Study on the Impact of Plasma Disruption on the Current Control of the ITER Coil Power Supply

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Abstract. ITER PF (Poloidal Field) AC/DC converters are adopting the topology of 12-pulse bi-directional thyristor rectifiers which are composed of back-to-back 6-pulse bridges. PF AC/DC converters are operated with current reversal mode for plasma initiation and ramp-up of plasma current, and forward and reverse converters are operated with current circulation mode to prevent dead-time interval around current zero-crossing point of a PF coil current. At least, a current path in a PF AC/DC converter should always be maintained to suppress surge voltage induced by plasma disruption (plasma disruption voltage) at the output terminals of the converter. In this paper, the effect of plasma disruption voltage to the circulating current control model is studied using the topology of ITER PF AC/DC converter. This paper shows that the converter can be operated safely in spite of plasma disruption with proper control logic.

1. Introduction

ITER coil power supply is required to keep the continuous current during current reversal. Dual 12-pulse converter with back-to-back bridge configuration can meet the requirement by the circulating current control method. There is potential risk of over voltage arising by the plasma disruption, which will destroy the converters in case the converter fails to keep the suitable conducting path. The circulating current control has to be designed to accommodate such a sudden transient caused by the plasma disruption [1]. This paper investigates the impact of plasma disruption on the circulating current control of a PF coil power supply, for example, ITER MC's (Main Converters).

2. Integrated Modeling of a PF Converter and Plasma Disruption

The disruption induced coil voltage for ITER CS and PF coils was reviewed from Ref. [2] and the induced voltage of PF3 coil (1.776 H) was implemented in the PSIM circuit simulation with the voltage source by analog behavior model as shown in Fig. 1. The voltage source ($V_{disruption}$) with maximum amplitude of 21 kV and an exponential decay constant of 0.33 sec was introduced in the converter circuit model in series as shown in Fig. 2. The amplitude of the induced voltage is extremely larger than the converter voltage so that it is inevitable from the over voltage risk on the converter terminals if the converter cannot keep the correct conduction path to allow the forward current path for the induced voltage. Figure 3 shows the controller model of the converter. There are two current feedback control loop. One is for total current feedback control and the other is for current difference feedback control. The current reference of the total current is supplied by external command and the current reference of the current difference is calculated in the controller. The current difference control is used to operate the converter in the manner of circulating current mode. The controlled value of the current difference is maximum around the zero-crossing point of coil current.

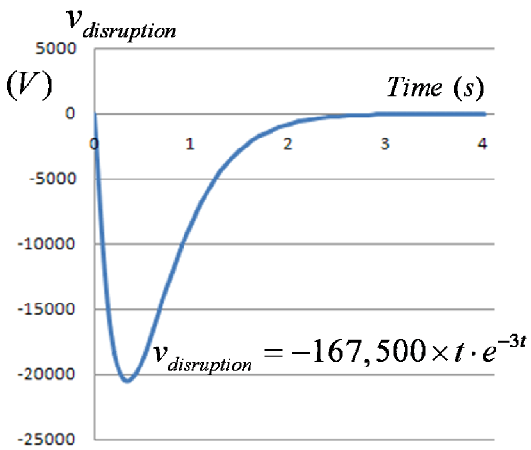

FIG. 1. The modeling of plasma disruption voltage of ITER PF3 coil.

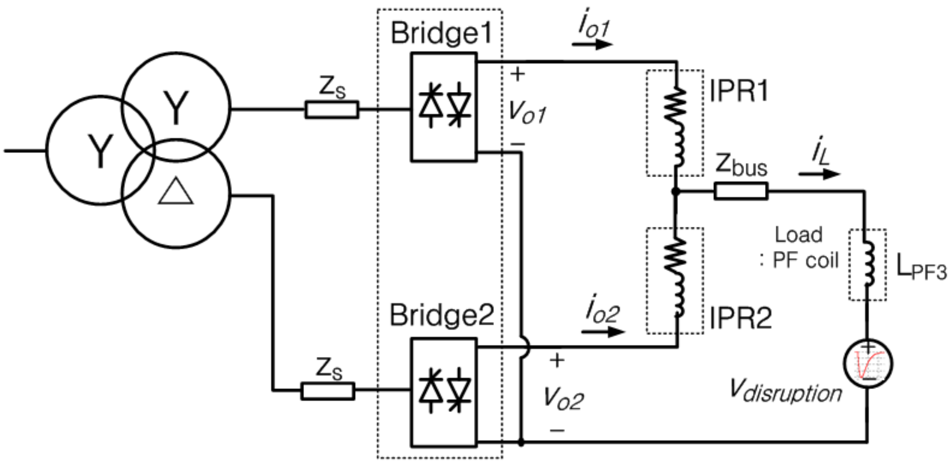

FIG. 2. The circuit diagram of a 12 pulse thyristor converter.

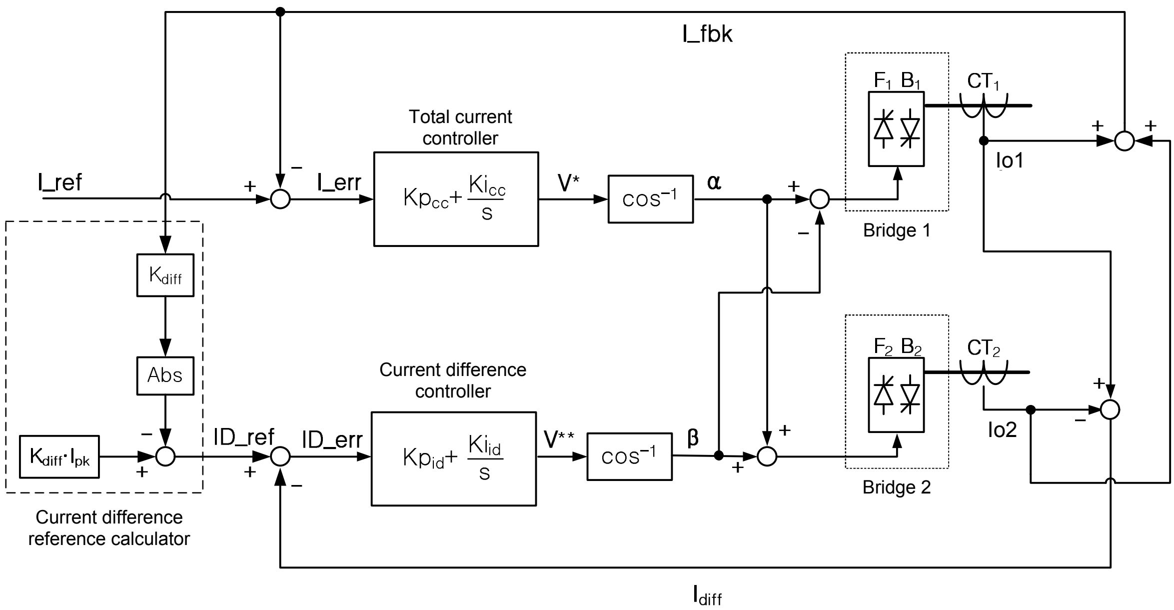

FIG. 3. The circulating current controller model.

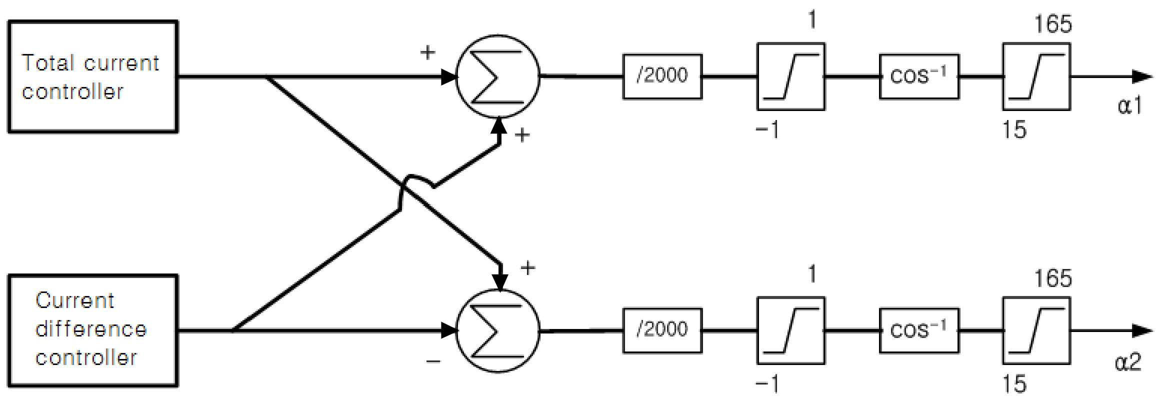

FIG. 4. Circulating current controller model without consideration of disruption.

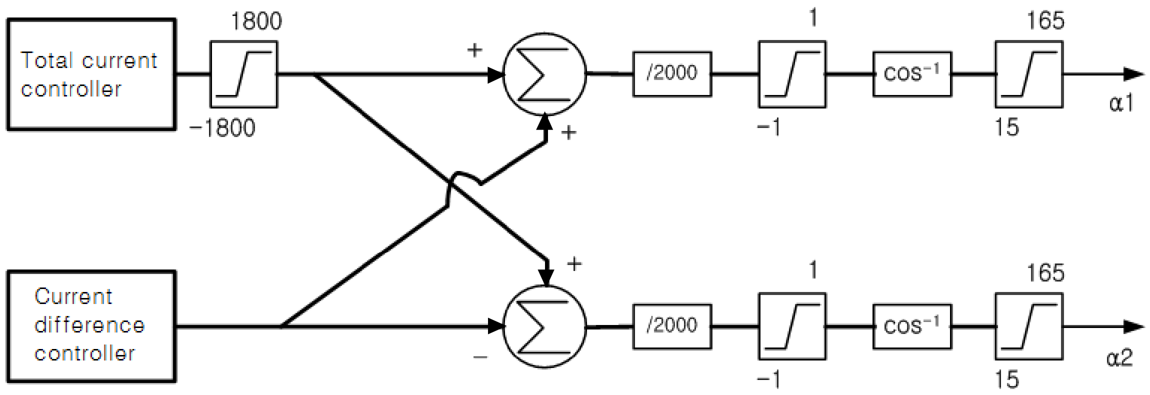

FIG. 5. Circulating current controller model with consideration of disruption.

Figure 4 shows the model of controller without consideration of disruption, where two types of limiter are applied. One is cosine value limiter and the other is α (thyristor firing angle) limiter. It should be noted that the output voltage of the MC is about 1,480 Vdc. If very large value of surge voltage by plasma disruption is induced PF coils, the input of arc cosine converter may be limited. Thus the function of current control is lost, and all of the thyristor switches in MC may be turned off simultaneously, and then the converter may be destroyed. Figure 5 shows the model of proposed circulating current controller. There is an additional voltage limiter at the output of total current controller. The limiting value of the voltage limiter is 1,800 Vdc which is slightly higher than the output voltage of the MC but less than 2,000 Vdc which is the dividing value of the arc cosine converter stage. The input value of arc cosine converter is not limited (or not saturated) anymore because the value of the total current controller is already limited. Thus α1 and α2 are not saturated and are located in the controllable range.

3. Result of Simulation

Figure 6 shows the simulated result with circulating current control by the controller model of Fig. 4 under the plasma disruption. Note that the plasma disruption occurs at 37 sec in this simulation. The possibility of large over voltage due to the current blocking around current zero (like Fig. 8) during current inversion is clearly seen in Fig. 6 (c) and (d).

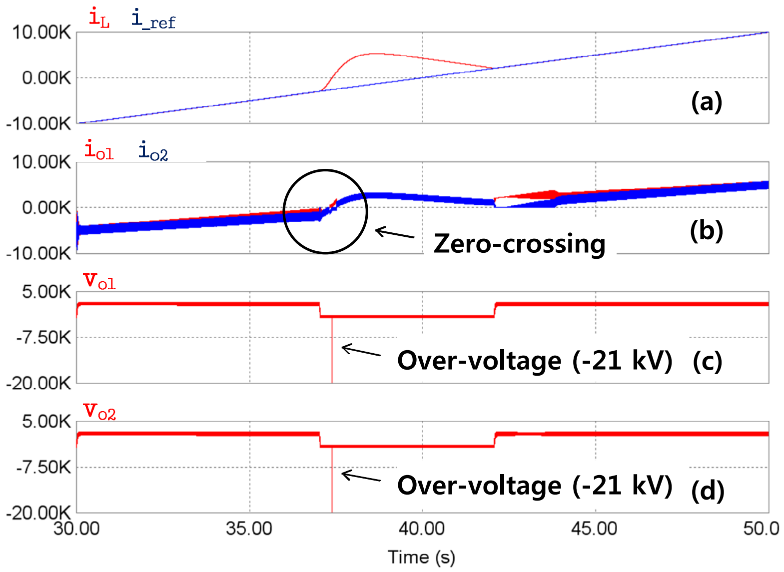

FIG. 6. The circulating current control by the controller model of Fig. 4 including plasma disruption at 37 sec, (a) current reference and load current, (b) output currents of the two bridges, (c) output voltage of the Bridge 1, (d) output voltage of the Bridge 2.

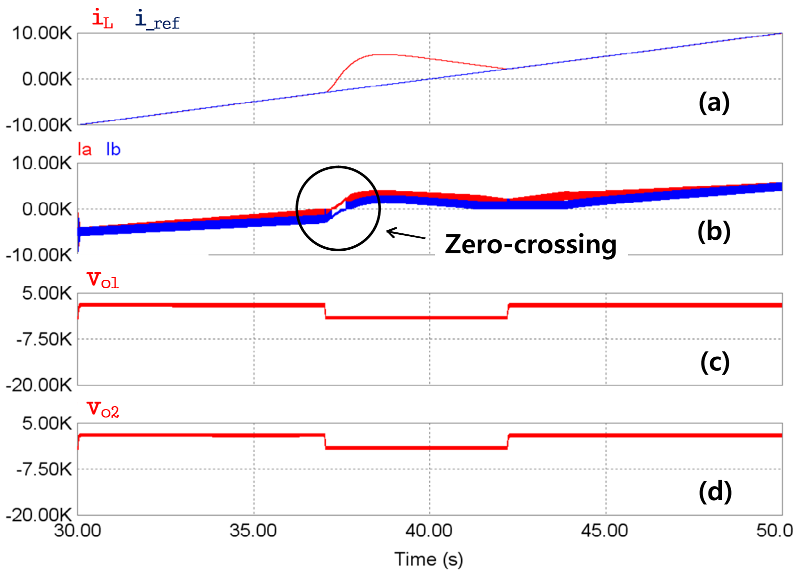

FIG. 7. The circulating current control by the controller model of Fig. 5 including plasma disruption at 37 sec, (a) current reference and load current, (b) output currents of the two bridges, (c) output voltage of the Bridge 1, (d) output voltage of the Bridge 2.

The main reason of this phenomenon is the limited phase control capability for the circulating current, which is caused by the saturation of the phase output. The improvement of the control dynamics was investigated by redesigning the control logic. Figure 7 shows the control performance through the current inversion with the plasma disruption without over voltage. Figure 9 shows safe gap between currents of two bridges in parallel. The main difference of the new control scheme is the location of the saturation limit in the control logic sequence. The

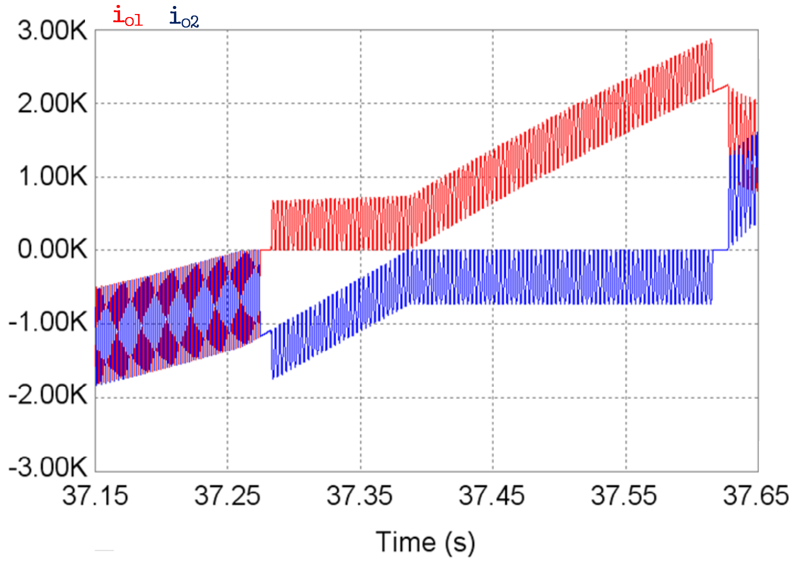

FIG. 8. The expanded waveform around the zero-crossing of Fig. 6 (b).

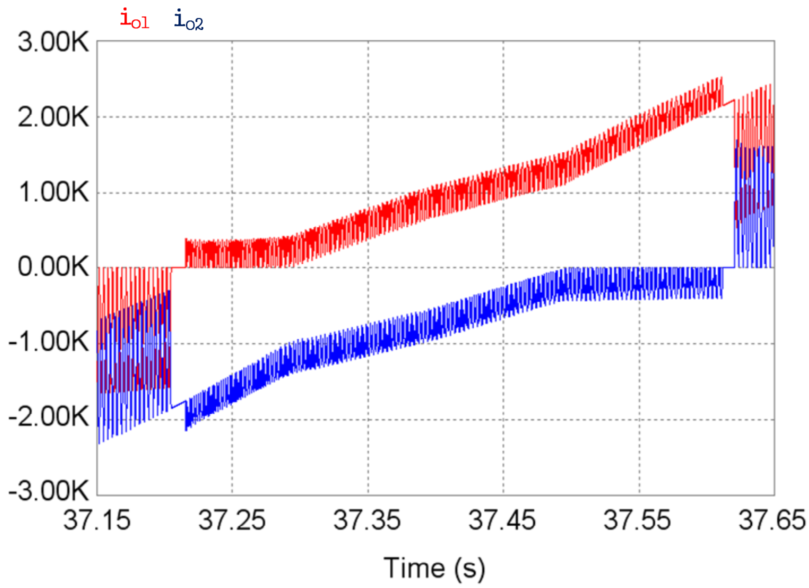

FIG. 9. The expanded waveform around the zero-crossing of Fig. 7 (b).

dependency of the current gap between the converters in parallel is examined to find the limitation of the present current controller.

4. Conclusion

In order to improve the characteristic of PF converter operation, the algorithm using circulating current mode was reviewed in the rapid and continuous change of load current between forward and reverse operation mode. A current controller model of PF converter was proposed to implement algorithm using circulating current mode and its performance was verified by PSIM simulation. The circulating current controller model was improved by adding an additional voltage limit at the output of total current controller and it showed the PF converter model operate safely without surge voltage at its output terminal in spite of the large voltage induced in PF coil by plasma disruption.

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Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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