# NCSX Engineering Design Document

## Design Description
## Electrical Power Systems (WBS 4)

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**NCSX CDR**

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## 1 INTRODUCTION

This document describes the design of the Electrical Power Systems (WBS 4) of the National Compact Stellarator Experiment (NCSX). The Electrical Power Systems WBS Element covers the supply and delivery of all AC and DC electrical power to all equipment associated with the NCSX experiment.

## 2 DESIGN REQUIREMENTS AND CONSTRAINTS

The main loads for the Electrical Power Systems come from:

- Stellarator Core Systems. The stellarator core has 3 modular coil circuits, 1 toroidal field (TF) coil circuit, and 5 poloidal field (PF) coil circuits in the initial configuration.
- Neutral Beam Injection (NBI) System. Two beamlines will be installed at the time of first plasma.

The Electrical Power Systems requirements for the coil systems are derived from the performance requirements for the coils. NCSX is designed to be a flexible, experimental test bed. To ensure adequate dynamic flexibility, a series of reference scenarios has been established in the **General Requirements Document**, provided as part of the Conceptual Design Report. These scenarios include the:

- Initial Ohmic Scenario
- 1.7T Ohmic Scenario
- 1.7T High Beta Scenario
- 2T High Beta Scenario
- 350kA Ohmic Scenario

TF, PF, and modular coil systems and the vacuum vessel will be designed to meet the requirements of all the reference scenarios. The Electrical Power Systems will be designed and initially configured to meet the requirements of the Initial Ohmic Scenario and will be capable of being gracefully upgraded to meet the requirements of all other reference scenarios.

Flexibility requirements have also been established. The dimensions in flexibility space include:

- Quasi-axisymmetry
- Internal and external iota
- Shear
- Beta
- Current profile

The coil systems shall be designed and the Electrical Power Systems will be upgradeable to accommodate flexibility requirements in each of these dimensions.

The NCSX Project develop coil current waveforms for each reference scenario. These waveforms are documented in the **Technical Data**, provided as part of the Conceptual Design Report. Based on these waveforms, maximum circuit currents and voltages were calculated. Power supply requirements were calculated based on the Transrex supplies at D-site. These are the same power supplies that were used for TFTR, some of which are currently being used by NSTX. There are a total of 74 power supplies located at D-site. The performance characteristics of these power supplies are tabulated in Table 1.

**Table 1 Transrex Power Supply Section Performance Characteristics**

| Parameter | Value | Units |
|---|---|---|
| No Load Avg. DC Voltage | 1012.85 | volt |
| Maximum DC Current | 30.0 | kA |
| Nominal Pulse DC Current | 24.0 | kA |
| Nominal Pulse ESW | 6.0 | sec |
| Nominal Pulse Repetition Period | 300.0 | sec |
| Maximum Continuous DC Current | 3.25 | kA |

NCSX will share these power supplies with NSTX. Power supply requirements for each phase of operation are tabulated in Table 2. In each circuit, the maximum current is less than 24 kA. The minimum number of power supply sections (1 kV, 24kA units) required for the Fabrication Project is 30, dictated by the requirements of the Initial Ohmic Scenario. The minimum grows to 58 for full operational capability.

Circuit ratings were established based on the maximum currents in each circuit over the full range of reference scenarios. Flexibility studies have been conducted and equilibria established at the extrema in flexibility space. Coil currents at these extrema have been constrained to stay within the rated currents defined in Table 2.

When operating at full parameters (maximum $I^2t$), the required repetition rate is once every 15 minutes. (The repetition rate is limited by the time required to cool down the modular coils.) The maximum RMS current required in any circuit is 980 A.

Maximum active and apparent power requirements and stored energy requirements were calculated over the full range of reference scenarios. All of the maxima occurred in the 2T High Beta Scenario. The maximum active power is 142 MW, with a maximum apparent power of 400 MVA. The maximum stored energy required is 93 MJ. These requirements are well within the capability of the D-site AC power system using the available line power and only a single MG set.

The remaining electrical loads should be comparable to electrical loads already handled by the C-site AC Power System during PBX-M operation.

## 3 DESIGN DESCRIPTION AND PERFORMANCE

The NCSX machine will be installed in the NCSX Test Cell formerly occupied by the PLT and PBX-M tokamaks. The existing D-site DC power conversion equipment will be utilized for NCSX in order to meet the operational requirements of NCSX in a robust and cost-effective manner. The D-site power conversion equipment will be shared with NSTX, feeding at most one machine in operation at any one time. A one-line diagram of the NCSX Electrical Power Systems is provided in Figure 7.

Existing D-site power supplies will be used to power all the NCSX coils that are powered in the initial configuration. Each of the nine (9) NCSX coil circuits has been mapped into an existing or to-be-reconfigured NSTX coil circuit, as shown in Table 2. Schematics of each circuit are provided at the end of the chapter in the figures identified in Table 2.

**Table 2 Power Supply Requirements by Phase of Operation**

| NCSX | M1 | M2 | M3 | PF1/2 [c] | PF3 | PF4 | PF5 | PF6 | TF |
|---|---|---|---|---|---|---|---|---|---|
| NSTX | TF Branch 1 | PF4/5 | PF2U | PF3U | PF2L | PF3L | PF1aU | PF1aL | OH |
| Schematic | Figure 6 | Figure 1 | Figure 4 | Figure 5 | Figure 4 | Figure 5 | Figure 3 | Figure 3 | Figure 2 |
| Phases 1, 2, and 3 (Initial Configuration) | | | | | | | | | |
| Parallel PSS [a] | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Series PSS | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 |
| Direction | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 |
| Total PSS | 2 | 2 | 2 | 4 | 2 | 2 | 4 | 4 | 8 |
| | | | | | | | | | 30 |
| Phase 4 | | | | | | | | | |
| Parallel PSS [a] | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 |
| Series PSS | 4 | 4 | 2 | 4 | 2 | 6 | 2 | 2 | 6 |
| Direction | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 |
| Total PSS | 4 | 4 | 2 | 8 | 2 | 6 | 4 | 4 | 12 |
| | | | | | | | | | 46 |
| Phase 5 | | | | | | | | | |
| Parallel PSS [a] | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| Series PSS | 4 | 4 | 2 | 4 | 4 | 6 | 2 | 2 | 6 |
| Direction | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| Total PSS | 4 | 4 | 2 | 8 | 8 | 12 | 4 | 4 | 12 |
| | | | | | | | | | 58 |
| Max current (A) | 24000 | 24000 | 24000 | 24000 | 21000 | 19000 | 8000 | 11000 | 18000 |
| Max $I^2t$ ($A^2$-s) | 4.9E+08 | 4.9E+08 | 4.9E+08 | 4.8E+08 | 3.1E+08 | 3.8E+08 | 4.0E+08 | 5.0E+08 | 8.3E+08 |
| $t_{ESW}$ (s) | 0.85 | 0.85 | 0.85 | 0.83 | 0.70 | 1.05 | 0.63 | 0.44 | 2.56 |
| I rms (A) [b] | 980 | 980 | 980 | 980 | 857 | 776 | 327 | 449 | 735 |

[a] Connected in anti-parallel

[b] RMS current based on 1.5s ESW every 900s

[c] PF1 and PF2 are connected in series

Real time feedback control of the magnet power systems will be accomplished via digital computer algorithms performed in a processor provided as part of the Electrical Power Systems work scope. The same Electrical Power Systems computer presently controlling the NSTX system will be used for NCSX. However NCSX will be using a dedicated program. Input/output data for this purpose will be communicated using new and old data network (PC Link and HSDL) in the FCPC building and links from C-site as required. Wiring between power systems components and the existing CAMAC crates will remain as is.

The composite AC power demand imposed by NCSX may be supplied by a combination of power derived from the grid and one of the D-site MG sets. Available grid power for the pulsed loads through XST-1 is limited to approximately 120MVA. The total grid power availability depends of the power factor. Present contractual arrangements with PSE&G allow for instantaneous peak power demand up to 120MVA without mention of power factor.

AC power distribution to the D-site MG and power conversion rectifiers all exist and have been in service for several years at levels greater than those required for NCSX. The C-site NBI was in operation for PBX-M. AC power distribution to NCSX auxiliary equipment will make use of existing equipment down to the 480V level under service conditions less than or equal to previous levels. Additional power panels will be purchased and installed in C-site NCSX Test Cell as required. Additional outlets and plug points will also be provided as needed. WBS 4 will provide power for all Diagnostics Systems equipment up to the power panels.

## 4 DESIGN BASIS

The bulk of work in this WBS element involves the reconfiguration of existing equipment that has been in use for several years at service levels equal to or greater than those required by NCSX. All work activities will be performed in accordance with Princeton Plasma Physics Laboratory (PPPL) Engineering and Safety procedures and directives. New NCSX Electrical Power Systems components will be designed, constructed, and installed in compliance with the applicable provisions of the PPPL Health & Safety Manual (ES&H-5008) and other documents as listed in DOE Orders (e.g., ANSI/NFPA 70-(latest edition), National Electric Code, ANSI C20-(latest edition) National Electric Safety Code, etc.).

## 5 DESIGN IMPLEMENTATION

The Field Coil Power Conversion (FCPC) Building houses all the power conversion equipment. Reconfiguring the coil power supplies so that they may be used for both NCSX and NSTX is a major activity that will have to be planned during the maintenance and shutdown periods of NSTX. The conversion transformers are located outside the building at the back of each of the rectifier units. The Safety Disconnect Switches (SDS) and the Hardwired Control System cabinet are also located in the FCPC building first floor.

Power cables will be installed from the D-site Safety Disconnect Switches (SDS) to the NCSX Disconnect & Ground Switches (DGS) to be located in the second floor of the FCPC building. Each leg of each circuit will be provided with 1/c-1000 mcm cable (5kV rated). A new overhead DC transmission system will be installed from D- to C-site to power the NCSX coils. Transmission will be via power cables from the NCSX Disconnect & Ground Switches (DGS) to the Power Cable Termination Box (PCTB) in the EF/OH building. Provision will be made to reverse the coil polarity with links inside the PCTB. Existing power cables from EF/OH building to the C-site MG basement will be reconnected for each circuit from the PCTB to the existing C-site Bus system at the Discharge Breaker Resistor Cubicles in C-site MG Basement.

The C-site Bus System/Local Disconnect & Grounding System (LDGS) is an existing system which was installed for earlier fusion devices located in C-site. The C-site Bus System is also already provided with a set of Local Disconnect and Grounding Switches (LDGS). These will be used for each NCSX circuit. Thus, each NCSX coil can be isolated and grounded at the coil end at C-site. The LDGS is designed such that the coils get shorted and grounded when the switch is open. After the Bus System switches, power will be delivered to the coil terminals via power cables in the Test Cell.

## 6 RELIABILITY, MAINTAINABILITY, AND SAFETY

There is a substantial experience in operating and maintaining the equipment in the Electrical Power Systems. On the basis of that experience, the equipment is expected to operate reliably and be readily maintainable. The equipment will be installed, tested, and maintained by experienced, trained personnel in accordance with Princeton Plasma Physics Laboratory (PPPL) Engineering and Safety procedures and directives.

## 7 COST, SCHEDULE, AND RISK MANAGEMENT

Table 3 is a summary of estimated costs for the Electrical Power Systems in the NCSX Fabrication Project. The total cost is estimated to be $5427K in year of expenditure dollars with an overall contingency of 17.4%. The dominant cost category is laboratory labor.

**Table 3 Electrical Power System (WBS 4) Costs**

| Total Estimated Cost (K$) | | | | | | | 4 Total |
|---|---|---|---|---|---|---|---|
| | | 41 Total | 42 Total | 43 Total | 44 Total | 45 Total | |
| | | | | | | | |
| Manufacturing Development | Labor/Other | | | | | | |
| | M&S | | | | | | |
| | Total | | | | | | |
| Design (Title I & II) | Labor/Other | 95 | | 224 | 404 | 516 | 1238 |
| | M&S | | | | | | |
| | Total | 95 | | 224 | 404 | 516 | 1238 |
| Fabrication/Assembly (incl Title III) | Labor/Other | | | | | | |
| | M&S | 111 | | 673 | 429 | 34 | 1246 |
| | Total | 111 | | 673 | 429 | 34 | 1246 |
| Installation/test | Labor/Other | 309 | 13 | 305 | 717 | 365 | 1708 |
| | M&S | | 1 | 1198 | | 34 | 1234 |
| | Total | 309 | 14 | 1503 | 717 | 399 | 2942 |
| Grand Total | | 515 | 14 | 2400 | 1549 | 949 | 5427 |

The schedule for implementing the Electrical Power Systems (WBS 4) may be seen in the **Project Master Schedule**, provided as part of the Conceptual Design Report**.** Title II for Electrical Power Systems will generally be completed in FY05. Installation and testing will be generally completed by the end of FY06.

Technical and cost risks should be minimal as this is primarily a reconfiguration activity of existing equipment being performed by experienced personnel. Careful planning will be required to mitigate schedule risk due to potential conflicts with the NSTX Project.

## 8 APPENDIX – CIRCUIT SCHEMATICS

**Figure 1 M2 Schematic**

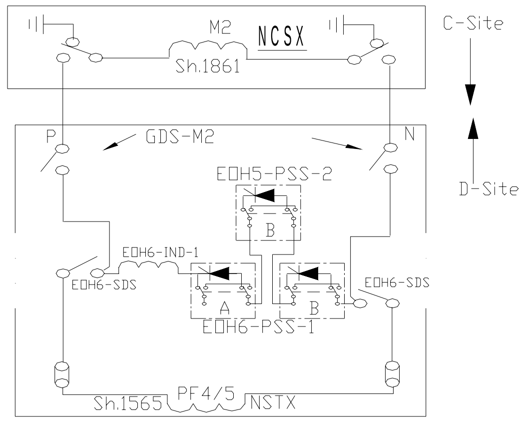



**Figure 2 TF Schematic**

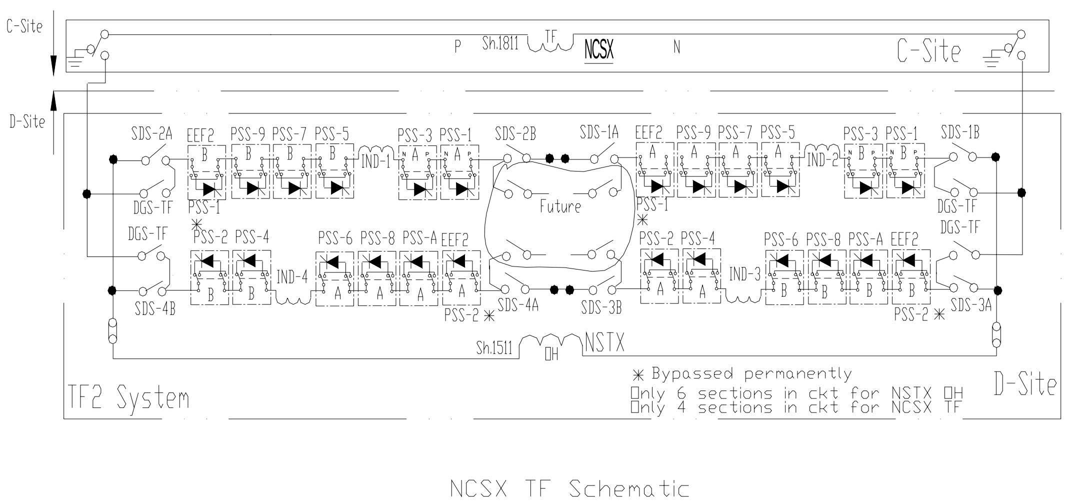


**Figure 3 PF5 and PF6 Schematic**

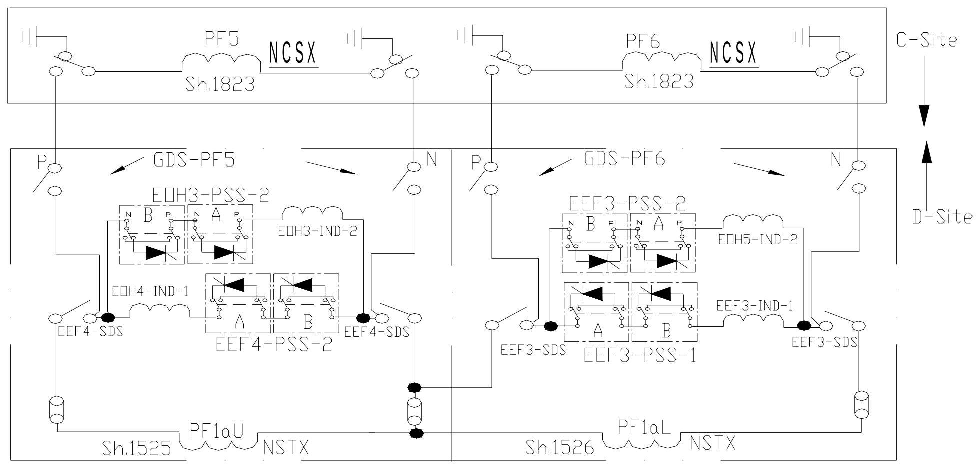



**Figure 4 M3 and PF3 Schematic**

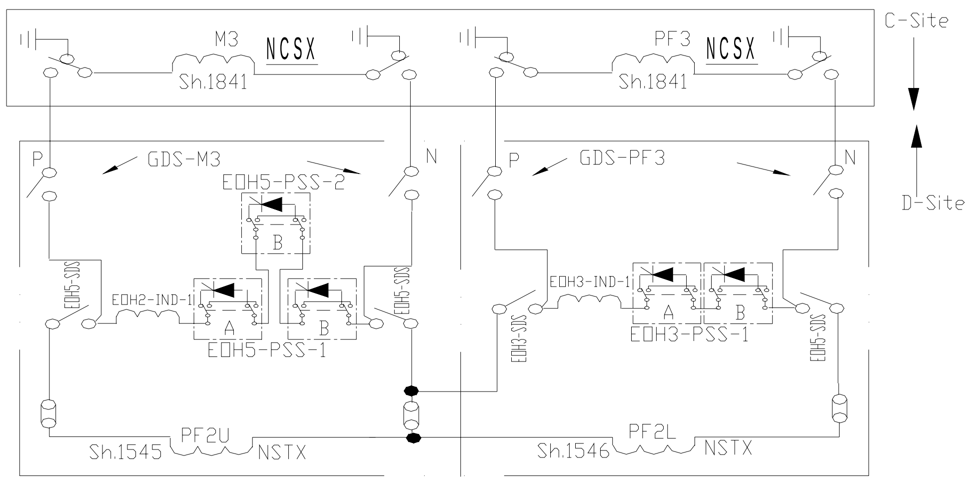


**Figure 5 PF1/2 and PF4 Schematic**

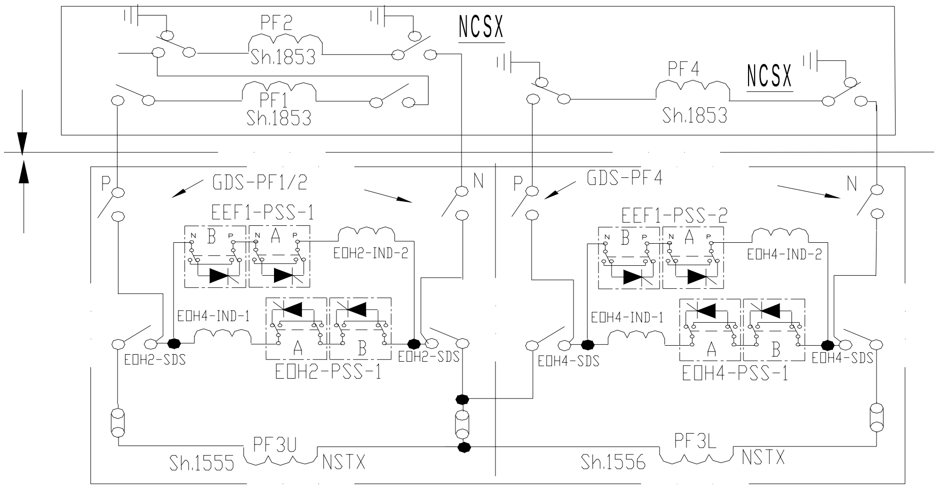
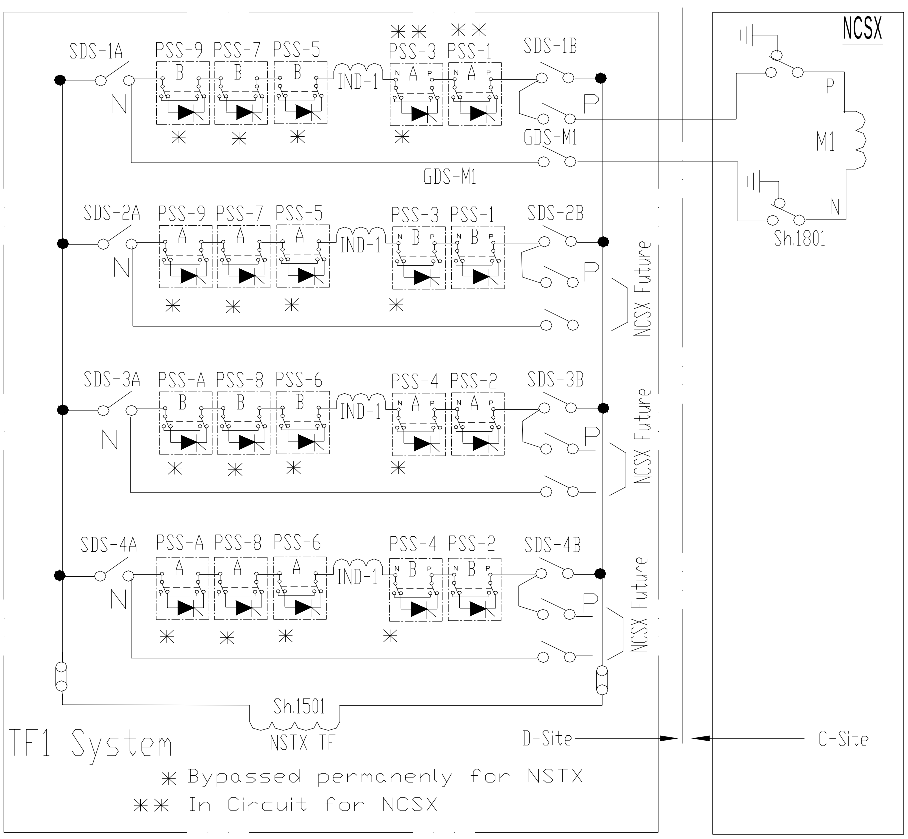
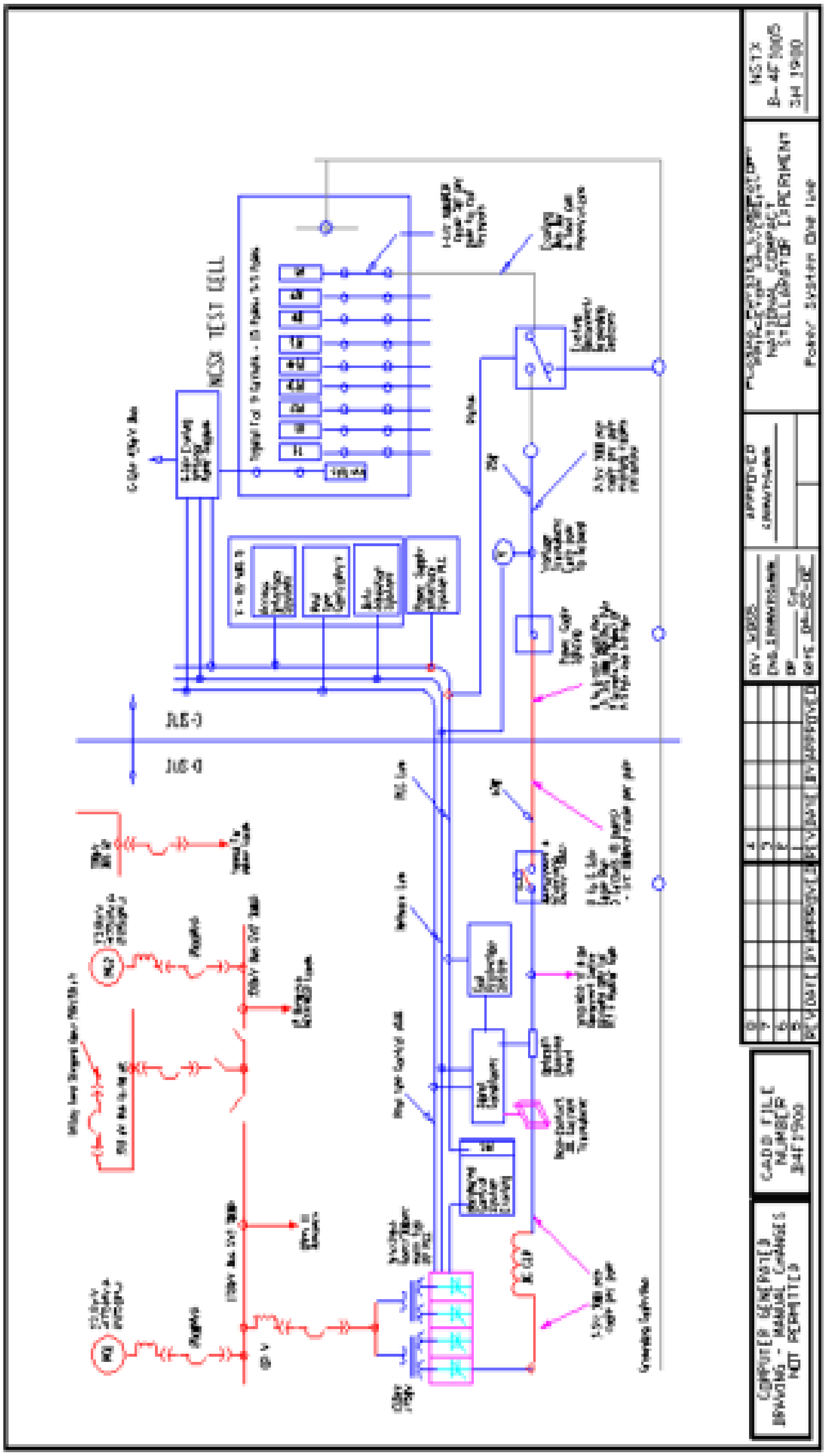



**Figure 6 M1 Circuit Schematic**




NCSX TEST CELL