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Voltage Enhancement Using Solid State Devices

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Abstract: ***The main objective of this project is to develop a simulation circuit to generate a high-voltage DC from the low-voltage DC by Marx generator principle. It develops an output approximately four times that of the input voltage by using capacitor and MOSFET/IGBT combination. For eg. if the input voltage applied is around 12v volts DC, then the output voltage is around 48 volts DC.This demo project consists of 4 stages and each stage is made of one MOSFET/IGBT, two diodes, and one capacitor. The MOSFET/IGBT is used as a switch; diodes are used to charge the capacitor at each stage without power loss. A pulse generator generates pulses for the capacitors to charge in parallel during on time. During off time of the pulses, the capacitors are brought in series with the help of MOSFET/IGBT switches. Finally, the number of capacitors used in series (4 in our project) add up the voltage to approximately 3 (4 capacitors-1 capacitor) times the supply voltage. This system structure gives compactness and easiness to implement the total system from a DC supply of 12V to get approximately (40V-50V).This concept in future can be extended to Generate High voltages (KV) using more number of capacitors. This technique is adopted for insulation testing of the electronic components, wires, gadgets, etc.***

I. INTRODUCTION

The potential benefits of electrical energy supplied to a number of consumers from a common generating system were recognized shortly after the development of the 'Dynamo', commonly known as the generator. The first public power station was put into service in 1882 in London. Soon a number of other public supplies for electricity followed in other developed countries. The early systems produced direct current at low-voltage, but their service was limited to highly localized areas and were used mainly for electric lighting. The limitations of D.C. transmission at low voltage became readily apparent. By 1890 the art in the development of an A.C generator and transformer had been perfected to the point when A.C supply was becoming common, displacing the earlier D.C system. The first major A.C power station was commissioned in 1890 at Deptford, supplying power to central London over a distance of 28 miles at 10 000 V. From the earliest 'electricity' days it was realized that to make full use of economic generation the transmission network must be tailored to production with increased interconnection for pooling of generation in an integrated system. In addition, the potential development of hydroelectric power and the need to carry that power over long distances to the centers of consumption were recognized. Power transfer for large systems, whether in the context of interconnection of large systems or bulk transfers, led engineers invariably to think in terms of high system voltages.

Figure 1.1 lists some of the major A.C transmission systems in chronological order of their installations, with tentative projections to the end of this century. The electric power (P)

transmitted on an overhead A.C line increases approximately with the surge impedance loading or the square of the system's operating voltage.

The rapidly increasing transmission voltage level in recent decades is a result of the growing demand for electrical energy, coupled with the development of large hydroelectric power stations at sites far-remote from centers of industrial activity and the need to transmit the energy over long distances to the centers. However, environmental concerns have imposed limitations on system expansion resulting in the need to better utilize existing transmission systems. This has led to the development of Flexible A.C. Transmission Systems (FACTS) which are based on newly developing high-power electronic devices such as GTOs and IGBTs. Examples of FACTS systems include Thyristor Controlled Series Capacitors and STATCOMS. The FACTS devices improve the utilization of a transmission system by increasing power transfer capability. Although the majority of the world's electric transmission is carried on a.c. systems, high-voltage direct current (HVDC) transmission by overhead lines, submarine cables, and back-to-back installations provides an attractive alternative for bulk power transfer. HVDC permits a higher power density on a given right-of-way as compared to a.c. transmission and thus helps the electric utilities in meeting the environmental requirements imposed on the transmission of electric power. HVDC also provides an attractive technical and economic solution for interconnecting asynchronous a.c. systems and for bulk power transfer requiring long cables.

Table 1.1 summarizes a number of major HVDC schemes in order of their in-service dates. Figure 1.2 provides a graphic illustration of how HVDC transmission voltages have developed. As seen in Figure 1.2 the prevailing d.c voltage for overhead line installations is 500 kV. This 'settling' of D.C voltage has come about based on technical performance, power transfer requirements, environmental and economic considerations.

II. CIRCUIT TOPOLOGY

BASIC ELECTRONIC MARX GENERATOR (EMG) TOPOLOGY:

The use, in the Marx generator circuit of Fig. 1, of just solid-state switches to charge and discharge the energy storage capacitors, without the passive elements Zi, was already an innovative concept presented and discussed elsewhere [12], called EMG (Electronic Marx generator). Fig. 2 shows the basic

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EMG topology, with n stages, capable of delivering negative high-voltage output pulses to a load (Portuguese Patent, PT-103150). Each stage of the EMG consists of a energy storing capacitor Ci, a diode Dci and two IGBTs (Tci and Tdi), where the subscript i∈ {1, 2, …, n-1, n}. The EMG operation of Fig. 2 can be basically understood, considering only two different operating modes. In the first mode, Fig. 3 a), switches Tci and Tdi are, respectively, on and off.

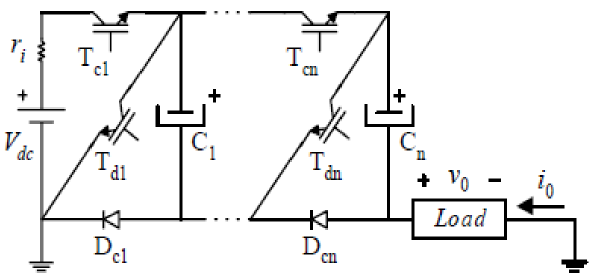


Fig 2

During this mode, the capacitors Ci are charged with total energy, $Ecap = n0.5CiVd2c$, from the dc power supply, *Vdc*, through Tci and Dci, with current peak limited by the internal resistance of switches, resulting in a small time constant that enables kHz operation

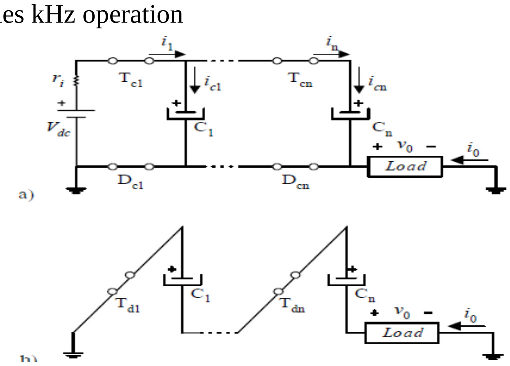


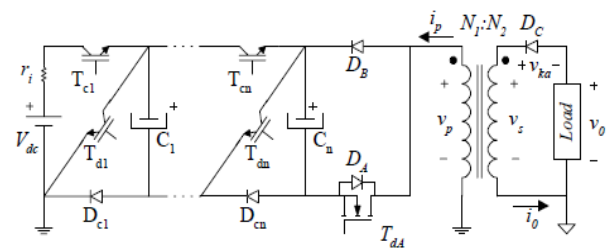
Fig 3

In the second operating mode, Fig. 3 b), switches Tci and Tdi are, respectively, off and on. During this period, capacitors Ci are connected in series and the voltage applied to the load is, approximately, $v0 = -nVdc$. Considering that, the capacitors charge time, *tc*, is made much longer than the discharge time, *td*, switches Tci and Tdi operate, respectively, with a long ($\delta c=tc/T$) and short ($\delta d=td/T$) switching duty cycle. It is important that, during the pulse, the voltage drop, due to the discharge of the energy storage capacitors, is only a few percent of each capacitor voltage. To guarantee this, the energy stored in the capacitors, *Ecap* , must be approximately 100 times greater than the energy delivered by each voltage pulse, to the load [15], $Epulse = nVdci0td$, where *td* is the on state period of *Tdi* and *i0* is the pulse current, in a
resistive load, with all capacitors charged with *Vdc*,, $i0 = nVdc$ *Zload* .

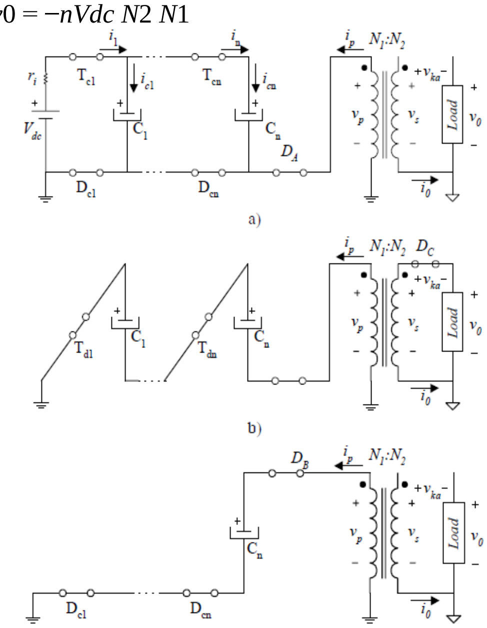
Due to the circuit topology, Fig. 2, it is necessary to avoid cross conduction between Tdi and Tci switches. Hence, an auxiliary circuit provides a time delay (i.e. dwell time), between switching input control signals, so that the turn-on control input to Tdi IGBTs is delayed with respect to the turn-off control input of Tci IGBTs, and vice-versa.

Electronic Marx Generator with output pulse transformer:
The topology of the EMG presented in Fig. 2 can be adapted, with few changes, to accommodate an auxiliary circuit to reset the core of a pulse transformer connected in the output, as shown in Fig. 4. The polarity of the output pulse depends on the polarity of the diode placed on the secondary of the transformer. In the case shown in Fig. 4 the pulses are negative.

Considering circuit in Fig. 2, the circuit in Fig. 4 presents an additional semiconductor switch, *TdA*, and two more diodes, *DA* e *DB*, to reset the transformer. Diode *DC* placed at the secondary, imposes a single voltage polarity onto the load, in this case negative pulses are obtained on the load. The operation of Fig. 4 circuit can be understood, considering only three different operating modes, with the simplified theoretical waveforms shown in Fig. 6. In the first mode, Fig. 5 a), switches Tci and Tdi (and TdA) are, respectively, on and off. During this period, capacitors Ci are charged with total energy, approximately, equal to (1). During this mode, diode *DA* is on and guarantees that the voltage applied to the primary of the transformer is approximately zero, as seen in Fig. 6 c). Diode *DC* on the secondary of the transformer assures that the voltage applied to the load is also near zero.



In the second operating mode, Fig. 5 b), switches Tci and Tdi (and TdA) are, respectively, off and on. During this period, capacitors Ci are connected in series and the voltage applied to the primary of the transformer, *v*1, is, approximately, equal to, $v0 = -nVdc$. Diode *DC* is on, so the voltage applied to the load is, $v0 = -nVdc\ N2\ N1$



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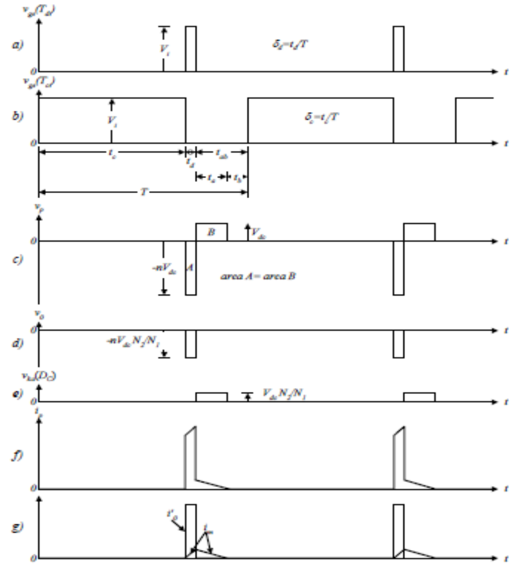
During this period, current *ip*, Fig. 6 f), is equal to, '0 $i\ p = im + i$, where *im* is the magnetizing current of the transformer, and i'0 is the secondary current reduced to the primary, 0 2 1 '0$i = I\ N\ N$. Considering a linear magnetic circuit, then im increases linearly as, $\Delta im = nVdctd\ Lm$, where *Lm* is the primary magnetizing inductance and *td* is the pulse width, Fig. 6 b). The load current *i*0 is given by, *i*0 = *v*0*Zload.*

In the third operating mode, Fig. 5 c), switches Tci and Tdi (and TdA) are off. In the first part of this period, ta, the voltage applied to the primary of the transformer is, approximately, *Vdc* (Fig. 6 c)) and the magnetizing current im has a path through *DB*. Since the voltage applied to the primary of the transformer has opposite polarity, im decrease linearly, $\Delta im = Vdcta\ Lm$. That, in terms, guarantees the reset of the transformer, sending this energy back to the energy storage capacitors. The capacitor with the lowest voltage receives this current, which increases the capacitor energy. During this period, diode *DC* on the secondary blocks a voltage,Fig.6e),*vka*=*VdcN*2*N*1



Considering the power supply voltage constant, *Vdc*, the voltage blocked by *DC* is always the same (voltage in each capacitor), independent on the number of stages in the Marx generator. However, increasing the number of stages, the primary voltage is bigger and so the reset time ta is longer, to guarantee that the volt-second product is equal, Fig, 7 c), during the pulse and during the reset period.

Taking into account Fig. 6 c), after the reset time, ta, im goes to zero and diodes are off. The voltage appliedto the primary of the transformer is zero during tb, after which the first operation mode begins again, Fig. 5 a). Regarding the drive signals, vgs(Tdi) and vgs(Tci), respectively, of semiconductors Tdi and Tci, the EMG of Fig. 4 is more complex than the EMG of Fig. 2. Due to the reset period, the drive signals to switches Tci must be delayed by tab, as can be seen in Fig. 6 b). This difference creates extra complexity for the semiconductors drives. In both circuits, the semiconductors must be driven synchronously, and as all the switches are at different potentials, it is required gate circuits with galvanic isolation (optical fibres are used to transmit the gate signals).

III. INTRODUCTION TO MATLAB

MATLAB is a software package for computation in engineering, science, and applied mathematics. It offers a powerful programming language, excellent graphics, and a wide range of expert knowledge. MATLAB is published by and a trademark of The MathWorks, Inc.

The focus in MATLAB is on computation, not mathematics: Symbolic expressions and manipulations are not possible (except through the optional Symbolic Toolbox, a clever interface to maple). All results are not only numerical but inexact, thanks to the rounding errors inherent in computer arithmetic. The limitation to numerical computation can be seen as a drawback, but it's a source of strength too: MATLAB is much preferred to Maple, Mathematical, and the like when it comes to numerics.

On the other hand, compared to other numerically oriented languages like C++ and FORTRAN,
MATLAB is much easier to use and comes with a huge standard library.1 the unfavorable comparison here is a gap in execution speed. This gap is not always as dramatic as popular lore has it, and it can often be narrowed or closed with good MATLAB programming (see section 6). Moreover, one can link other codes into MATLAB, or vice versa, and MATLAB now optionally supports parallel computing. Still, MATLAB is usually not the tool of choice for maximum-performance Computing.

The MATLAB niche is numerical computation on workstations for non-experts in computation. This is a huge niche—one way to tell is to look at the number of MATLAB-related books on mathworks.com. Even for supercomputer users, MATLAB can be a valuable environment in which to explore and fine-tune algorithms before more laborious coding in another language.

Most successful computing languages and environments acquire a distinctive character or culture.

In MATLAB, that culture contains several elements: an experimental and graphical bias, resulting from the interactive environment and compression of the write-compile-link-execute analyze cycle; an emphasis on syntax that is compact and friendly to the interactive mode, rather than tightly constrained and verbose; a kitchen-sink mentality for providing functionality; and a high degree of openness and transparency (though not to the extent of being open source software).

What is SIMULINK

Simulink (Simulation and Link) is an extension of MATLAB by Math works Inc. It works with MATLAB to offer modeling, simulating, and analyzing of dynamical systems under a graphical user interface (GUI) environment. The construction of a model is simplified with click-and-drag mouse operations. Simulink includes a comprehensive block library of toolboxes for both linear and nonlinear analyses. Models are hierarchical, which allow using both top-down and bottom-up approaches. As Simulink is an integral part of MATLAB, it is easy to switch back and forth during the analysis process and thus, the user may take full advantage of features offered in both environments. This tutorial presents the basic features of Simulink and is focused on control systems as it has been written for students in my control systems.

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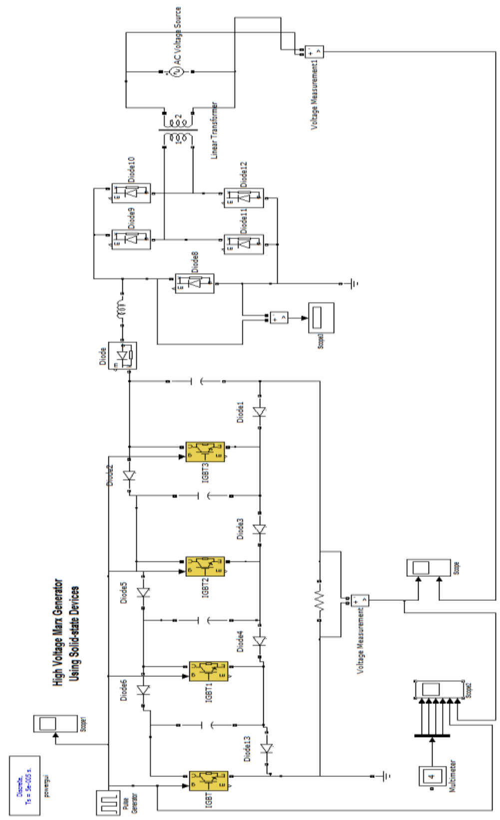
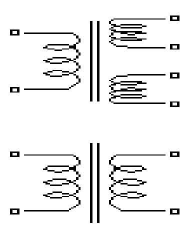
IV. SIMULATION CIRCUIT

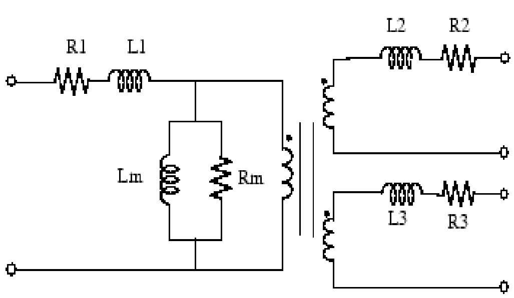


COMPONENTS USED IN SIMULATION:

a. Linear Transformer:



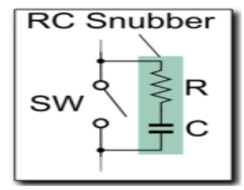
The Linear Transformer block model shown consists of three coupled windings wound on the same core.



The model takes into account the winding resistances (R1 R2 R3) and the leakage inductances (L1 L2 L3), as well as the magnetizing characteristics of the core, which is modeled by a linear (Rm Lm) branch.

b. RC Snubber Circuit:

A simple RC snubber uses a small resistor(R) in series with a small capacitor(C).This combination can be used to suppress the rapid rise in voltage across a thyristor, preventing the erroneous turn-on of the thyristor, it does this by limiting the rate of rise in voltage (dV/dt) across the thyristor to a value which will not trigger it. An appropriately-designed RC snubber can be used with either DC or AC loads.



c. Insulated Gate Bi-Polar Transistor (IGBT):

The **insulated-gate bipolar transistor** (**IGBT**) is a three-terminal power semiconductor device primarily used as an electronic switch which, as it was developed, came to combine high efficiency and fast switching.

The IGBT combines the simple gate-drive characteristics of MOSFETs with the high-current and low-saturation-voltage capability of bipolar transistors. The IGBT combines an isolated gate FET for the control input, and a bipolar power transistor as a switch, in a single device. The IGBT is used in medium- to high-power applications like switched mode power supplies, traction motor control and induction heating. Large IGBT modules typically consist of many devices in parallel and can have very high current handling capabilities in the order of hundreds of amperes with blocking voltages of 6000V, equating to hundreds of kilowatts

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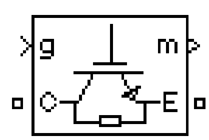


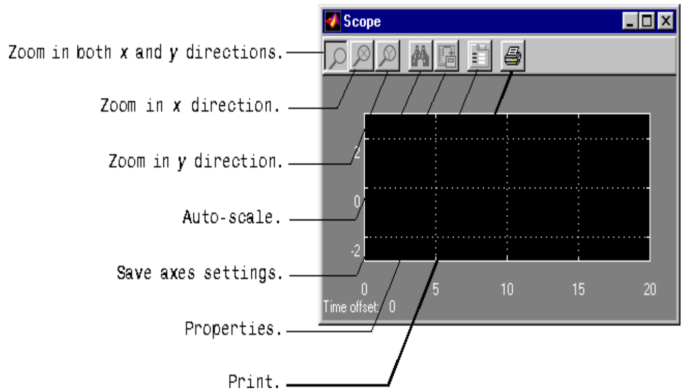
d. Scope:

The Scope block displays its input with respect to simulation time. The Scope block can have multiple axes (one per port); all axes have a common time range with independent *y*-axes. The Scope allows you to adjust the amount of time and the range of input values displayed. You can move and resize the Scope window and you can modify the Scope's parameter values during the simulation.

When you start a simulation, Simulink does not open Scope windows, although it does write data to connected Scopes. As a result, if you open a Scope after a simulation, the Scope's input signal or signals will be displayed.

If the signal is continuous, the Scope produces a point-to-point plot. If the signal is discrete, the Scope produces a stairstep plot.

The Scope provides toolbar buttons that enable you to zoom in on displayed data, display all the data input to the Scope, preserve axes settings from one simulation to the next, limit data displayed, and save data to the workspace. The toolbar buttons are labeled in this figure, which shows the Scope window as it appears when you open a Scope block.



e. Powergui:

The Powergui block opens a graphical user interface (GUI) that displays steady-state values of measured current and voltages as well as all state variables (inductor currents and capacitor voltages).The Powergui block allows you to modify the initial states in order to start the simulation from any initial conditions.It allows load flow computation and initialization of three phase networks containing machines.The Powergui block also displays impedance versus frequency plots when Impedance Measurement blocks are present in your model.If you own the Control System Toolbox, the Powergui block can generate the state-space model (SS) of your system and automatically opens the LTI Viewer interface for time and frequency domain responses.Copy the Powergui block in the top level of your model and double-click on the block to open the interface.The main menu of the Powergui block provides tools to:

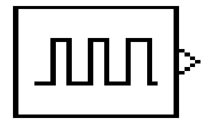
- Display steady-state voltage and currents
- Display and modify initial state values
- Perform load flows and machine initialization
- Display impedance vs frequency measurements
- Use the LTI Viewer of the Control System Toolbox
- Generate a report of the steady-state calculations

f. Diode:

The diode is a semiconductor device that is controlled by its own voltage Vak and current Iak. When a diode is forward biased (Vak > 0), it starts to conduct with a small forward voltage Vf across it. It turns off when the current flow into the device becomes 0. When the diode is reverse biased (Vak < 0), it stays in the off state.

g. Pulse Generator:

The Pulse Generator block generates a series of scalar, vector, or matrix pulses at regular intervals. Theblock's **Amplitude**, **Period**, **Dutycycle**,and **Starttime** parameters determines the characteristics of the output signal. All must have the same dimensions after scalar expansion and must be of the same data and numeric (complex or real) type.Use the Pulse Generator block for continuous systems. To generate discrete signals, use the Discrete Pulse Generator block.



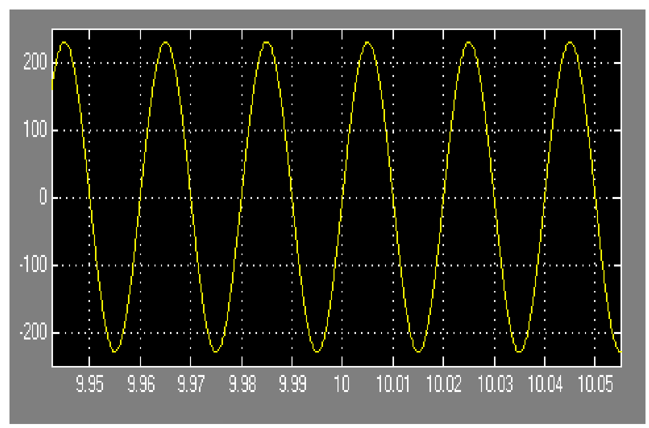
h. Multi meter:

This block measures the voltages and currents specified in the **Measurements** parameter of SimPowerSystems blocks in your model. Choosing voltages or currents through the Multimeter block is equivalent to connecting an internal voltage or current measurement block inside your blocks.

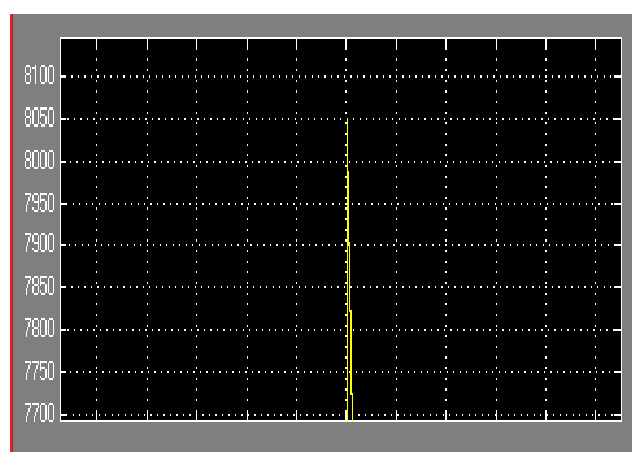
V. RESULTS

1. SIMULATION WAVEFORMS:

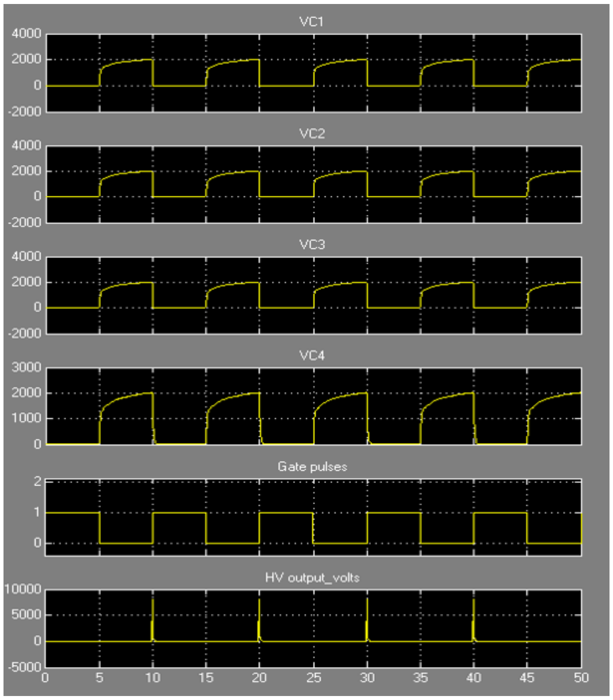
1.1. SOURCE VOLTAGE:



1.2. IMPULSE VOLTAGE at LOAD:



1.3. CAPCITOR VOLTAGES,GATE PULSES AND HV OUTPUT:



VI. CONCLUSION

In this paper, solid-state devices such as IGBTs and diodes are used in Marx generator to replace of gap switches and resistors. Furthermore, it is reasonable that IGBT drivers Utilise method of self-supplied power. The experimental results of both resistive and plasma load indicate that it can easily generate repetitive high voltage rectangle pulses with low voltage power source

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We would like to express our sincere appreciation to our guide, **Mr. G .Lakshminarayana**, for all of his patience, guidance, encouragement, and support throughout our graduate studies. His profound knowledge, rigorous attitude toward research and creative thinking has been a source of inspiration for us throughout the years and will benefit our careers as well as our whole personal lives.

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