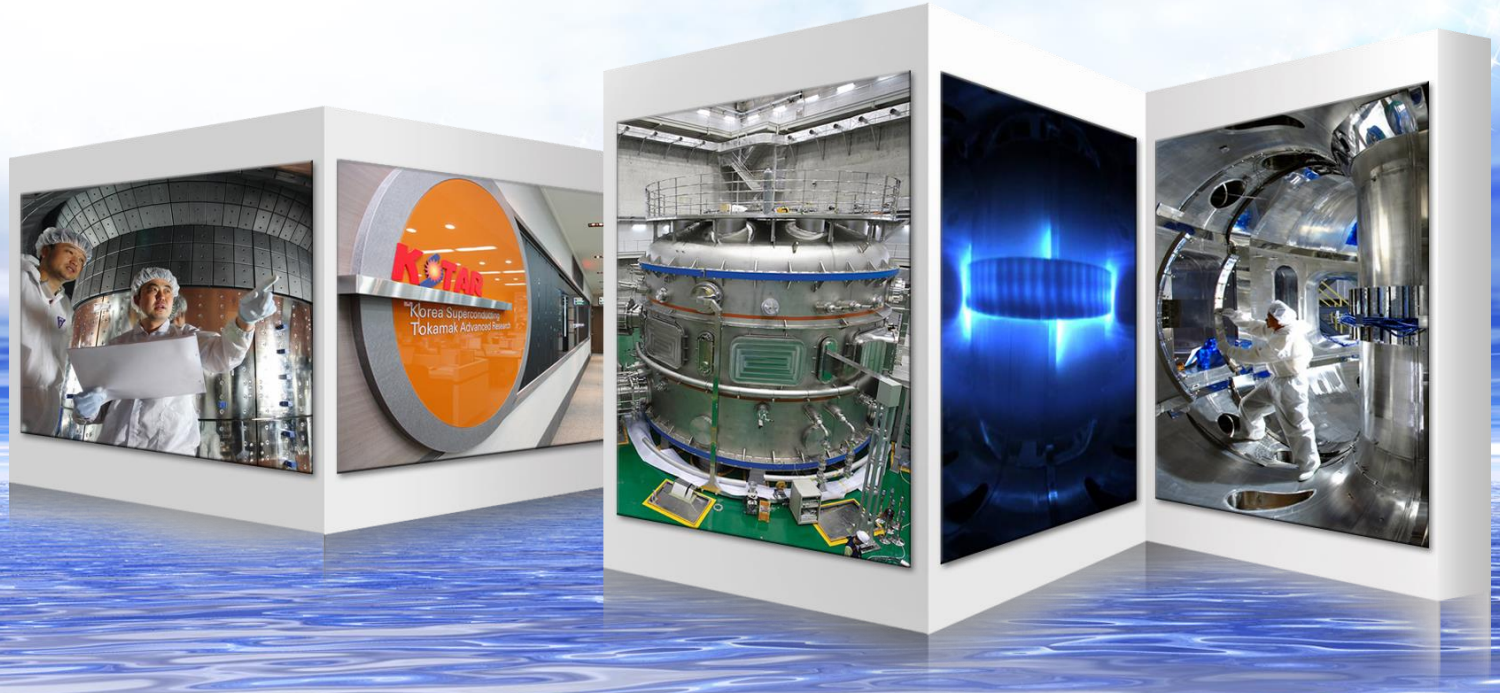
KSTAR IVCC Coil and Power Supply



April 22, 2014

National Fusion Research Institute

CONTENTS

NFRI

I IVCC (In-Vessel Control Coil) Configuration

II IVC (In-Vessel Vertical Coil) Power Supply

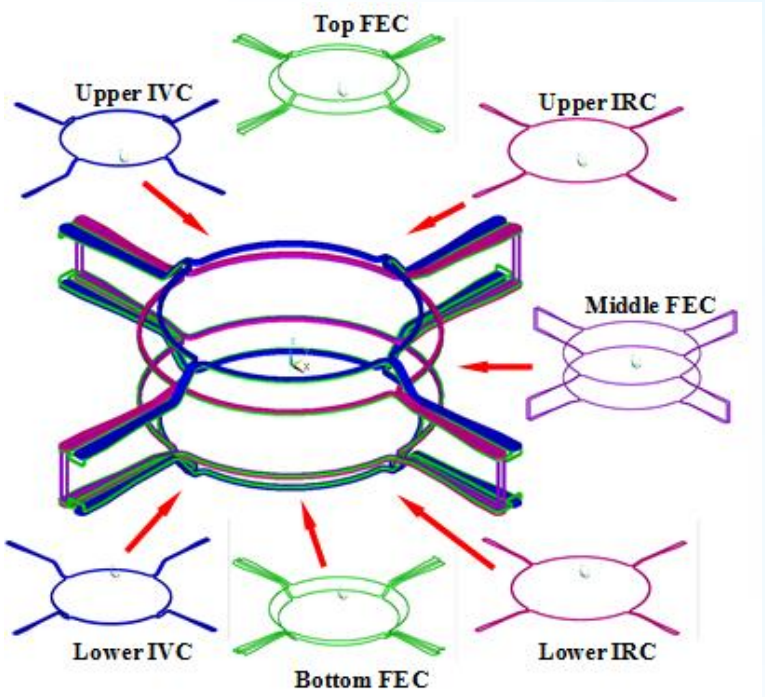
III IVCC Power Supply

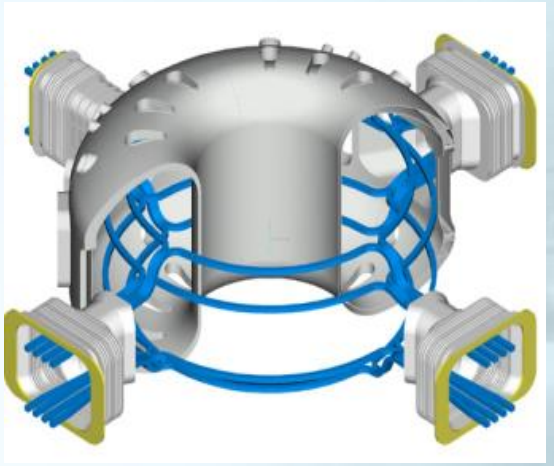
IV Summary & other issues

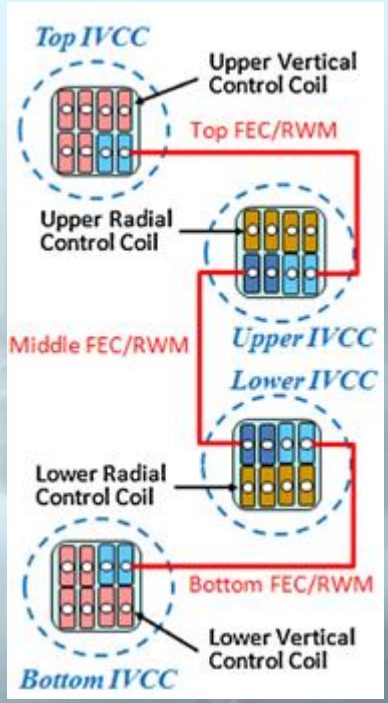
1.1 IVCC (In-Vessel Control Coil) configuration

IVCC configuration and connection scheme of segmented coils

- IVCCs are to be used for the fast plasma position control, field error correction, and feedback stabilization of resistive wall mode in the KSTAR device
- 4 coil sets for position control and RWM (or FEC)
- Each coil is split into four segments (totally 16 segments)
- 8 copper conductors in each segment
- The segment connections are made from the outside of the vessel



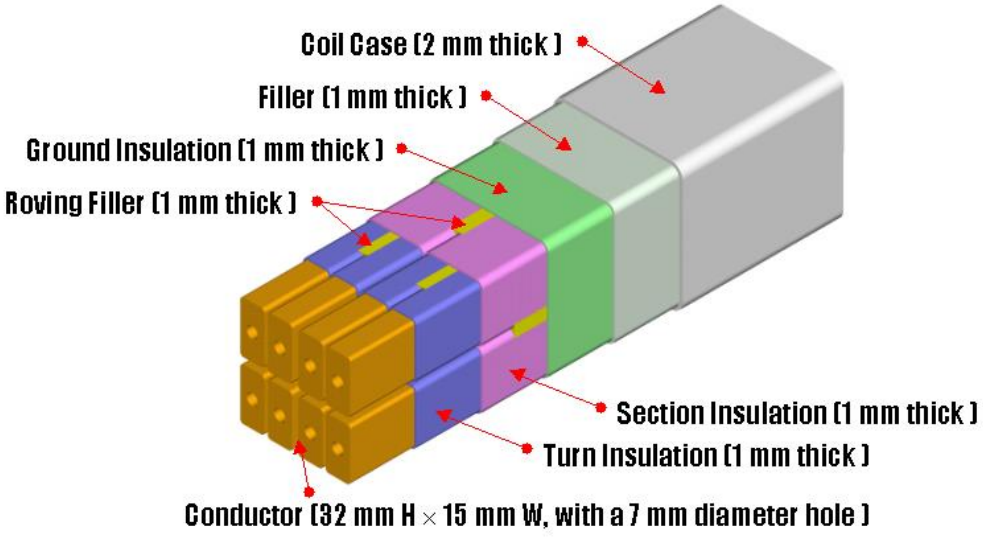


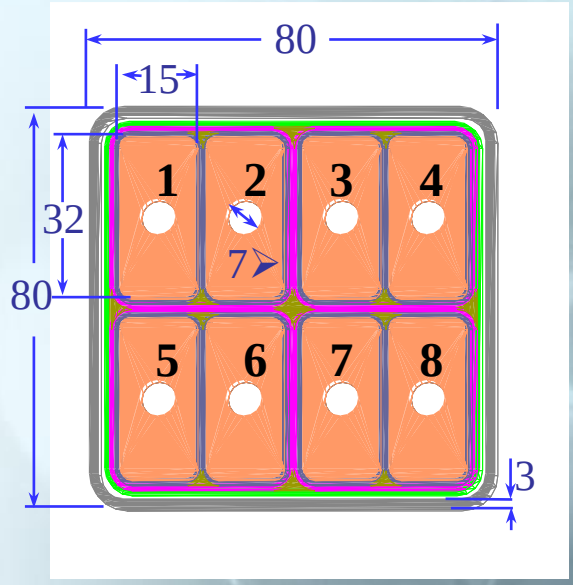


1.2 Cross sectional view of IVCC

Cross-section and major parameters

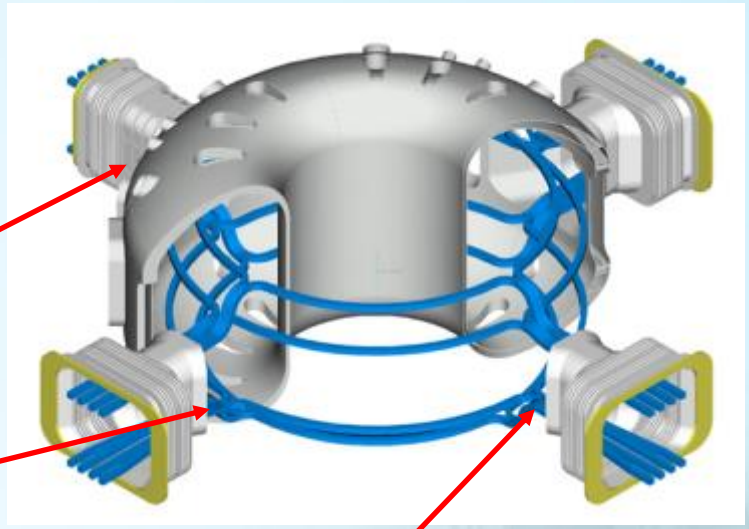
Parameters	Value and dimensions
Coil radius	2,120 mm (Top & Bottom IVCC), 2,500 mm (Upper & Lower IVCC)
Coil case	3 mm thick STS 316LN
Conductor	32 mm x 15mm with 7 mm dia. Hole, Half hard copper(UNS10300)
Turn insulation	1 mm thick Kapton/glass fiber/epoxy
Section insulation	1 mm thick glass fiber/epoxy
Ground insulation	1 mm thick glass fiber/epoxy
Total Cross-section	80 mm x 80 mm

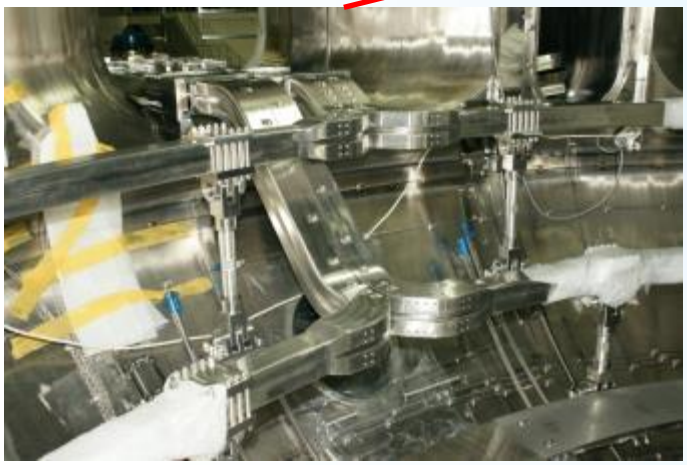




1.3 IVCC inside the vacuum vessel

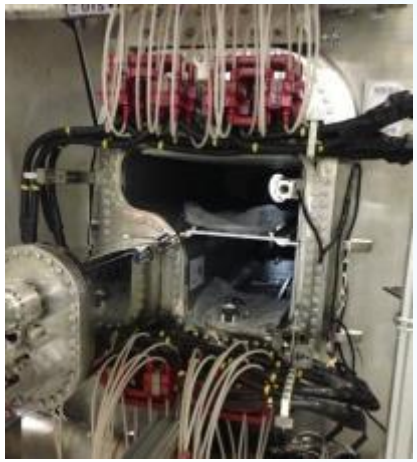
- IVCC inside the vacuum vessel

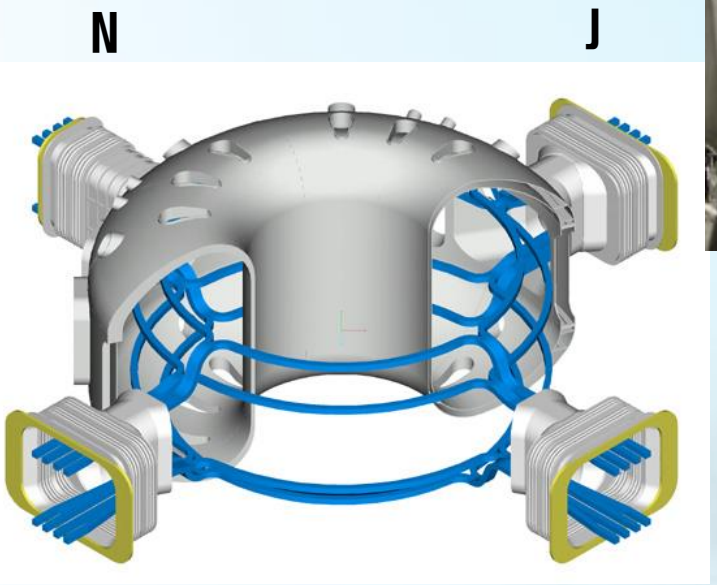




1.4 IVCC outside the vacuum vessel

- IVCC outside the vacuum vessel





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I IVCC (In-Vessel Control Coil) Configuration

II IVC (In-Vessel Vertical Coil) Power Supply

III IVCC Power Supply

IV Summary & other issues

2.1 Specification

IVC (In-vessel Vertical Coil) specification

- ○ Number of coils : 2 (Upper and Lower)
- ○ Upper and Lower IVC are anti-serially connected
- ○ Number of turns : 6 [U/L each]
- ○ Load parameter : 21.56 mΩ, 0.74 mH

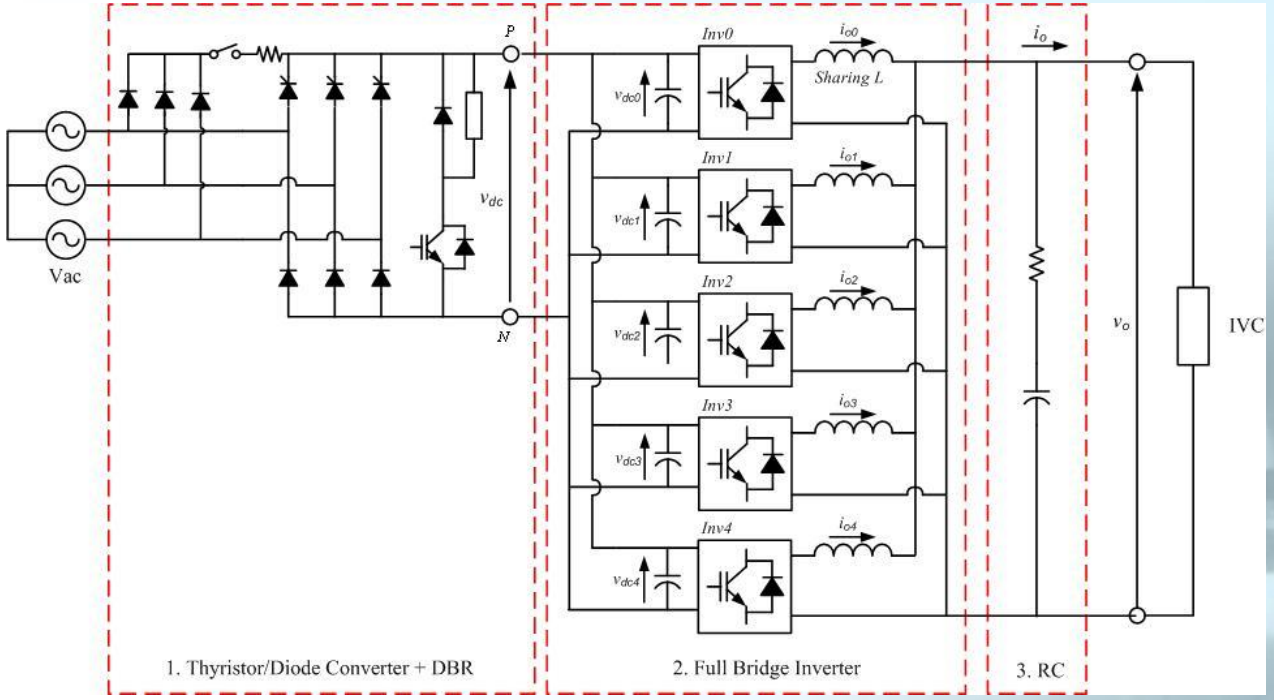
IVC power supply specification

- ○ Output : 1kV, 10kA (4-quadrant operation)
- ○ switching frequency : 4kHz (max 5kHz is possible)
- ○ Max di/dt : 1kA/ms
- ○ operation time : 300 sec (AC mode)
- ○ 5 inverter units are connected in parallel to provide output current
- ○ 1 Inverter unit
  - • H-bridge based on IGBT
  - • 8 IGBTs per inverter unit : 1 IGBT (1700V, 1200A) x 4 parallel x 2 arm
- ○ water cooling

2.2 Schematic diagram of IVC Power Supply

IVC power supply configuration

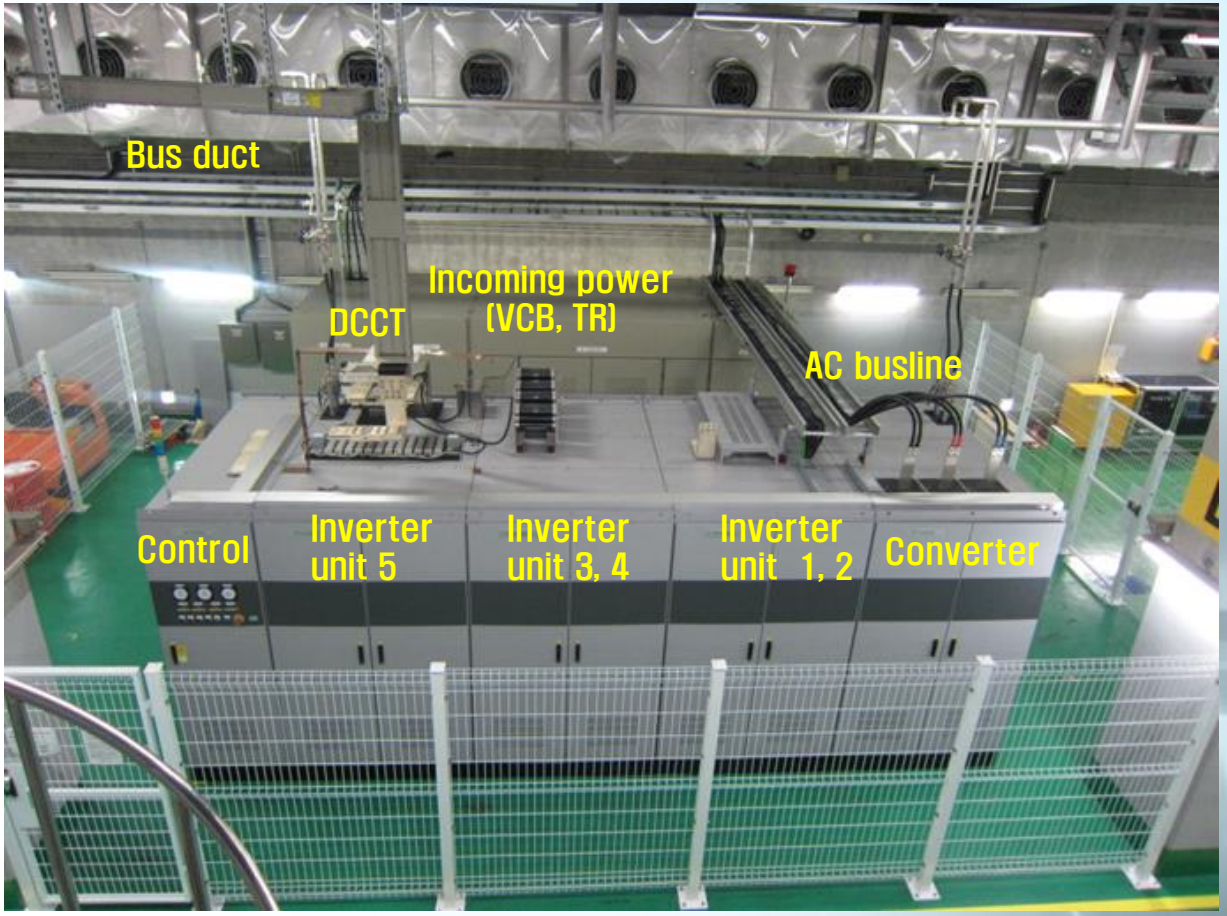
- ○ 1 converter feeds 5 inverter units
- ○ RC filter circuit is applied to reduce surge voltage
- ○ Matching inductor : 50uH (25uH x 2)
- ○ output bus line : bus duct [30m]



2.3 IVC power supply components

IVC power supply components

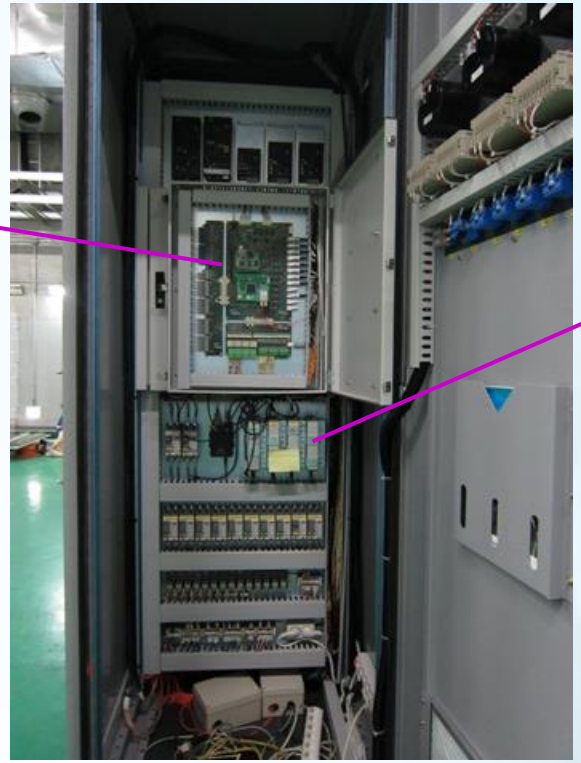
- ○ Power system : Transformer(6.6kV/0.8kV, 4MVA), VCB (2 for 6.6kV, 1 for 0.8kV)
- ○ IVC PS : 1 control panel, 1 converter panel, 3 inverter panels



2.4 IVC power supply components (Control)

Control panel

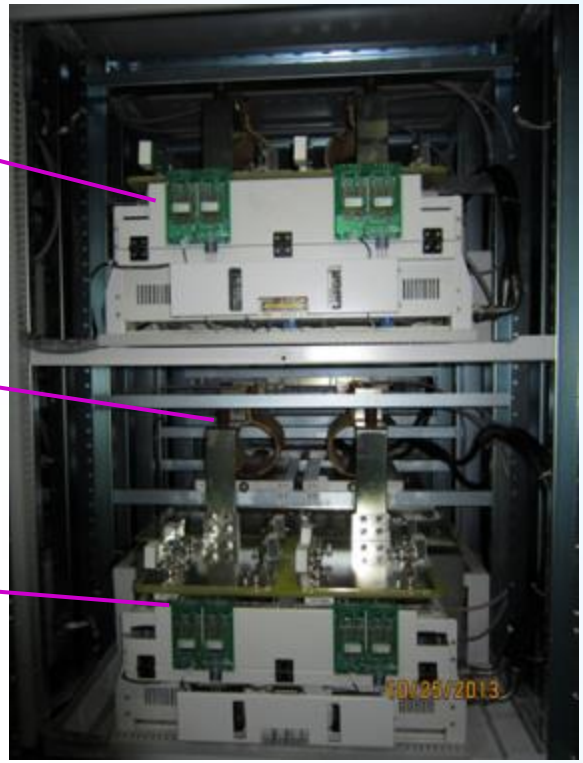
- ○ DSP board controls converter and inverters
- ○ Data exchange between DSP and PCS (or KSTAR control system)
  - • high-speed data : Analog method is applied to reduce communication delay
  - • slow-speed data : Digital method is applied using VME-based LCS



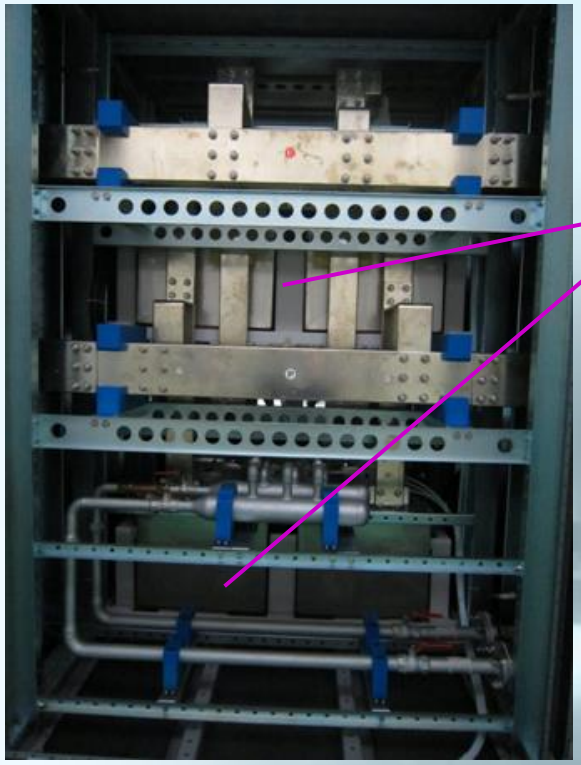
2.5 IVC power supply components (Inverter)

Inverter panel

- ○ 2 inverter units per inverter panel
- ○ DC link capacitors are used to reduce dc link voltage fluctuation
  - • number : 12EA (1 inverter unit)
  - • Capacity : 4600uF, 300A



Front view

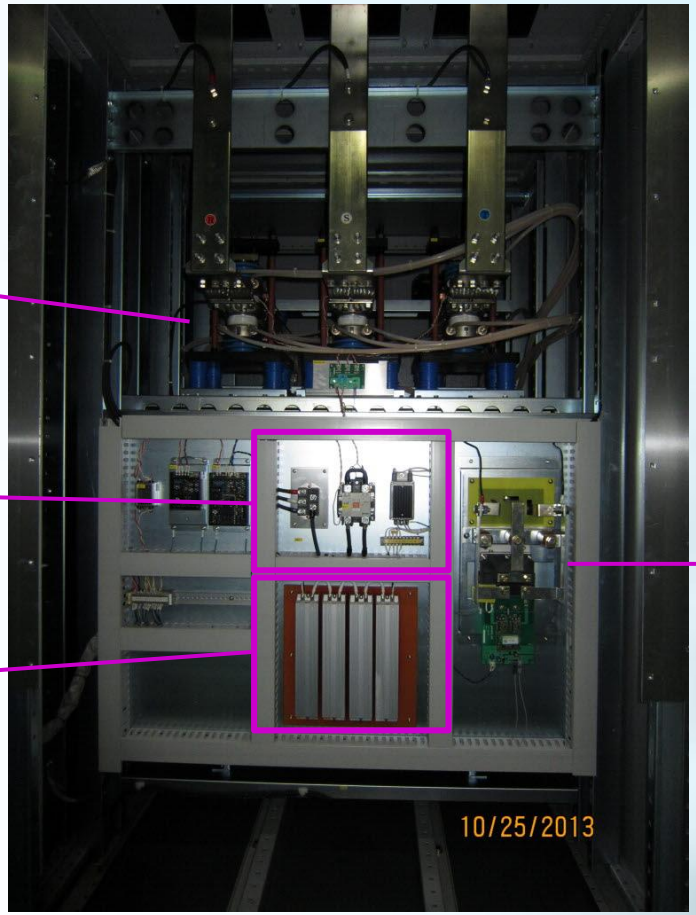


Rear view

2.6 IVC power supply components (converter)

Converter panel

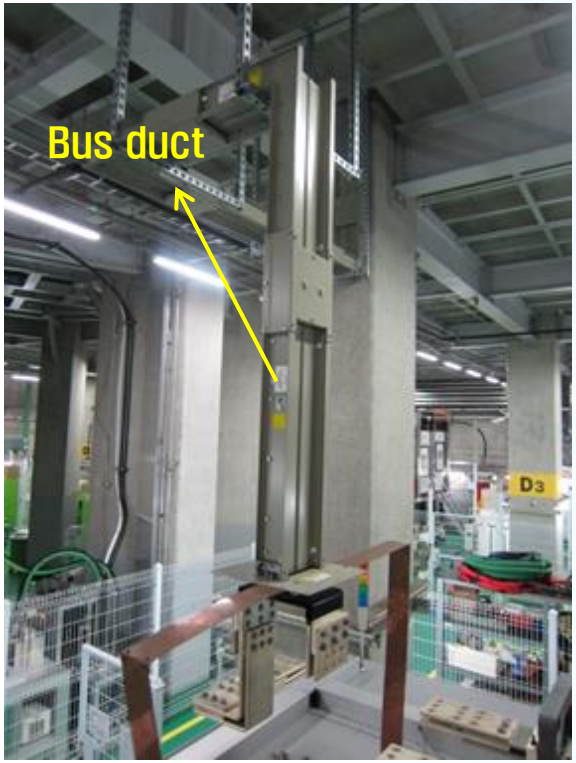
- ○ Pre-charging circuit, converter, discharge resistor, DB(Dynamic Braking) system
- ○ DBS is currently not used because there is no overvoltage in DC link

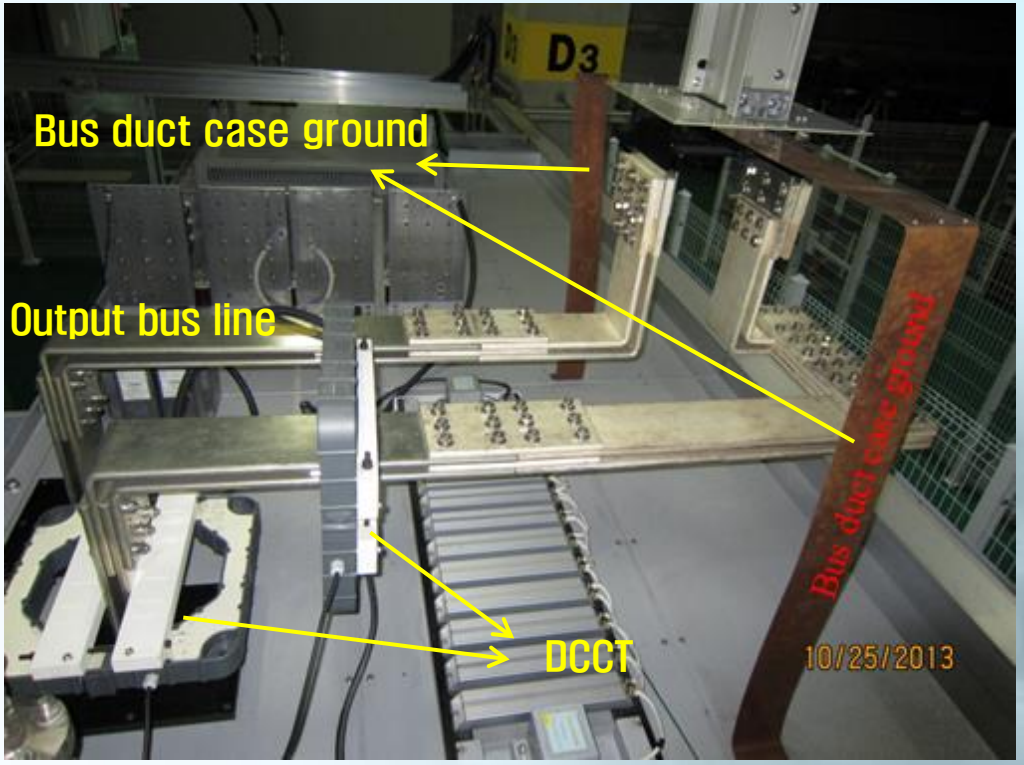


2.7 IVC power supply components (bus duct)

Bus duct

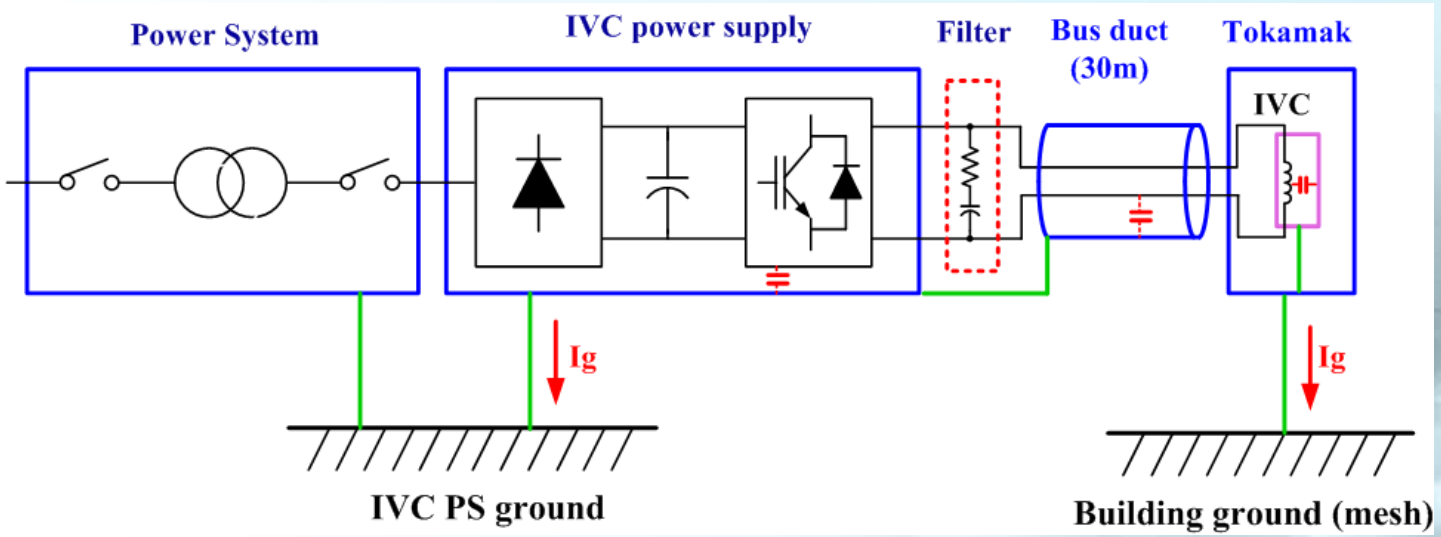
- ○ Bus duct for output bus line [length : 30m]
- ○ Cross section : 2,500 mm^2
- ○ The case of bus duct is connected to IVC ground





2.8 IVC PS grounding

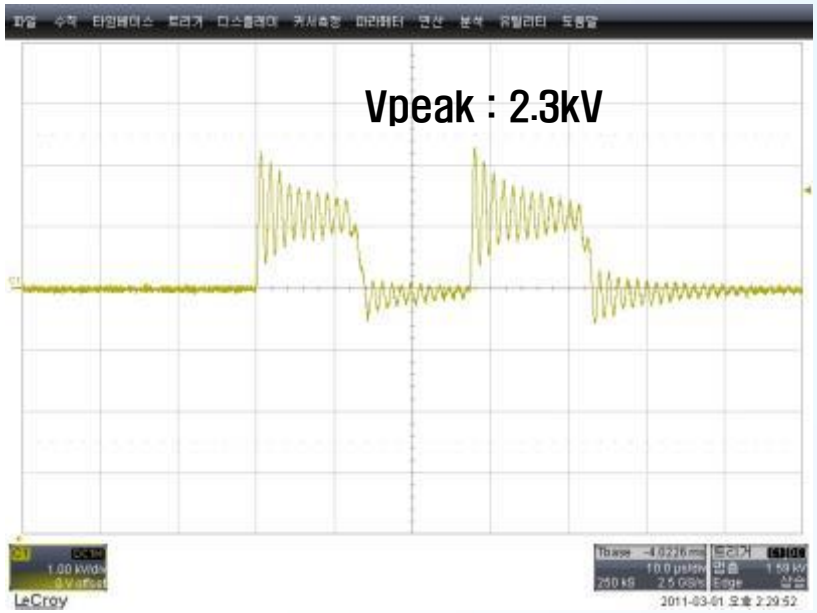
- IVC power supply grounding
  - ○ Input and output power lines are not connected to ground
  - ○ enclosure of power system, IVC power supply and bus duct is connected to IVC ground which is separated from the tokamak ground
  - ○ But, the case of IVCC is connected to the tokamak ground



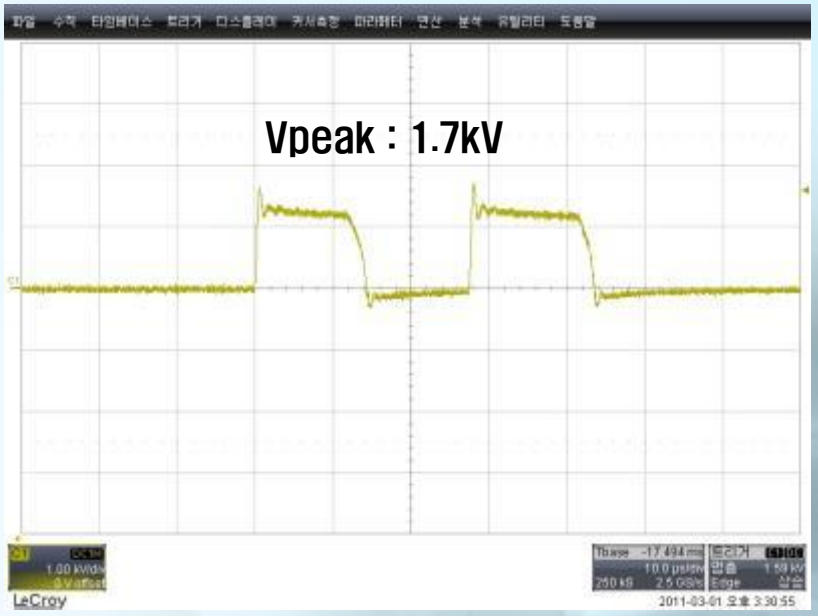
2.9 Voltage waveform of IVC PS

Voltage waveform

- ○ The voltage waveform includes surge component (twice the rated voltage) and oscillation (due to the inductances)
- ○ RC filter circuit is located between output terminal and bus duct
- ○ After installing RC filter, the surge voltage and oscillation was reduced



Without RC filter

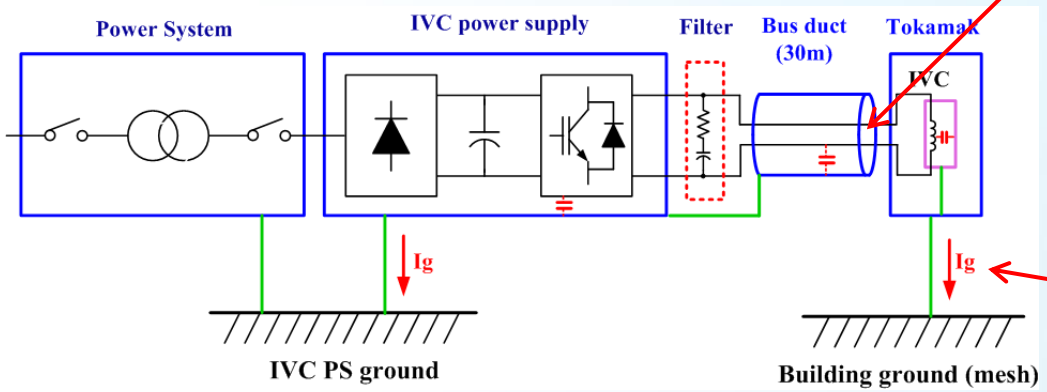


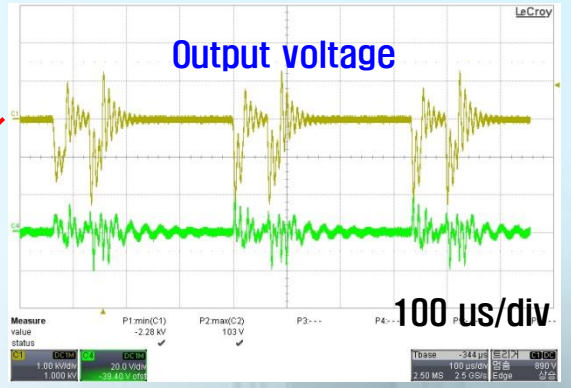
With RC filter

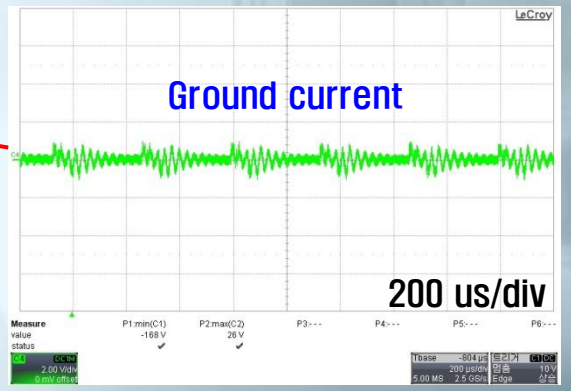
2.10 Noise issue

IVC PS switching noise

- Despite the RC filter, the output voltage measured around port includes surge and oscillation components
- The high dv/dt makes leakage ground current through stray capacitance between IVC and case [case is connected to ground]
- Most of diagnostic signals in tokamak contain switching noise







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I IVCC (In-Vessel Control Coil) Configuration

II IVC (In-Vessel Vertical Coil) Power Supply

III **IVCC Power Supply**

IV Summary & other issues

3.1 IVCC Specification

- IVCC(In-vessel Control Coil) specification
  - ○ IRC coil
    - • number of coil : 2 (Upper and Lower)
    - • number of turn : 4 [U/L each]
    - • Upper and Lower IRC are serially connected
    - • Load parameter : 14.26 mΩ, 0.56 mH
  - ○ RWM coil
    - • number of coil : 12 [Top : 4, Middle : 4, Bottom : 4]
    - • number of turn : 2
    - • The connection of RWM coils can be changed according to the required function (ex. RMP, RWM, MHD, FEC, NTV, etc)
    - • Load parameter can be changed according to the coil connection
      - – maximum load resistance : 15mΩ (including bus line)
      - – maximum load inductance : 44uH (received from physics)

3.2 Requirements for IPS (IVCC Power Supply)

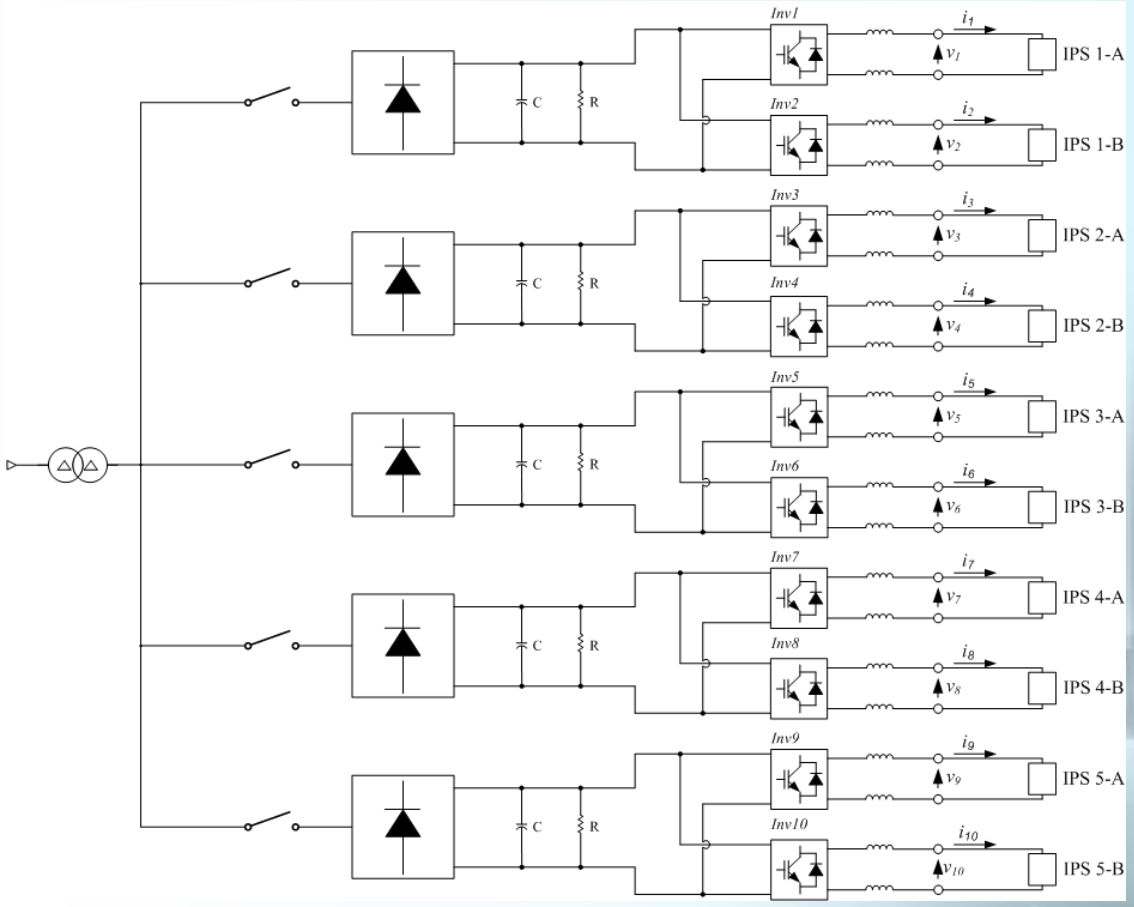
Requirements

- ○ The number of power supply : 5
  - • 1 for IRC, 4 for RWM coils
  - • All power supplies have same specification and configuration
- ○ Output : 500V, 5kA
  - • 4 quadrant operation
- ○ switching frequency : 10kHz
- ○ configuration
  - • 1 power supply : 1 converter + 2 inverter units (1 inverter unit : 2.5kA)
  - • 1 converter feeds 2 inverter units
  - • 2 inverters can be operated independently or in parallel
- ○ operation time : continuous
- ○ The Existing RMP power supply will be replaced by IPS (new power supply)

3.3 Conceptual design of IPS

Conceptual design of IPS (new power supply)

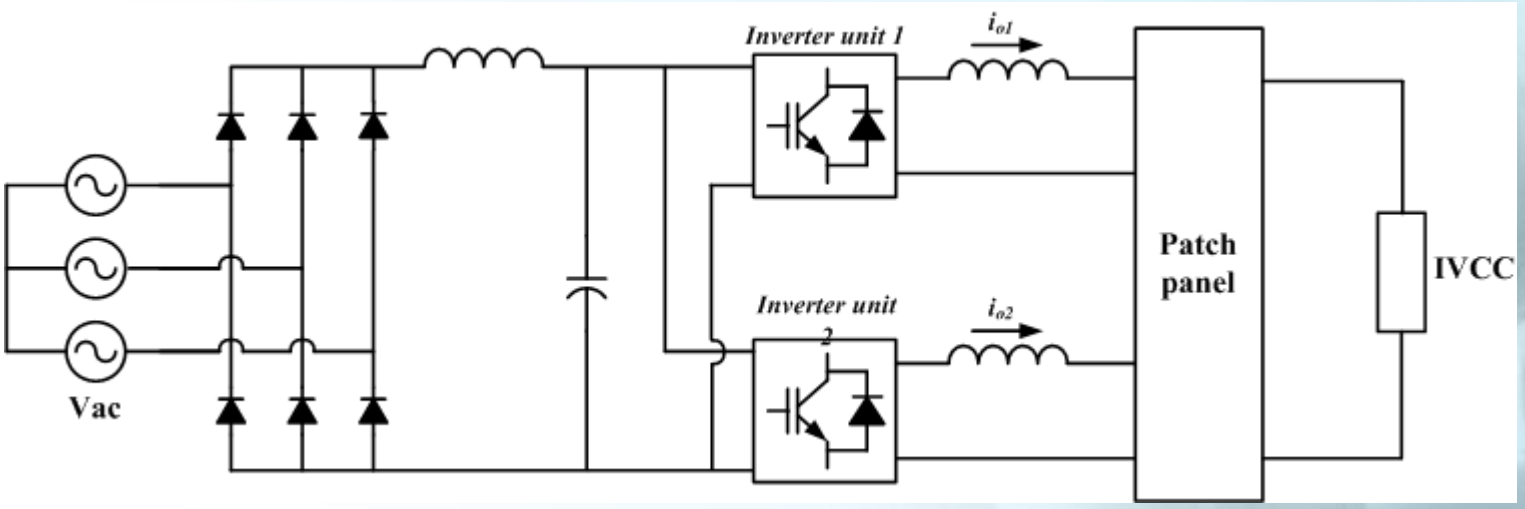
- ○ The number of power supply : 5
- ○ The capacity of power system is under design stage



3.4 Basic design of IPS

Basic design of IPS

- ○ Input voltage : AC 410V
- ○ Converter : Diode converter (including pre-charging circuit)
- ○ Inverter : H-bridge based on IGBT
  - • the number of IGBT : 24EA per 1 inverter unit
- ○ Filter circuit will be designed in the detail design stage



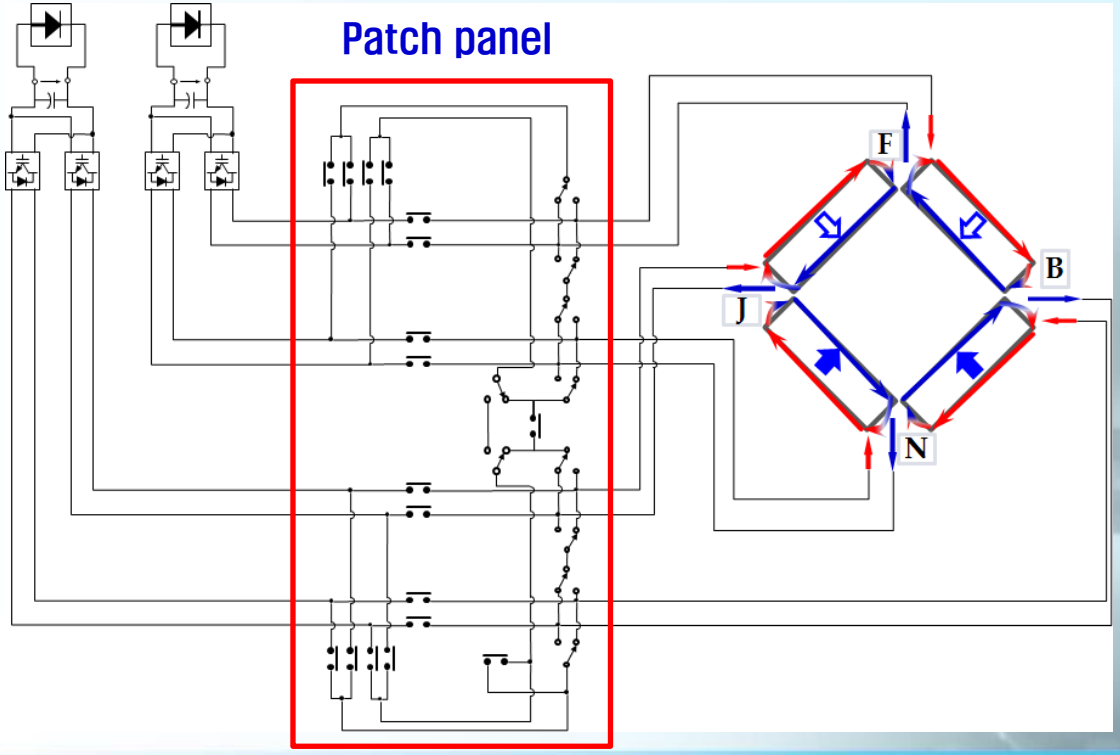
3.5 Concept of patch panel

Connection scheme of patch panel

○ Patch panel will be designed for various connections

○ In the middle RWM coil,

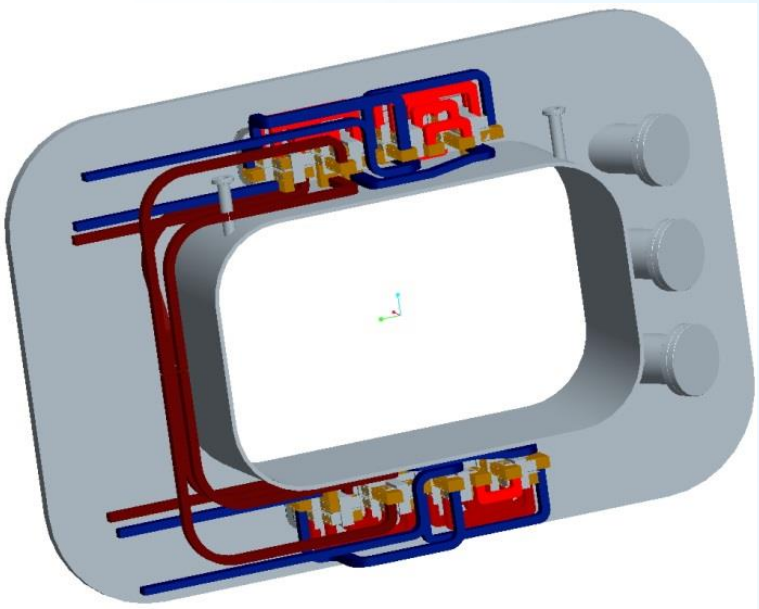
- 1 power supply → serially connected coil (5kA, parallel operation)
- 2 power supplies → 2 pair coils (5kA, parallel operation)
- 2 power supplies(4 inverters) → 4 independent coil [2.5kA, independent operation]



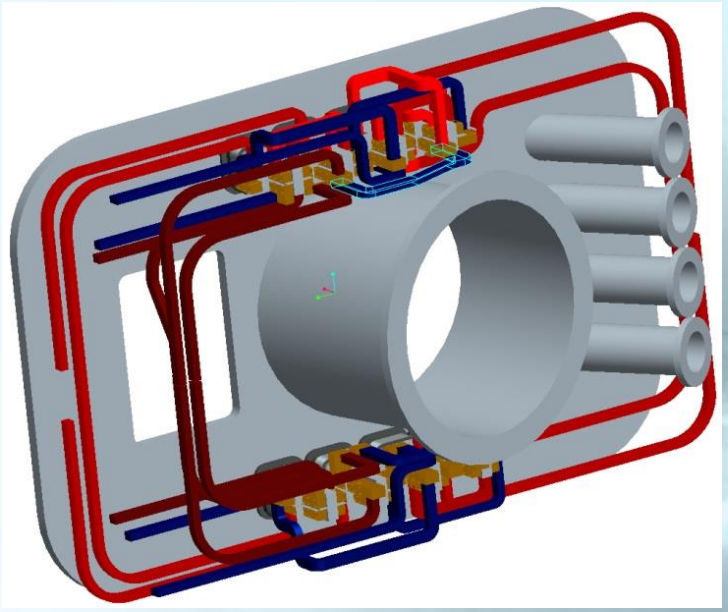
3.6 Port connection (1)

Port connection

- ○ There are 4 ports outside the vacuum vessel for connection
- ○ J, N ports have same configuration of B port
- ○ F port : more complex because of IVC, IRC, RWM coil connection
- ○ Due to the narrow space around each port,
  optimal design is required to minimize the interference with other equipments



B port

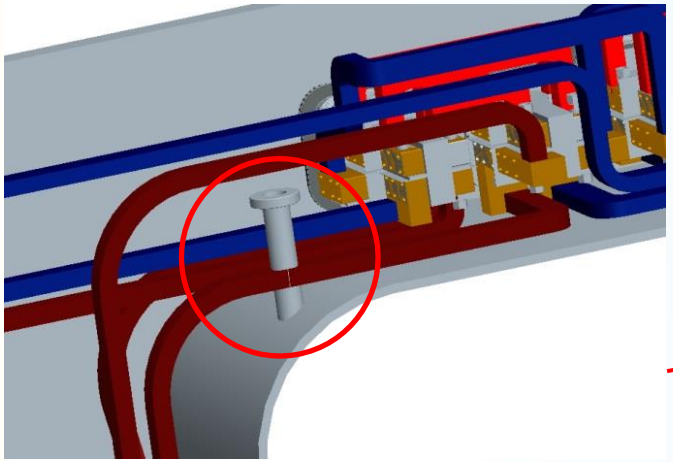


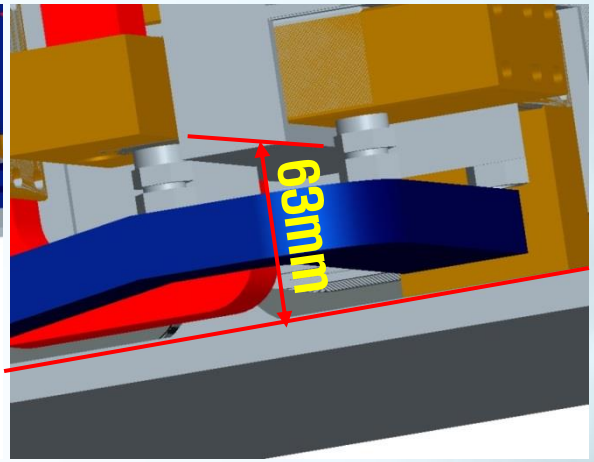
F port

3.7 Port connection (2)

Space problems for port connection

- ○ 6 power lines will be connected in Each port (B, F, J, N port) for RWM coil
  - • cross section area of power line is considered 500 mm^2 for 5kA current conducting
  - • For easy cable routing and connection, consider 2 cables with an area of 240 mm^2
  - • Therefore, total 12 power cables will be installed in each port
- ○ The distance between IVCC lead and Pumping port is 63mm in B port
- ○ Considering insulation, many power cables and interferences in a confined space, it is difficult to find optimal design for port connection





B port

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I IVCC (In-Vessel Control Coil) Configuration

II IVC (In-Vessel Vertical Coil) Power Supply

III IVCC Power Supply

IV Summary & other issues

4.1 Summary

Summary

○ IVC power supply has been operated since 2010

○ switching noise problem of IVC power supply

- The high dv/dt makes leakage current between IVC and ground
- Switching noise affects diagnostic signals connected to tokamak ground

→ It must be resolved in the near future

○ The requirements for IPS were decided

○ The design will be carried out for the following items

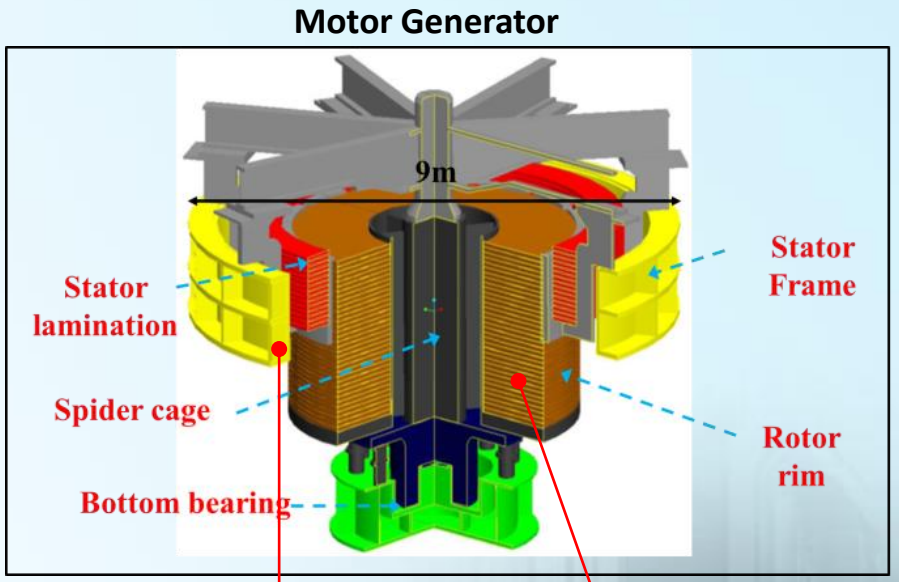
- port connections between IVCC and bus lines around port
- patch panel
- IPS including power system

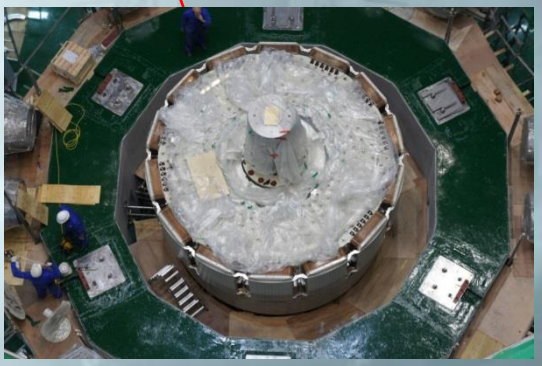
○ The cost estimate of IPS is in progress

4.2 Other issues (MG-1)

Motor Generator (MG) system in KSTAR

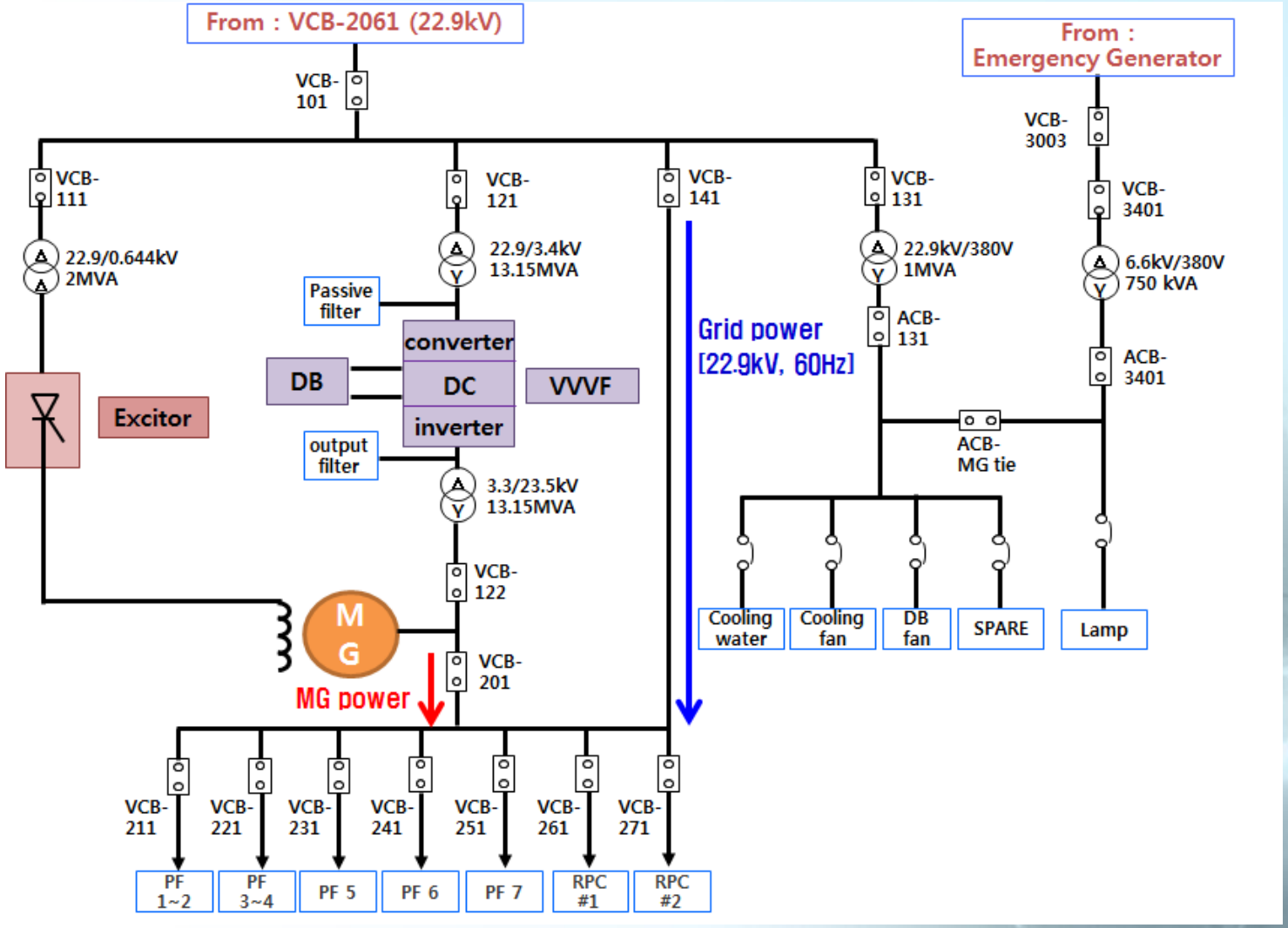
SPECIFICATION			
GENERATOR		VVVF	
Type	Vertical	Capacity	12 MVA
Pole	14 Pole, salient	Rated Voltage	3.3 kVac
Capacity	200 MVA	Rated Current	2,100 A
Rated Speed	480 ~ 548.5 rpm	Control Method	Inverter, PWM
Connection	3 Phase, Y	Frequency	0~64 Hz
Rated Voltage	22.9 kVac	EXCITATION SYSTEM	
Rated Current	5,042 A	Capacity	2 MVA
Weight	564 TON	Rated Voltage	580 Vdc
Storage Energy	2,193 MJ	Rated Current	1,532 A
Total Harmonics	THD 9%	Control method	Converter,





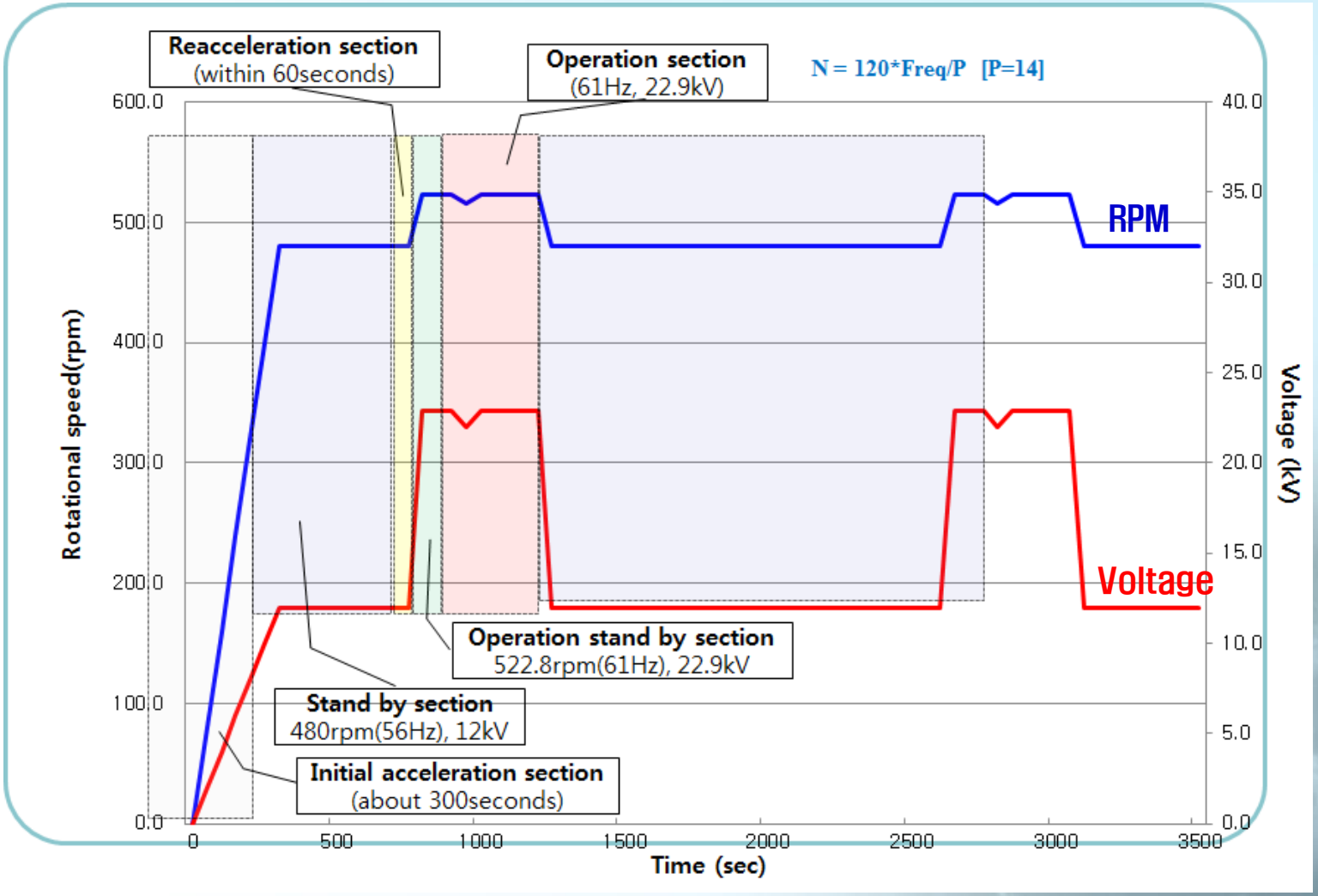
4.3 Other issues (MG-2)

MG power system



4.4 Other issues (MG-3)

MG Operation Scenario & duty cycle



4.5 Other issues (MG-4)

MG system commissioning plan

- ○ Each individual performance test is being conducted without any dummy loads
- ○ A dummy load test at 38MVA capacity with PF MPS will be conducted in May. 2014
- ○ 200MVA capacity test with SC loads is planned to be conducted in Nov. 2014
- ○ The Plasma test using MG at 80MVA is planned to be conducted in Nov. 2014

MG system in NSTX

- ○ Specifications
  - • Power, operation duty cycle, operation range of MG voltage, frequency, etc
- ○ Experiences for MG operation
  - • considerations in MG operation
  - • influence on the transformer according to the frequency variation
  - • fault conditions or components occurred frequently in MG operation

End of slide

Thanks you for your attention !