



**NSTX**

**NSTXU-CALC-53-01-00**

**Modification of the TF Coil Power System PSCAD Model**

**June 15, 2011**

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## PPPL Calculation Form

Page 1 of 1

Calculation # 53-01 Revision # 0 WP #, if any 1540 (ENG-032)

Purpose of Calculation: (Define why the calculation is being performed.)

The TF circuit is to be changed from four parallels to eight parallels to meet the upgrade requirement of 130kA

References (List any source of design information including computer program titles and revision levels.)

1. General Requirements Document: NSTX\_CSU-RQMTS-GRD Revision 3
2. PPPL Calculation # 10-03 : Design Point Spreadsheet by C. Neumeyer
3. Control Wiring Diagram : B-4F1005 Sheet 1501U
4. Statement of Work for PSCAD simulation : D-NSTX-SOW-5X-111
5. Subcontract for PSCAD study with Nayak Corporation: S008914-F

Assumptions (Identify all assumptions made as part of this calculation.)

All the PSCAD data are based on the design point spreadsheet by C. Neumeyer.

The AC system start frequency is 80 Hz.

Calculation (Calculation is either documented here or attached)

See attached document.

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

Some modifications are made to Nayak PSCAD model to analyze the TF coil power system.

The currents in the eight parallel TF coil power supply are balanced.

The short circuit currents are within the limits.

The conductor temperature rise is within the limits.

Cognizant Engineer's printed name, signature, and date

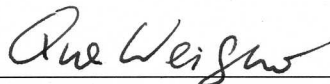
Analysis by Nayak Corporation

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**I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.**

Checker's printed name, signature, and date

Weiguo QUE



06/16/2011

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### 1.1 Modification of TF Power Supply Model

Om's TF power supply model working frequency is 60 Hz. In reality, the motor-generator working frequency is 80 Hz. Some parameters in the PSCAD model need to be changed:  
 [Sync\_Machine] base angular frequency: 60 Hz-> 80 Hz  
 [Multimass] electrical bass frequency: 60 Hz -> 80 Hz  
 [Freq\_Meas] rated frequency: 60 Hz -> 80 Hz  
 [fp\_int] pulse duration: 0.0067 [s] -> 0.0044 [s]

### 1.2 PI Controller

Current is measured in each of the eight branches using ammeters. This means DCCTs dynamics is ignored. These current measurements are used by the converter current controller where a closed loop P-I control algorithm will control the converter firing angle  $\alpha$  such that the current in each branch is  $1/8^{\text{th}}$  of the total TF demanded current. The P-I control includes an inversion angle limiting algorithm with a margin angle  $\gamma$  of  $15^\circ$ . The pulse generation circuit, closed loop current controller and alpha angle limiting circuit are all shown in following figures. Input to the controller is the measured current in the parallel branch and ordered current. The output of the controller is the alpha angle. The proportional gain K is 0.21. The integrator time constant is 3 second. The integrator is applied when I error falls below 6.5 kA.

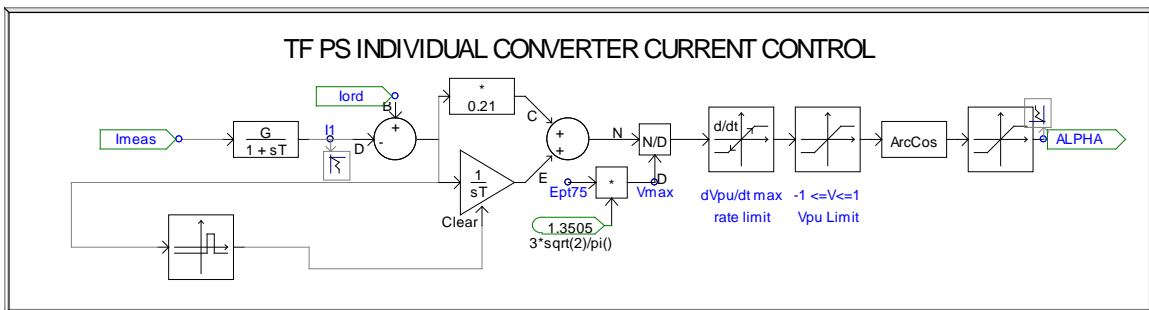
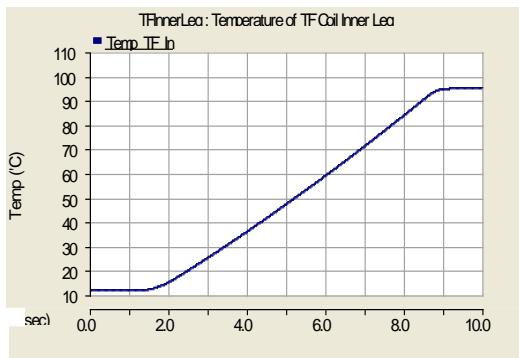


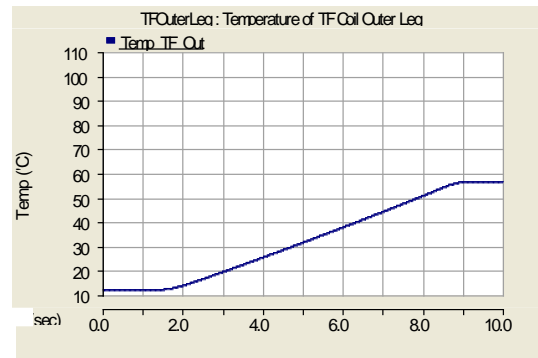
Figure 2: TF power supply PI controller

### 1.3 TF Coil Variable Resistance Calculation Results

Temperature of the coils at any instant of time are calculated using the formulae and data given in Charles's meeting notes for PSCAD model of TF and OH coils. The result is shown in Figure 3.



TF coil inner leg temperature rises from 12 °C to 94.9 °C



TF coil outer leg temperature rises from 12 °C to 56.4 °C

Figure 3: TF coil leg temperature rise during one shot.

### 1.4 TF Coil Current Waveform

TF coil current pulse was initiated at 1 second. The required flat top current is 130 kA and the flat top duration is 6.5 seconds. The TF coil current waveform is shown in Figure 4. The current in each branch is shown in Figure 5. The flat top of the each branch current is about 16.25 kA.

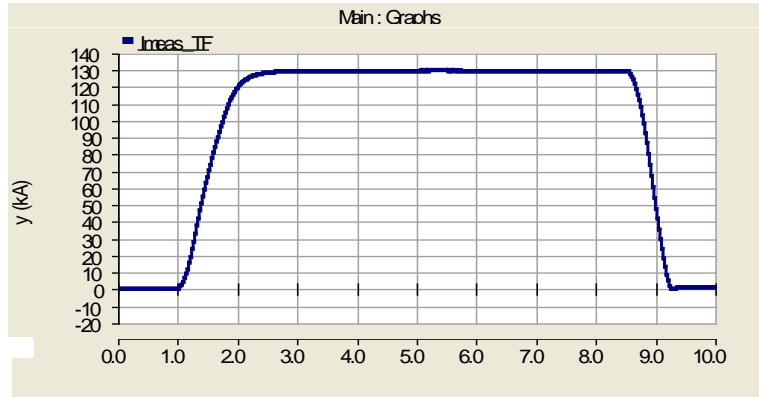


Figure 4: TF coil current waveform

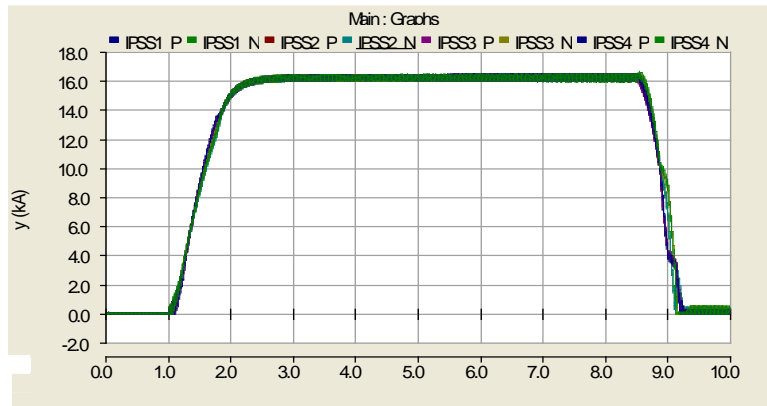


Figure 5: TF power supply eight branches current waveform

### 1.5 TF Waveform $I^2t$ Calculation

TF current waveform  $I^2t$  calculation is performed during the simulation. The result is shown in Figure 6. At the end of the shot, the simulation result of  $I^2t$  is  $1.2007E+5$  (kA\*kA\*Sec). The theory calculation result is  $1.1965E+5$  (kA\*kA\*Sec). The results are very close.

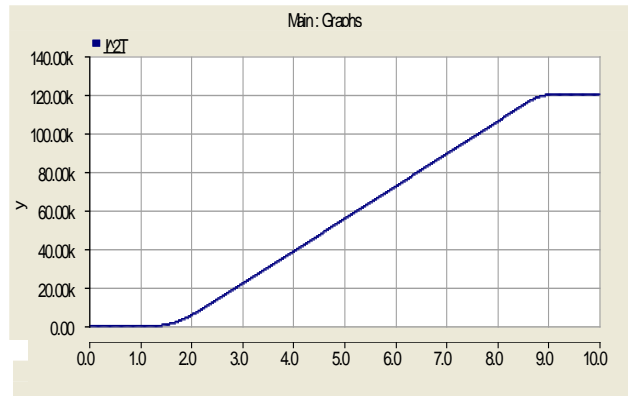


Figure 6: TF waveform  $I^2t$  calculation

### 1.6 TF Current Controller Performance

The output of the PI current controller is the alpha angle. The alpha angle during one shot is shown in Figure 7. The maximum limit of the alpha angle is calculated dynamically based on the converter current and line-to-line voltage which is shown in Figure 7 (blue).

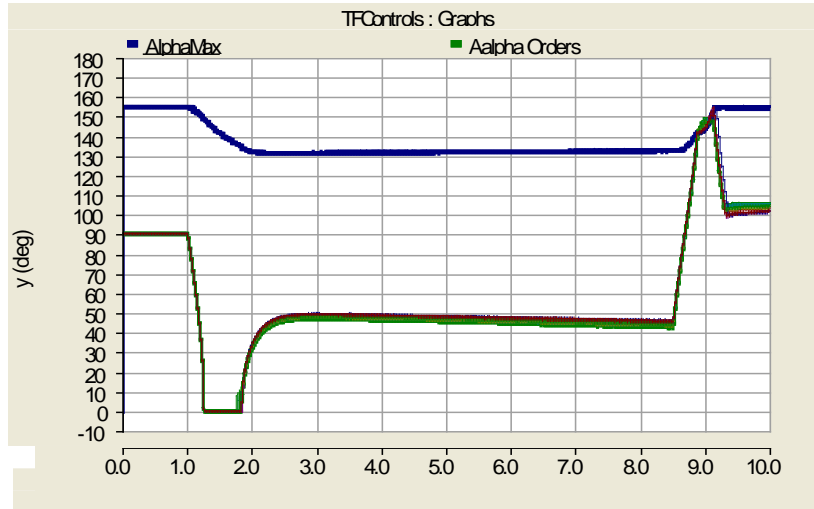


Figure 7: Alpha angle control and alpha limits calculation

### 1.7 Synchronous Machine Performance

The motor-generator AC system frequency drops from 80 Hz to 72.8 Hz. The power reversal after 8.5 second can also be noticed in a slight increase in generator speed.

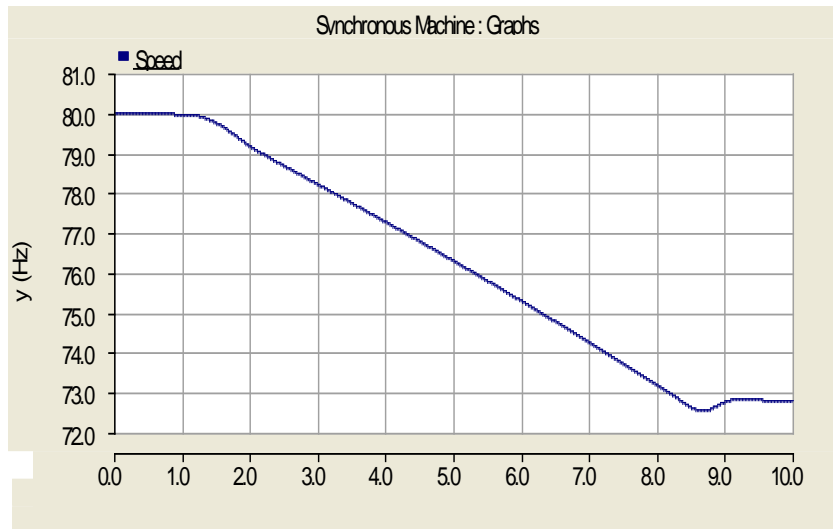


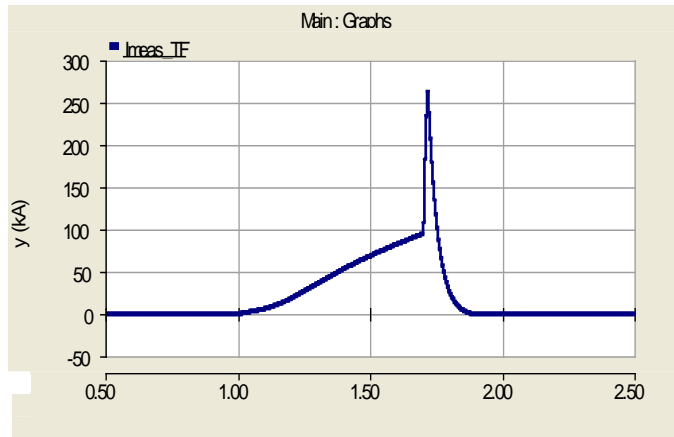
Figure 8: Motor-generator AC system frequency change

### 1.8 Short Circuit Fault at TF Coil

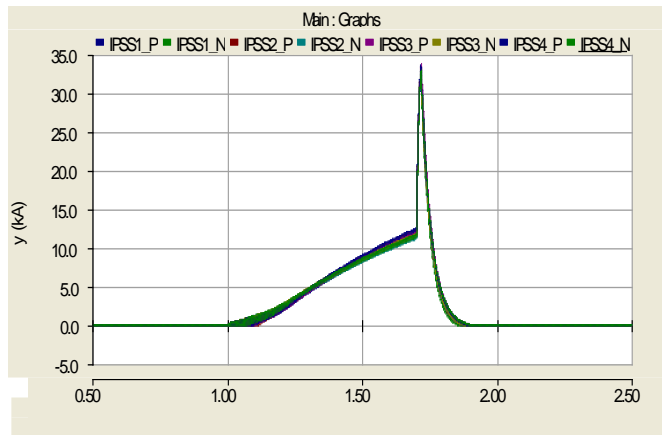
The short circuit fault is at the TF coil. The short circuit current in the TF coil and the branch converter current are calculated. Once the converter currents reach the over-current limit (22 kA), the block and bypass signal is sent out to all the power supply with 10 msec delay. Since the short circuit current is related to the fault time during the shot, the short circuit current is calculated over the entire pulse duration. The maximum TF coil short circuit current is 263.4 kA and it happens at 1.7 second, which is shown in Figure 9.

Table 1: Short circuit at TF coil

Time (sec)	TF Branch Max. Short Circuit Current(kA)	TF Coil Short Circuit Current (kA)
1.2	28.1	219.4
1.4	33.9	262.4
1.5	33.7	262.9
1.6	34.4	263.1
1.7	33.8	263.4
1.8	33.6	262.2
1.9	31.3	242.7
2.0	28.8	225.8
3.0	25.4	199.9
8.0	26.9	211.5
8.6	16.4	126.1



TF coil short circuit current at 1.7 second



TF branch short circuit current at 1.7 second

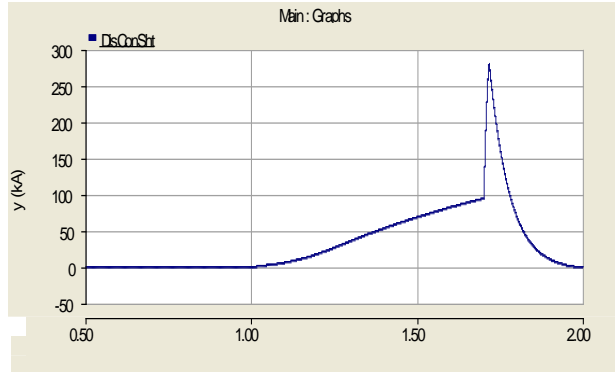
Figure 9: TF coil and power supply branch short circuit current

### 1.9 TF Short Circuit Fault at Disconnect Switch

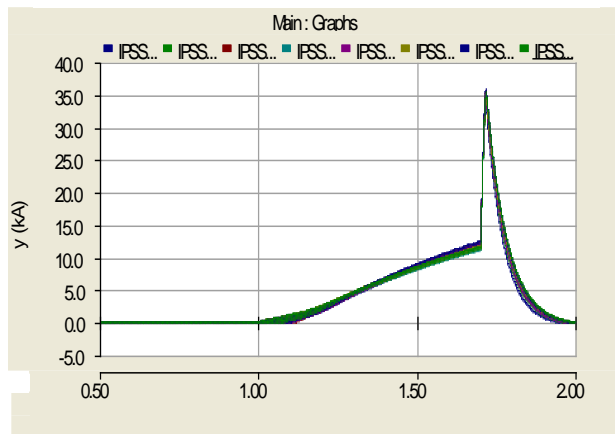
The short circuit fault is at the disconnect switch. The short circuit current simulation results are shown in Table 2 and Figure 10.

Table 2: short circuit at disconnect switch

Time (sec)	Disconnect Switch Short Branch Max. Current (kA)	Total Short Circuit Current (kA)
1.2	30.6	234.7
1.4	35.5	277.1
1.5	35.5	277.6
1.6	35.6	278.3
1.7	35.9	279.7
1.8	35.9	279.7
1.9	33.1	258.6
2.0	31.6	242.1
3.0	27.8	215.6
8.0	29.1	228.3
8.6	17.4	134.1



Total short circuit current at 1.7 second



Branch short circuit current at 1.7 second

Figure 10: TF disconnect switch short circuit fault current



## 2 MODIFICATION of OH COIL POWER SYSTEM PSCAD MODEL

The OH coil is a solenoid centered on the machine axis which acts like the primary of a transformer. To maximize the delivery of flux to the plasma while limiting mechanical stress, the OH coil is operated bi-directionally. So the objective of the OH power supply is to initialize the current as rapidly as possible and then to provide control with 4-quadrant operation at  $V=+/-6kV$  and  $I=+/-24kA$ . Two anti-parallel branches are used and each branch has three power supplies in series. Each of the branches will include a Current Limiting Reactor (CLR), inductance value of which will be designed using this PSCAD model.

Some modifications are made to Om Nayak PSCAD model:

- 1: The OH power supply is changed from 8 kV to 6kV and the load inductance is changed from 57.4 mH to 42.9 mH.
- 2: AC power system start frequency is changed from 60 Hz to 80 Hz.

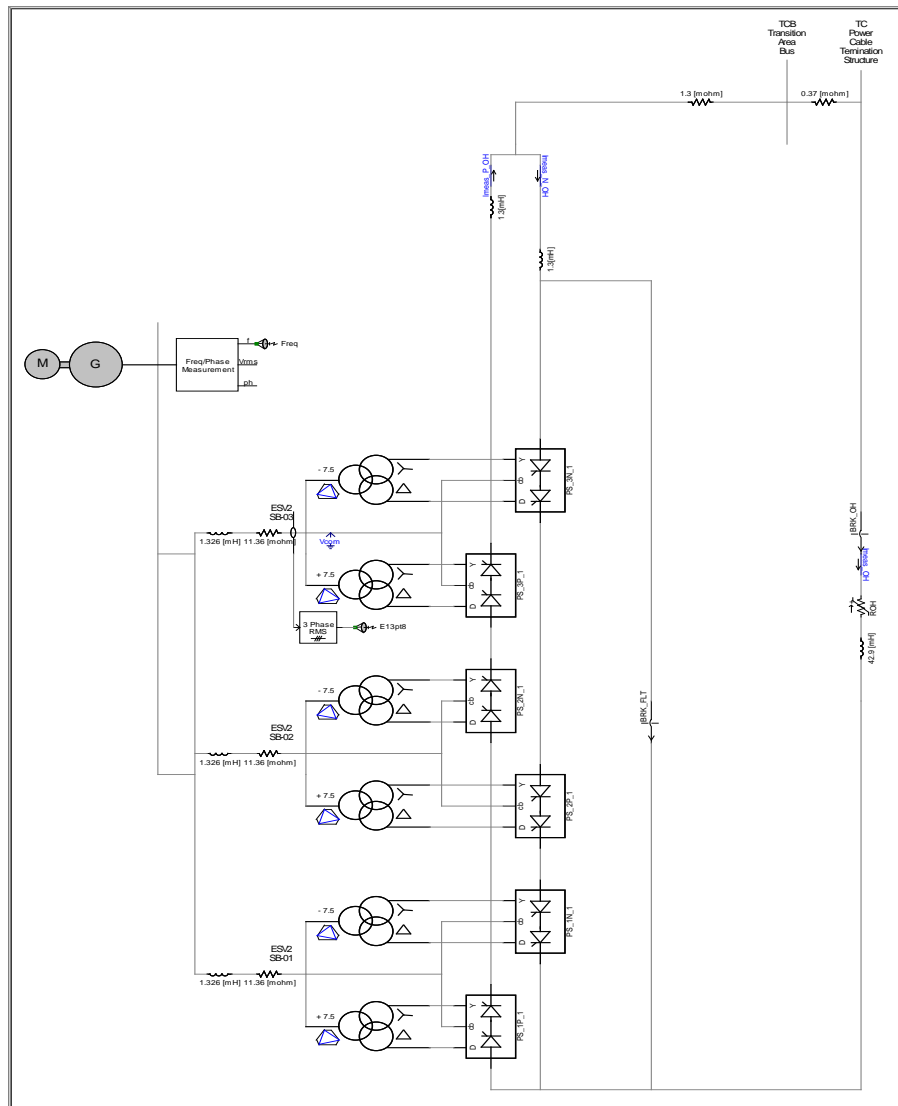


Figure 11: OH power supply system schematic

### 2.1 Modification of OH Power Supply Model

Om's OH power supply model operates at 8KV. The new model operates at 6 kV. The working frequency is also changed from 60 Hz to 80 Hz. Some parameters need to be changed as section 1.1, TF power supply.

### 2.2 PI Controller

The proportional gain K is 0.25. The integrator time constant is 3 second. The integrator is applied when I error falls below 8.5 kA. OH\_V\_RateLimit is 8 [1/s]. The short circuit breaker resistance is 5.5 uohm.

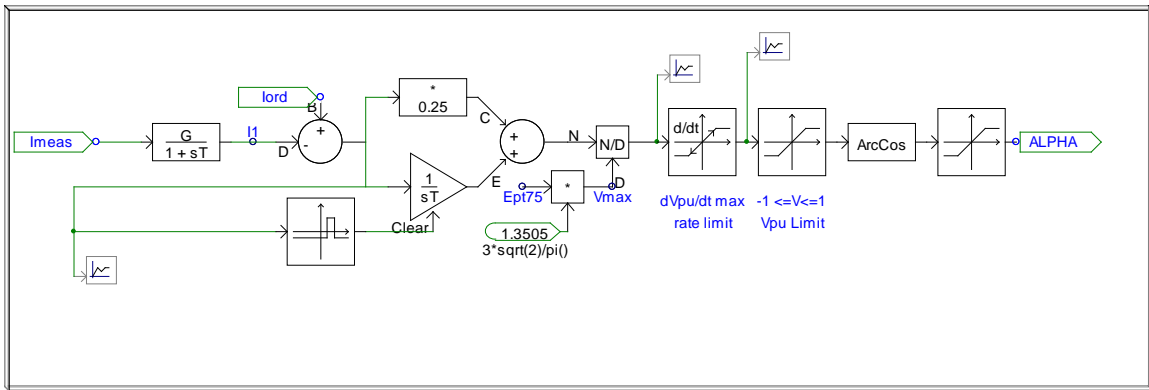


Figure 12: OH power supply PI controller

### 2.3 OH Coil Current Waveform

OH coil current pulse was initiated at 3 second. The OH coil current waveform is shown in Figure 13. The green curve is the ideal current waveform and the blue curve is the real current waveform using the P\_I controller.

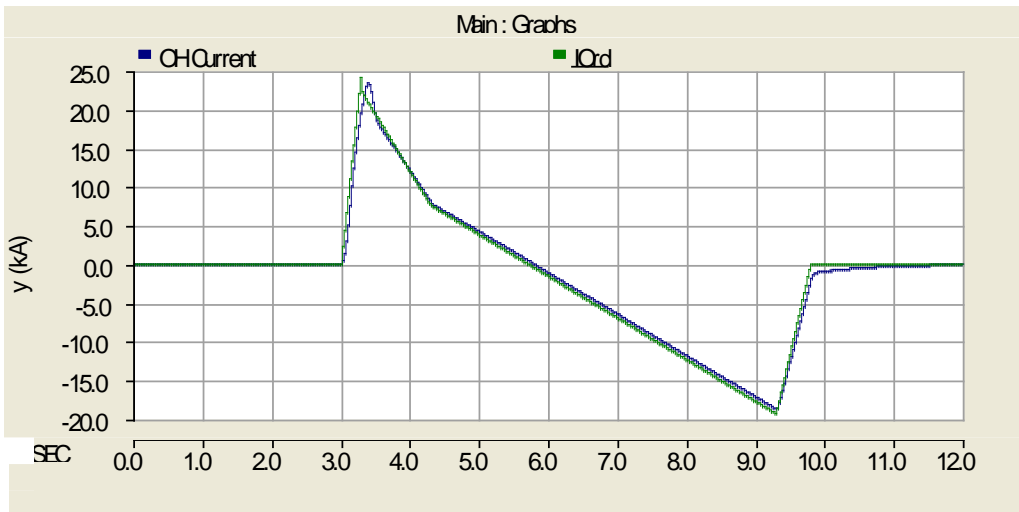


Figure 13: OH coil current waveform

## 2.4 OH Current Limiting Reactor (CLR) Performance

The current limiting reactor value need to be determined based on the performance under the short circuit fault. Two short circuit fault conditions are chosen for the evaluation. Once the converter currents reach the over-current limit (28 kA), the block and bypass signal is sent out to all the power supply with 16 msec delay.

### 2.4.1 The negative branch is shorted while the positive branch is conducting.

The short circuit current is calculated at the different fault time with 540 uH CLR. At 3.3 second, the positive branch short circuit current is worst. The short circuit current is also calculated with different CLR value at the same fault time (3.3 second).

Table 3: OH short circuit current using 540 uH CLR at different fault time

Time (sec)	Positive Branch Short circuit (kA)	Negative Branch Current (kA)	OH Coil Current (kA)
3.1	47.9	42.8	5.1
3.2	48.7	34.8	13.9
3.3	48.8	28.9	19.9
3.4	33.0	10.8	22.2
3.5	36.5	18.7	17.8
3.6	38.7	22.5	16.2
3.7	37.9	22.9	15.0
3.8	37.1	23.5	13.6

Table 4: OH short circuit current at 3.3 second using different CLR

CLR Value (uH)	Positive Branch Short circuit (kA)	Negative Branch Current (kA)	OH Coil Current (kA)
540	48.8	28.9	19.9
750	46.9	27.0	19.9
1000	44.7	24.8	19.9
1300	42.7	22.8	19.9

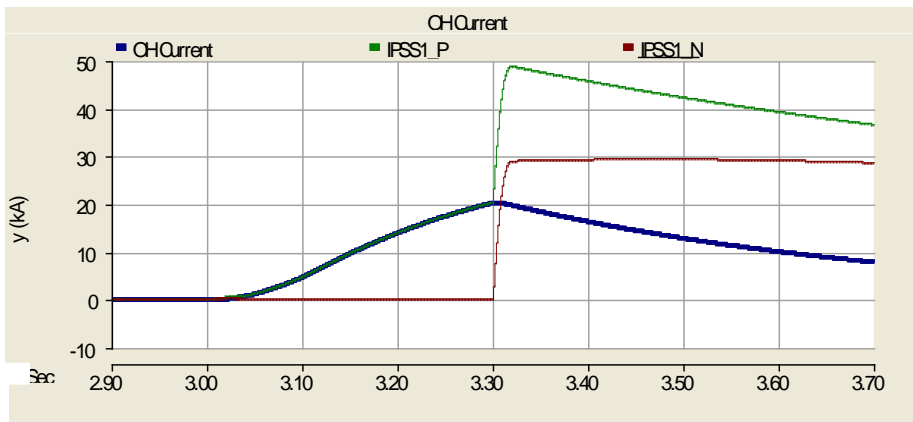


Figure 14: OH coil and branch short circuit current waveform using 540 uH CLR (fault at 3.3 second)

**2.4.2 The positive branch is shorted while the negative branch is conducting.**

The short circuit current is calculated at the different fault time with 540 uH CLR. At 9.2 second, the negative branch short circuit current is worst. The short circuit current is also calculated with different CLR value at the same fault time (9.2 second).

Table 5: OH short circuit current using 540 uH CLR at different fault time

Time (sec)	Positive Branch Short circuit (kA)	Negative Branch Current (kA)	OH Coil Current (kA)
8.0	28.4	39.5	11.1
8.5	28.7	42.4	13.7
9.0	30.8	47.1	16.3
9.1	30.9	47.6	16.7
9.2	31.1	48.4	17.3
9.3	27.0	44.6	17.6
9.4	19.3	33.1	13.8

Table 6: OH short circuit current at 9.2 second using different CLR

CLR Value (uH)	Positive Branch Short circuit (kA)	Negative Branch Current (kA)	OH Coil Current (kA)
540	31.1	48.4	17.3
750	28.9	46.2	17.3
1000	26.5	43.8	17.3
1300	24.8	42.1	17.3

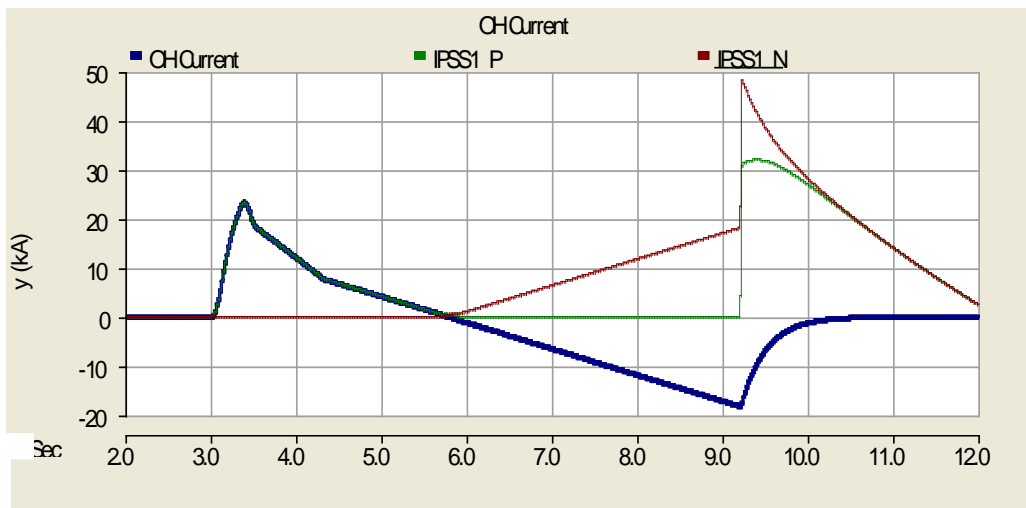


Figure 15: OH coil and branch short circuit current waveform using 540 uH CLR (fault at 9.2 second)



# Statement of Work (SOW)

for

Development of PSCAD Simulation Models for the  
TF & OH Power Systems of the NSTX Center Stack  
Upgrade

D-NSTX-SOW-5X-111

**Prepared by:** \_\_\_\_\_

**Approved by:** \_\_\_\_\_



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# **1 INTRODUCTION**

National Spherical Torus Experiment (NSTX) is a magnetic fusion confinement device which has been in operation since 1999. An upgrade project is underway which will replace the central core of the machine, called the “Center Stack”, consisting of the inner legs of the Toroidal Field (TF) coil as well as the Ohmic Heating (OH) coil, with a new assembly of a larger diameter operating at higher current and magnetic field levels. The upgraded device will be in operation in 2011.

Changes in the TF and OH power supply systems are necessary to meet the requirements of the new coils. The upgraded power supply systems need to be analyzed to confirm that they meet the performance requirements and that their short circuit behavior is within the limits of the associated equipment. The PSCAD software was used to perform the analysis of the original design and is the preferred tool to model and analyze the upgraded design. For reasons of efficiency it is desired to subcontract the creation of the PSCAD models to outside experts. The models thus created will be used by PPPL staff, with consultation by the experts who created them, to study the power supply systems’ behavior and to establish the design basis.

The PSCAD study must be completed by August 15<sup>th</sup> 2009 in order to support several design reviews which will be held soon thereafter. In order to meet this schedule the PSCAD tools should be ready for use by June 15<sup>th</sup> 2009.

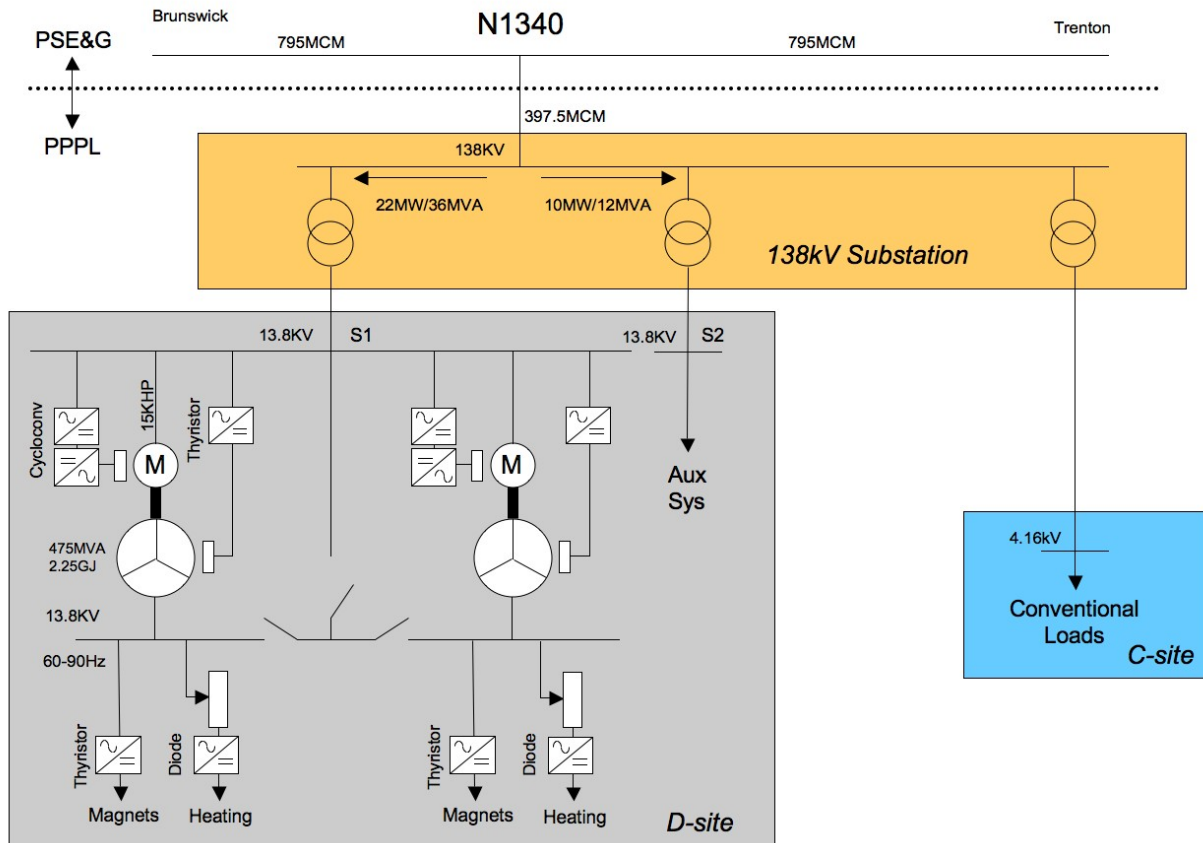
This document outlines the features and functions to be included in the TF and OH models and gives the schematics and parameters of the circuits and components.

## **1.1 BACKGROUND**

### **1.1.1 AC Power System**

PPPL receives AC power from the grid at 138kV but, other than special test cases, does not use it directly for powering its experimental devices. Instead, a pair of large vertical shaft motor-generator (MG) sets are charged up using grid power and used as energy storage devices to provide pulsed power to experiments such as NSTX. A simplified one-line diagram is given in Figure 1.





**Figure 1 PPPL AC Power System**

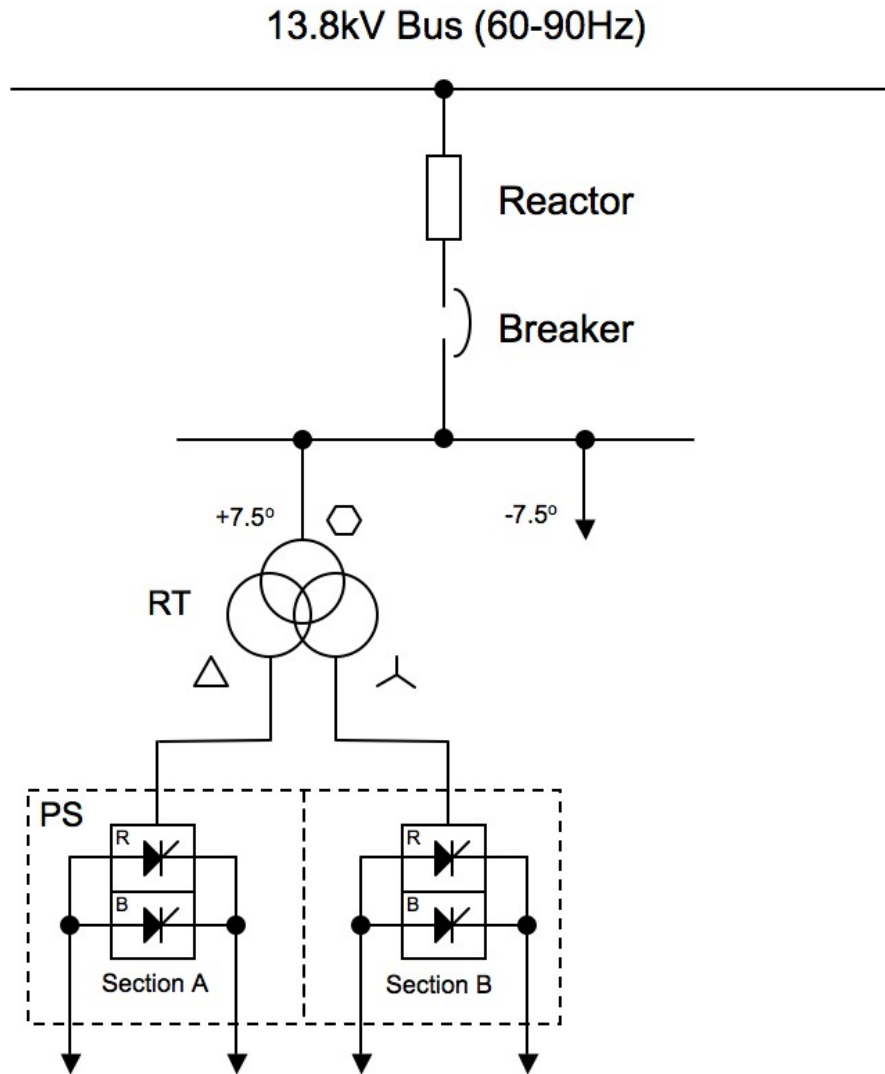
For NSTX, only one of the two MG sets will be used since it has sufficient capacity. A summary of the generator characteristics, along with the current limiting reactor at the output (not shown in Figure 1, but which limits short circuit current downstream), is given in file “D-Site\_Generator\_Reactor\_Specs.pdf” attached to this SOW.

### 1.1.2 Power Supplies

PPPL utilizes a standard, modular thyristor AC/DC converter unit with multiple units connected in series, parallel, and anti-parallel as necessary to power the TF and OH systems. As depicted in Figure 2 each “Power Supply” (PS) includes a three winding “Rectifier Transformer” (RT) and two “Power Supply Sections” (PSS). Each PSS consists of a 6-pulse bridge rectifier (R) external thyristor bypass (B).

The transformer primary windings are Polygon/Delta-Wye, with the polygon arranged to produce either  $+7.5^\circ$  or  $-7.5^\circ$  phase shift depending on the phase sequence of the 13.8 kV input

to the polygon. Thus an effective 24 pulse conversion can be accomplished. Details of the transformer are given in “FCPC\_Transformer\_Specs.pdf” attached to this SOW.

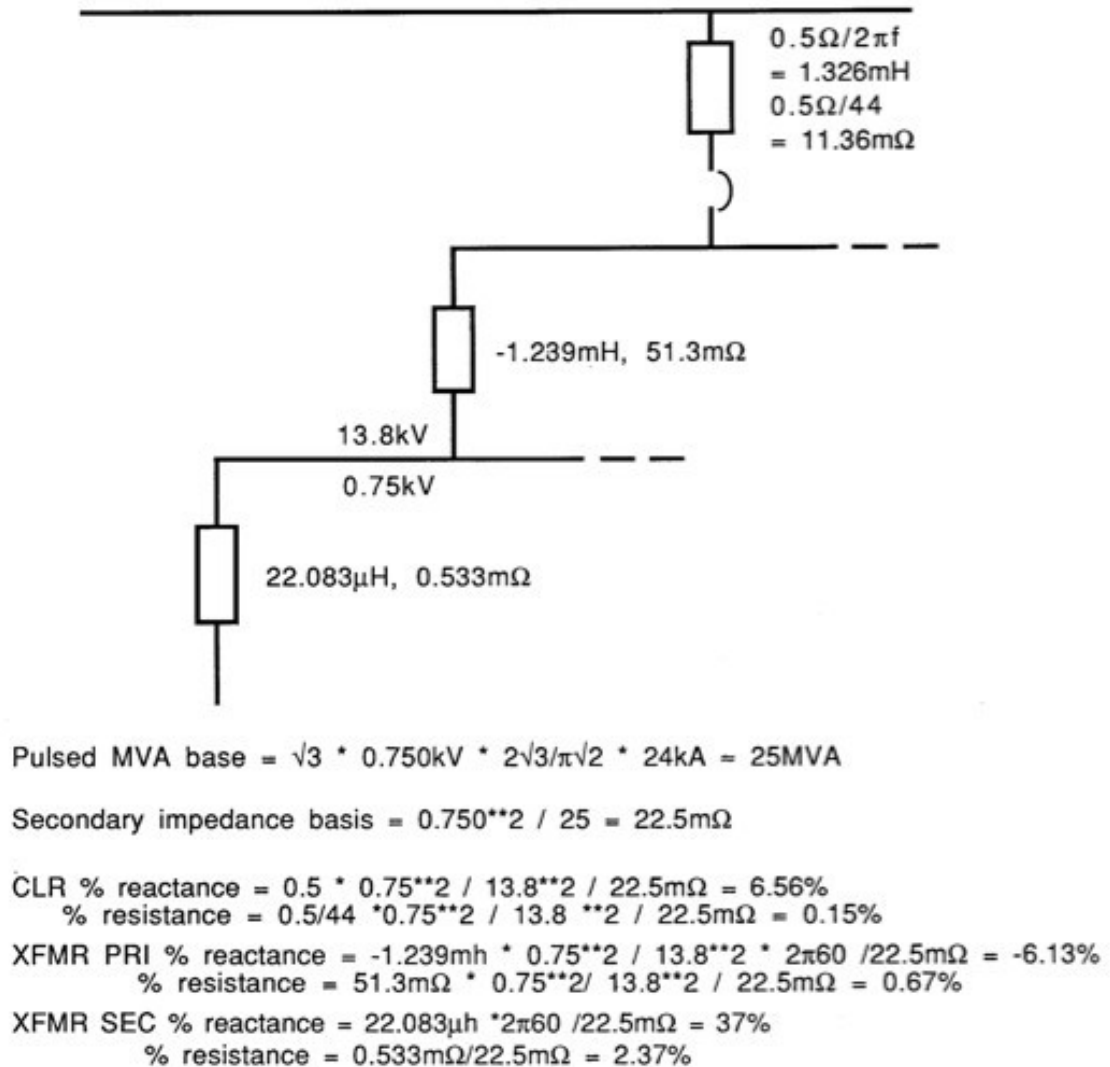


**Figure 2 Standard Power Supply Unit**

Each PSS is rated 1 kV/24 kA-6sec/300sec. Each PSS consists of a 6-pulse bridge rectifier (R) external thyristor bypass (B). The 6-pulse bridge rectifier R consists of six parallel “Power Modules” (PM). Each PM is a 6-pulse bridge consisting of two series thyristors in each bridge arm, total of twelve thyristors per PM, total of 2 series x 6 parallel thyristors per bridge arm position in each R of each PSS. The thyristor bypass B consists of two parallel “Bypass Modules” (BM). Each BM consists of six parallel paths, each with two series thyristors, total of twelve thyristors per BM, total of 2 series x 12 parallel positions in each B of each PSS. All

thyristors are identical with on-state resistance of  $152\mu\Omega$  and forward voltage drop of  $0.94V$ . Each thyristor is equipped with an RC snubber with  $R=15\Omega$  and  $C = 1\mu F$ .

An impedance diagram of the standard PS unit is given in Figure 3.



**Figure 3 Impedance Diagram of Standard Power Supply Unit**

Each PSS accepts a control command corresponding to the thyristor delay angle  $\alpha$ , as well as control bits for “Convert” (controls whether or not the rectifier thyristor gates are suppressed or fired) and “Block Bypass” (controls whether or not the bypass thyristor gates are suppressed or fired controls whether or not the rectifier thyristor gates are suppressed or fired).

Each PS includes a “Fault Detector” (FD) which detects various fault conditions such as overcurrent and reacts by overriding the “Convert” and “Block Bypass” control commands and forces the unit into a state where the gate pulses to the rectifier PM thyristors are suppressed and those to the BM thyristors are fired.

A centralized real-time control computer called the “Power Supply Real Time Controller” (PSRTC) executes control algorithms based on reference inputs from a higher level “Plasma Control System” (PCS) as well as coil current measurements and, once every millisecond, issues updated commands to the power supply units (Convert, Block Bypass, and  $\alpha$ ).

### 1.1.3 Toroidal Field (TF) System

The objective of the TF power supply is to drive the current to its “flat top” value as soon as possible, to hold the current constant during flat top for a specified duration, and then to discharge the current as soon as possible. The system design must include contingency for the case when a fault in the power supply system prevents the controlled discharge of the current such that it discharges exponentially according to its L/R time. The TF waveform required for the CS upgrade is given in Figure 4, based on a simple model of the power supply behavior. The required flat top current is 129.6kA and the flat top duration is 6.5 seconds.

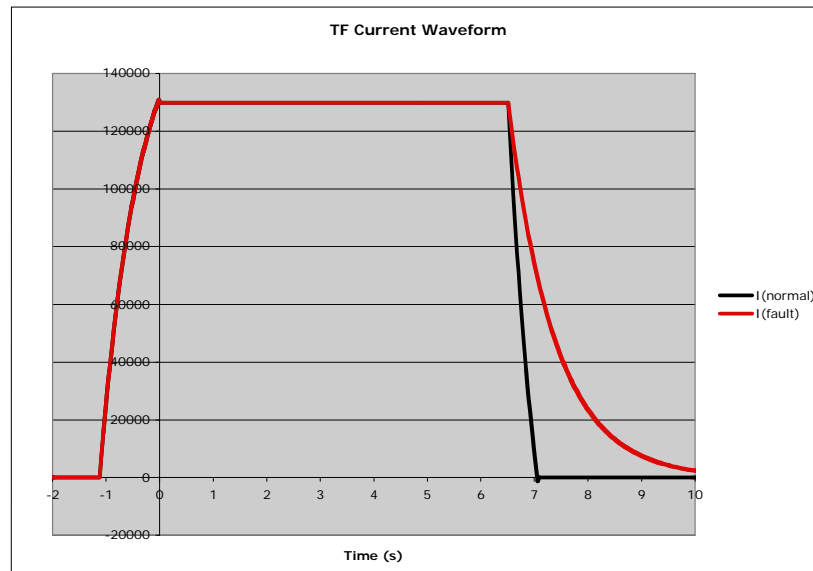
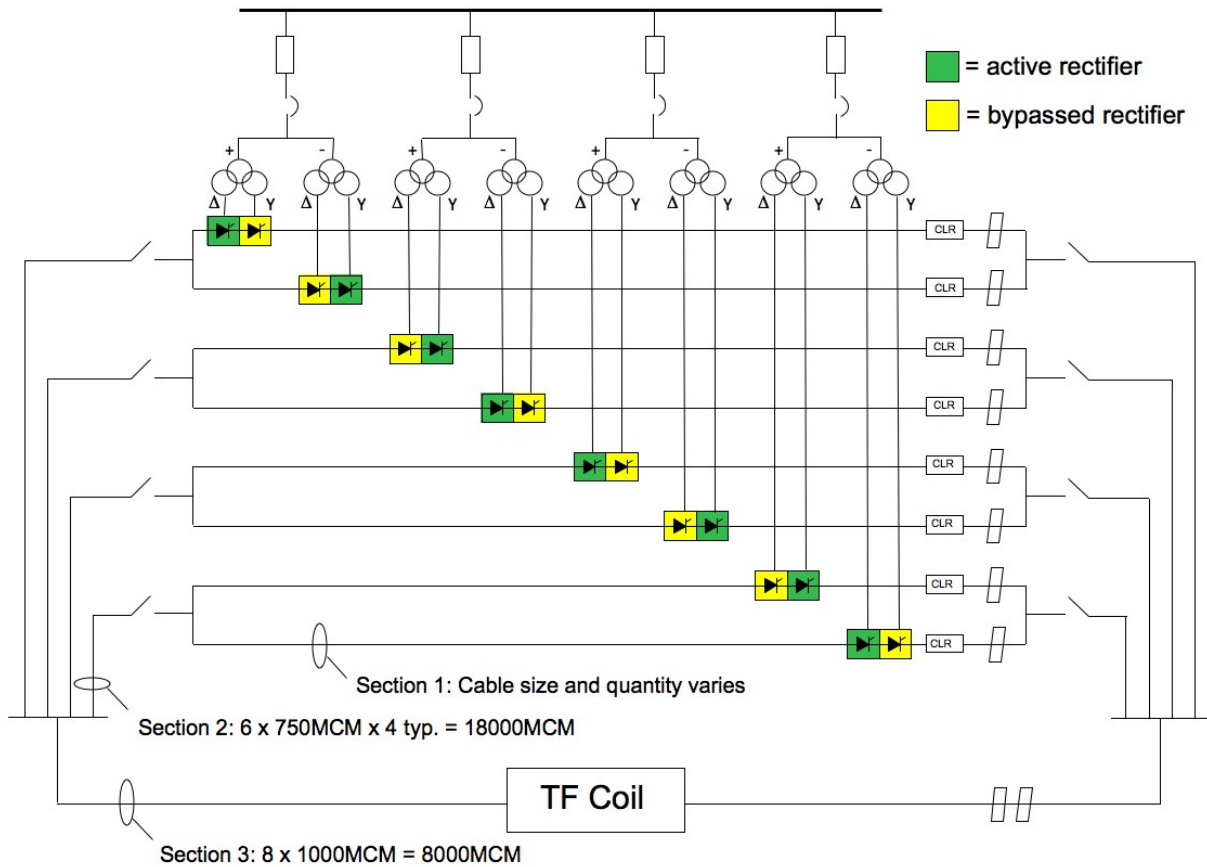


Figure 4 TF Current Waveform

A simplified schematic of the TF power supply system is given in Figure 5.



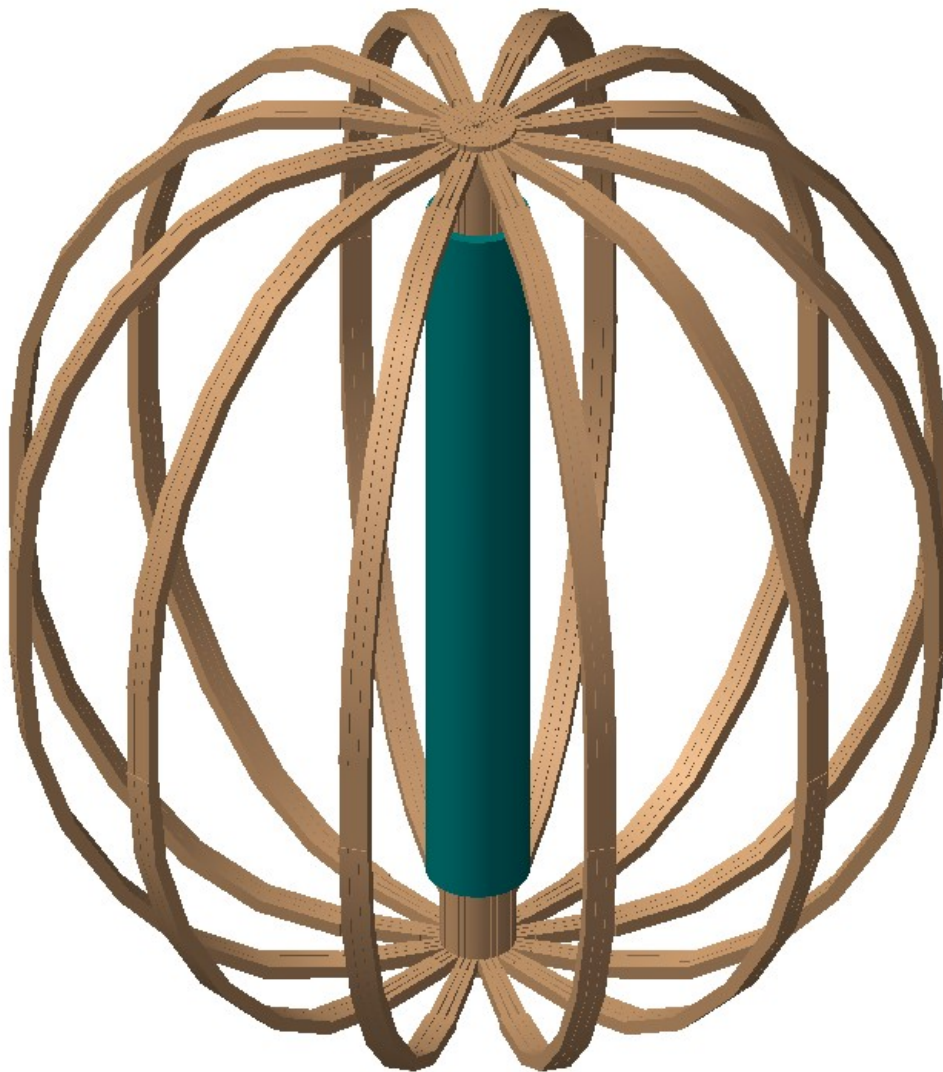
**Figure 5 Simplified Schematic of TF Power Supply System**

Eight parallel branches are used, each with one power supply unit (two series PSS). One of the two series PSS will be active as a rectifier, the other will be bypassed. This is based on the requirement for a 1kV driving voltage for the TF system, and the use of the bypassed PSS acting as a redundant blocking device in case of a short circuit in the PSS, preventing the other seven branches from back-feeding such a fault. Each branch consists of one active PSS with phase shifts such that there are two sets of four PSS in parallel, each set forming a 24-pulse converter.

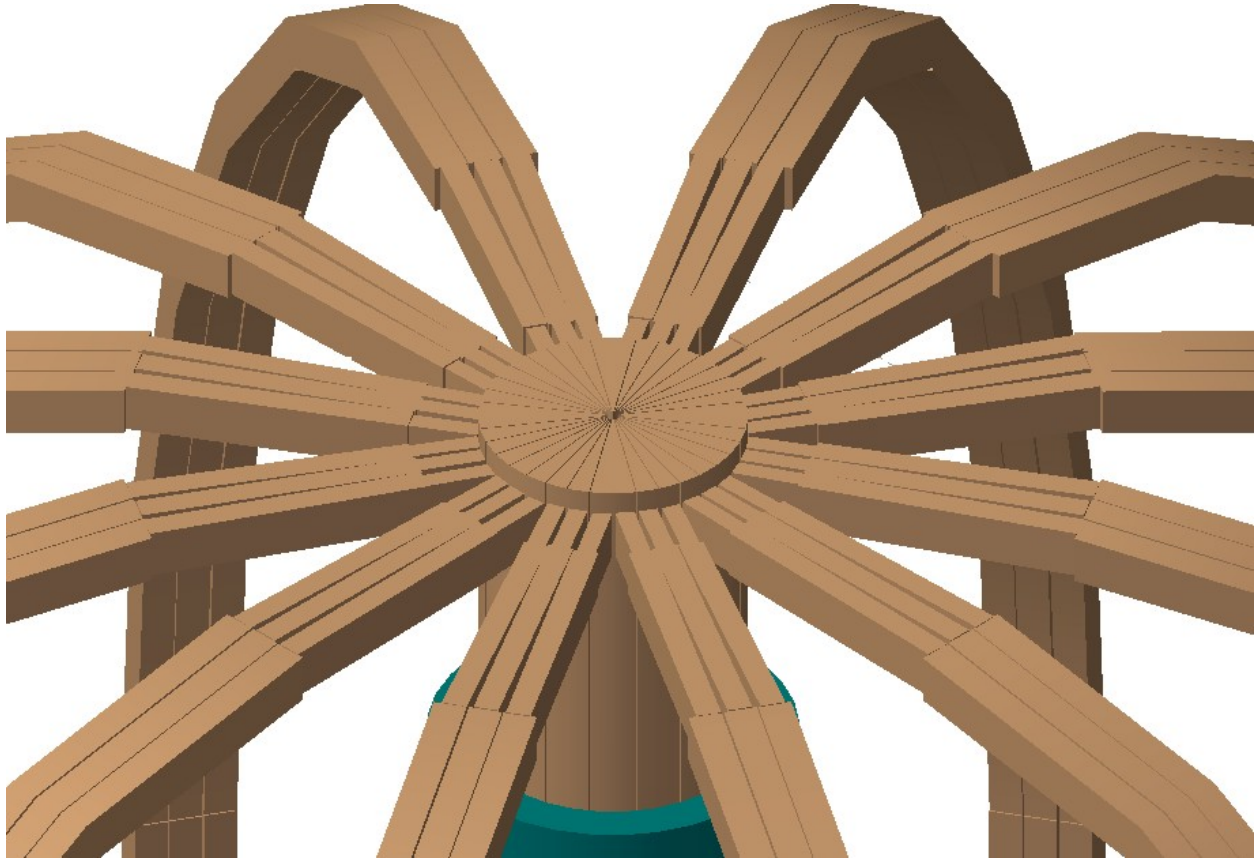
Each of the eight branches will be provided with a 270uH Current Limiting Reactor (CLR). Due to the physical layout of the equipment and details associated with the modification of and additions to existing cable runs, the cabling details of the eight parallels differ somewhat, such that their cable resistances are imbalanced. However, this effect is swamped by other series impedances. See circuit schematic B-4F1005 Sheet 1501U (attached to this SOW as file “TF\_Schematic.pdf”) for details including the branch resistance values.

Current is measured in each of the eight branches using DCCTs. These current measurements are monitored by the PSRTC where a closed loop P-I control algorithm will target the current in each branch to be 1/8 of the total TF demanded current. The P-I control will include an inversion angle limiting algorithm with a margin angle  $\gamma$  of  $15^\circ$ .

The TF coil consists of 36 turns connected in series. As shown in Figure 6 and Figure 7 each turn includes a wedge shaped inner leg section on the axis of the NSTX machine and an outer leg return section.



**Figure 6 TF Coil and OH Solenoid**



**Figure 7 TF Coil, Zoom View**

Characteristics of the inner and outer leg turns are given in Table 1.

**Table 1 TF Coil Inner and Outer Leg Characteristics**

		Inner Leg	Outer Leg
Conductor net cross sectional area (copper)	sq mm	2872	3775
Conductor length (per turn)	sq m	5.33	6.90

The TF coil is water cooled but the effect of the cooling can be neglected during the pulse. The starting temperature at the beginning of a pulse is 12°C, and the bulk average temperature at the end of the pulse is approximately 100°C in the inner legs and 50°C in the outer leg.

The inductance of the TF coil is 4.5mH.

### 1.1.4 Ohmic Heating (OH) System

The OH coil is, in effect, a solenoid centered on the machine axis which acts like the primary of a transformer. The objective of the OH coil is to develop an initial magnetic flux, and then once the plasma region is ionized and forms a single turn secondary to the transformer, to drive the plasma current by induction. To maximize the delivery of flux to the plasma while limiting mechanical stress, the OH coil is operated bi-directionally. So the objective of the OH power supply is to initialize the current as rapidly as possible and then to provide control with 4-quadrant operation at  $V=+/-8kV$  and  $I=+/-24kA$ .

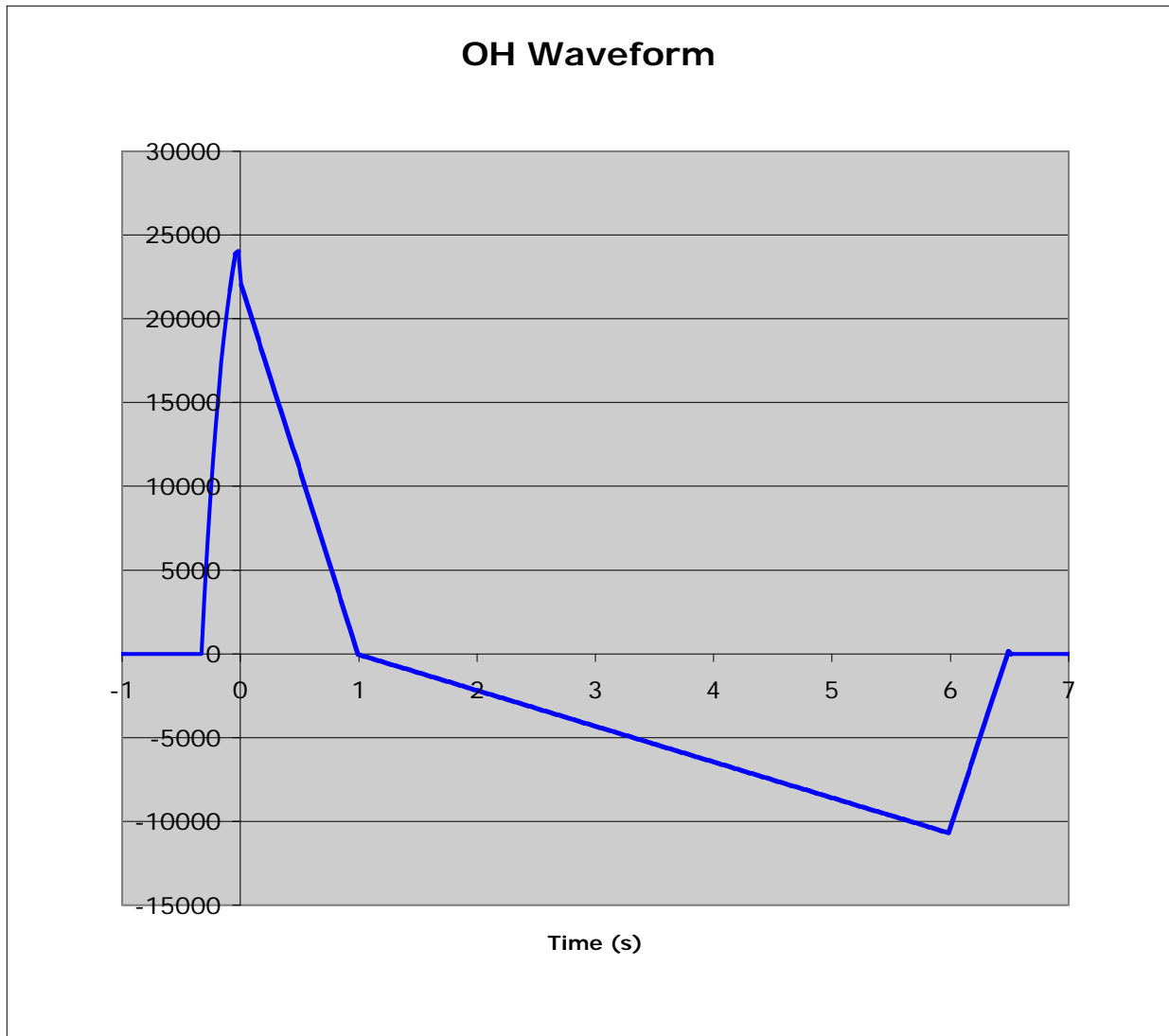


Figure 8 OH Current Waveform



A simplified schematic of the OH power supply system is given in

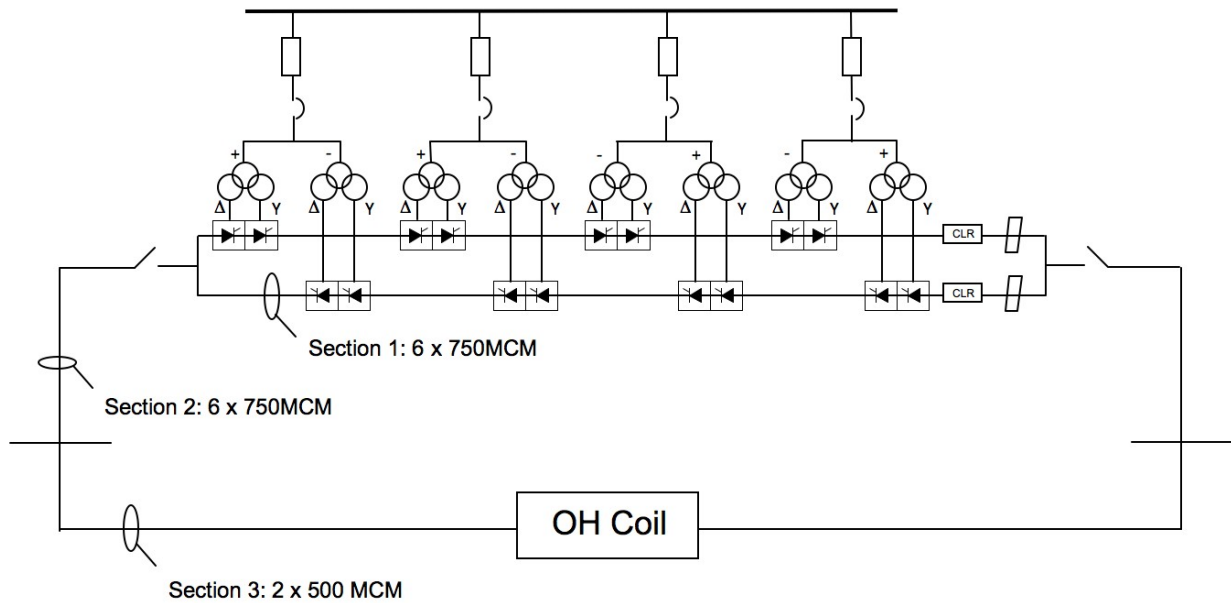
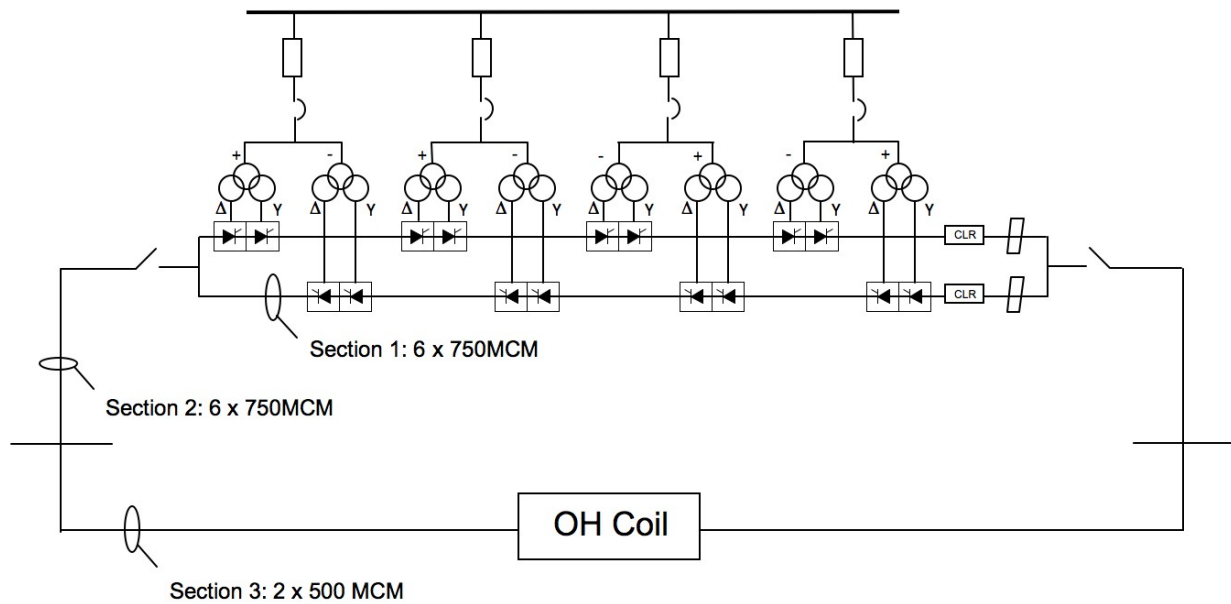


Figure 9.



**Figure 9 Simplified Schematic of OH System**

Two anti-parallel branches are used, each with four power supply units, eight series PSS. Each of the branches will include a Current Limiting Reactor (CLR), inductance value TBD. Each branch consists of two sets of four PSS in series, with each set forming a 24-pulse converter.

Thus if all PSS are switched in, the instantaneous voltages of each branch are equal. See circuit schematic B-4F1005 Sheet 1515U (attached to this SOW as “OH\_Schematic.pdf”) for details including the branch resistance values.

Current is measured in each of the branches using DCCTs. These current measurements are monitored by the PSRTC where a closed loop P-I control algorithm will feedback on a targeted reference current. The P-I control will include an inversion angle limiting algorithm with a margin angle  $\gamma$  of  $15^\circ$

The PSRTC also will manage anti-parallel operation whereby, within a specified current band around current zero, a circulating current control will be used such that the firing angle of the two branches (“Forward” (F) and “Reverse” (R)) are related according to  $\alpha_R=180^\circ-\alpha_F$ . Outside the current band, only the active branch will receive gate pulses via the “Convert” command and the inactive branch will be blocked via the “Convert” and “Block Bypass” commands.

The OH coil is a solenoid which is wound around the inner leg of the TF coil as shown in **Figure 6**. Characteristics of the coil conductor is given in Table 2.

**Table 2 OH Coil Conductor Characteristics**

Conductor net cross sectional area (copper)	sq mm	167.4
Conductor length	m	1556

The OH coil is water cooled but the effect of the cooling can be neglected during the pulse. The starting temperature at the beginning of a pulse is  $12^\circ\text{C}$ , and the bulk average temperature at the end of the pulse is approximately  $100^\circ\text{C}$ .

The inductance of the OH coil is 57.4mH.

## **2 MODELING REQUIREMENTS**

Modeling shall be performed in PSCAD. The following sections outline the requirements for the modeling of the MG sets, power supplies, and the TF and OH systems. Ideally the TF and OH system models will be set up to run simultaneously, but this is not a strict requirement (in case the model becomes too large or the execution time becomes too long). The advantage of combined modeling would be the more accurate simulation of MG slowdown.

## **2.1 MG SET**

Modeling of the MG set (only one will be used) shall be sufficiently detailed to capture the following effects:

- adjustable starting speed over the range of 50-90Hz
- withdrawal of energy and consequential slowdown and change in AC frequency due to:
  - electrical power output to system(s) being modeled (i.e. TF and/or OH);
  - electrical power output to “Neutral Beam Injection” (NBI) system according to a data table;
  - electrical power output to “Poloidal Field” (PF) power supply system according to a data table;
  - windage and friction.
- effective impedance during short circuit including output reactor.

Note that it is not necessary to model the motor behavior, it can be assumed turned off during the pulse. Also, it is not necessary to model the exciter response, the 13.8kV bus can be assumed constant voltage (infinite) for load studies other than short circuit.

## **2.2 POWER SUPPLIES**

### **2.2.1 Rectifier Transformers**

Initial work can use a simple three-impedance representation of the three-winding transformer, and the  $\pm 7.5^\circ$  phase shift feature can be neglected. However it is desirable to develop a full mutual inductance model of the transformer in the final phase of the work including the phase shifts.

### **2.2.2 Rectifier and Bypass**

The rectifiers, comprised of the parallel power modules (PM), can be modeled as single entities with equivalent impedances for the series/parallel thyristors and their snubbers; it is not required to model the individual PM. The same is true for the bypass modules BM.

### **2.2.3 Control**

The rectifier modeling shall include phase locked loop gate pulse control including inversion angle limiting and anti-parallel control (in the OH) with adjustable inputs for  $\gamma$  and the current level for parallel/anti-parallel transition.

The rectifier modeling shall include fault detection of the load current of each PSS with adjustable trip level. The response in case of fault shall be to suppress the rectifier thyristors and fire the bypass thyristors.

## **2.3 TF SYSTEM**

There are two objectives for the TF system modeling.

The first objective is to model the exponential rise of current, flat top control, and discharge of current including the following effects:

- Voltage regulation of thyristor converters due to commutation effects;
- Slowdown of MG set;
- Heating of TF coil inner and outer legs and consequential change in ohmic resistance;
- Steady state circulating current and transients due to phase shift between branches of 24-pulse converter;
- Control of the current in the eight parallel branches using P-I control.

The second objective is to model the short circuit behavior including the following effects:

- Short circuit faults located at various points in the circuit including thyristor shorts, DC faults on the rectifiers, DC faults in the cabling, and DC faults at the load terminals;
- Inclusion of impedance of MG set;
- Fault detection and the suppress, bypass action of the power supply controllers.

Based on the above objectives it is desired to include individual models of the eight power supply units which comprise the TF system. However, for each power supply unit only one PSS

will operate as a rectifier, the other will be in bypass. Detailed layout of components shall be in accordance with circuit schematic B-4F1005 Sheet 1501U.

## **2.4 OH SYSTEM**

There are two objectives for the OH system modeling.

The first objective is to model the exponential rise of current and the remainder of the OH current waveform based on P-I control against a target waveform in a data table including the following effects:

- Voltage regulation of thyristor converters due to commutation effects;
- Slowdown of MG set (but only if the OH model is included with the TF model in a global simulation);
- Heating of OH coil and consequential change in ohmic resistance;
- Control of the current using P-I control.

The second objective is to perform modeling to guide in the choice of CLR inductance including the following cases:

- Short circuit faults located at various points in the circuit including thyristor shorts, DC faults on the rectifiers, DC faults in the cabling, and DC faults at the load terminals;
- Inclusion of impedance of MG set;
- Fault detection and the suppress, bypass action of the power supply controllers;
- Steady state circulating current and transients due to phase shift between branches of 24-pulse converter, for cases where some PSS are not operating (reduced system voltage).

Based on the above objectives it is desired to include individual models of the eight power supply units which comprise the OH system. However, taking advantage of symmetry, it would be acceptable to include individual models of four power supply units with scaled parameters in case the inclusion of all eight proves too demanding. Detailed layout of components shall be in accordance with circuit schematic B-4F1005 Sheet 1515U.

### **3 CONSTRAINTS**

- a. Preliminary result is required by June 15, 2009.
- b. This SOW shall cover work performed from date of issue up to an expiration date of October 15, 2009.
- c. The maximum total expenditure covered by this SOW is \$50K.
- d. SOW performer shall be Nayak Corporation, 475 Wall St., Princeton, NJ08540 (refer to Justification of Non-Competitive Procurement JNCP form submitted for this work).

### **4 APPLICABLE DRAWINGS & DOCUMENTS**

In addition to the drawings and documents cited in prior sections, the calculations performed for the baseline NSTX TF are attached for information only in file "Original\_NSTX\_TF\_Calculations.pdf". The modeling covered by this SOW shall follow the methods described in this SOW.

### **5 DELIVERABLES**

The deliverable items shall include the PSCAD files plus a write-up as necessary to describe the modeling features and instructions for running the models.

In addition, a training session shall be organized to familiarize PPPL staff with the modeling features and instructions for running the models.