# Design issues of the TF AC/DC converter for the ITER coil power supply system

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## 1. Introduction

The ITER Toroidal Field (TF) coil system is composed of 18 series-connected superconductor coils (L=17.5 Henry), related protection circuits, and an AC/DC converter. The converter for the TF coil system is a 12-pulse and 2-quadrant converter with the two thyristor bridges connected in parallel through the inter-phase reactor. The rated current of the converter is 68 kA, and no-load output voltage is 900 V when 66 kV AC input is used.

Because ITER is a pulse system that uses huge power during the pulse, there are additional critical issues in designing the AC/DC converters. In this study the following issues in designing the TF AC/DC converter are discussed to improve the characteristics of the TF coil system;

- Fault current issues related with AC input voltage and operational scenario.
- Junction temperatures during the faults and the thyristor numbers per an arm.
- Efficient and reliable bypass method including resuming.
- Protection sequence for the fault conditions.
- Reactive power reduction method.
- Estimation of the optimum inductance of the DC Reactor (DCR).

## 2. The Issues and the Results

In this section each of the design issues of the AC/DC converter are reviewed to improve the reliability and performance of the system. The cost effect is also considered in making the final decisions for the issues.

### *2.1 Fault Current Issues*

Fault current is the main parameter to determine the valve size of the ITER AC/DC converter, and the fault current is in proportion to the input voltage of the converter transformer. In the original design of the TF system the converter is connected to a 66 kV AC line during current charging phase and changed to a 22 kV AC line during flattop phase as shown in Fig. 1. The junction temperatures of the thyristor, when the thyristor number in parallel per an arm is 11, are calculated in Table 1. It shows that the junction temperature could be decreased easily if the AC input to the converter transformer is changed from 66 kV to 22 kV line. The increase of the current charging time from 0.5 hr. to 1.5 hr would not be a critical factor in operating the TF system.

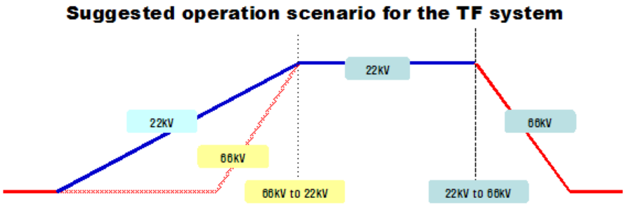


Fig. 1. Suggested operation scenario for the ITER TF coil AC//DC converter to decrease the DC short current.

Table I: Temperature of the worst thyristor with the different scenario and different conditions. (Simulation Conditions; $T_{case}$ =85℃, thyristor = 5STP52U5200, U.F. = 1.4, $\alpha$ = 0.1)

| AC Input | Short Type | 11 parallel | | 8 parallel | |
|---|---|---|---|---|---|
| | | 20 msec | 80 msec | 20 msec | 80 msec |
| 22 kV | *UDCS | 105 | 107 | 116 | 119 |
| | **DDCS | <100 | <100 | <100 | <100 |
| 66 kV | UDCS | 169 | 179 | | |
| | DDCS | 112 | 110 | | |

* UDCS; Upstream DC Short
**DDCS; Downstream DC Short

### *2.2 Bypass Method*

In order to minimize the fast-discharge event of TF magnets, the TF converter should have the capability to be set to a freewheeling mode. A bypass switch is used in freewheeling the coil current, and the switch should be controlled properly during the exiting time from a bridge mode to a bypass mode and during the exiting time from a bypass mode to a bridge mode. No matter what kind of fault is, the freewheeling should be set first, and the system is ready back to the bridge operation after the fault is cleared. There are four possible bypass methods to be applied to the freewheeling such as internal bypass and three external bypasses as shown in Fig. 2, and the compared characteristics of the bypass methods are summarized in Table 2. As the 1st priority method internal bypass is chosen and as the 2nd priority external bypass scheme2 is chosen considering the simulation results. The test result with a reduced model will make it clear which would be the best choice.

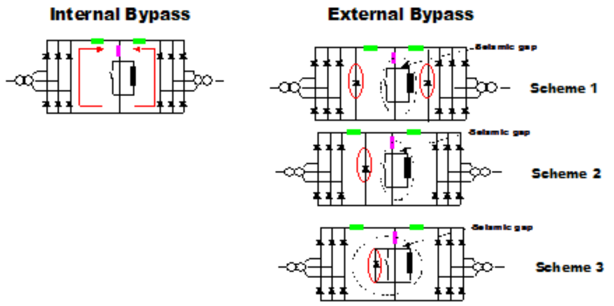


Fig. 2. Possible bypass methods of the ITER coil current.

Table 2: Compare table between the bypass methods.

| | |
|---|---|
| Internal Bypass (IB) | - Cost effective.<br>- Complex control |
| External Bypass (EB) Scheme1 | - Simple operation than IB.<br>- Biggest cost.<br>- Effects are same with IB |
| External Bypass (EB) Scheme2 | - Cost effective among EB.<br>- Simple operation than IB.<br>- Useless for the down DC |
| External Bypass (EB) Scheme3 | - Fast coil protection,<br>- But slow for converter protection.<br>- Other effects are Same EB scheme2 |

*2.3 Protection Sequence*

A single sequence to cover all the faults and normal cases is preferable to be a reliable bypass and protection sequence. Also the sequence should include resuming operation, but blocking of coil current and the following situation should be avoided during the sequence;

- Converter gate blocked and coil current flow through TR 2nd winding
- Bypass action fails.
- DC voltage is transferred to TR 1st winding.
- Cannot open AC circuit breaker after 80 msec.

Through the various simulations the unique protection sequences for the internal bypass and external bypass sheme2 are fixed respectively.

*2.4 Reactive Power Reduction Method*

The minimum dc voltage needed to maintain the flat-top current is $V_{\text{drop by the busbar resistance}}$ = 1.1 mΩ x 68 kA = 80 V, and the minimum AC input for this DC voltage is 6.6 kV. In the other hand the maximum reactive power with AC 22 kV input (DC 266 V output) is $Q_{max}$ = 226V * 68kA = 18Mvar. Even though no reactive power is generated at the flat-top when AC 6.6kV is used as an input, the reactive power to be saved by an additional hardware is limited to 18 Mvar. This value is only 2 % of the maximum reactive power generated in the system, and therefore hardware change to save this small amount is not so effective in the view of the cost and space point of view. Instead of the hardware change, it would be better to apply the operational scheme that could save the reactive power such as freewheeling-charging or alpha angle control at the flat-top as shown in Fig. 3 when there needs even a small amount of compensation.

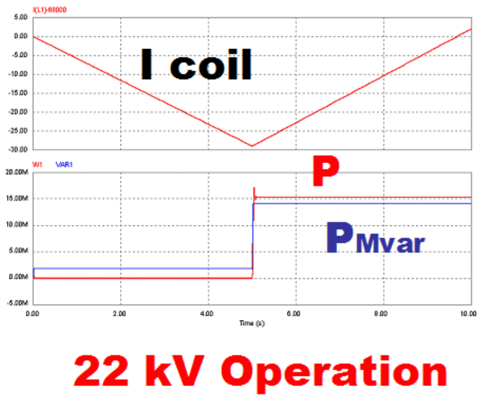


Fig. 3 Coil current and reactive power during a freewheeling-charging operation to decrease the.reactive power.

*2.5 Optimum Inductance of DCR*

The roles of the DCRs in the parallel-connected converter are to limit the ripple current and the DC short current. The ripple made by the circulation current between the converters is closely related with the current zero-crossing scenario and fast change of alpha angle, but TF converter has no zero-crossing problem and alpha angle could be changed with a safe time interval. Therefore the critical factor to determine the DCR inductance is the DC short current. The inductance of 13 μH, given in DDD4.1, is well fitted to the 66 kV AC short current and current ripple of 20 %. If 22 kV AC input is used even during the current rising phase, the inductance of the TF DCR could be reduced further.

## 3. Conclusions

It is recommended that 22 kV AC input could be used even during the current rising phase of the TF coil to decrease the thyritor valve size of the TF AC/DC converter. As a bypass method, the 1st priority is the internal bypass and the 2nd priority is the external bypass scheme2. If the internal bypass is turned out to be unstable after testing the method with a reduced model, the other scheme could be used. Single bypass sequence has been made not to meet some bad situation, and it is concluded that the effort to decrease the reactive power by changing the hardware would not be efficient. Also the DCR inductance could be reduced more if input voltage is decreased from AC 66 kV to 22 kV during the current charging phase of the TF coil.

## REFERENCES

[1] Design Description Document for the ITER Pulsed Power Supply System, DDD4.1(2001) ITER Office