

FAST DISCONNECT SWITCH FOR ALS STORAGE RING RF SYSTEM HIGH VOLTAGE POWER SUPPLY*

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Abstract

ALS is the 1.9GeV third generation synchrotron light source which has been operating since 1993 at Berkeley National Lab. Our team is now working on the design of a new RF power source (replacement of the existing 320kW klystron with 4 IOT's). In the new design the existing conventional crow-bar klystron protection system will be replaced with a fast disconnect switch. The switch will be constructed out of 16 high-voltage IGBT's connected in series equipped with static and dynamic balancing system. The main advantage of using this new technology is faster action and virtually no stress for the components of the high voltage power supply. This paper will describe the hardware design process and the test results of the prototype switch unit.

INTRODUCTION

All high power RF amplifiers using electron tubes have to be equipped with fast acting systems protecting them from arc damage. The classical approach uses mercury containing ignitron connected in parallel with the protecting device, which in case of emergency shorts the high voltage power supply. An alternative way to achieve the same goal is to use the switch connected in series with the protected device. Generally, series switches have substantial advantages over the crowbars:

- Faster action (typically <2us versus 5-10us for crowbars)
- No stress on HV power supply elements (transformer, choke and rectifier)
- HV can be turn back on within microsecond after disconnect action which might save the circulating beam in the ring.
- No series current limited resistors required.
- No danger of mercury contamination.
- Simpler control circuitry.

The series disconnect switch could be built using vacuum tube or a stack of solid state devices (IGBTs or MOSFETs). Solid state devices are less expensive than vacuum tubes; they have a lower forward voltage drop and longer lifetimes. There are a few companies like Diversified Electronic Inc, North Star Research Corp and Polarity Inc. who are using IGBT technology to build high voltage, high current disconnect switches/modulators.

We decided to design and build our own low cost disconnect switch. The main reason for this decision was lower cost and fast on-site service capability by existing staff, which is important, since ALS has to deliver light to hundreds of users on the 24/7 basis.

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DEVICE CHOICE

The new ALS RF system will be based on four 80kW IOT (Inductive Output Tube) amplifiers with the total DC power requirements up to 500kW (14A at 36kV). In order to decrease the overall cost of the switch and decrease the power dissipation in switch itself we were looking for the IGBT with the high voltage handling capabilities and the small dissipation factor (forward voltage drop to opening voltage ratio). The new IXYS IXEL40N400 4kV, 20A, IGBT with the dissipation factor<0.1% and the price below 100\$, was by far the best choice. The ALS disconnect switch will contain 16 4kV IGBT modules connected in series with the total voltage handling capabilities up to 64kV. This large excess voltage capability will create a large redundancy factor and increase its operational reliability since the switch could continue to operate even with several faulty IGBT modules.

SERIES CONNECTION OF THE IGBT'S

The main problem associated with series connection of the solid-state devices is the necessity to ensure the uniform distribution of the voltages across each unit in static and dynamic conditions.

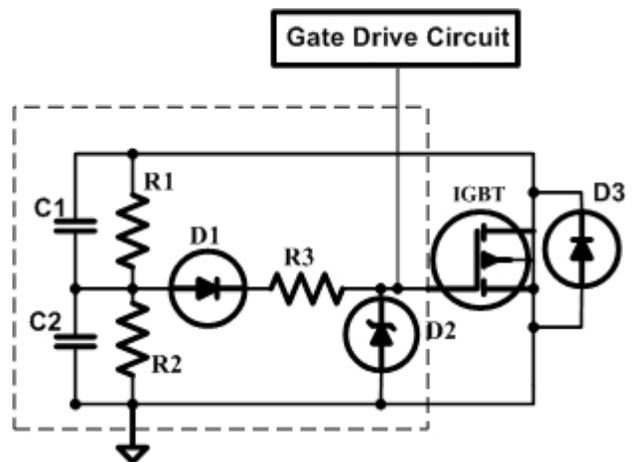


Figure 1: Gate drive circuit.

The static voltage balancing can be easily achieved by connecting in parallel with each device resistor with the resistance value, which will create the current flow significantly higher than the leakage current of the worst solid state device in the chain. The more difficult problems to deal with when connecting the chain of solid state devices in series are dynamic unbalance conditions which could be created due to the unequal switching characteristics of the solid state device or unequal delay in the drive chains. The simplest dynamic voltage balancing

circuit we found and tested is described in [1]. The circuit (see Fig.1) which consists of two capacitors, three resistors, and two diodes is attached to each IGBT device and provides a very effective active gate control effect. In addition, the effect of the added circuit on the switching time of the solid state device is minimal what translates into only minor increase of the switching losses.

IGBT DRIVE CIRCUIT

Motorola MC33153 single gate driver has been chosen to drive each IXYS IXEL40N400 IGBT. This device can source 1A and sink 2A and is equipped with the choice of desaturation or overcurrent protection circuits. The desaturation circuit which has been activated in our set-up monitors IGBT collector voltage and turns off the device if this voltage rises above certain limit. This circuit uses an external high voltage diode and comparator built into the MC33153 driver itself. When the IGBT is “ON” saturated diode will pull down the voltage on the fault desaturation input. When the IGBT pulls out of saturation or is “OFF”, the current source will pull up the input and trip the desaturation comparator. The output of the comparator will feed two latches. One will turn-off the IGBT for the remainder of the cycle when the fault is detected. The second latch will change the status at the “Fault Output” pin to an error stage. The error signal will be then sent via the fiber optic line to the disconnect switch control circuit. Each IGBT driver board requires two DC power supplies (+20 and +5V) with a total power requirements of about 1W. Each source has to be insulated from the ground potential at the full switch voltage capability. The high voltage insulated driver AC power system is shown in Figure 2. The 50kHz sine-wave signal is generated by an ILC8038 waveform generator and then amplified by low cost 100W audio amplifier. The output transformer has single turn primary winding feeding 16 ferrite toroids (Fair-Rite 75material) with 9 secondary turns.

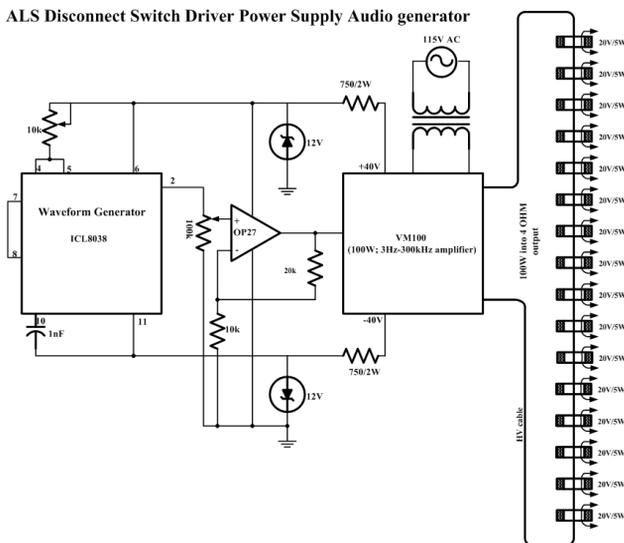


Figure 2: High voltage insulated driver AC power system.

DISCONNECT SWITCH MODULE

The single 4kV 20A disconnect switch module is shown in Figure 3. The IGBT chip will be mounted at the heat sink made out of extruded aluminum and the base surface area 50 in².

The switch will be cooled by forced air flowing along the heat sinks fins. Communication between each of the sixteen switch modules and the control unit will be done by fast fiber-optic (one receiver and one transmitter per module).

ALS DISCONNECT SWITCH IGBT 4kV/20A MODULE

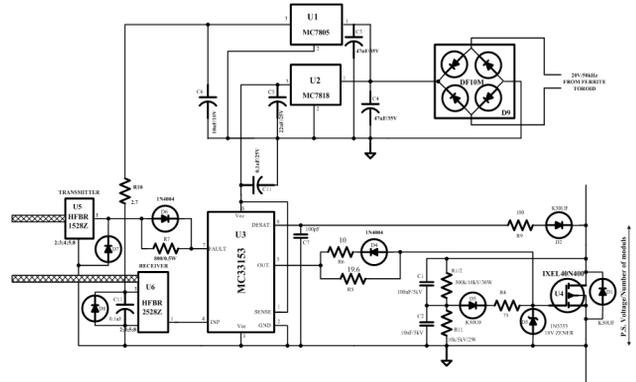


Figure 3: Single 4kV 20A disconnect switch module.

PROOF OF PRINCIPLE CIRCUIT

We have built and fully tested into resistive load the stack of two modules presented in Figure 3. During the maximum instantaneous current handling capabilities test both switches were tripping off by desaturation protection circuits at 130-140A. Figure 4 shows oscilloscope picture of the voltage on the first and second switch module during turn-on/turn-off cycle (V=7kV;I=35A). The voltage balance between the two IGBT’s was unchanged for a time difference in the application of the control voltages to the switch drivers by as much as 100ns. Both switches survived 24h endurance test during which they were cycled 20000times (V=7kV; I=35A).delivered as a turn-key EPICS controlled high power amplifier/transmitter.

CONCLUSION

The ALS “proof-of-principle” fast disconnect switch has been design, built and fully tested with positive results. The mechanical design of the final unit is under way. The switch will be installed as a part of the second stage of the ALS storage ring upgrade project during 2010 ALS scheduled shut-down break.

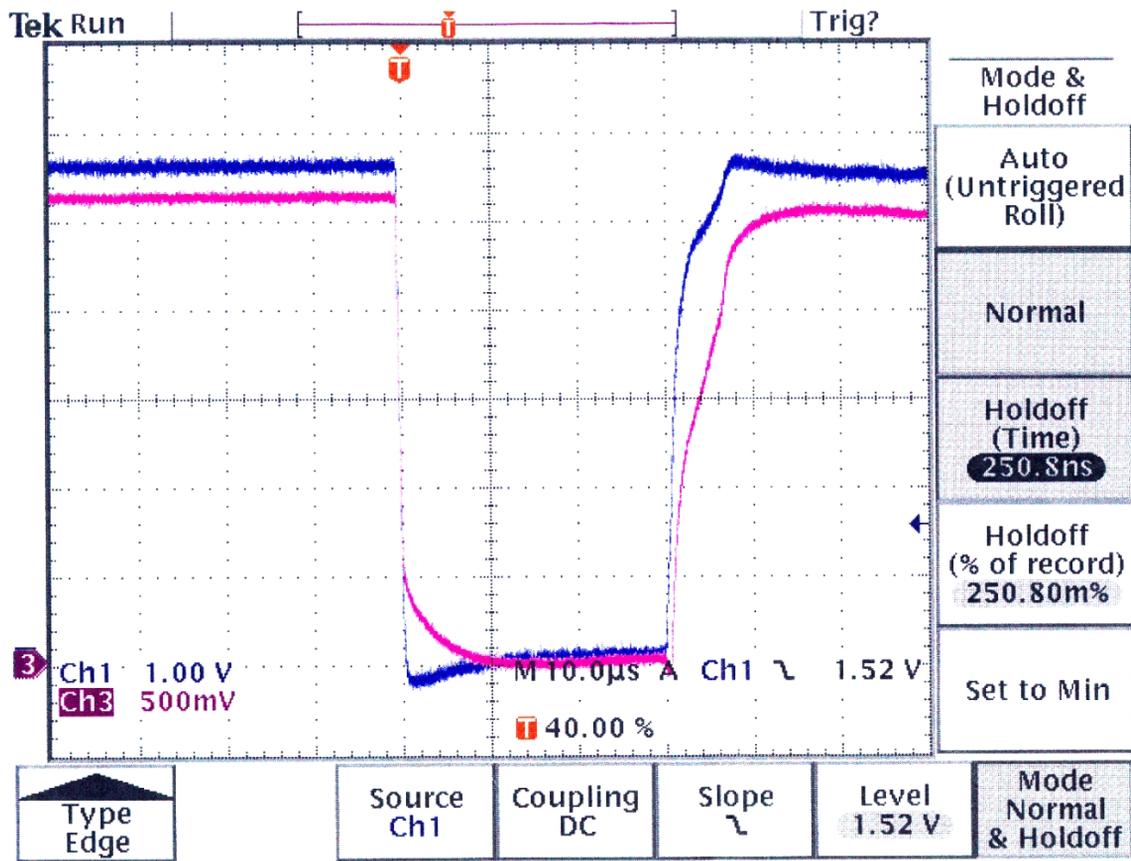


Figure 4: Oscilloscope output of the voltage on the first and second switch module during turn-on/turn-off cycle (V=7kV; I=35A).

REFERENCES

[1] Ju Won Baek, Dong-Wook Yoo, Heung-Geun Kim, "High-Voltage Switch Using Series-Connected IGBT's with Simple Auxiliary Circuit," IEEE

Transactions of Industry Applications, Vol 37, No 6 November/December 2001.

[2] MOTOROLA "MC33153 Single IGBT Gate Driver Data Sheet."