Design Aspects of 4kV, 1A Series Connected IGBT Switch for Triode Based ICRH Amplifier Protection

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Abstract

High power RF and microwave tubes used in RF oscillator and amplifier circuits need few hundred kilo-watts to few mega-watt high voltage (~30kV) DC power supplies. They have features like low ripple, good regulation, fast protection along with facility for remote operation and control. Fast protections were developed in house to protect the tubes,that act within 10µsec and also limit the fault energy within 10 Joules. This is achieved by short circuiting the 400kW to 3MW rated DC power supplies with a ignitron based crowbar system, which causes enormous stress on the power supply as well as power lines.It is envisaged that a series IGBT switch rated at 4kV, 1A would be suitable for 2kW stage ICRH amplifier, and would be scaled in future for higher voltages (e.g. 15 and 30kV) of switch development.This paper presents advantages and problems of IGBT series connections, preliminary design of static and dynamic voltage equalizing circuits, transmitter, receiver with driver circuits with optical input signal and simulation results.

1. Introduction

High Power ICRH System of 1.5MW has been developed for ICRH experiments in tokamak like ADITYA, SST-1.

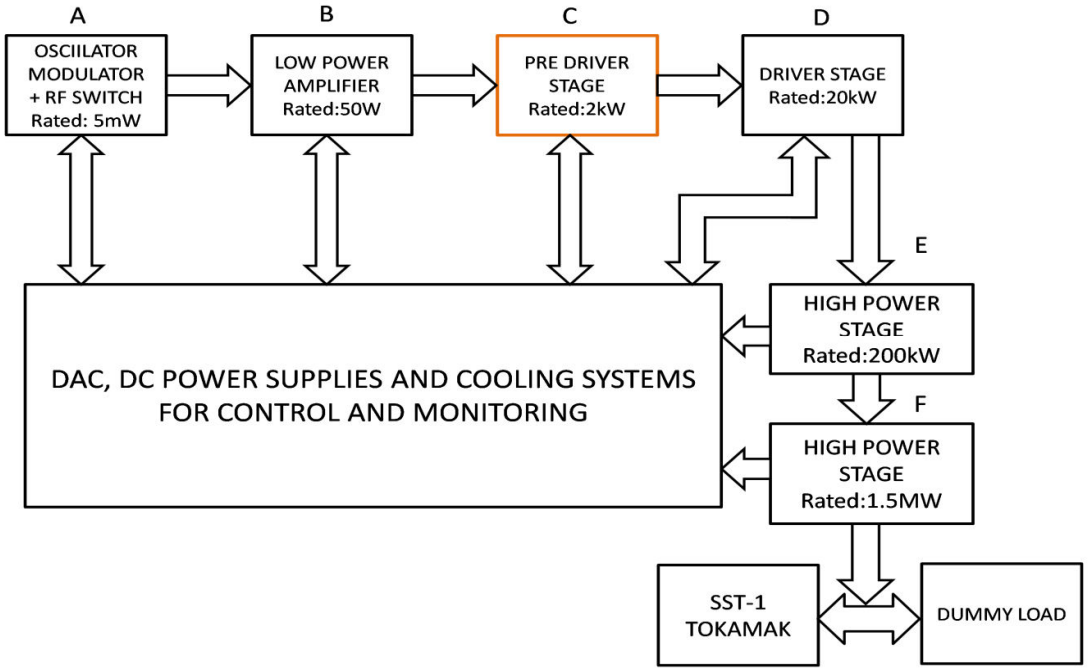


Fig. 1Schematic of High Power ICRH System

The high power chain of 1.5MW RF amplifier comprises of l pre-pre driver 2kW, pre-driver 20kW, driver stage 200kW amplifiers. They are fed with different DC power supplies rated 4kV, 1Amp; 7.5kV, 6Amp & 14kV, 35Ampas shown in Fig.1.

Pulsed and continuous high power microwave tubes need to be protected against arc faults within the tube. If the energy dumped in such arc fault is more than the critical crater energy of the tube, irreparable damage can occur to the tube. When the conventional power supply feeds the high power microwave tubes, a reliable protection is needed. To ensure complete protection and proper safety of the tube, a crowbar system which is tested separately to limit the energy is installed at the RF lab of IPR. A current monitoring and interlock system has been also set up which (at the time of fault) trips the AC input to the power supply by opening the Vacuum Contactor.

2. Problem

High power amplifiersare provided with arc fault protection circuit based on crowbar. The crowbar shorts the power supply whenever the arc fault has occurred, so that most of the current passes through it, limiting the current through the load (high power microwave tubes) [1]. Because of very high power ratings, (few hundred kilowatt to 3MW) the short circuit on the dc side creates huge stress on the power supply, crowbar device and power lines.

3. Requirement

With the development of solid state devices such as IGBTs (Insulated Gate Bipolar Transistor) short circuits of conventional supplies can be avoided by using a suitable solid-state series switch that can open the fault [2-3]. If a series switch is used in place of crowbar the intentional high power short circuits and associated stresses on the power supply as well as power lines can be avoided.

The main requirement of this project is to provide protection against the arc faults like over voltage and over current condition. When arc fault is detected then IGBT becomes turn OFF within few μS. It must me assured that IGBTs are not damaged during turn ON and OFFoperation. To meet the high voltage rating several such IGBT must be operated in series connection. Series operation of IGBTs have several isolation and control requirement as shown in Fig.2.

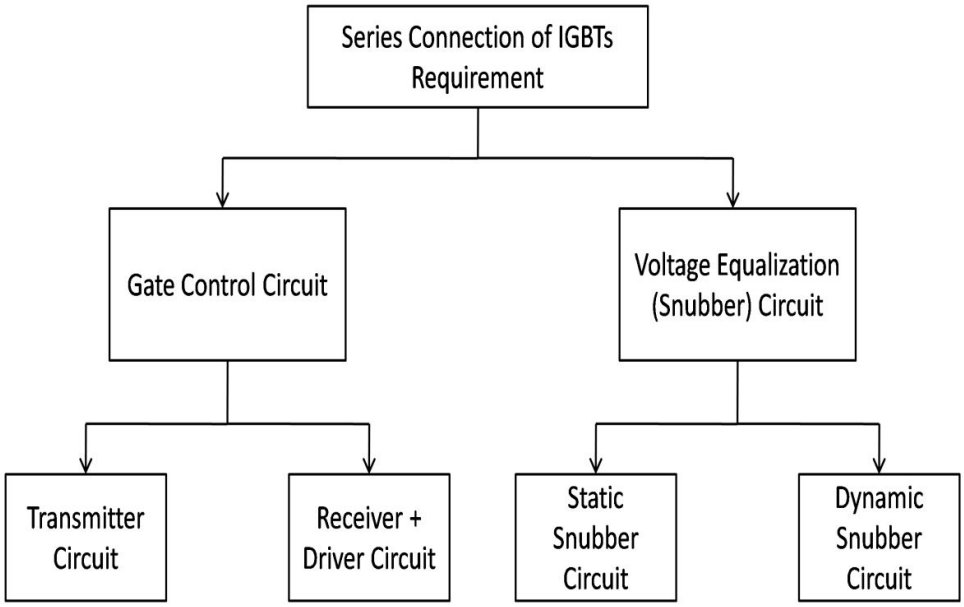


Fig. 2Series Connection Requirement

Special voltage balancing steps are needed to avoid device failures. Resistors are connected across each IGBT for static voltage balancing circuit. Dynamic voltage balancing achieved by snubber circuits comprising resistor, capacitor and diode connected across each IGBT. It provides the protection against the high dV/dt and improves the performance. Snubber circuit takes care of differences in switching instants among the devices [5].

Advantages of Snubber Circuit

- To reduce total losses due to switching.
- To reduce or eliminate voltage or current spikes.
- Limits dI/dt or dV/dt.
- Transfer power dissipation from the switch to a resistor or a useful load.

4. Schematic of System

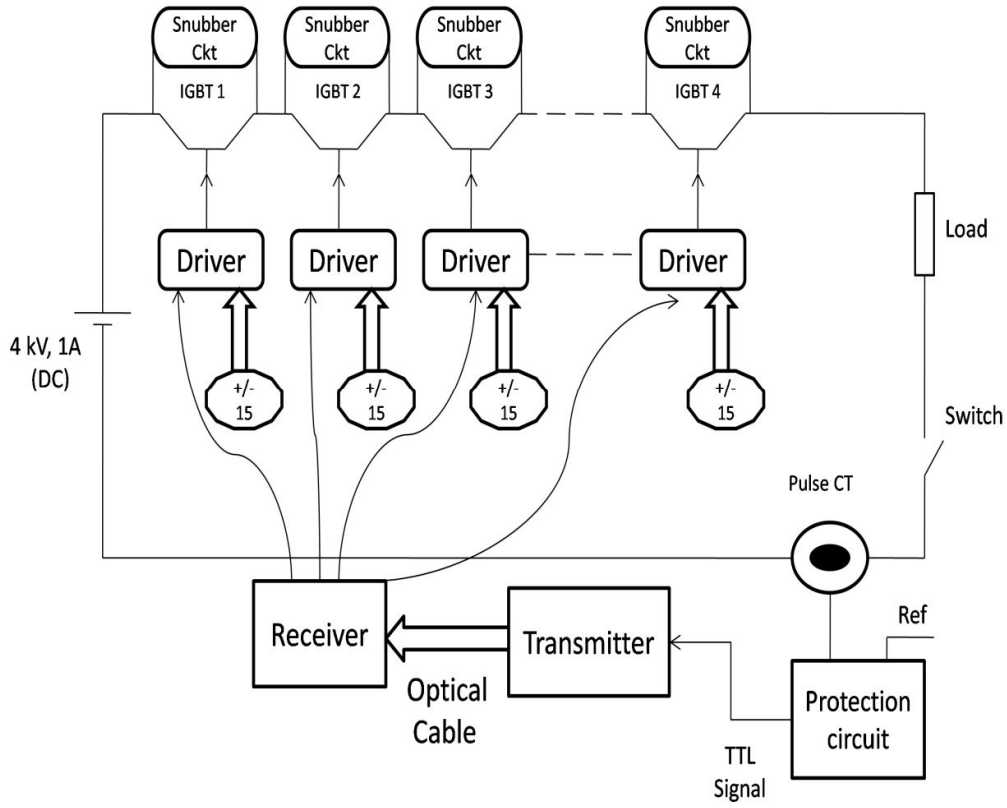


Fig.3Schematic of Proposed System

The schematic of proposed system is shown in Fig.3. When arc fault occurs, a pulse transformer (CT) is used for sensing over current and protection circuit generates the TTLsignal. Transmitter gets TTL output from this logic gate and converted it in to optic signal. Opticalsignal is received by receiver circuit which is converted back to TTL signal and given to the driver circuit.Driver circuit used to control the gate voltage of different IGBTsto open the load circuit in the event of arc fault. For isolation purpose each receiver + driver circuit has separate power supply. Snubber (static and dynamic) circuit is placed across each IGBT for voltage balancing purpose.

5. Simulation

Driver circuit need to provide +15 V to gate terminal of IGBT when it receives the logic high signal from receiver circuitto turn ON. Similarly -15 V when it receives the logic low signalto completely turn OFF the IGBT.Multisim software is used for the simulation of driver circuit shown in Fig.4.

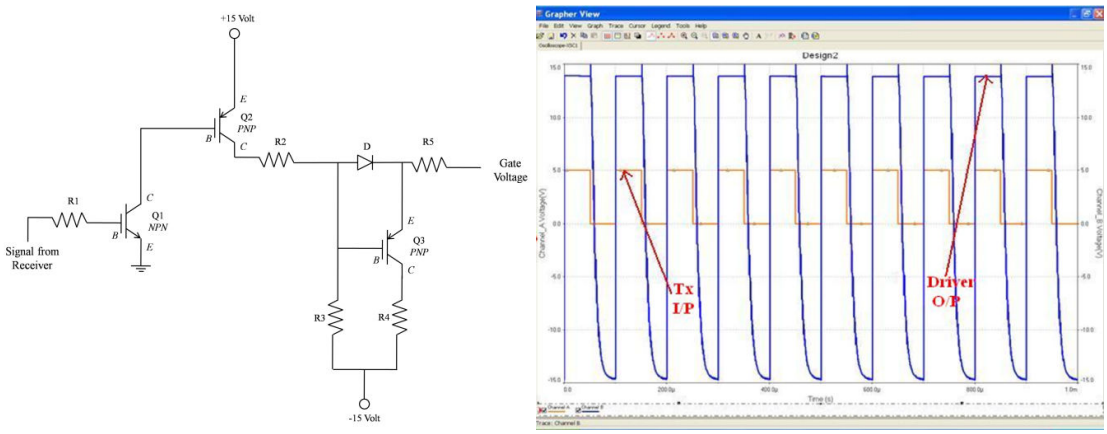


Fig.4Driver Circuit Simulation

One NPNand two PNPtransistors are used in this circuit. When +5 V is applied as input to the driver circuit then transistor Q1 and Q2 conducts. The current flow from emitter to collector provides +15 V at anode terminal of diode. In this condition diode is in forward biased, but transistor Q3 is in off condition. So +15 V would be available as the output of circuit which switches ON the IGBT.

Similarly, when logic Low (0 Volt) is applied at the input the transistors Q1 and Q2 are in off state and transistor Q3 conducts and the output would be -15 V that would switch OFF the IGBT.

6. Test Results

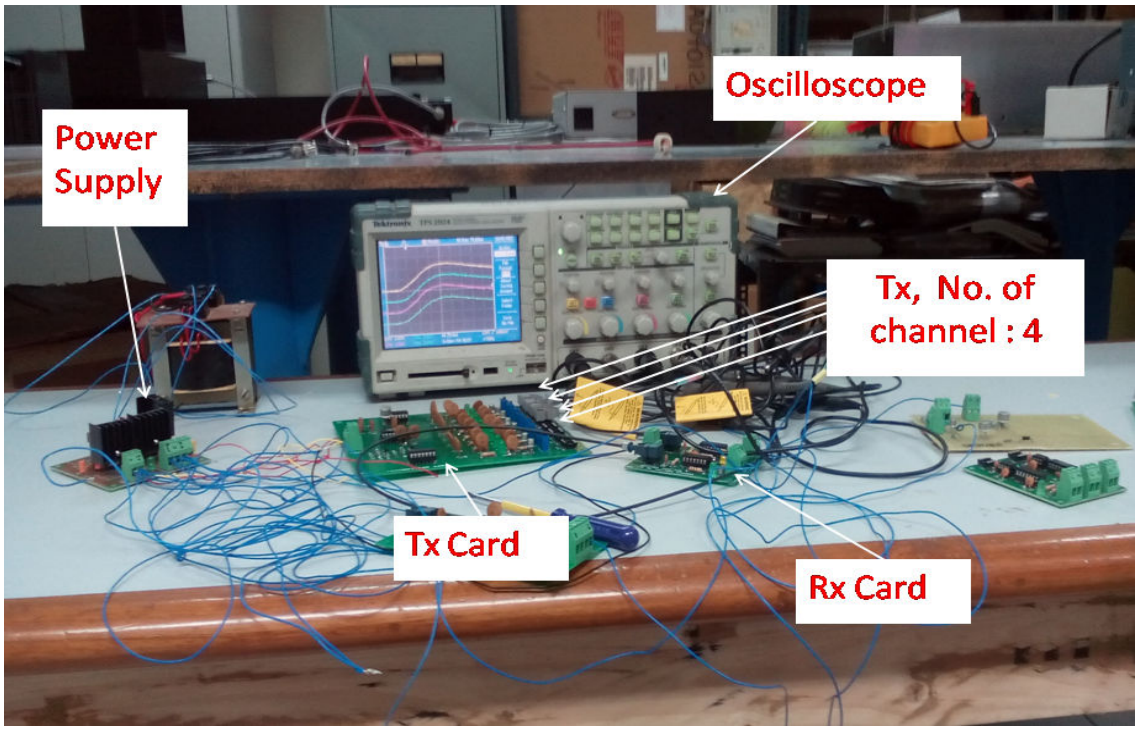
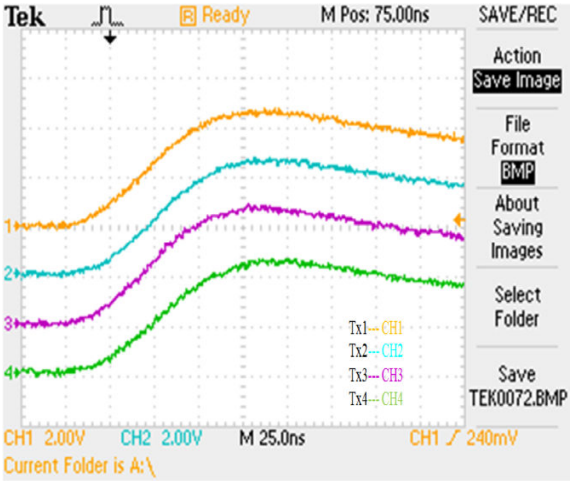


Fig.5 Test Setup

The test setup for transmitter and receiver circuit is shown in Fig.5. Here, output of four channel transmitter circuit is tested by applying the +5 volt at the input.



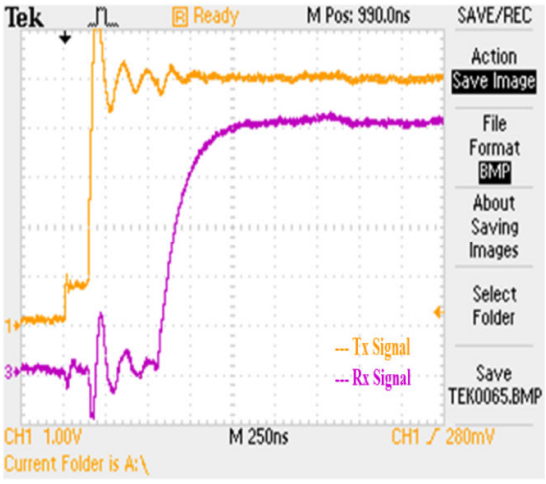


Fig.6Synchronization of 4-Tx's ChannelsFig.7Delay between Transmitter and Receiver

Synchronization of four channel of transmitter is shown in Fig.6.The outputs of four channels are in good synchronization as shown in 25ns/div time scale. Delay between transmitter and receiver shown in Fig.7 in 250ns/div time scale.

7. Conclusion

Solid-state switch (series IGBTs) opens within few µsec in the event of any fault like over current and arc fault detection.Optical Transmitter and Receiver circuit connected by the optical fiber cable provides necessary isolation to low voltage protection and control circuits.

8. Future Scope

It is neededto measure the delay between four channel transmitter and receiver as welldelay between the transmitter and driver.Static and dynamic voltage equalization circuits have been designed for voltage balancing purpose.

References

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