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RESEARCH ARTICLE

DEVELOPMENT AND APPLICATION OF PULSE TECHNIQUE TO POWER SYSTEM PROTECTION

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Abstract

A novel pulsed power generator based on IGBT stacks is proposed for wide pulsed power utilizations because it can produce high voltage pulsed output without any step-up transformer or pulse forming network, it has benefit of fast rising time, easiness of pulse width variation, high recurrence rate and rectangular pulse shapes. Proposed scheme consists of multiple power stages which were charged parallel from series resonant power inverter. Depending on the number of power stages it can boostutmost voltage up to 60 kV or higher with no limits of power stages. To minimizecomponent for gate power supply, a simple and robust gate drive circuit which delivers gate power and gate signal concurrently by way of one high voltage cable is proposed. For gating signal and power a full bridge inverter and pulse transformer produces on-off signals of IGBT gating with gate power concurrently and it has very good characteristics of protection of IGBT switches over arcing condition. It can be used for various type of pulse power utilization such as plasma source ion implantation, sterilization, water and gas treatment which needs few kHz pulse recurrence rate with few to ten of microseconds pulse width.

Introduction:-

The electrical distribution system is vital for dependable delivery of power but is prone to disturbances or electrical faults. Power disruption due to faults in distribution network cost millions of naira annually for utilities and their customers Adler, et al (2008). Around 75% - 90% of the total number of fault are provisional, lasting for a few cycles and can be cleared by a recloser. Usually these provisional faults occur when phase conductors fleetingly contact other phases or connect to the ground. However, in case of a lasting fault, a conventional recloser stresses the equipment with fault current and produces voltage sag every time it switches after an event. One solution is to use pulse-reclosers to inject a low energy test pulse into the line before attempting a reclose. The term pulse-recloser used in this paper is a general term for switching tools with pulse testing capabilities. Intelli Rupter Pulse Closer is an example of a pulse-recloser This device is a unique alternative to conventional automatic reclosers and has the ability to work in stand-alone mode as a fault interrupter. These tools can also be used for fault isolation in distribution system and islanding operation in smart grids. Both sides of the device are equipped with accurate voltage and current sensors that make available high resolution (64 samples/cycle) time-stamped event data (Goebel,2000). Recorded data can then be used for fault classification, assessment of the fault location and to confirm proper operation. In particular, the current and voltage pulse waveforms contain vital information. For real-time utilizations, time do major analysis can be used to make available basic information and screen the data to find

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windows of possible pulses. It is sometimes difficult to detect these pulses as diverse type of loads, faults or transformers may influence the pulse amplitude or duration. In this paper, we model a dictionary learning framework based on matrix factorization algorithm to stand for time domajor pulses in the space of sparse codes which leads to a higher classification accuracy

For the pulse power supply, there are numerous type of models widely used such as Marx generator, hard-tube type pulse generator, thyratron type pulse power generator with pulse forming line etc. . These type of pulse power supply generally use mechanical switches such as spark gap and thyratron for their major switches. Recently some type of pulse power supply topology which uses semiconductor switches as a major switch have been proposed because it has some benefit such as long life-cycle, high pulse recurrence rates, compact size and low weight. In this work a novel semiconductor switch based pulse power supply using series resonant capacitor charging inverter and modified marx generator is proposed. Total 72 series connected IGBTs are forming up to 60 kV pulse output voltage and very simple gate driver circuit is modeled to synchronize Insulated-Gate Bipolar Transistor (IGBT) gate signals without any trouble. Also, it shows good characteristic of arc protection which is obligatory for pulse power utilization. The structure and distinctive features of proposed pulse power supply are described. The developed pulse power supply was tested for various type of utilizations and detailed experimental waveform shows that proposed scheme has many benefit.

Importance:
The major aim of this work is to develop and apply pulse technique to power system protection.Its specific objectives are:

1. To evaluate the concept of pulse techniques in power system protection.
2. To model a suitable pulse technique for the power system protection
3. To evaluate the various benefits in the use of pulse technique in power system protection.
4. To make necessary recommendations based on the findings of the study
5. It will serve as reference material for future research

Power-system protection:
Power-system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the disconnection of faulted parts from the rest of the electrical network (Rim,2004). The objective of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible still in operation. Thus, protection schemes must apply a very pragmatic and pessimistic approach to clearing system faults. The tools that are used to protect the power systems from faults are called protection tools.

Structure of the pulsed power generator:
The structure of the proposed pulsed power generator is shown in Fig. 3.1. It is made of nine stages comprised of eight power cells, a power transformer (TRpower) and two control transformers (TRcont) (Deb, et al.,2003). Each power cell consists of one IGBT (Eupec Inc, BSM300GB120DLC, 1200 V, 300 A), one storage capacitor (Electronic Concepts Inc, UL30BLO120, 120 µF, 1000 V) and one bypass diode (Ixys Inc, DSEI60-12 A, 1200 V, 60 A) with full bridge charging rectifier circuits. The size of the power stage is 50 cm (W)×40 cm (D)×10 cm (H) and total size of 60 kV pulsed power generator with 15 kW charger is 61 cm (W) × 61 cm (D) × 130 cm (H). A high frequency series-resonant current source inverter is employed to charge capacitor of each power cells. The charging energy supplied to the storage cells is controlled by means of inverter operating frequency variation. Each power transformer has eight isolated windings W1, W2 … W8 placed in such a manner to equalize their leakage inductances. In turn each winding is connected to the input rectifier Dr of a particular cell.

The power loop passes through the cores of the power transformers so that each one has one turn primary winding. The number of the secondary turns has been selected to properly match the impedance of the resonant inverter supplying the power loop at full load and to avoid transformer core saturation at any conditions. Eight cells assembled in series make up one stage of the generator. All links within cells and stages have been minimized and configured in order to make available self -compensation of forward and backward current with a goal of reducing the stray inductance of the pulsed power generator. One can see that the generator has flexible structure. Any polarity of the output pulse can be easily obtained by reconnection of inputs and outputs of the stages.

Previous works:
Benmouyal, et al., (1999) described IEEE standard inverse characteristic equations for overcurrent relays. This paper introduces the new standard “IEEE standard inverse relays”. It make available an analytic stand foration of relay operating characteristic curve shape in order to facilitate coordination when using microprocessor. Sutherland (1999) presented Utilization of transformer ground diverse protection relays. Tr relays (device 87G) have been used to protect the windings of resistance grounded transformers. A number of strategies have been utilized with electromechanical relays digital protective relay of protection.Wang, et al (2001) modeled the Multifunctional Numerical Transformer Protection and Control System with Adaptive and Flexible Features. The numerical transformer in this paper is a powerful, multifunctional, adaptive, flexible system whichmake available a lot of possibilities for diverseutilizations in transformer protections and similar utilizations are as such as shunt r generator protections, etc. The advanced features in this new system show a further step in the development of current numerical protection and control systems with improved protection functionality and almost unlimited flexibility for solving most utilization cases. Darwish, et al (2001) have presented the model of A Novel Overcurrent Relay with widespread characteristics based on relay characteristic modelling. The relay algorithms have been implemented using Digital Signal Processor (DSP) on a real time basis and simulated in computer only for overcurrent protection. The modeled relay has the flexibility in selecting the appropriate characteristic for the system requirement. This numerical relay offers only the overcurrent function. Ito, et al (2001) presented the Multifunction High Speed Operating Current Diverse Relay for Transmission Line diverse relay as a transmission line unit protection. High speed operation was achieved by communicating the instantaneous values of the three phase currents, sampled at 600Hz in a 50Hz system. Watanabe, et al (2001) modeled an enhanced decentralised numerical busbar protection relay utilizing high speed sampling. Advancement in numerical and communication technologies have enabled the development of a new busbar protection relay with enhanced performance, high reliability and cost saving capability. This also integrates the circuit breaker failure protection, substation disturbance recording.

Ian Hall, et al (2003) described a New Line Current Diverse relay using GPS Harmonization which is applicable for use over Synchronous Digital Hierarchy (SDH) com numerical line current diverse relay has proved to be one of the most successful types of transmission line protection system. This achieves harmonization of sampling timing amid two or more substations using GPS standard time information. Kojovic, et al (2003) described Efficiency of restricted ground fault protection with diverse relay types. This paper presents a root cause analysis of a ground diverse (restricted earth fault) protection mis-operation including characteristics, and computer simulations performed to determine causes and solutions. High power laboratory tests were conducted to confirm the simulation results in actual conditions and to compare effective restricted earth fault protection model and operation using a relay and a multifunction.Fernando Calero (2004) described the rebirth of Negative Quantities in Protective Relaying with Microprocessor focus is on the uses of negative. The emphasis is on numerical relays since they have facilitated the calculation of symmetrical components. The simplicity in the calculation in current numerical relays has reinforced their use in the theory and methods used by current protective relaying tools.

Cheng Li-jun (2004) presented the Research of the sampling method for CT saturation for Numerical busbar protection. The synchronizing identifying principle and algorithm for CT saturation checking have been successfully used in the numerical busbar protections. Seila Gruhonji presented the Utilization and Settings Inverse Time Relay Characteristics Feeder Overcurrent Protection. This paper deals with what can appear during switching on a long and loaded distribution feeder is considered. The high inrush currents can cause unnecessary operation first or second stage of the feeders setting of overcurrent protections and other available options are checked by using simulation program as so as program for protective device coordination. Kavehnia, et al (2006) dealt with Directional Overcurrent Relays. In this paper, a new method is proposed in order to optimize coordination of directional overcurrent relays based on genetic algorithm. It can determine optimal operation characteristics, current setting multiplier and time setting multiplier of directional overcurrent relay concurrently. The ability to consider both linear and non-characteristics of relays is one of the benefit of the proposed method.

Methodology:-
Pulse testing technology has become available as an integrated package for overhead and underground utilizations. These tools are becoming increasingly popular in distribution system and transferring the huge volume of data into useful information is an vital task to fully take advantage of the tools. The following reviews the basic operation of pulse-reclosers. A. Pulse Testing Operation Pulse testing operation initiates a three-phase pulse and inverse-pulse test of each pole separately to evaluate the line status. This is accomplished by a sub-cycle close-open operation of switchgear contacts. This operation will produce a pulse with a duration of 0.25-0.45 cycles which reduces the

injected energy during fault testing and prevents damage to equipment. Starting from one phase, in case that the pulse test does not find a fault, having high pulse voltage and low current magnitude, the device initiates the close operation in that phase. The process will continue until either all three phases are closed or a fault (high fault current) is detected in one of the phases. In this case, the operation stops and all poles are open at the end of the pulse testing.

Figs. 3.1 and 3.2 show the response to a provisional and a lasting fault with pulse testing technology. Note that SS and LS stand for source-side and load-side measurements, respectively. In case of a lasting fault, both the pulse and the inverse pulse in phase C detect high fault current level and the device will keep all the contacts open. From Fig. 2, the peak fault current of 1400 A can be observed as the result of -20 -10 0 10 20 -20 -10 0 10 20 0 5 10 15 20 25 -2 -1 0 1 2 Fig. 3.2. Response to a lasting fault in phase C. pulse testing. This magnitude may vary amid800-1500A depending on fault position and feeder characteristics

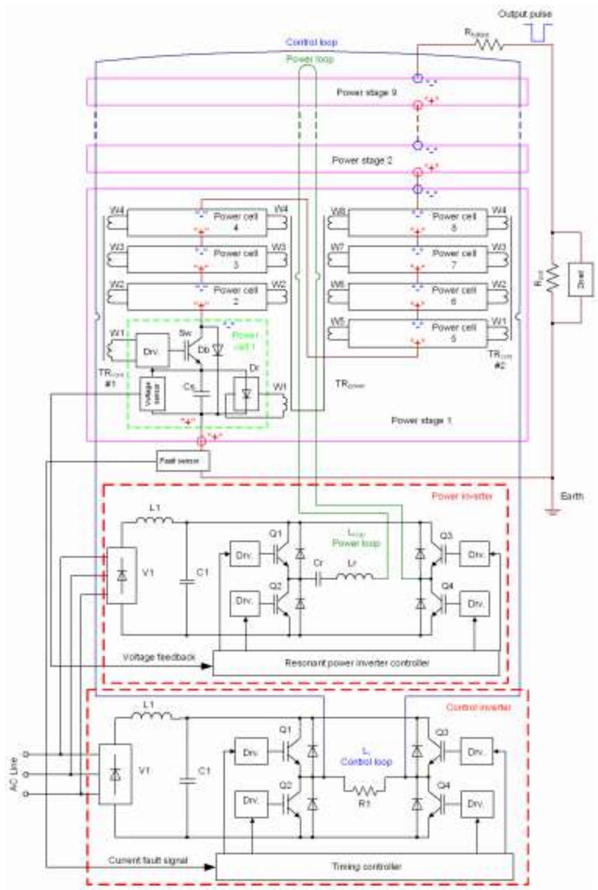

Fig 3.1:- Proposed pulsed power modulator structure (size: 61 × 61 × 130 cm).

The other lowest point is ended with a fault current sensor that monitors a load current with a goal of fault condition determination. In general, the pulsed power generator works like a voltage source keeping constant amplitude of a flat top at diverse load resistance values. To realize this, the voltage of the power cell connected to earth is stabilized with a feedback loop taking a real time signal from the storage capacitor of cell. Mentioned above tension distribution technique assures the voltage difference amidany power cells of the pulsed power generator is less than 5% of the controlled one. Even in a standby mode when no pulses are produced and the energy consumption of the cells is very minute due to their low quiescent current, the five-percent difference is accurately kept. The inverter used for charging of the storage capacitors of the generator is a simple series full bridge resonant inverter (refer to Fig. 3.1). Four switches Q1, Q2 … Q4 driven from the inverter controller via drivers run at the utmost frequency of about 50 kHz under full load and at frequency of order 10. . .20 Hz in the standby mode.

A resonant tank includes a capacitor Cr, inductor Lr and the current loop Lloop having an inductance of 2.6 µH. Power loop is performed with a non-shielded high voltage cable which has a big enough diameter of inner wire. The tank engine frequency is equal to 100 kHz. 2.2. Proposed current loop gate driver circuit The proposed gate driver circuit is shown in Fig. 3.2. In this scheme, both gate control signal and gate power are delivered by attractive way of control loop concurrently. It does not require additional isolated power for feeding gate circuit and any optic cable for signal transfer. And it shows very good characteristics of short circuit protection.

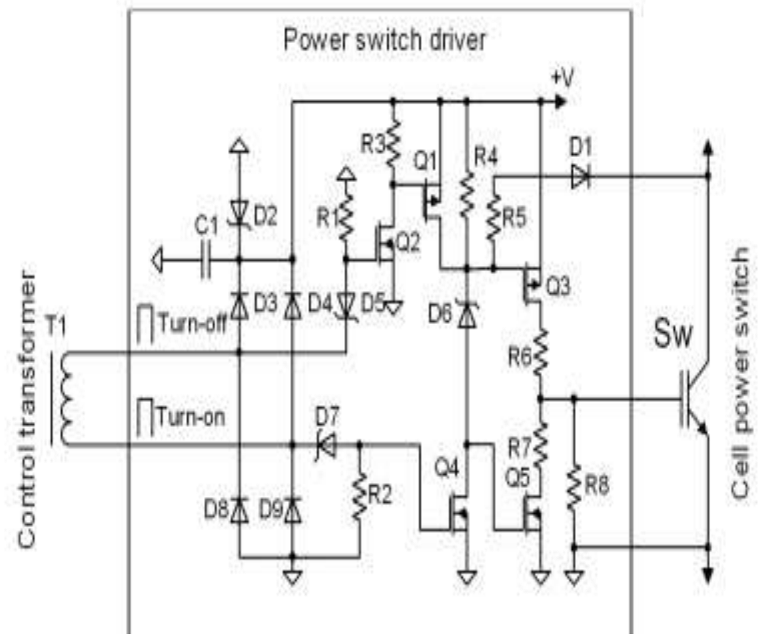

Fig 3.2:- Proposed simple gate driver circuit using high voltage cable with arc protection.

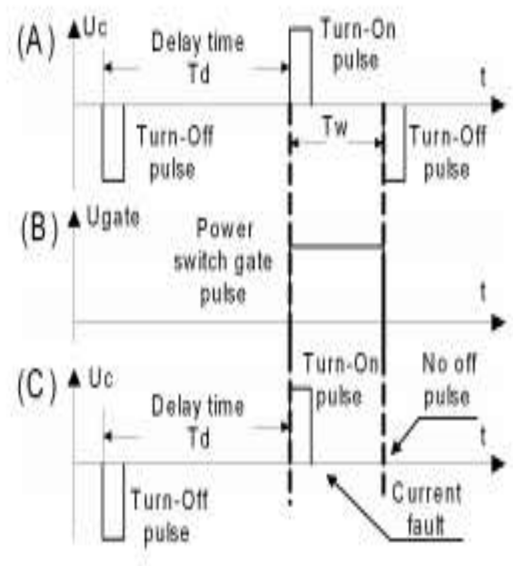

Fig 3.3:- Driver operation principle illustration.

A high voltage cable having proper isolation, which is made as control loop, passes through a toroidal core of control transformer T1 forming primary winding as single turn. The direction and the real level of the current in control loop are very vitalmodel factors in proposed scheme. This is because all the signal and power required to operate all the gate of series IGBTs is delivered by control loop current using single turn high voltage cable, it can minimizethe complexity and system cost largely. Since the power switch is controlled by means of short pulse of diverse direction currents which mark the body of a real control pulse, it can easily adjust the pulse width during operation. It is shown in Fig. 3.3

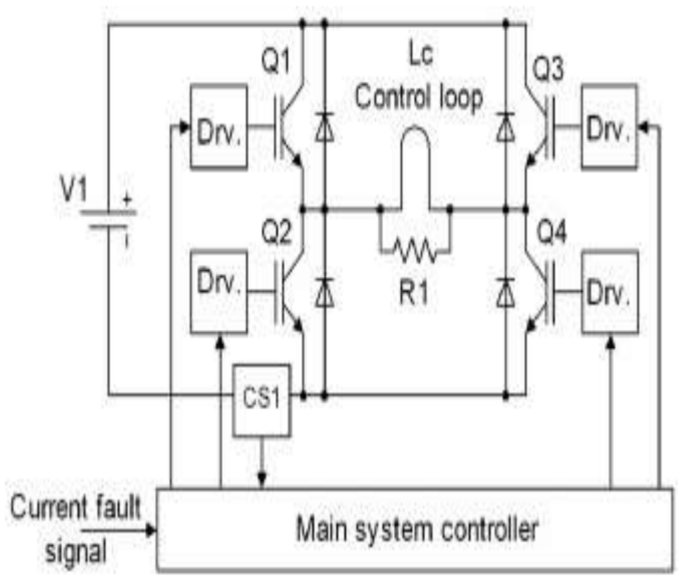

Fig 3.4:-Control inverter simplified scheme.

The current pulses are produced by a full bridge inverter managed by the major system controller in Fig. 3.4. The inverter loaded with the inductance of the control loop but an additional inductor or resistor can be placed in series to it for operation.

Experimental Results:

Figures 4.5-4.7 show pulsed power generator experimental waveforms for various output condition with resistive load conditions using resistor. Figure 4.5 shows voltage

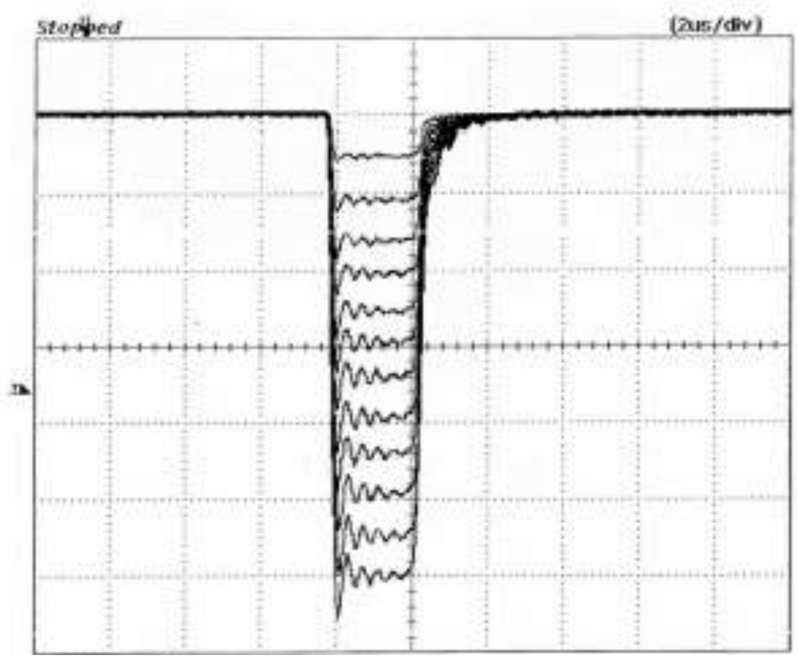

Fig 4.1:-Pulse output voltage variation with resistive load (5 kV ~ 60 kV, 10 kV/div.).

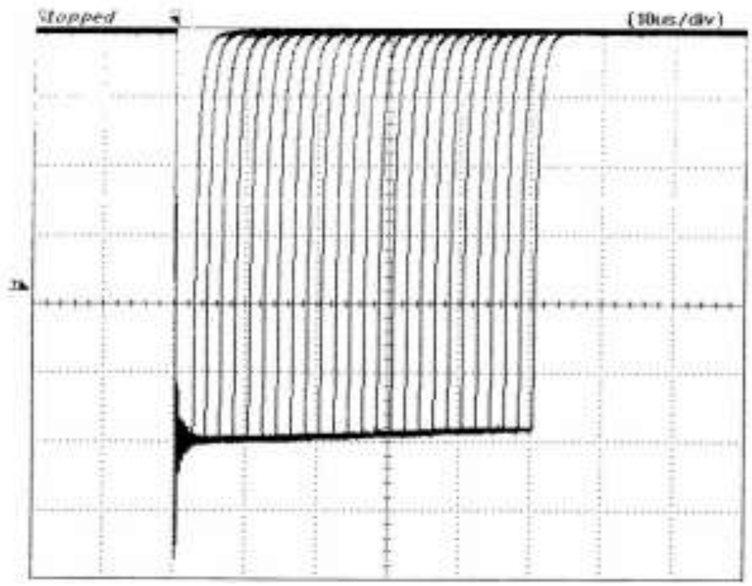

Fig. 4.2:- Pulse width variation waveforms with resistive load (2 µs ~ 50 µs, 10 kV/div.).

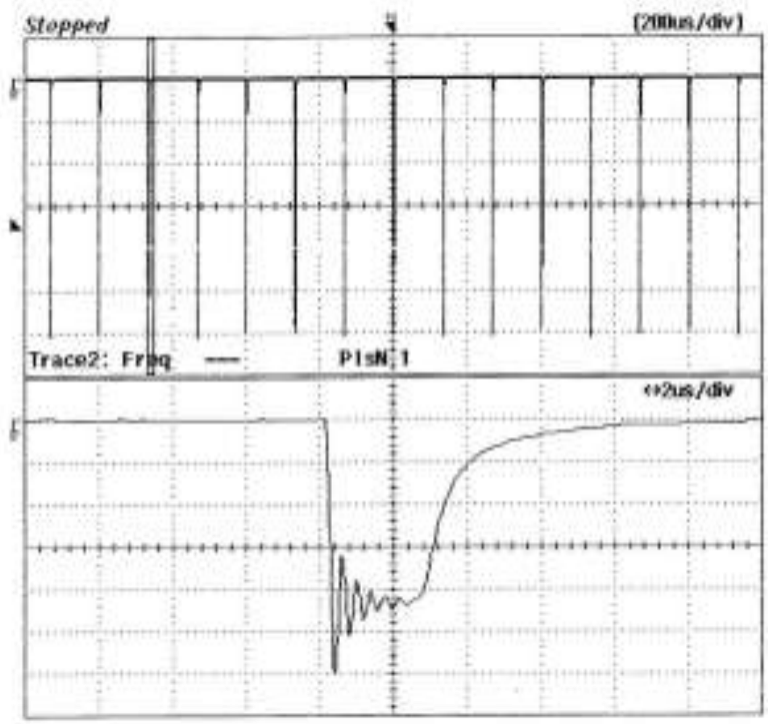

Fig. 4.3:- Utmost pulse recurrence rate waveform with resistive load (3 kHz, 10 kV/div.).

Variable waveform from 5 kV to 60 kV can produce any voltage within 60 kV pulse output. Pulse width variation experimental results are shown in Fig. 4.6. It can produce pulse width from 2µs up to 50µs. Fig. 4.7 shows utmost pulse recurrence rate operation of 3 kHz output pulse. It can be operated with recurrence rate for continuous operation. Fig. 4.8 shows arc protection performance when it was operated with plasma chamber. If arc is produced, it automatically cuts off the gate voltage and IGBT switch is protected from short circuit current.

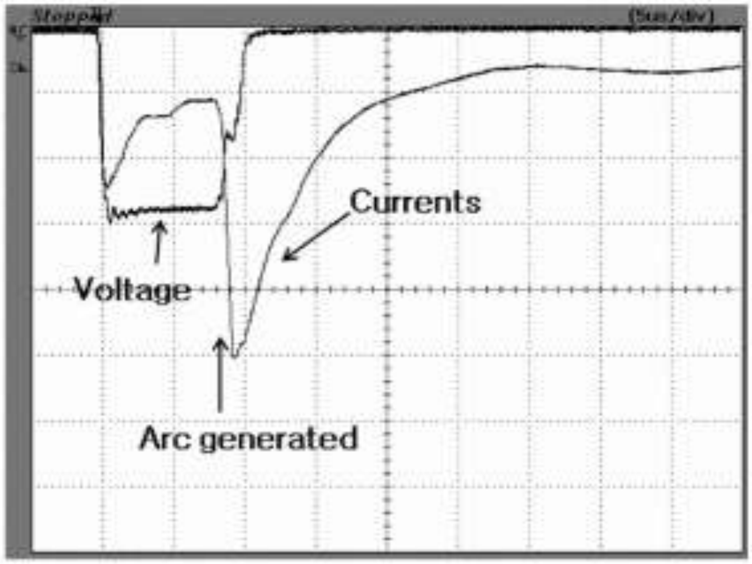

Fig. 4.4:- Arc protection waveforms when it is operated with plasma chamber (100 A/div., 10 kV/div.).

Conclusion:-

In this work, a novel IGBT based pulsed power generator is proposed. The proposed scheme consists of series connected 9 power stages and each power stage has series connected 8 power cells. Each cell produces up to 850V DC to archive utmost 60 kV pulse generation. Proposed pulsed power generator was tested under dummy load and plasma load conditions. It was confirmed that our pulsed power generator shows good control characteristics that is required for pulsed power utilization.

The proposed pulsed power supply based on IGBTs has the following features;

1. Compact size and lower weights were achieved by using series resonant charging inverter and simple construction.
2. High efficiency during overall conditions (> 90%).
3. Dynamic voltage distribution without active control was accomplished and voltage difference amidpower cells were restricted to less than 5%.
4. Novel gate driver circuit which delivers gate signal and power concurrently with safe arc protection was modeled.
5. Self-regulated overload protection without additional circuits.

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