ADVANCED BUCK CONVERTER POWER SUPPLY "ABCPS" FOR APT *

R. Street, T. Overett, E. Bowles
General Atomics, San Diego, California 92186-5608 USA

Abstract

To meet the Nation's needs for Tritium one proposal is to use a high-power proton Linac, The Accelerator for the Production of Tritium or APT project **. The 1700 million electron volt (MeV) proton beam accelerator will be powered by radio frequency (RF) klystrons. A direct current (DC) power supply is required for each of the approximately two hundred and fifty 1-megawatt (MW) continuous wave klystrons in the RF power system. The requirements are that the power supply meet output performance specifications, provide fault protection for the klystron, have high efficiency, high reliability, good maintainability, and be readily manufacturable. As the power supplies are one of the largest cost elements in the accelerator, a technology review was made to determine the most economical approach to satisfy the requirements. A switch-mode power supply employing a buck-regulator was identified as being potentially the lowest cost approach. As the switch represents a certain development risk, a small-scale prototype has been constructed for evaluation, and has resulted in the decision to fabricate a full-scale prototype power supply. The prototype design and performance test information will be made available to potential suppliers. A description of the concept follows.

1 INTRODUCTION

The proposed APT plant will use proven accelerator based technology. The 1700 MeV proton accelerator will utilize three standard 350 megahertz (MHz) klystron RF sources to drive the RF Quadrupole. There will be two hundred and forty one 700 MHz klystron RF sources to power the normal temperature low-energy linac and the super-conducting radio frequency cavities in the high energy linac to create the high-energy proton beam.

2 APT RF POWER SYSTEM

The APT plant requires one high voltage power supply (HVPS) for each of the 244-klystron RF power sources. Three HVPS provide 2 MW DC to 1.2 MW (RF) klystrons and the rest supply 1.6 MW DC to 1 MW (RF) klystrons. Two-MW DC power supplies rated for 95 Kilovolts (kV) @ 21 Amperes (A) DC are planned throughout for commonality.

*Work supported by DOE under contract DE-AC04-96al89607.

** George P. Lawrence's invited talk at this conference.

In addition to meeting specification requirements in section 4, the HVPS must also provide fault protection for the klystron, have high efficiency, high reliability, good maintainability, and be readily manufacturable. As the HVPS are one of the largest cost elements in the accelerator, a technology review was made to determine the most economical approach to satisfy the requirements. The results of that review indicated a switch-mode power supply employing a buck-regulator was potentially the lowest cost approach to satisfy all plant requirements.

The buck-regulator topology is potentially the most economical because the high voltage rectifier bridge and the high voltage step-up rectifier transformer are removed from the power supply. All other topologies, including the resonant power supply utilize expensive magnetic components, which increase their costs and complicate their manufacturability.

To accomplish this, the 230-kV high voltage, utility distribution transformers would become the rectifier transformers. The transformer secondary voltage is rectified to provide twelve pulse DC power to the system. This also simplifies and reduces the cost of the utility distribution system for APT because the usual branch circuits and components used to step-down the utility voltage to a workable medium voltage are not required.

The utility source 230-kV, 677 megavolt-ampere (MVA) line feeds four substations. Each of four substations (Fig. 1) will contain two, 60 MVA isolation transformers for a total substation capacity of 120 MVA. This allows each substation to feed twenty five percent of the HVPSs. For redundancy, two high voltage rectifier bridges would be connected to the secondary of each distribution transformer. There would be a total of eight rectifier-transformers and sixteen rectifier bridges. Interphase transformers tie the rectifier outputs from the phase-shifted transformers to make twelve pulse ripple. The transformer secondary is eighty-two kV rms. It is then rectified to 115 kV DC. Each rectifier bridge will be sized to support twice the usual number of HVPSs, in case one rectifier is out of service. Each of the four DC transmission grids would feed a minimum of sixty-one power supplies. Only three HVPSs will actually operate at 21 A. The remaining HVPSs will operate at 17 A. Fig. 1 shows a typical distribution substation pair of rectifier transformers including the DC rectifiers dedicated to the RF power system.

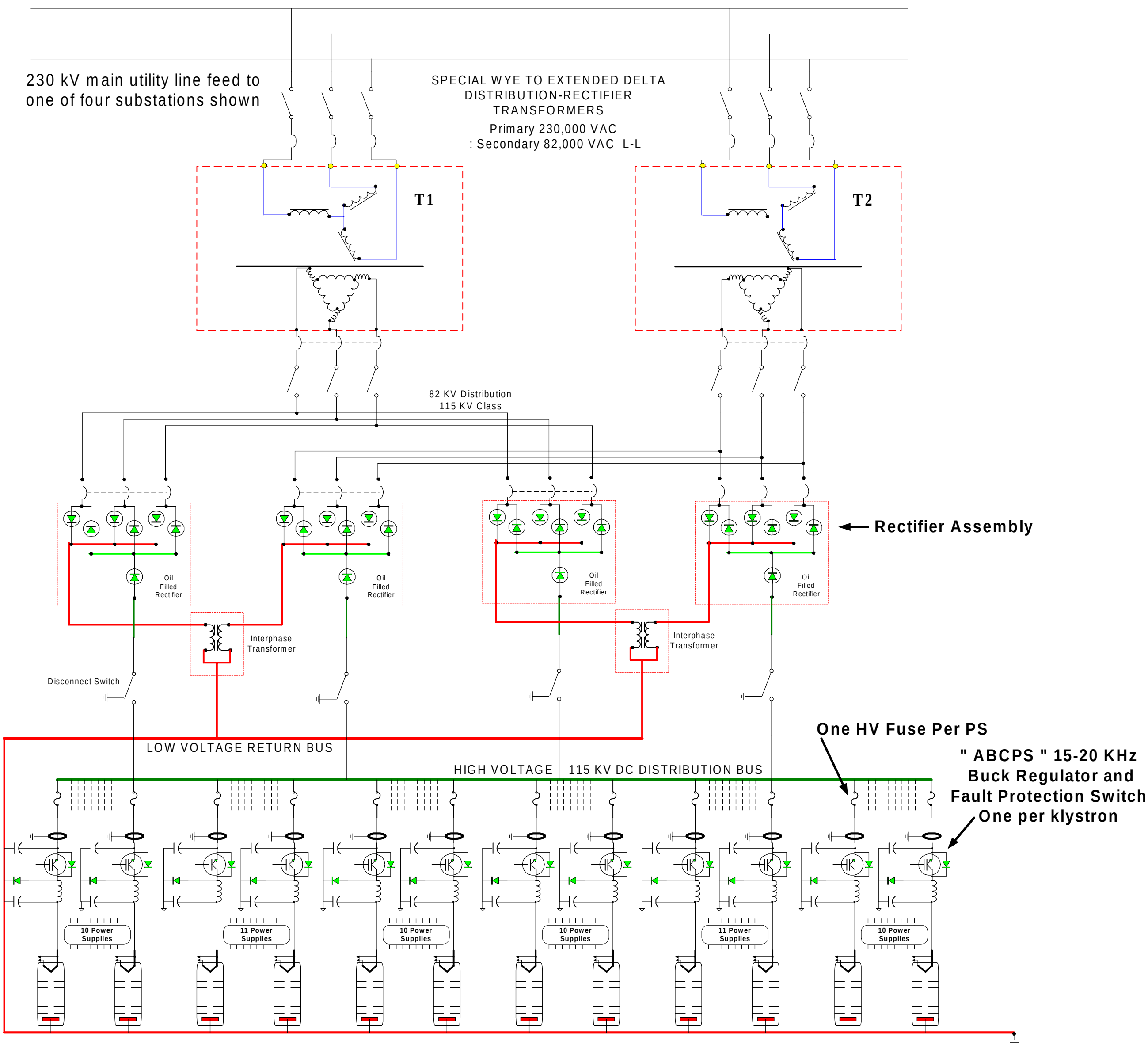

Figure 1: “ABCPS” DC Distribution System for APT

3 ABCPS

The Advance Buck Converter Power Supply, (ABCPS) is connected directly to the DC distribution bus. The topology of this converter is a DC to DC buck chopper which regulates the applied voltage to one klystron. A circuit schematic of a single ABCPS is shown in Fig. 2. The raw HVDC input is switched at approximately 20 kilohertz by a HV IGBT switch and charges the output capacitor through a switching inductor. A freewheeling diode transfers the inductor energy into the output capacitor during the IGBT switch off time. The circuit operates in the discontinuous current mode.

Additional output filter sections reduce output ripple voltage and also provide instantaneous fault energy limiting to the klystron. During operation, when the klystron may arc internally, the IGBT switch will interrupt the high voltage power supply output current in one microsecond or less. To prevent damage to the klystron, less than 40 joules will be deposited during an internal plasma arc. Individual primary high voltage fast acting fuses will be used for back-up power supply and klystron load protection.

The high voltage IGBT switch assembly is designed for ease of maintenance. The IGBTs, heat sinks, and gate drive circuits are mounted on plug-in circuit cards. Fiber optic signal isolation is utilized throughout the HVPS. The entire switch assembly can be bench manufactured and does not require special manufacturing or heavy assembly equipment. In addition no large magnetic cores are needed. All the HVPS inductors are single layer wound air-core coils. The majority of the HVPS components are standard off the shelf types. This manufacturing approach reduces cost and procurement lead-time.

The most critical circuitry in this ABCPS is the high voltage solid-state switch. This switch is a string of paired IGBTs connected in series to hold off the 115-kV DC input. References [1] through [6]. The IGBTs are paired to provide redundancy. Uniform voltage sharing across each device is critical under all operating conditions. Each IGBT will have an independent gate control circuit. Once the fault is detected, the IGBT switch can operate in less than one microsecond to protect the klystron and provide fast voltage regulation and control.

4 HVPS OUTPUT CHARACTERISTICS

Output DC voltage: Continuously variable- 4 to - 95 kV
Output DC polarity: Negative with respect to ground
Output voltage set-point accuracy: +/- 400V
Output voltage rate of increase: 10 kV / second max.
Output current rate of increase: 200A / second max.
Regulation range: 10 – 95 kV
Regulation requirements (line & load): +/- 400 V max.
Ripple @ any 60 Hz harmonic: 800 V pk to pk max.
Total ripple (all causes): 1100 V peak to peak max.
Voltage stability: +/- 0.4% max.
Output DC current: 0 - 21 A
Load fault protection: 40 Joules max.

REFERENCES

[1] V.Chitta, S. Hong, and David A. Torrey, "Series Connection of IGBTs with Active Voltage Balancing", IEEE 1997

[2] P.R. Palmer and A.N.Githiari, "The Series Connection of IGBTs with Active Voltage Sharing", IEEE PESC 1997, pp.637-644

[3] C.Gester, P. Hofer, N Karrer, "Gate-control Strategy for Snubberless Operation of Series Connected IGBTs", PESC 1996, pp.1739-1742.

[4] P.R. Palmer and A.N. Githiari, "The Series Connection of IGBTs with Optimized Voltage Sharing in the Switching Transient" Proceedings of IEEE PESC 1995, Vol. 1, pp.44-49.

[5] C.Gester, "Fast High Power/High Voltage Switch Using Series Connected IGBTs with Active Gate-Controlled Voltage Balancing", APEC 1994, pp.469-472.

[6] M.Tsuneoka, M. Takeuchi, and I. Takahashi, "The Design of RF Power Supply using DC-DC Converter", IEEE 1989, pp.1206-1209.

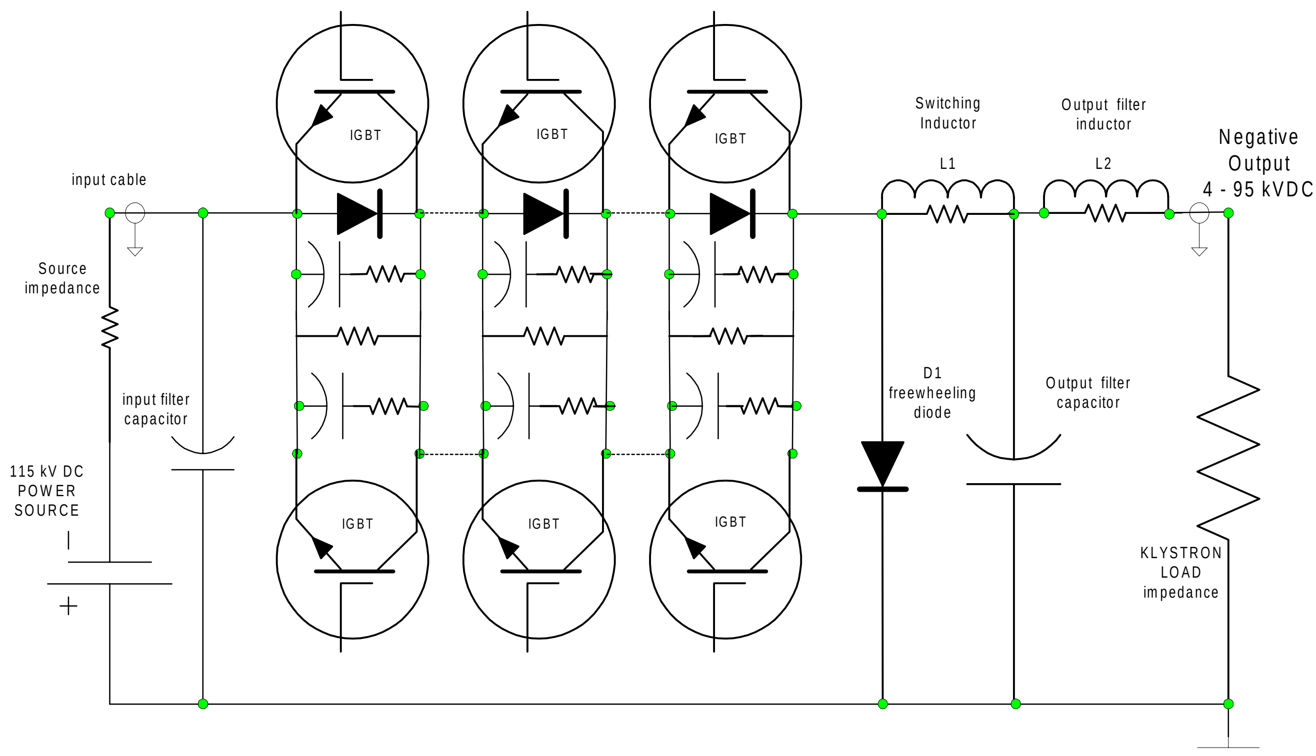

Figure 2: ABCPS Schematic