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# DIII–D ICRF High Voltage Power Supply Regulator Upgrade*

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**Abstract — For reliable operation and component protection, of the 2 MW 30–120 MHz ICRF Amplifier System on DIII–D, it is desirable for the amplifier to respond to high VSWR conditions as rapidly as possible. This requires a rapid change in power which also means a rapid change in the high voltage power supply current demands. An analysis of the power supply's regulator dynamics was needed to verify its expected operation during such conditions. Based on this information it was found that a new regulator with a larger dynamic range and some anticipation capability would be required.**

**This paper will discuss the system requirements, the as-delivered regulator performance, and the improved performance after installation of the new regulator system. It will also be shown how this improvement has made the amplifier perform at higher power levels more reliably.**

## INTRODUCTION

After early operation it was determined that the response time of the high voltage power supply regulator needed to be improved for optimal operation of the amplifier system at full rated power [1]. Since building a new power supply would have been cost prohibitive, it was decided to take a closer look at the existing hardware and determine what if anything could be done to improve it's transient performance.

## SYSTEM REQUIREMENTS

The original specification for the power supply written by ABB called for less than 10% variation in anode voltage for all power levels of operation [1]. This means that for a nominal anode voltage of 22 kV that the voltage may not droop by more that 2.2 kV. Furthermore the supply needed to respond to load changes in the order of 1 ms from full load to no load and vice versa. These relatively modest requirements are necessary since we are operating the final amplifier tube at its upper limit with regards to anode current and particularly its Screen Grid current. At the upper power limit of these tubes one needs to carefully adjust the operating point as not to exceed either the anode dissipation or the screen current. Too large of a change in the anode voltage causes a change in the operating point of the tube which usually causes a fault and termination of the rf pulse.

## INVESTIGATION

Fig. 1 shows the voltage response for the FPA anode voltage. As can be seen from the plots the supply was not able to regulate with the required voltage output during the initial application of rf.

The large droop in anode voltage caused excessive screen grid current which in turn caused the protective circuits of the transmitter to be activated. In this case the protective circuits limited the output power as can be seen in trace #2 of Fig. 1. Upon further investigation it became obvious why the supply was not able to handle the required impulse. The power supply design is based around an SCR controller operating at a nominal 480 vac. 12.47 kV is fed to a step-down transformer who's output is fed to the SCR regulator and then to a step-up transformer rectifier which in turn has an LC filtering network between it and the amplifier (Fig. 2). Since the design of the controller requires a zero crossing before conduction can start there is an inherent 16 ms response delay in the system. This is an addition to other delays associated with the various feedback circuits and other passive circuit elements.

There were two modes of unsatisfactory operation found. The first was the large droop in voltage early in the pulse. This was caused by the fact that the SCR unit just cannot respond faster than the first zero crossing or about 16 ms for the 3 phase input. As can be seen from Fig. 1, after this

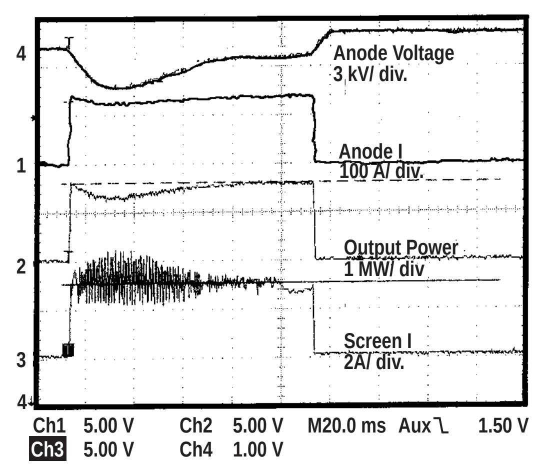


Fig. 1. Pre upgrade PFA waveforms. 1–anode current, 2-output power, 3-screen current, and 4-anode voltage.

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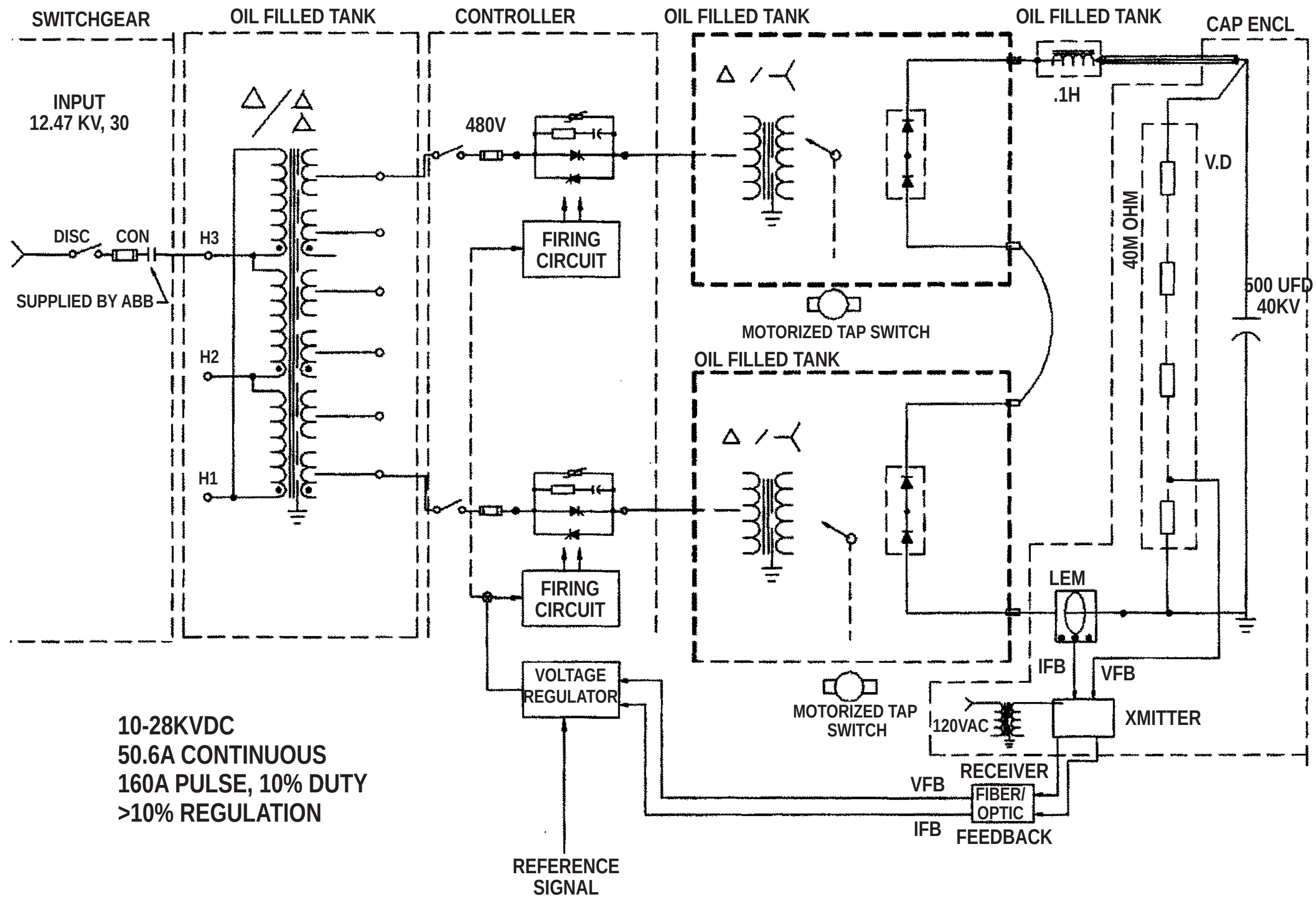

Fig. 2. H.V.P.S. diagram.

initial dip in voltage the output would rise to the desired voltage and regulate rather well for the remainder of the pulse. The second mode of improper operation was caused by the regulators "over current" protection circuitry. When operating at very high power levels into DIII–D, the system would occasionally block rf production due to fast changes in antenna loading associated with changing plasma conditions. These blocks would cause the transmitter to go from full output power to no output and back to full power on the order of 10's of ms. This would cause the regulator circuit to shut off the SCRs at the termination of the rf. However, the slow turn off of the SCR's would lead (~ 16 ms) to a slight overshoot in voltage which then caused the regulator to phase the SCRs to a full off condition. When the regulator tried to catch up with the current demand associated with the re-application rf, the SCRs would be suddenly phased for full conduction. This would result in an over current condition and cause the SCRs to shut down. The capacitor bank would quickly be discharged and the rf power would decline until a screen over current condition in one of the amplifier stages would terminate the rf completely.

The two problems required two different answers. First was the SCR over current shutdown. It was decided to modify the way in which we required the rf to come back on after a transmission line or antenna fault. We first shortened the off time thus not allowing the SCRs to completely phase back, secondly we request the power to be reapplied in a step fashion thereby spreading the $\Delta I$ over a slightly longer time period. This seems to have alleviated most of the over current type faults. The second problem required a much more sophisticated approach. What was needed was a circuit that could foretell when the current demand would be coming and what that demand would be. Since the amplitude and shape of the rf could be remotely controlled in real time, a circuit that knew what that demand would be has not yet been designed what was know was when the pulse was about to happen. The droop could be avoided by just adding a delay to the rf request and using the original request to start a preboost. Fig. 3 shows a simplified circuit for the FPA power supply regulator.

What was done was to tell the regulator to increase the output voltage an adjustable amount and for an adjustable length of time before the actual beginning of the rf pulse. It was found that this set up can only be optimized for a given power and voltage condition, but experimentation has shown that by setting it for a nominal power output of 2 MW, satisfactory results are achieved for pulses of less power as long as the requested anode voltage is held constant. Fig. 4 shows the voltage improvement for a high power pulse. Note that not only is the anode voltage held

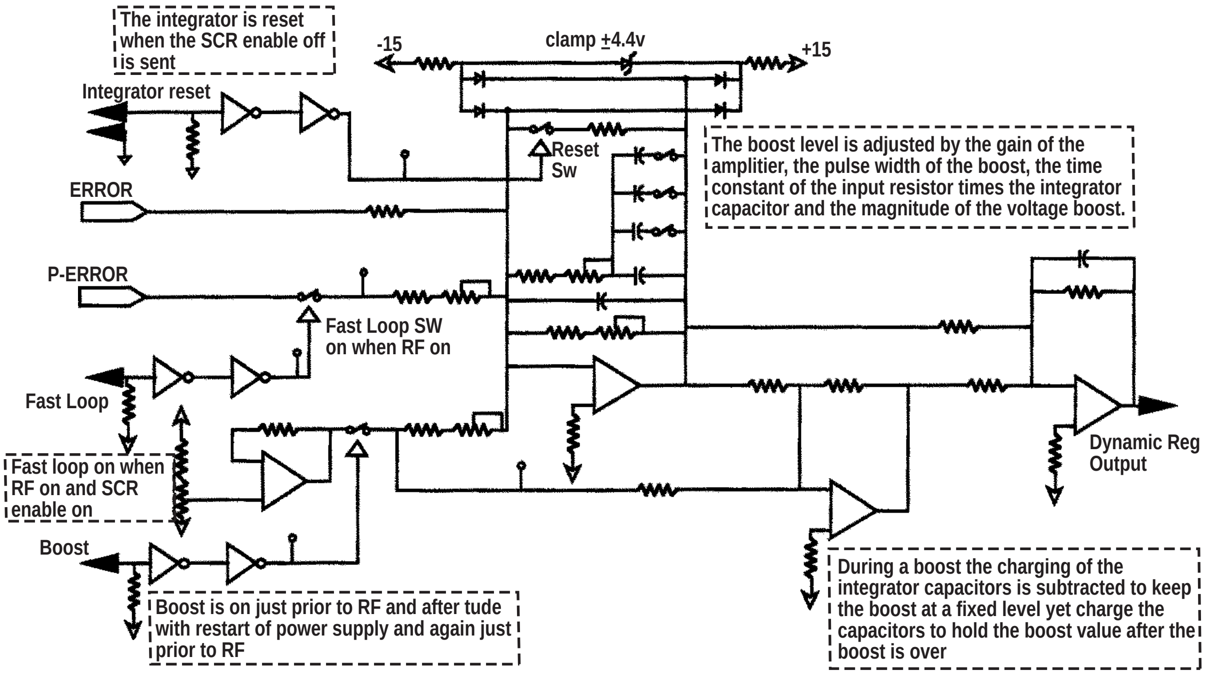


Fig. 3. Upgraded regulator diagram.

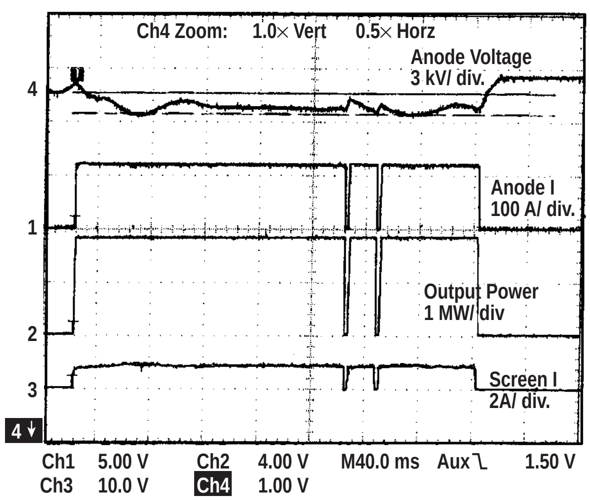


Fig. 4. Post upgrade FP waveforms. 1-anode current, 2-output power, 3-screen current, 4-anode voltage.

constant but that the screen grid current is also constant and much lower in amplitude.

## SUMMARY

As can be seen from the comparison between Figs. 1 and 4, there has been a significant improvement in the initial voltage droop which is most evident in the screen grid current. This has allowed the amplifier to operate much nearer specified maximum output power without over dissipation or excessive screen current. This has also led to improved reliability or quality of the rf pulse during plasma operations where the load variations can cause large swings in plate loading.

## REFERENCE

[1] W. Schminke *et al.*, "Upgrade of ICRH generators for ASDEX/W VII," 12th Symposium on Engineering Problems of Fusion Research, Monterey, 1987.