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NSTX TOROIDAL FIELD COIL TURN TO TURN SHORT DETECTION

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Abstract: The National Spherical Torus Experiment (NSTX) was designed, installed, and commissioned in the existing facilities at Princeton Plasma Physics Laboratory (PPPL) in 1999. Most of the hardware, plant facilities, auxiliary sub-systems, and power systems originally used for the Tokamak Fusion Test Reactor (TFTR) were used with suitable modifications to reflect NSTX needs. A major upgrade was undertaken on NSTX. The TF has been upgraded to provide one tesla field from the present 0.5 tesla field. This entailed a much higher Toroidal Field Current from 71.2kA to 129.8kA, and required major configuration changes including doubling the number of parallel strings of rectifiers along with associated power loop changes. Before the planned upgrade the machine developed turn to turn fault of the Toroidal Field Coil bundle. The machine was shut down and the Upgrade work started earlier than planned. It was decided to provide a turn to turn fault detection and trip for the upgraded toroidal field coil. A unique scheme was developed to detect a turn to turn fault in TF. This paper gives a description of the turn to turn short detection scheme that has been implemented.

INTRODUCTION

The Magnet Coil power supply system located in the D-Site of PPPL, was installed for TFTR. DC systems were reconfigured and modified to supply the NSTX Upgrade coil systems. No changes have been made in the AC system including the Utility feed to the facility. The Power supply systems for NSTX upgrade are for the Toroidal Field (TF), Poloidal Fields (PF) with twelve individual circuits), the Ohmic Heating Solenoid (OH) coil circuit, the Coaxial Helicity Injection (CHI) system, and the Resistive Wall Mode Coils (RWM). Table 1 gives the details of the NSTX coil system circuits for the upgrade mode. All the DC power loops are kept floating. The Coaxial Helicity Injection (CHI) system is retained. For CHI operation, the vacuum vessel is divided into two electrically separate parts. These act as the two electrodes for the CHI. Thus the vessel sections are also required to float during CHI operation.

Few months before the planned upgrade of NSTX, a fault developed in the center stack TF bundle shorting some of the turns in the bundle. Reference describes the possible causes of failure. Based on this experience improvements have been made in the center stack. As part of the improvements a new and unique coil inter turn fault detection system has been developed and incorporated in NSTXU. This paper describes the salient aspects of this system.

SALINET ASPECTS OF NSTXU POWER SYSTEM

Thyristor Power Supplies at D-Site

PPPL has 37 modular power supplies each rated with two sections of 1kV 24kA pulsed, originally procured for TFTR (Figure 1) with conversion and bypass modules. A power supply has two sections, each of which provides an equivalent rating of 1 kV, 24 kA – 5.5 seconds equivalent square wave (ESW) every 300 seconds. Each power supply is fed by one three winding transformer with a polygon primary and delta/wye secondary. The polygon is arranged to produce + 7.5° or -7.5° phase shift depending on the phase sequence of the 13.8 kV input to the polygon. The DC outputs from the D-Site thyristor rectifiers are fed to the coils as per Table 1.

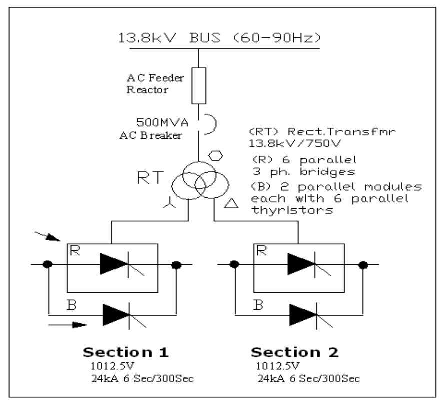

Figure 1
Typical Power Supply with two sections
R: Rectifier; B: Bypass

Circuit	Type	Volts (kV)(3)	Series/ Parallel PSS	Volts (kV)	ESW Current (kA)(4)	ESW time (sec)
TF	I	1	1/8	1	129.8	7.08
OH	III	+/-8	6/2	6	+/-24	1.47
PF1a Upper	IV	+/-1	1/2	1	18	5.5
PF1a Lower	IV	+/-1	1/2	1	18	5.5
PF1b Upper(1)		1	1/1	1	13	2.1
PF1b Lower(1)	I	1	1/1	1	13	2.1
PF1c Upper		1	1/1	1	16	4.34
PF1c Lower		1	1/1	1	16	4.34
PF2 Upper	II	2	2/1	2	15	5.5
PF2 Lower	II	2	2/1	2	15	5.5
PF3 Upper	IV	+/-2	2/2	2	16	5.5
PF3 Lower	IV	+/-2	2/2	2	16	5.5
PF4	I	2	2/1	2	16	5.5
PF5	I	3	3/2	3	34	5.5
CHI	I	2	2	2	24	0.8
RWM1,2,3(2)	I	+/-1	1	1	3.33	.5
RWM4,5,6(2)	I	+/-1	1	1	3.33	.5

(1) Power supplies will be provided during next stage
(2) Switching Power Amplifiers are used for these circuits
(3) Available Volts
(4) Peak current in circuit is same as ESW current.

Table 1
NSTX Circuit Types and Ratings (Upgraded system)

Coil circuits

The circuits are listed in the Table 1. Type I are two wire unidirectional; Type II are three wire unidirectional; Type III are two wire bidirectional and, Type IV are three wire bidirectional circuits. A DC current limiting reactor is provided for each branch of the power supply to reduce the rate of rise of short circuit current, and to insure better sharing of the load when parallel branches are used and /or limit the circulating current. The major change for the upgrade is for the TF circuit.

Toroidal Field (TF) Power Loop

The NSTX TF coil (Figure 2) is a Type I circuit. For the upgrade the TF Current has to be increased from 71.17 kA for 1.3 seconds every 300 seconds to 129.8kA pulsed current of 7.2 seconds duration every 2400 seconds. This requires that the number of branches be increased from four to eight parallel power supplies. Also the design has also to be such that the period between the pulses can be reduced from 2400 seconds to 1200 seconds.

Each parallel has two 1 kV Transrex power supply sections in series. One of the sections will be kept on electrical bypass thus effectively acting as a diode. This prevents the other parallel supplies from feeding into a fault across the terminals of one parallel.

The existing four Safety Disconnect Switches (SDS) of the TF with additional parallel supplies will be used. Thus two parallels will feed via each switch. Note that the switches can handle two strings of power supply for the upgrade mode. Limited space makes it very difficult to install additional switches in the first floor. Also the existing TF Ground Switch will be used without any changes.

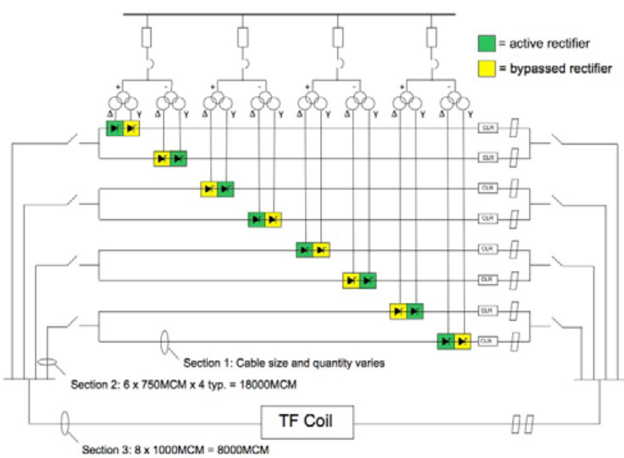

Figure 2
TF Power Supply circuit (Type I)

The power cabling for the TF was enhanced to meet the upgraded requirements. The controls for the TF and OH circuits have been changed to a Programmable Logic Controller (PLC), replacing the electro-mechanical relays used earlier. A new digital Firing Generator (FG) was designed and installed. This receives commands over a fiber optic communication link for the thyristor phase control delay angle “α” and to generate firing pulses at the appropriate phase of the incoming AC voltage. The phase angle command “α” is computed and generated by the Power Supply Real Time Controller (PSRTC) based on the required current. The PSRTC is programmed such that the required coil current gets established. The existing Fault Detector for the rectifiers has been retained but will be replaced with a new design during the second stage.

Two fiber optic DCCTs have been installed in the circuit to measure the total TF current. One of these sets of DCCTs are for control purposes to establish current balance in the branches. The second set will be used for protection.

A. Turn to Turn fault detection

The TF coil for NSTXU has 36 turns. The center stack has all the 36 conductors of the turns. Outside the center stack there are twelve bundles and each bundle has three turns. As stated earlier the TF conductors carry a pulsed current of 129.8kA. Thus each bundle will have about 390kA during the pulse.

A fiber optic DCCT with a sensor cable of 50 meters in length was purchased from Alstom Grid type A COSI CT-F3. This sensor fiber cable has been installed towards the top half of the twelve TF bundles such that the sensor fiber is placed in clockwise direction in one bundle and in the anticlockwise direction in the next bundle. Thus the resultant current sensed is zero under normal operating conditions. If a turn to turn fault develops in any one bundle the resultant current will be nearly130kA as sensed by the fiber. This will initiate a trip. See Figures 3, 4, & 5 for details.

The DCCT has essentially the following parts: a) Sensor Fiber Cable, b) Sensor Intelligence Module, c) Sensor Electronics Chassis. This is a Faraday Effect current sensor. The current in a conductor induces a magnetic field affecting the propagation of light traveling through an optical fiber around the conductor. The resultant angular shift which is directly proportional to the current is measured and amplified. The trip signal from the Electronics Chassis is transmitted to the PLC. When this signal is generated the PLC will issue a command to suppress and bypass the rectifiers.

Based on tests in PPPL, the unit has a time response under 40uS for a step change in current. See Figure 5.

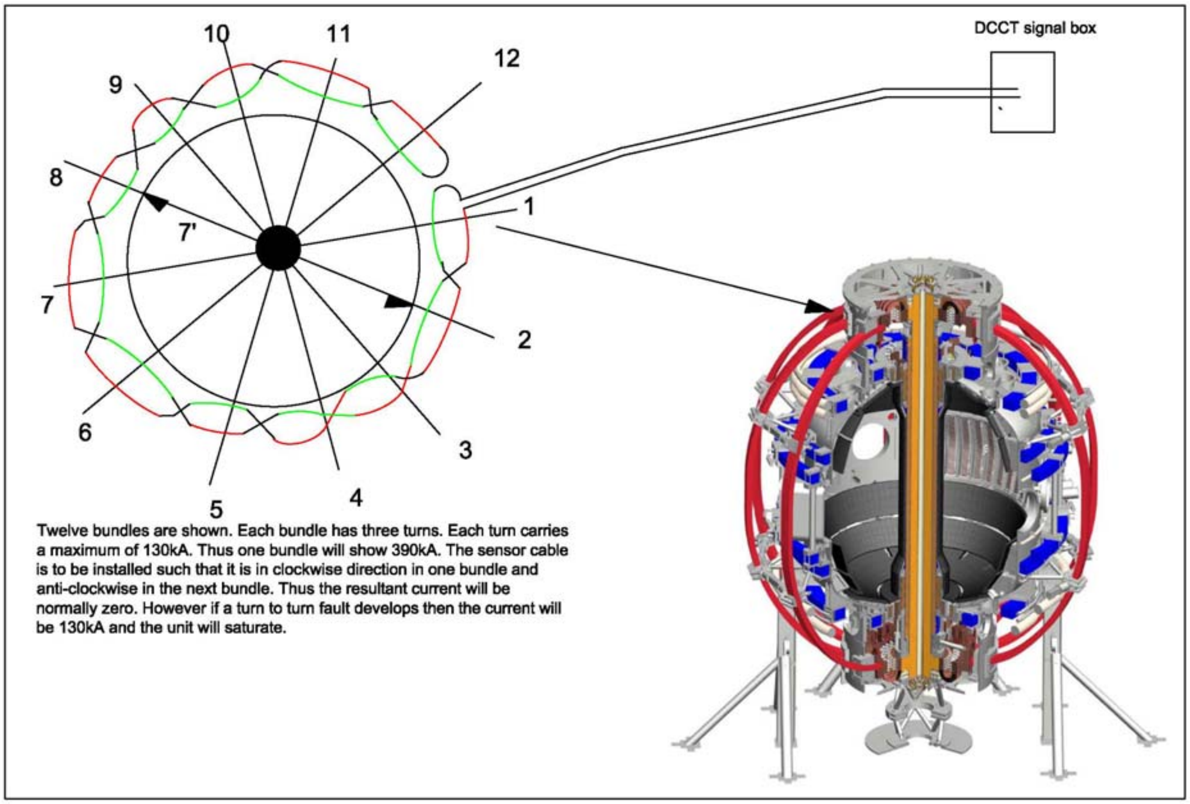

Figure 3
Turn to Turn Fault Detection Scheme - concept

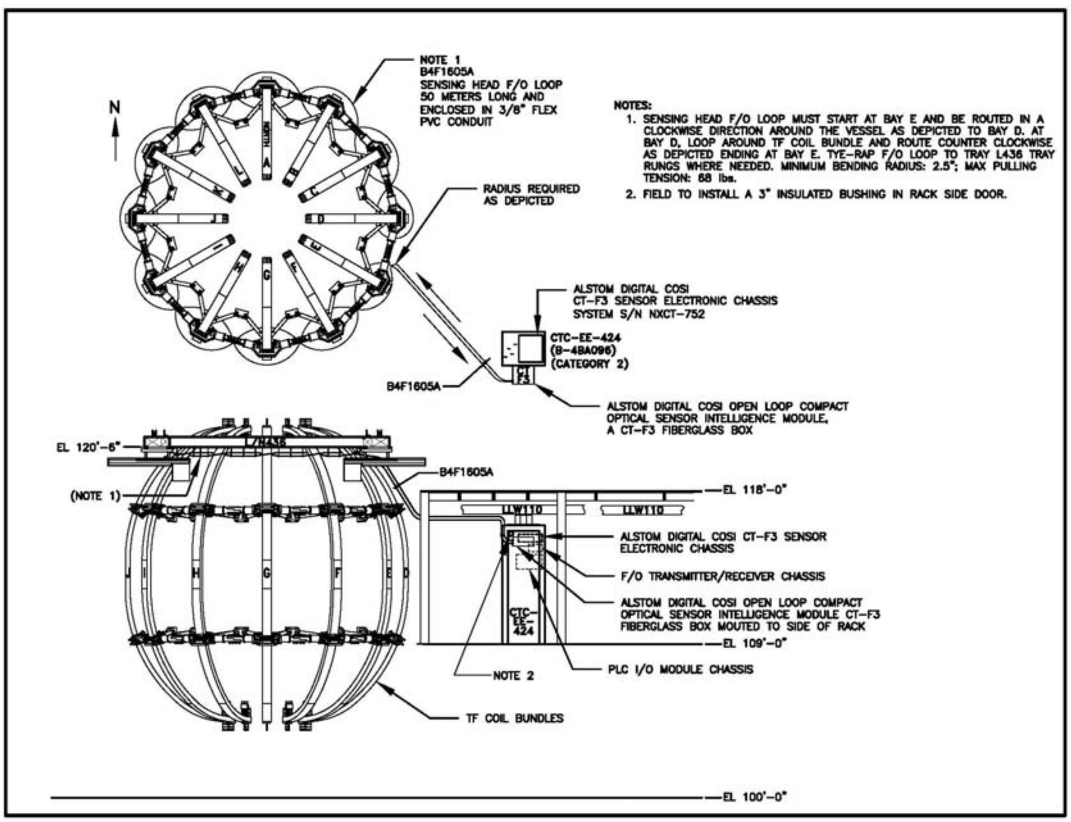

Figure 4
Turn to Turn Fault Detection Scheme installation

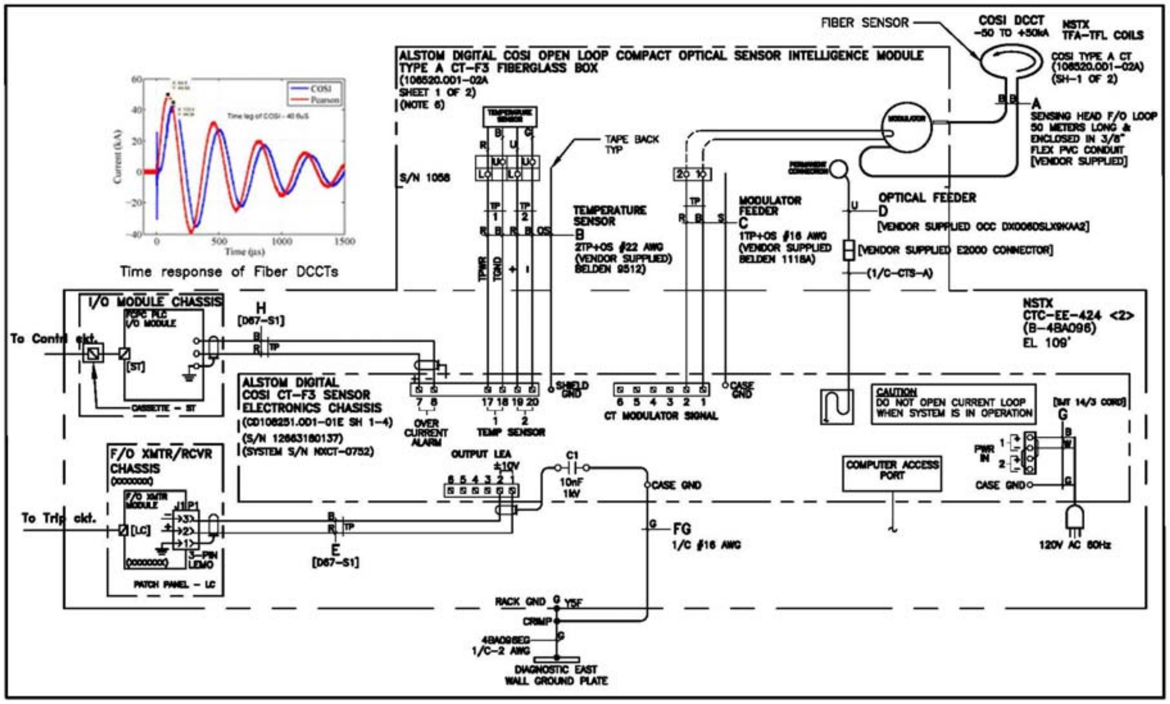

Figure 5
Turn to Turn Fault Detection Scheme wiring diagram

B. Periodic Testing

A 500 turn solenoid is installed through which the sensing fiber is routed. By injecting a current in the solenoid the sensor is tested periodically.

CONCLUSIONS

If a turn to turn fault occurs the sensor installed will detect the resultant change in the affected bundle and initiate a trip. .

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