MAIN INJECTOR POWER DISTRIBUTION SYSTEM*

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Abstract

The paper describes a new power distribution system for Fermilab's Main Injector. The system provides 13.8 kV power to Main Injector accelerator (accelerator and conventional loads) and is capable of providing power to the rest of the laboratory (backfeed system). Design criteria, and features including simulation results are given.

1 INTRODUCTION

Studies done prior to Main Injector construction showed that the existing substation – Master Substation (MSS) would not be sufficient for its needs. A new substation (Kautz Road Substation - KRS) was needed to serve the power needs of the Main Injector as well as provide alterative source of power for critical loads at the Laboratory. Since KRS would be fed from different point of the 345 kV utility grid, Laboratory would gain an additional degree of power distribution system's reliability. Particular attention was given to the rapid cycle rate of the Main Injector accelerator (1.5 sec.) and the potential effects on the power distribution system.

2 SYSTEM DESIGN CRITERIA

The new power distribution system had to meet many requirements. It had to be incorporated into an existing plant and meet specific design criteria. Latest power quality standards as well as operational experience at the laboratory served as guidelines.

2.1 Compatibility with Existing Power Distribution System

The existing power distribution system imposed the following criteria:

- 13.8 kV distribution must be 3-wire with a 100% concentric neutral return, multiple grounded.
- New transformers at KRS must be compatible with existing transformer at MSS (345/13.8 kV, Δ/Y, 8.5%).

The above requirements narrowed the choices for distribution cable and substation transformers – two most critical and expensive elements of the distribution system.

The new substation has 2 relocated and 2 new power transformers.

2.2 Compliance with IEEE Standard 519

This standard is a recommendation that attempts to reduce the harmonic effects at any point in the entire system by establishing limits on harmonic currents and voltages at the point of common coupling (PCC). Limits on individual harmonics and total harmonic distortion (THD) became one of the most important design criteria for harmonic filters.

2.3 Reliability

Existing power distribution system has had its share of reliability problems. The new system's reliability has been enhanced was by the following design choices:

- The cable is 750 MCM, Aluminium with EPR insulation.
- All cables in concrete encased conduits.
- All transformers rated between peak and average power. All transformers would have round coil. This criteria was applied to all 13.8 kV and 345 kV transformers.
- All harmonic filter elements rated at peak power.
- State-of-the-art relay protection system employing microprocessor and PLC based technology.
- Over voltage protection coordinated with continuous and impulse ratings of the devices being protected. Station and distribution class arresters placed in critical locations would serve this purpose.
- Fully functional SCADA system.

2.4 Backfeed Capability

In addition to providing power to all Main Injector technical systems, the new power distribution system provides some power redundancy to the laboratory:

- First, KRS is fed from different point of the 345 kV utility grid than MSS.
- Second, some critical loads can be fed from either MSS or KRS.
- Finally with either substation out of service, some degree of laboratory operations would be maintained.

2.5 Power Requirements

The KRS power requirements are summarized in Table below:

Table 1. Main Injector distribution system requirements.

Requirement	
Dipole and quadrupole power, peak	120 MVA
Dipole and quadrupole power, average	60 MVA
RF, beamline power supplies, peak	30 MVA
RF, beamline power supplies, average	20 MVA
Main injector conv. loads, average	10 MVA
Backfeed capability, peak	40 MVA
Backfeed capability, average	30 MVA
Accelerator cycle time	1.5 sec.
Total Harmonic Distortion at PCC	3.75%

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3 SYSTEM DESCRIPTION

3.1 Block Diagram.

Figure 1 shows simplified diagram of the Fermilab's power distribution system.

The system consists of two 345/13.8 kV substations – MSS and KRS. Some critical loads can be fed from either substation (feeders 46A, 46B, 23, 24) or serve as an additional tie between substations in backfeed mode. A dedicated triple feeder (21/22) gives additional capacity for power transfer between substations.

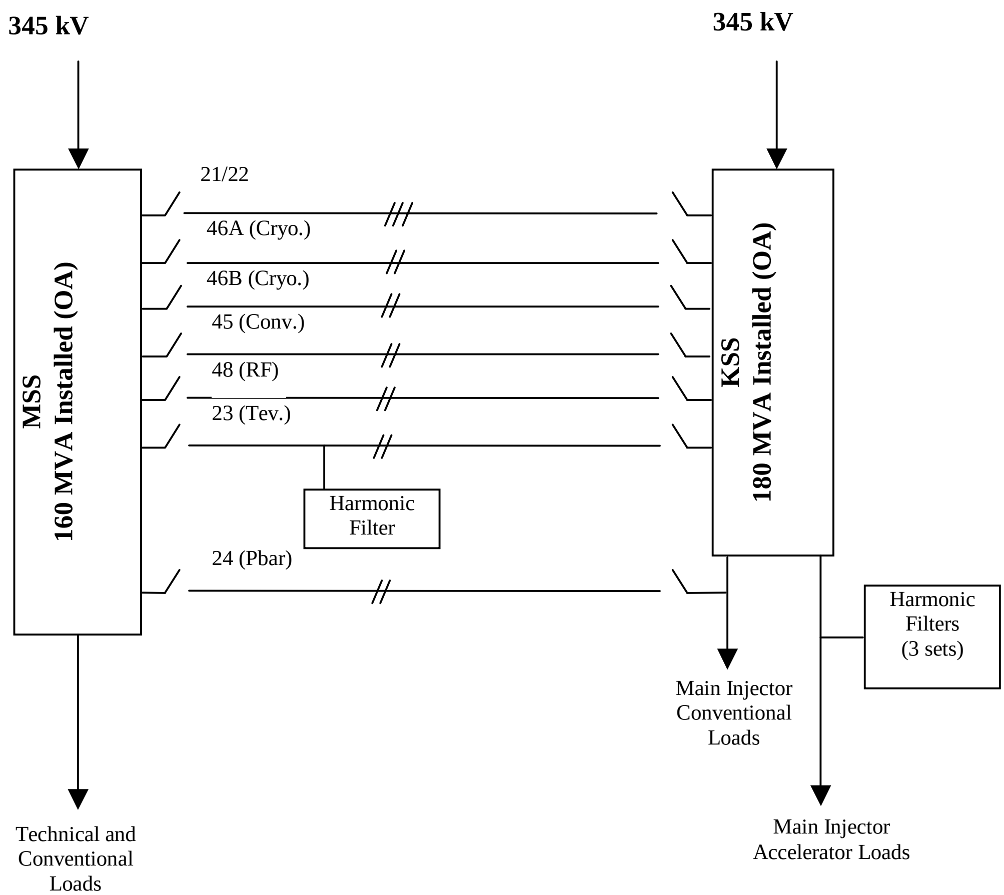

Figure 1. Simplified single line diagram of the Fermilab's power distribution system

A total of 4 sets of harmonic filters provide harmonic correction and power factor correction for:

- Tevatron dipole and quadrupole magnet power supply system (feeder 23).
- Main Injector dipole and quadrupole magnet power supply system (2 sets, KRS bus 6-1 and 7-1).
- Main Injector beam line power supply system (1 set, KRS bus 8-1/9-1).

3.2 Harmonic Filter Design

General specifications for the harmonic filtering were:

- Compliance with IEEE Standard 519 such as individual and total harmonic distortion (THD).
- Transient stability.
- Utilization of the Main Ring harmonic filter.
- Power rating equal to peak harmonic load.

The work on harmonic filter design started with measurements of line current harmonics generated by the prototype of Main Injector dipole power supply. Measurements were taken at various load levels from 10% to 110% of the power supply rated current. The maximum amplitudes of harmonics were recorded. Computer model of entire power distribution system was developed. Harmonic sources were introduced into the model using harmonic spectrum taken from experimental data. An individual harmonics and THD were observed while different topologies for the harmonic filter were considered. Design criteria along with cost optimization resulted in a final harmonic filter configuration as shown in Figure 2. The harmonic filter consists of the following elements:

- High pass filter. A series RC circuit provides filtering of high frequencies and damping of transient oscillations. A 60 Hz bypass around damping resistance is provided to reduce losses.
- 720 Hz trap. It provides filtering of 11^{th} and 13^{th} harmonics present in the distribution system due to 12-pulse SCR-type power supplies.

- 1440Hz trap. It provides filtering of 23rd and 25th harmonics present in the distribution system due to 12-pulse SCR-type power supplies.

The filter configuration shown in Figure 2 was utilized in KRS in bus 6-1 and 7-1 serving Main Injector dipole and quadrupole power supply systems. Main Injector beamlines and RF systems utilized a filter relocated from the decommissioned Main Ring. A 60 Hz bypass was added to this filter for energy savings.

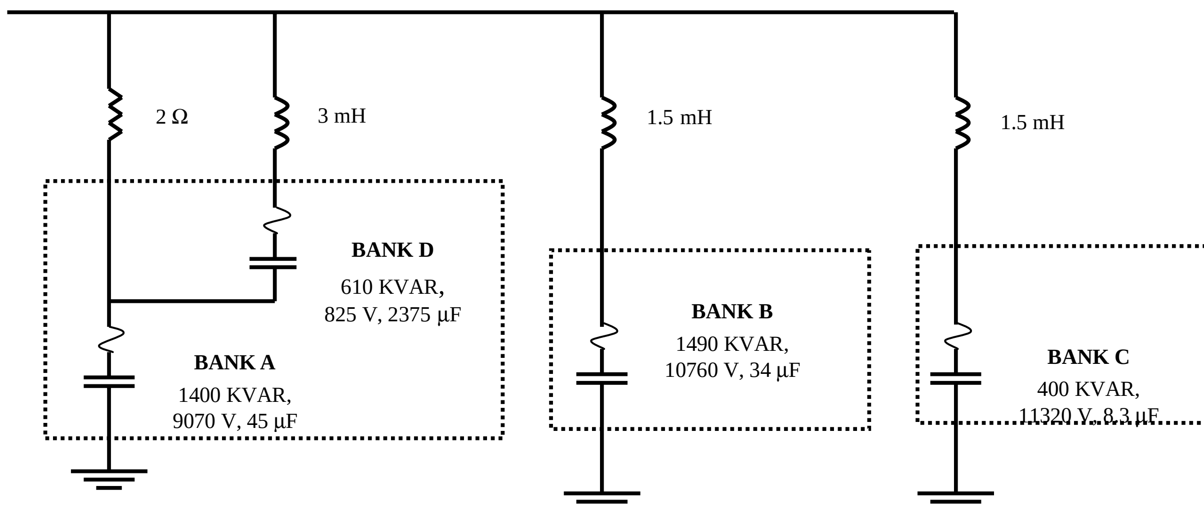

Figure 2. Harmonic filter single line diagram.

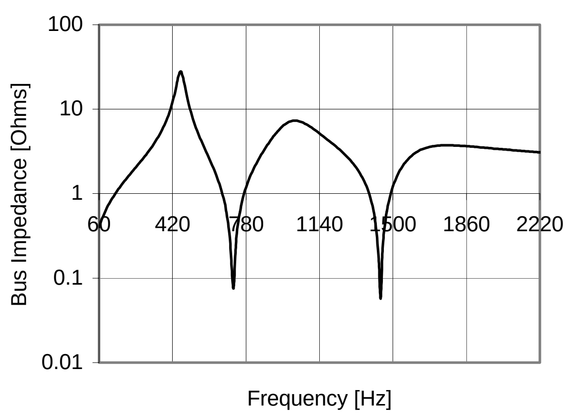

Figure 3. Bus 6-1 frequency response.

3.3 System Frequency Response

Bus 6-1 frequency response is shown in Figure 3. The graph shown is a result of the simulations. The actual frequency response of the system was measured and it confirmed its basic characteristics:

A fine-tuning of 720 Hz and 1440 Hz traps was done using tuning capacitor sections of bank B and bank C.

3.4 System Transient Response

A computer simulation of the system's transient response without transient suppression is shown in Figure 4. This particular event is a turn-on of the bus 6-1 harmonic filter. It shows a damped oscillatory response of the system. The 460 Hz oscillations energy is deposited in the harmonic filter's damping resistor. The size of the damping resistor is a result of a compromise between voltage overshoot, high-pass corner frequency and cost.

A 10 kV rated, MOV type, station class arresters are placed in the substation directly on the bus feeding harmonic filters. They effectively clip any voltage overshoot with amplitude higher than 14 kV.

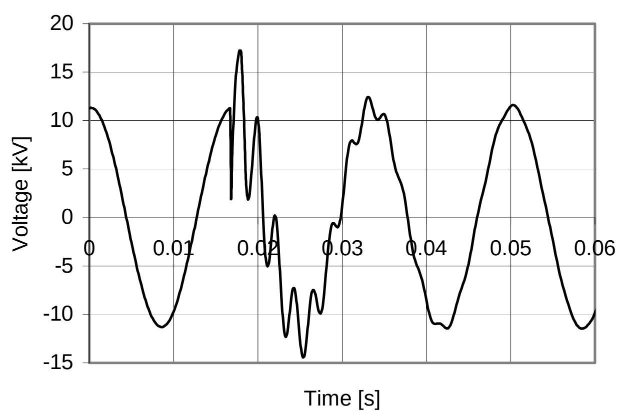

Figure 4. Bus 6-1 transient response.

4. CONCLUSIONS

The goal of the Main Injector power distribution project was to design and build a distribution system that was reliable and controlled the potentially damaging effects of harmonics generated by the magnet power supplies. After 5 years of operation it seems this goal has been achieved: there have been no failures of the feeders, transformers, or switchgear.