THE IGNITOR ELECTRICAL PULSED POWER SUPPLY SYSTEM

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Abstract—To properly regulate currents inside IGNITOR poloidal (PFC) and toroidal (TFC) field coils a system of 15 thyristor ac/dc converter has been designed. The total electrical power drawn by the 400 kV Grid has been minimized performing a multi-steps iterative optimization process. In this way the most appropriate current distribution within each PFC has been identified and the coil geometry modified, easing the requirements on the power supplies and on the adopted materials. A specific design has been carried out for each ac/dc converter to minimize the requested reactive power. As a result the total installed power has been reduced from about 3300 MVA down to 2400 MVA.

I. INTRODUCTION

IGNITOR (Fig.1) electromagnetic system is composed by the Toroidal Field Coil (TFC), 13 Poloidal Field Coils (PFC) and an Electromagnetic Press (Press). The scope of the last one is to compensate part of the mechanic stresses affecting TFC structure during IGNITOR operation at the highest performances.

Each coil current is regulated by means of suitable set of complex ac/dc thyristor converter, composed by a number of basic units (Graetz). The general design of the whole IGNITOR Power Supply System (IGNITOR PPS) has been completed including a technical-economical feasibility analysis performed with the support of major Italian industries in the field. A preliminary design of the IGNITOR PPS had been performed starting from a first equilibrium scenario. The results was a total installed power (defined as \( V_{\text{max}} \times I_{\text{max}} \)) equal to 3300 MVA with a substantial reactive component. To reduce as far as possible the total power drawn by the Grid, the following means have been used:

- an iterative, multi-steps optimization process of the coil currents scenario (par.II);
- a specific design of each ac/dc converter using, when needed, dedicated scheme (sequential control or internal freewheeling) to reduce the reactive power requirements (par.III);
- inclusion of Static Var Compensator (SVC) and Current Harmonic Filtering (HF) units inside one, integrated system (par. IV).

II. ITERATIVE OPTIMIZATION PROCESS

The iterative-multi steps optimization process has been performed to find a different set of coil currents in any case meeting the following requirements:

- compatibility with the plasma equilibrium scenario;
- compatibility with the required \( V_{\text{loop}} \) and the \( \frac{d\Phi}{dt} \);
- max acceptable temperature in the conductors and the in the insulating coil materials;
- max acceptable electromechanical stresses on both coils and supporting structures;
- thyristor type availability on the market.

Taking into account the above mentioned constrains, the following alternatives have been considered, for each coil:
At the end of the optimization process a suitable set of PFC and TFC has been found. The related currents and the total required power (about 1000MVA) are shown in Fig.2 and Fig. 3, respectively.

III. IGNITOR AC/DC CONVERTER

Four, 3 secondaries main step down transformers, MSDT, (400/36 kV; 2x130 MVA + 1x80 MVA) supply the ac/dc converter through a set of suitable three windings transformers. The MSDT power is shared between two secondaries in order to reduce the short circuit currents and to make possible the selection of 36 kV as secondary voltage level, for economical reasons. The third secondary has the scope to make possible the circulation of the homopolar component of the current. On the secondary side of each MSDT is located an integrated unit (Fig.4) composed by SVC (50 MVAr) and HF (THD<1.5%) systems.

In this framework, the basic requirements for the IGNITOR ac/dc converter design are:

- thyristor controlled units;
- current regulation mode (2 or 4 quadrants depending on the load currents; Fig.2);
- 12 phases reaction, at least;
- minimization to the total number of the basic 6 phases (Graetz) units;
- minimization of the reactive power consumption.

In the final design the total Graetz units have been reduced from 84 down to 70 and, consequently, the converter 3-windings transformer from 42 down to 35. Each one of these should have specific current and voltage rating. A technical-economical analysis has been performed with the support of the Italian industry and the transformer design has been optimized and the total number of transformer types has been limited to 7. The reduction, as far as possible, of the total number of the Graetz units has been a direct consequence of the installed power decreasing, from 3300 MVA down to 2400 MVA, due to the iterative optimization process and the specific ac/dc converter design.
Special attention as been paid to the design of the switching systems on the dc side. We can note (Fig.5) the following devices:

- automatic crow-bar, including non linear resistors, to protect the system against very high (up to > 100 kV) overvoltages during major plasma disruptions;
- switching unit for the plasma breakdown: suitable sets of resistors are inserted by means of static switches;
- switching unit to insert resistors, at the end of plasma flat-top, to de-energize TFC and PFC coils in support of the ac/dc converters; it has to be noted that, during this phase, currents in the coils are requested to go to zero with the same rate than that one of the plasma (Fig.2) in order to avoid plasma disruption;
- switching unit to insert emergency resistors in any case coils must be de-energized in case of converter or Grid failure;
- pyrobreaker (explosive fuse) back-up unit: to avoid fatal overheating inside the coils, these units are triggered in the case one of the de-energizing switching units fail to operate.

IV. LAYOUT MAIN CHARACTERISTICS

IGNITOR’s ac/dc converters are connected to the coils by a complex system of bus bars. In order to obtain the maximum as possible layout flexibility converters (with related auxiliaries and switching units) are installed inside standard outdoor containers, located as near as possible to the related transformers (Fig. 6a,b), and connected to the coils trough insulated bus-bar (fig. 6c).

V. CONCLUSION

The detailed design of the IGNITOR Electrical Power Supply system has been performed and technically - economically optimized with the support of major Italian companies in the field.

The impact of the IGNITOR load (Fig.4) on the Grid has been studied by the relevant Italian authority (GRTN). Results have been found to be consistent with the European connection requirements.

Fig. 5 : Typical Schematic of an IGNITOR ac/dc converter (PFC 14)
Fig. 6: a, b) converter container; c) insulated bus-bar (TFC, 350 kA)

\[ D = 340 \text{ mm}; \ S_2 = 5 \text{ mm} \]
\[ d = 100 \text{ mm}; \ S_1 = 20 \text{ mm} \]