Series Connected Power Semiconductor Devices (IGBTs) Requirement over Crowbar Device

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***Abstract*—Solid state devices (IGBTs) are available in today's life for providing higher and higher voltage rating, but still it not satisfied require high voltage for some application. Direct series connection of solid state devices is needed to meet high voltage requirement. This series connected switch can be controlled by the gate signal when any fault is detected. It also needed that the series connected switch not damage during turn ON and turn OFF time. This paper describes the different requirements for series connection of IGBT and how to control the IGBT.**

***Index Terms*—HV Solid State Switch (IGBT), Series Connection, Crowbar, Protection**

I. INTRODUCTION

High voltage DC power supply is required for RF and microwave tube used in ICRF amplifier. There is requirement that this load is not damage at the event of some fault (over voltage, over current). So crowbar is a device which used to provide the protection against the fault condition by short circuiting the load [1].

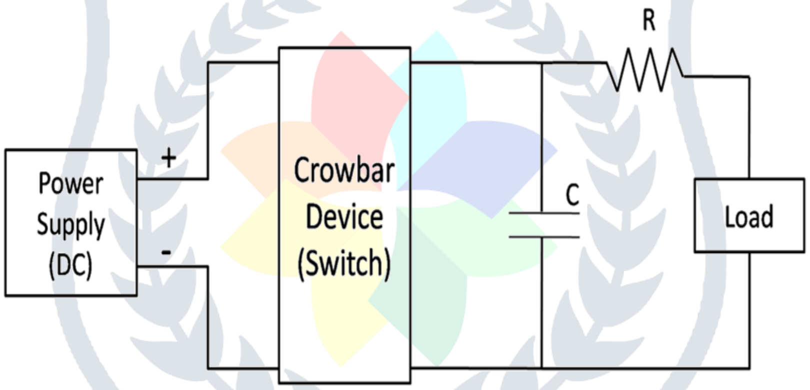

Fig.1 General outline of the Crowbar System

The fault current is detected by the protection system and introduced (fired) the crowbar, thus most of the current passing through it and it prevent the damage to load from any fault condition as shown in Fig.1. In this method the capacitor is used in parallel with this switch (device) and when arc fault occur crowbar close and protect the load. Now energy storage capacitor is starting to discharge. When arc fault clear then this capacitor is charge again and it's required some time to turn ON the voltage. In this process there is also chance of some stress on load, power supply line and crowbar device. So there will be requirement of other technique which provide high voltage to load without provides any stress on load.

II. OBJECTIVE

The main objective is to provide high DC voltage to RF tube by connecting Semiconductor devices (IGBT) in series and turn OFF the voltage in case of fault condition with in few µs by controlling the gate signal of IGBT (Insulated Gate Bipolar Transistor). A series switch would open the fault current to protect the load without need of a short circuit.

III. PROBLEM IN SERIES CONNECTION

In series connection of IGBT there is requirement of protection circuit which turn OFF (open) the IGBT switch in fault condition. The main problem with a series connection of semi-conductor devices (IGBT) is the unequal distribution of voltage between them in both steady and transient state [2]. This unequal voltage sharing is mainly due to the spread of device parameters, external circuit parameters and some delay of signals. This unbalance voltage can be greater than the individual unit voltage rating and the failure of the device causes the final failure of a series of connecting devices.

IV. DIFFERENT METHODS (TECHNIQUES)

There are several methods for minimizing the voltage difference across individual devices in series connection of IGBTs. The voltage difference is mainly due to the semiconductor switch (device) parameter spread and gate delay [2]. So careful selection of semiconductor device which have low parameter spread and synchronized gate signal to minimize voltage unbalance. There is also Voltage balancing (snubber) circuits, active gate control circuits and voltage clamping circuits are used to minimize voltage unbalance.

A. Active gate control Technique

In the active gate control techniques, IGBT gate terminal is controlled by a control circuit to the voltage unbalance and this will increase or decrease the rate of change of the collector - emitter voltage (V_{CE}). The main advantage of this method is to avoid using passive components, but balancing voltage can not always be guaranteed.

The method given by A. Raciti et al, one semiconductor device is retained as the reference (master) devices and other semiconductor devices operate as a slave, that are controlled by the master device applies [3]. This method does not significantly increase the energy losses, but the series connection of more than two devices make the voltage sensor circuit complex and expensive. The method given by P.R. Palmer et al, all devices is connected in series are controlled by common reference. The reference value set by user [3]. Control is not as complex as in A. Raciti mehod and losing power device depends on the growth rate of the reference voltage. In S. Hong et al and H. Kon et al, method collector - emitter (V_{CE}) voltage controlled by applying a positive charge to gate terminal if it is higher than the reference value , but the problem is that the high power loss during transient states of devices to turn OFF [4-5]. J.W. Baek et al, show a simple circuit for balancing the voltage with resistors, capacitors and diodes [6]. Therefore, this method does not increase the switching loss, but control circuit is complex requires a high sensitivity and high speed devices.

B. Voltage Clamping Technique

In voltage clamping techniques the collector emitter voltage is clamp at reference voltage level. This method is easy to implement in relation to the above method is not required any complex digital circuits. The IGBT collector – emitter voltage (V_{CE}) is clamped by zener diode over voltage protection circuit. The main disadvantage of this method is that it increases the loss of energy in the first device to be clamped because it experience both high voltage and high current until other devices turn OFF, so there is reduced efficiency of the application.

V. PROPOSED TECHNIQUE (SOLUTION) FOR SERIES CONNECTION

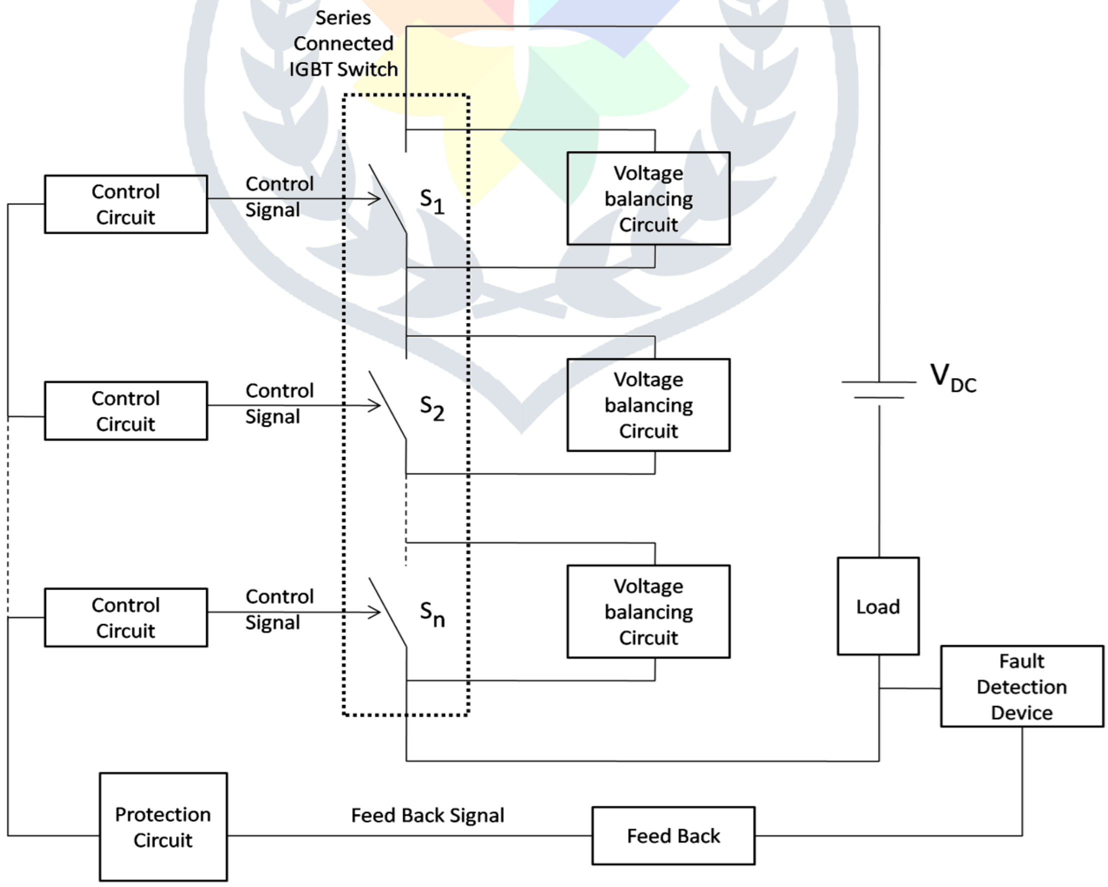

Fig.2 Series Connection of Semiconductor switches

Semiconductor devices (IGBT switches) are connected in series between high voltage DC power supply and load as shown in Fig.1. Here, the basics blocks used in this proposed technique are fault detection device, feed back, control circuit and voltage balancing circuit.

A. Fault Detection Device

There are several devices available for sensing the current i.e, Pulse CT (Current Transducer). This pulse CT is able to measure the over current and give it to protection circuit.

B. Protection Circuit

In this circuit comparator compared the detected current through pulse CT with the reference value and check whether the current value exceed the safe value or not. If current value less than or equal to the safe value then protection circuit generates Logic High pulse otherwise it generates Logic Low pulse.

There is also requirement that the control circuit is isolated from power supply. So, fiber optic cable is used between transmitter card and receiver card as shown in Fig.3. Transmitter gets the electrical signal from feed back and it converted it in to optical signal and applied to receiver through fiber cable. Receiver convents this signal back in to electric signal.

The fiber optic isolation is necessary to prevent vulnerable low system power control from damage due to such high insertion DC voltage. Fiber optic cable has advantage that it can be scalable for few killo volt to hundred killo volt. This isolation scheme can be used for future scaling purpose.

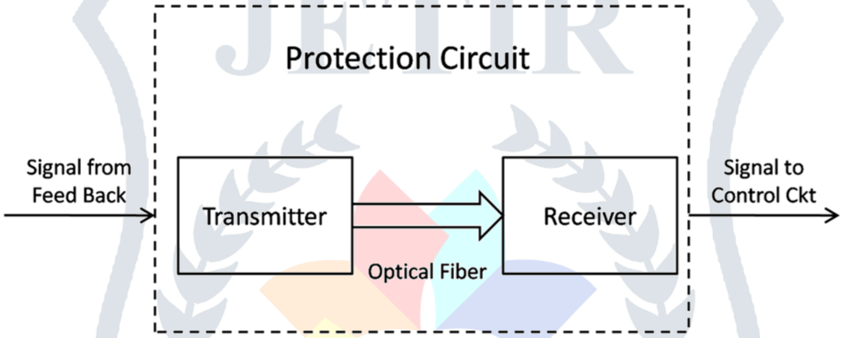

Fig.3 Protection Circuit

C. Control Circuit

This circuit received signal from the protection circuit either Logic High pulse or Logic Low pulse as shown in Fig.4. When Logic High pulse given to the control circuit it generates the positive voltage to turn ON the series connected switches and when Logic Low pulse given then it generates the negative voltage to turn OFF the series connected switches.

Each IGBT (switch) is fluctuating DC voltage different, so the individual control circuits must be isolated from each other and from the power lines at the input.

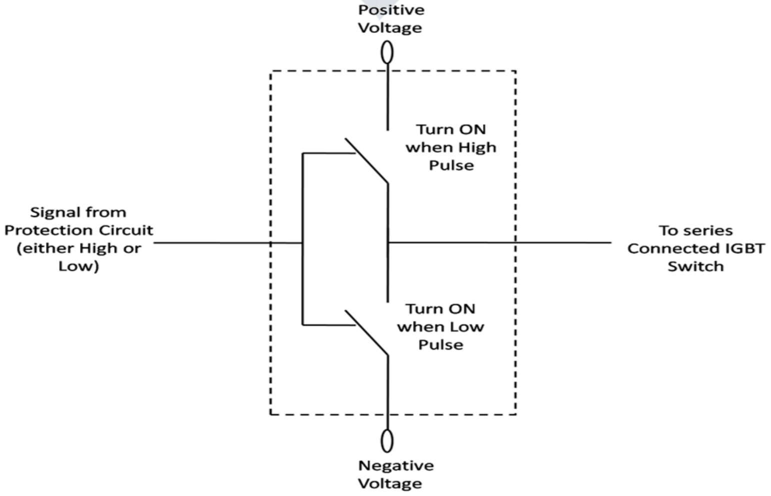

Fig.4 Control circuit

D. Voltage Balancing Circuit

It is necessary to control the unbalance voltage across the IGBT (switch) in static and dynamic conditions [2]. So there is requirement of voltage balancing circuit across each switch to prevent the damage of switch.

In static voltage balancing circuit suitable value of resistor is connected across switch and in dynamic voltage balancing circuit suitable value of resistor and capacitor is connected across switch. The value of static resistor, dynamic resistor, dynamic capacitor and also its power and voltage rating its depends on the characteristics of IGBT (switch), voltage across switch (IGBT), cut off current, minimum turn ON time of IGBT etc.

VI. WORKING FLOWCHART

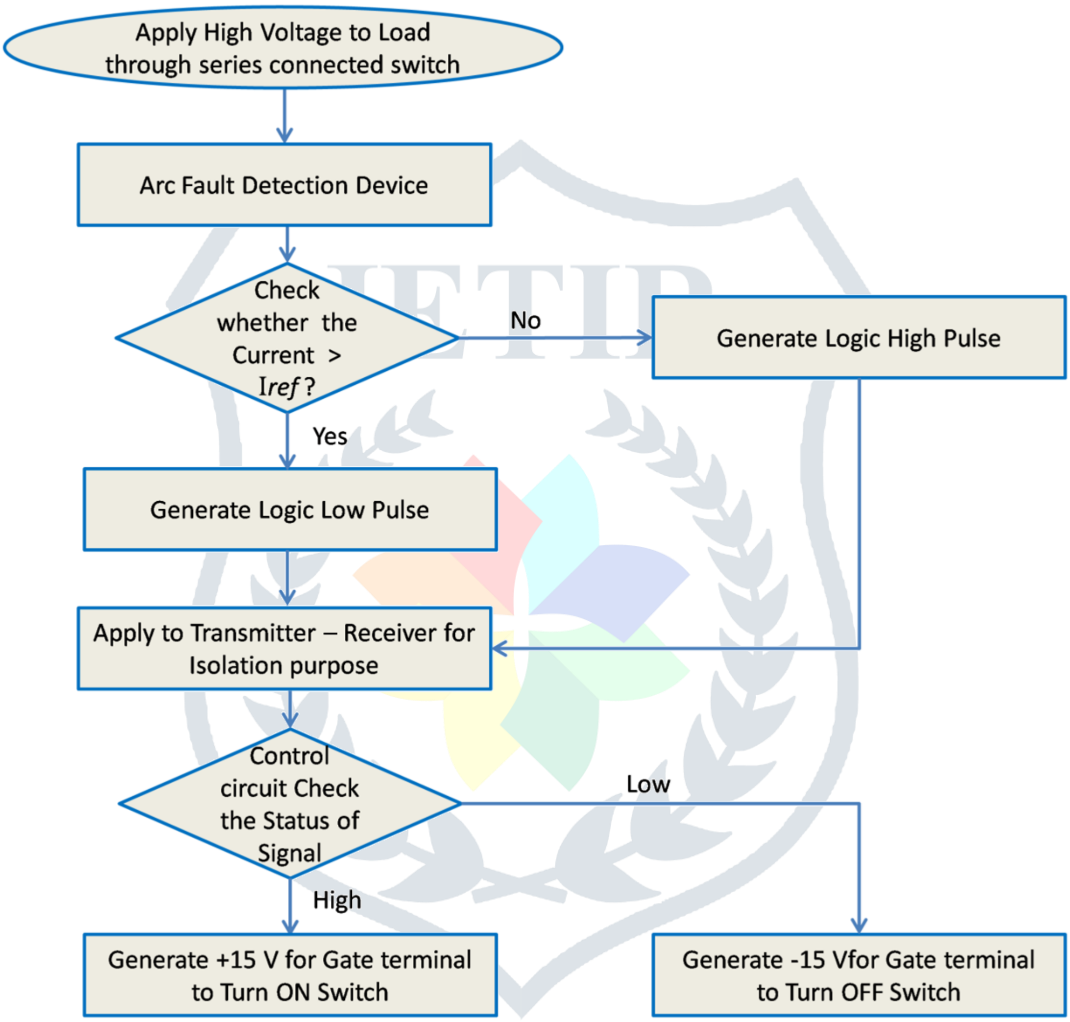

Fig.5 Working Flow-Chart

As shown in Fig.5 high voltage DC power supply is applied to load through series connected IGBT switch. Arc fault detection device is used to sense the over current condition. Then comparator circuit check the current is greater than the reference current (*Iref*). If yes then protection circuit generates logic low pulse other wise it generates the logic high pulse. This logic pulse converted into the optical signal and transmitted by transmitter card through fiber optic cable. Then the optical signal is received by the receiver card and converts back into the electrical (logical) signal. As shown in Fig.3 transmitter and receiver card are used for isolation purpose. Now receiver signal is applied to the control circuit which generates the control signal for IGBT switch to turn ON or OFF. Control circuit provide +15 volt to turn ON the IGBT switch when it gets high logic signal from receiver otherwise it creates -15 volt to completely turn OFF the IGBT switch.

VII. CONCLUSION

By using series connection of solid state device, it is possible to get high voltage for load. There also features of turn OFF the high voltage at the event of arc fault and immediately turn ON the high voltage when fault clear. Voltage balancing circuit across each IGBT and isolation of low power control circuit from high power supply is necessary and most important part while designing the series connection of IGBT.

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