma system

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Abstract: An initial design for a power circuit of a new plasma system is proposed and implemented in MatLab code. The plasma device is a torus and requires an excitement of wires, which are wrapped around the torus for a toroidal field and a poloidal field coil placed at the outer part of the device. This poloidal coil structure ignites an electrical field inside the chamber and that yields to a circular magnetic field inside the plasma. The proposed electrical design for this poloidal field equipment has some components including the alternating current unit and the direct current one. The circuit first uses an ac-dc converter, in order to transfer the ac grid to the dc one. Then it uses a switching scheme and a discharge circuit. The operation voltages for the poloidal field are estimated to be 1 kV, respectively. It has been proven that the designed system can produce an almost dc current with 66 V fluctuation, which is under the limit of 6%, considering the high voltage of 1kV.

Keywords: *Poloidal field, Plasma, Converter, Ignition*

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1. INTRODUCTION

The energy consumption of the world grows rapidly due to the industrial production and population. That causes a deficit in energy supply and only a certain proportion of this energy demand can be fulfilled by the renewable energy sector as an alternative and partially environmental-friendly character [1]. We argue as “partially friendly” because the footprint of energy is not so clean in terms of turbine, generator, photovoltaics and other equipment production. In terms of conventional fuels, many of the developing countries (with 80% usage ratio) suffer from those fuels due to environmental pollution [1]. In a most recent trend, the reaction against the climatic change arises world-widely and the international initiatives improve day by day on thermonuclear fusion energy as alternative and future energy resource [2].

In the fusion engineering applications, the power of stars are wished to be produced in the laboratory conditions via a controlled electromagnetic media. In this frame, plasmas either in RF or DC formation play an important role to produce the conditions of fusion events [3-5]. Therefore, electrical and/or magnetic confinement is vital for those plasma systems. Both generation and control of plasma are main tasks in the field of fusion. Especially, the fusion community focuses on the ideas of realization of International Thermo nuclear Experimental Reactor (i.e. ITER) project [6-7]. In what scale the plasma is generated, one of the main tasks is to design and implement an appropriate power system for the plasma unit. This paper handles some of the problems associated with the power supplies of the toroidal and poloidal coils of a new plasma system. Although our aim is not the implementation of a fusion device, the emerging of plasma structure inside the chamber is important for many applications such as medicine, material engineering, etc. In our system, since the plasma device is small, the required voltage for the poloidal field (PF) and toroidal field (TF) systems are considered as 1kV and 5kV, respectively.

The designed systems have AC-DC converter topologies, which are suitable for the high voltage. Those have missions on sustaining the stability over the feeding of plasma and cutting the power, if something occurs erroneously in the electrical part. It uses a cascade voltage increase at the output terminals and those can be applied to the poloidal field coils. Thus, a new power equipment is designed in accordance with this poloidal field coils.

2. VOLTAGE MULTIPLIER SYSTEM

A multiple voltage multiplier system is formed by several diodes, capacitors and a source. The AC input signal is cascaded in amplitude by successive stages. Indeed, after these successive layers, a DC signal is obtained from the output of the converter. Therefore, in many literature [8-10], these are called as AC-DC converters. Historically, this kind of voltage cascades systems were invented by John Douglas Cockcroft and Ernest Thomas Sinton Walton in 1932 and called as CW type cascades [11]. At the beginning, the CW voltage cascades were complicated and the reliability on the DC production was low. After the improvement in semiconducting material production sector, fast diodes and high frequency capacitors were produced and applied to the CW type voltage cascades. In general, multiple voltage multipliers are used out of the transformers. Therefore, the topologies of the voltage cascades are determined on that whether a joint terminal of the transformer exists or not. The voltage cascades with CW and IT types are used in the applications with no-joint terminal transformers. The difference between the CW and IT voltage cascades is the number of layers in the sense that it is even for CW type.

The multiple voltage cascades are the converters by using a DC voltage generated by the discharge of the capacitors attached serial to each other in a right order. Therefore, the preferences on the diodes and capacitors are important to drive the converter. For instance, in a CW type converter, a fluctuation can occur depending on the values of capacitor discharge time, which is strictly related to the charge amount and equivalent capacitance. To avoid this effect, the input frequency would be increased and the current should be decreased. Therefore, the voltage cascades are better for high frequency applications [12]. In the case of the absence of high capacity capacitor, one can make serial and parallel connections to reach the desired value for high voltage, however if the cascades are increased too much, that also causes a negative effect to get the control.

3. PLASMA SYSTEM

Fig. 1 shows a torus-shaped plasma cell. It has a vacuum feature under 10-5 mbar. It has an external wind system, which is responsible for the formation of toroidal electrical field inside the vessel. The outer wrapped windings over the vessel are for the poloidal electric field. The core structure denoted by a brown color provides a homogeneous field distribution at the middle of the vessel.

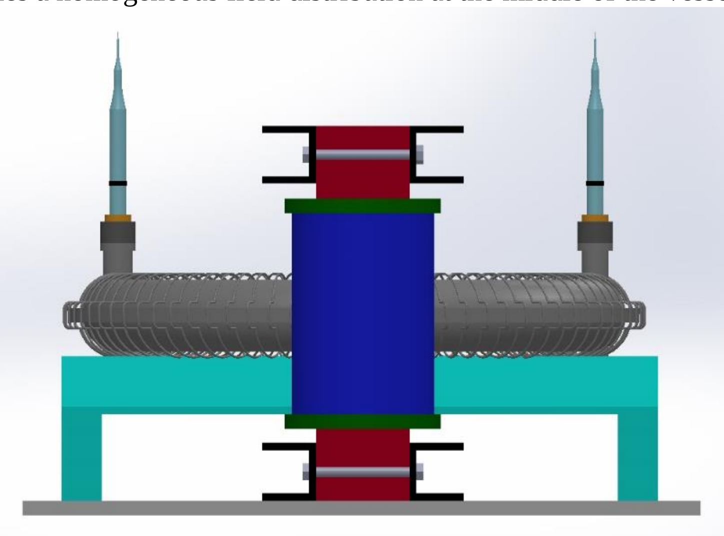

Figure 1. The plasma device with poloidal and toroidal windings and Langmuir probes.

In the poloidal field coils, the voltage cascade is composed of 5 stages to have the voltage value of 1 kV as in Fig. 2. Table 1 gives the circuit elements to form the PF power circuit.

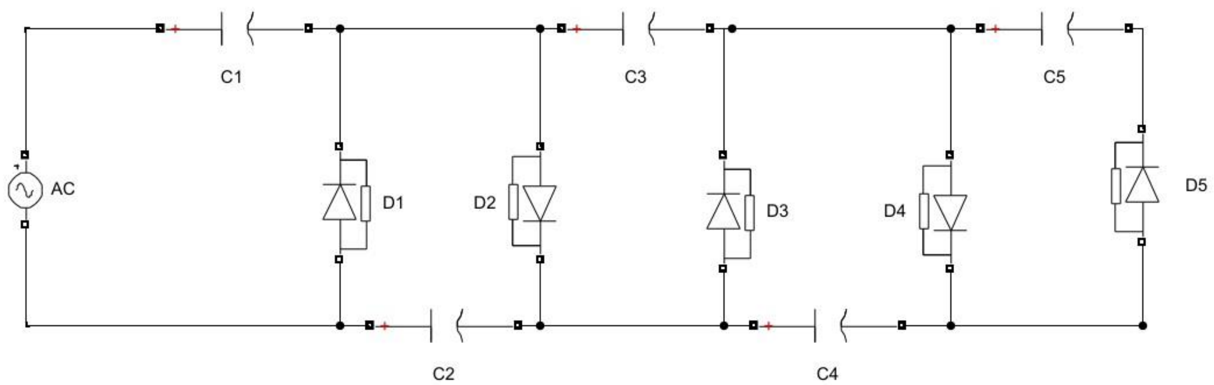

Figure 2. AC/DC Converter in PF System.

In Fig. 3 the MatLab Simulink model is shown. Here the waveforms are obtained by measurement scopes for voltage, current and power. The values in this table gives the optimal values for the HV value.

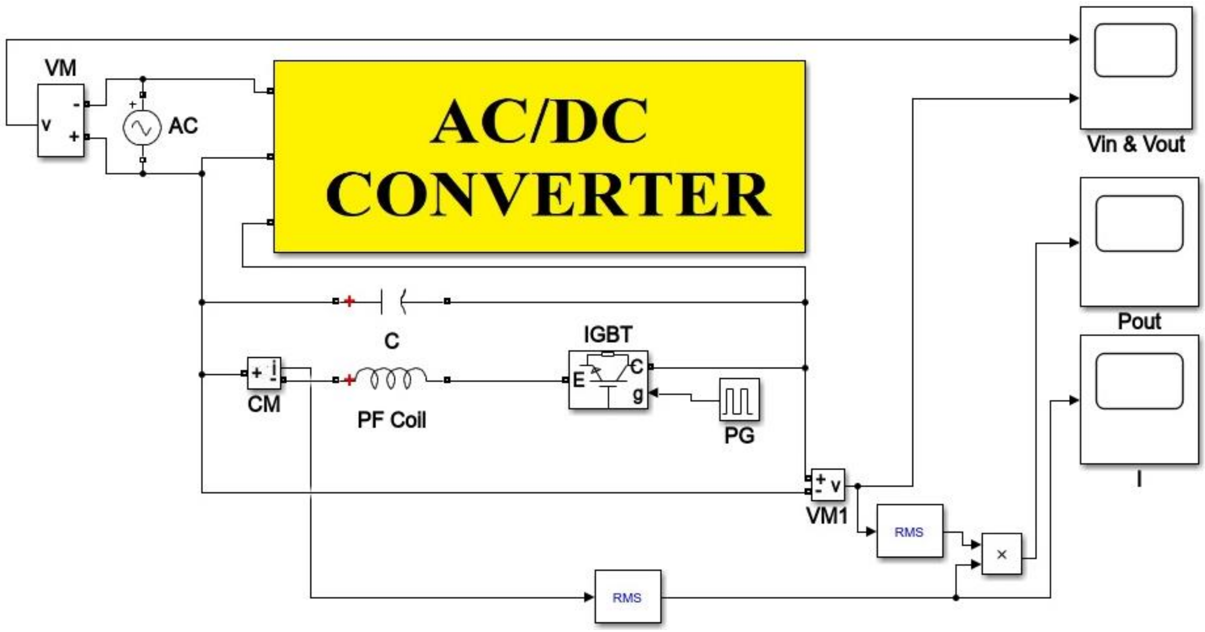

Figure 3. AC/DC Modules in PF System.

Table 1. Parameters of PF system

Item	Specification
Input Voltage(AC)	220 V
Output Voltage(DC)	~1 kV
Output current	~0.82A
L_{load}	462.3 µH
C_{load}	0.137 µF
C_n	100 µF
f_c	20 kHz

According to circuit output, 20 kHz frequency is found to be adequate and there is no need to decrease the frequency further. In the case of TF coils, the output current is found as 50 mA, however it becomes 800 mA for PF coils.

4. RESULTS and DISCUSSION

Fig. 4 shows the input and output voltages of PF converter. While an AC waveform with a maximal value 220 V and 50 Hz is given at the input terminals, a high voltage amplitude with 1 kV is obtained with very small fluctuation. The amplitude of the fluctuation is about 66 V and it is in the limit of 6.0 %.

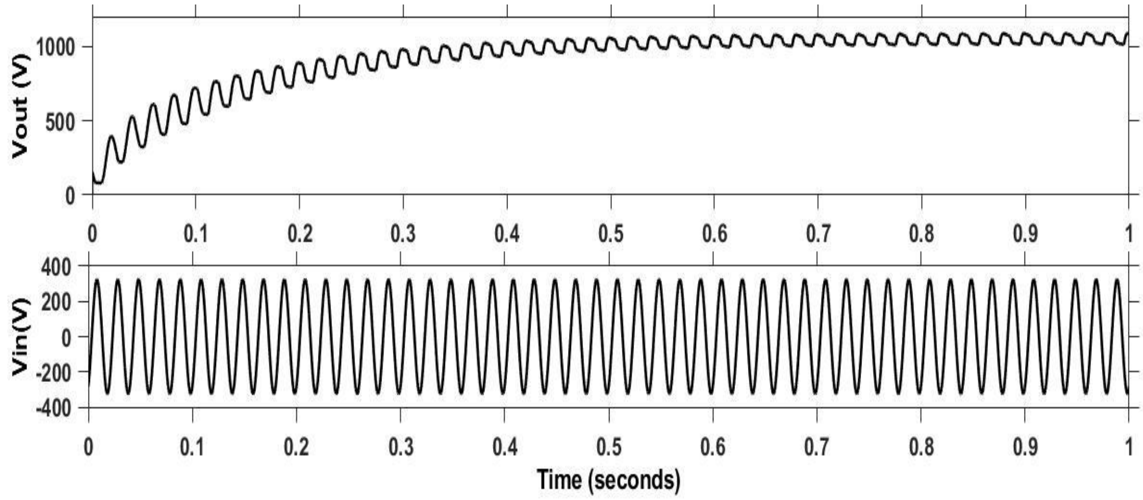

Figure 4. Input and output voltages of PF converter versus time.

Instantaneous power deviation *P* is simulated in Fig. 5. This power gives the total gained power by the converter system including the PF coils. This plot proves that power increases up to 2 kW depending on the oscillation period.

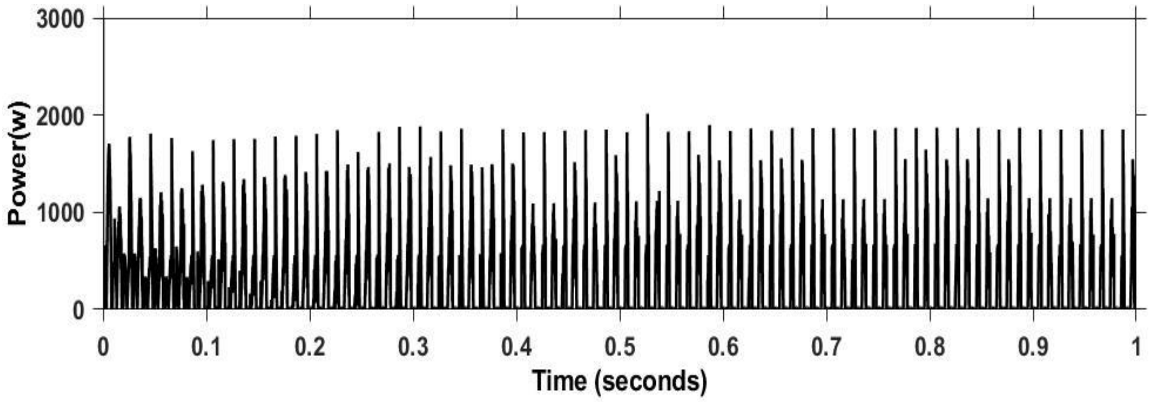

Figure 5. RMS Power deviation of PF converter.

Fig. 6 shows current over the PF coil versus time. The maximal current (i.e. *I* = 120 A) has been obtained during a very short time of 20 ms after the switch is on. The current form in the inset of Fig. 6 has been reached. The current is stabilized at 0.82 A. The current stabilization is achieved in 0.4 s as seen in the inset.

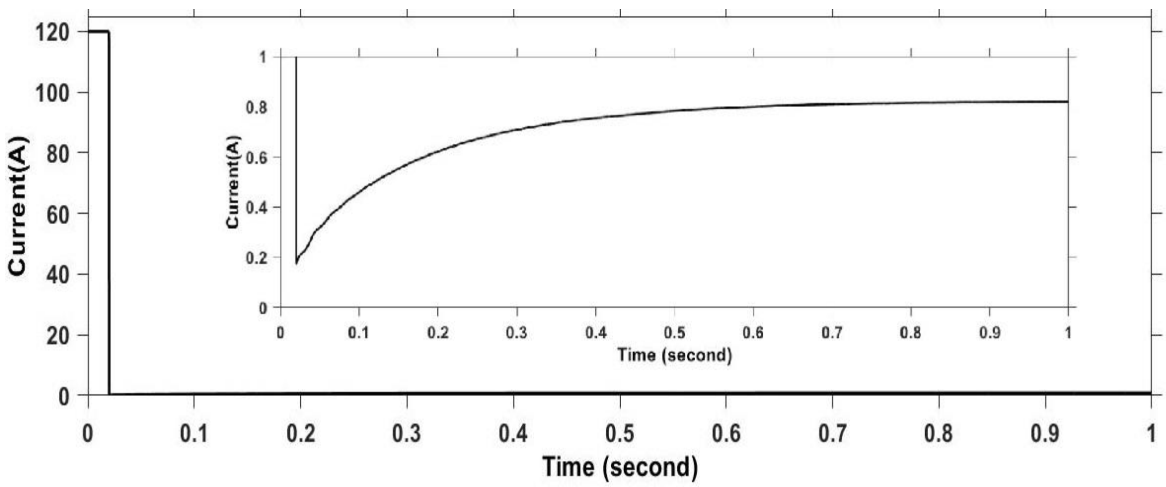

Figure 6. The output current over the PF coil just after the switch on.

5. CONLUSIONS

In this study, an initial design of a new torus shaped plasma device has been performed. Besides, a voltage cascade system with 5 stages has been designed for the input power requirement of a PF coil in a plasma cell. The electrical parameters have been ascertained for the PF coils. It has been proven that the designed system can produce almost a dc current with 66 V of fluctuation, which is under the limit of 6.0 %, considering the high voltage of 1kV. The resulting current value has been estimated as 0.82 A, which is sufficient for a low-pressure plasma device.

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