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The Rio Madeira HVDC System – Implementation and Commissioning of Bipole 1 and the Connector to Acre-Rondônia

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SUMMARY

The basis for the Rio Madeira Project was conversion of 100% of the energy generated in two different hydro power plants to DC in the same location, the Coletora Porto Velho Substation. Two very long HVDC overhead lines are used to transmit up to 6300 MW from the Northwest of Brazil to the national consumption center (São Paulo) through two 3150 MW classic thyristor controlled bipoles. In addition, two back-to-back converters, 400 MW each, are also included in order to benefit the region close to the power plants, with the aim to connect a new and very strong network to an old and very weak one.

As a consequence of the project's complexity, the system commissioning is also complex. It is impossible to simultaneously start up the complete system, which has led to demands for an appropriate commissioning plan based on step-wise starting up of the system.

This paper is written before completion of the commissioning, in a moment where parts of the system are in operation and parts are ready to start to transmit power. Thus, it will present results concerning back-to-back commissioning and preparations for power transmission in the bipole 1.

KEYWORDS

HVDC, power converters, power transmission, substation, valve converters, back-to-back, bipole, rectifier, inverter, harmonic filters.

1. Introduction

The Rio Madeira HVDC System comprises a total of 7100 MW of converter capacity required to transmit the power from the hydroelectric plants of Santo Antonio and Jirau to local load centers as well as to the main power consuming areas in south-eastern Brazil. This capacity is split between two bipolar transmission lines rated 3150 MW each and two back-to-back blocks rated 400 MW each. ABB is responsible for the supply of the HVDC parts of Bipole 1 and the two back-to-back converter blocks. This paper discusses the implementation and commissioning of the equipment in the ABB supply.

The Rio Madeira transmission was auctioned under a concession process for each of the various lots comprising the system. This approach resulted in the overall system being owned by a number of entities, each of which selected their own suppliers for the equipment and services. A similar concession process was applied to the generation facilities, which resulted in a complex process for administrating the overall system. This aspect needs to be borne in mind when implementing the necessary interfaces and again when commissioning the different parts in each supply.

Further, one of the notable features of the Rio Madeira generation complex is the run of river design with low head turbines and very small reservoirs, giving the generating plants two characteristics which influence the transmission system implementation. These are: 1) the use of bulb turbines of small rating with very low inertia and 2) very large variations in seasonal power flow. The transmission system design takes this into account. However, the commissioning and early operation are impacted by the sequence of readiness for the various parts available for testing.

Figure 1 shows the conceptual design for the Rio Madeira project according to the auction.

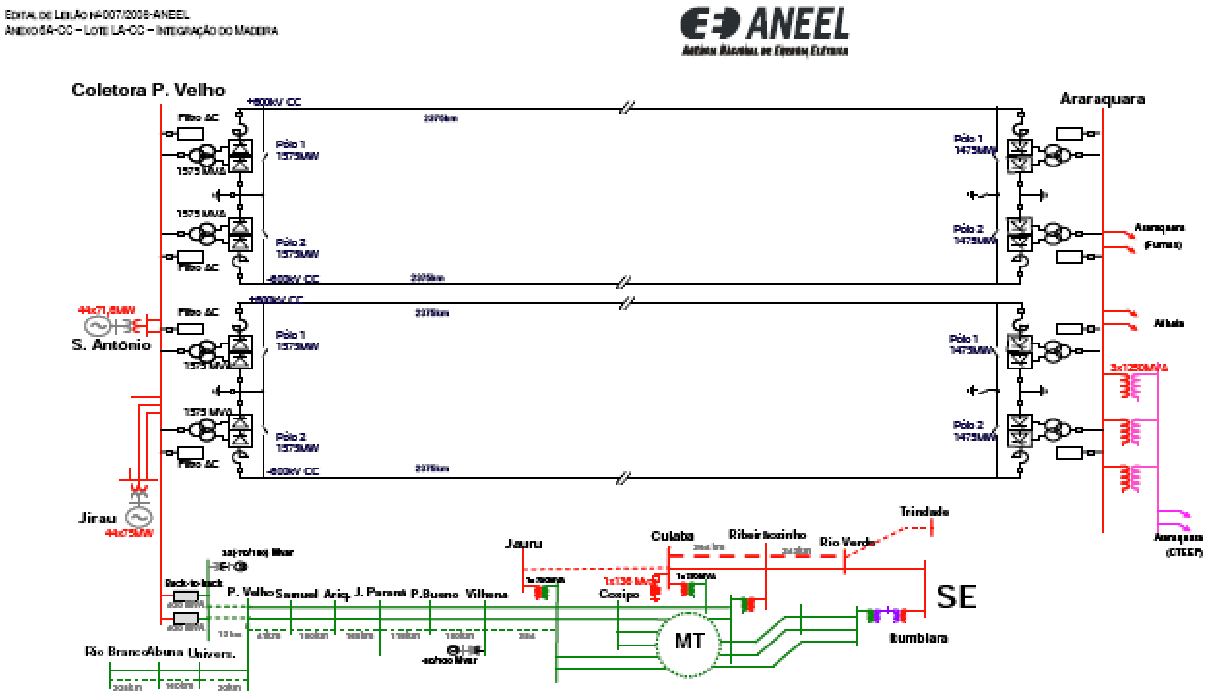

Figure 1: Conceptual design for the Rio Madeira project.

The two back-to-back blocks of 400 MW are used to connect the 500 kV Rio Madeira collector system (generators and rectifiers) to the very weak Acre-Rondônia 230 kV system, and this was the first delivery to be put into operation. ABB offered a solution using Capacitor Commutated Converters

(CCC) without synchronous compensators. The commissioning of this system is described in this paper, as well as the early operation of this very challenging interconnection.

Bipole 1 is rated 3150 MW, ± 600 kV, at the rectifier, and employs a configuration with one 12-pulse converter per pole. This configuration has been used in many projects. However, here many different operating configurations are required, including metallic return with various combinations of line poles and parallel operation with Bipole 2. There are also operating modes such as reduced voltage and Hi-Mvar, none of which are new, but together with the numerous other configurations this makes a complex set of requirements in one system. The implementation and proposed commissioning plan for the project are described in this paper including progress to date and details about the necessary coordination between generation and transmission.

2. Back-to-back commissioning

2.1. Local network characteristics

Back-to-back tests were completed by the end of 2012 under special network conditions on both sides. It is important to mention that the inverter side has a very weak network, which is the main reason for using a back-to-back converter. In addition, the 500 kV side, the side of the hydro power plants, had just a few generators in operation during the back-to-back energization and transmission tests; only four generators in Santo Antonio power plant were available, which is the minimum amount to prevent self-excitation.

Furthermore, there was a 500/230 kV parallel transformer connected during tests. As described in section 3 below, this transformer was intended to assist generator testing in the Santo Antonio hydro power plant.

2.2. Commissioning analysis tools

The ABB HVDC control system platform, called MACH2 (Modular Advanced Control for HVDC) has a tool for recording and analysis of transient responses called TFR. Transient responses, presented in the next section, were captured during the back-to-back commissioning tests. These data represent the real measurements observed during the commissioning tests.

2.3. Commissioning results

In this section the commissioning results for one back-to-back block are presented. The basics test results will be shown in order to demonstrate appropriate system operation. The test sequence was: 1) first deblocking test, 2) blocking test, 3) DC current step and 4) AC voltage step.

2.3.1. First deblocking test

This test type shows the performance of the system during the startup and bringing the system up to the appropriate operational point. Figures 2 and 3 present rectifier and inverter performance for first deblocking test.

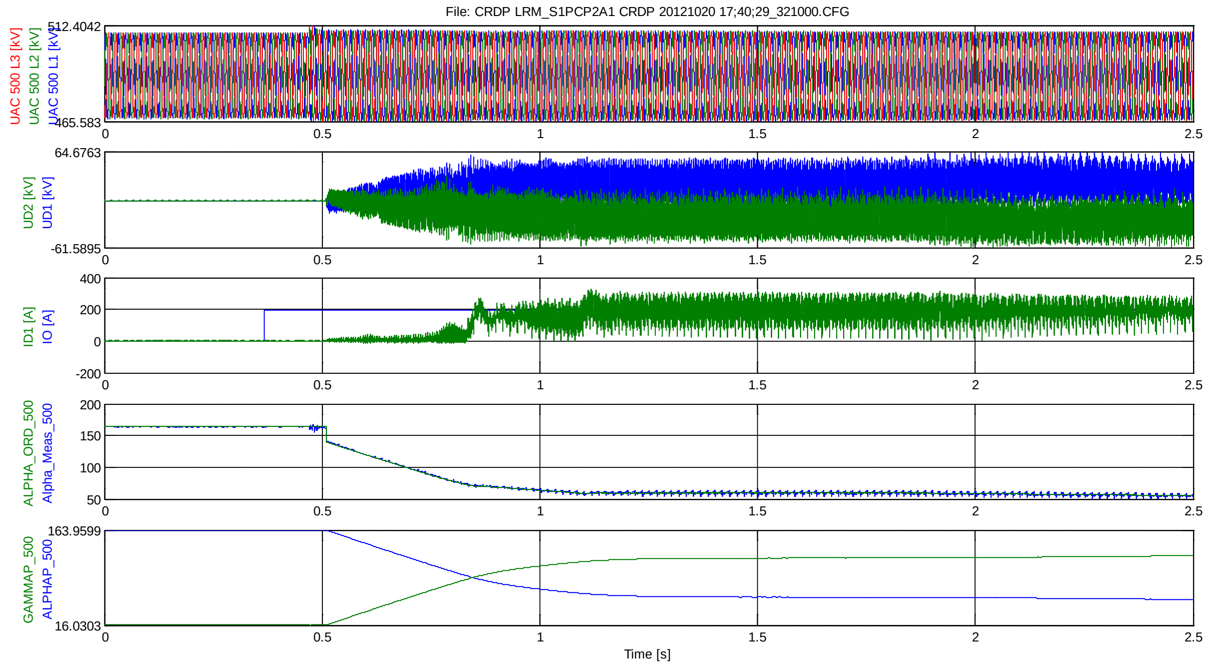

Figure 2: Rectifier performance.

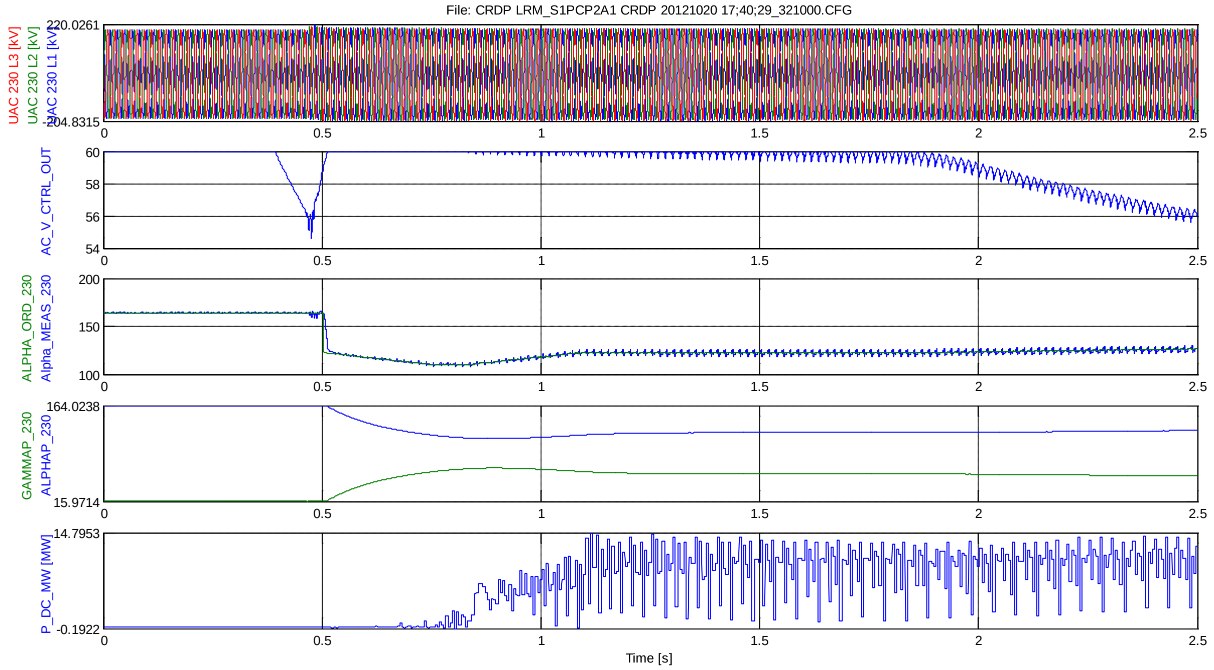

Figure 3: Inverter performance.

The AC voltage variations on the rectifier and inverter busbars during the deblocking test were within the acceptable range. The control angles, the DC current and DC voltage were performing as expected. It can also be seen that the DC power ramped up smoothly. Steady state operation was reached as predicted.

2.3.2. Blocking test

Blocking tests were developed for both the rectifier and inverter sides. Figures 4 and 5 present rectifier and inverter performance for rectifier blocking tests.

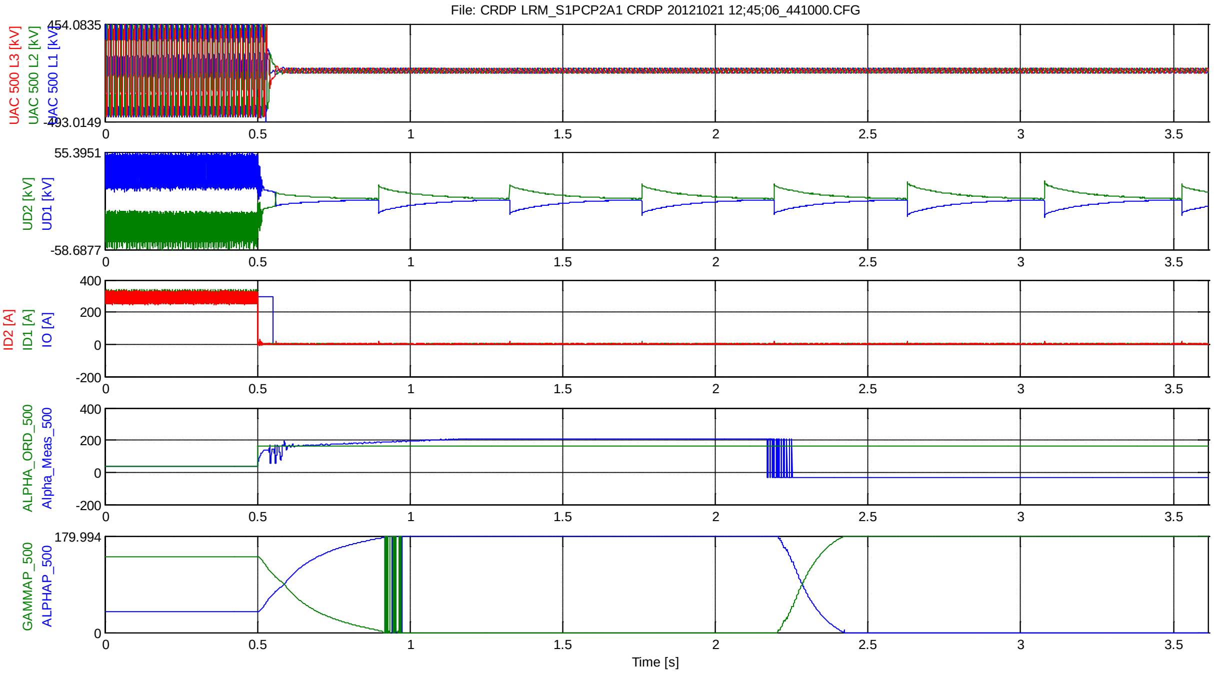

Figure 4: Rectifier performance.

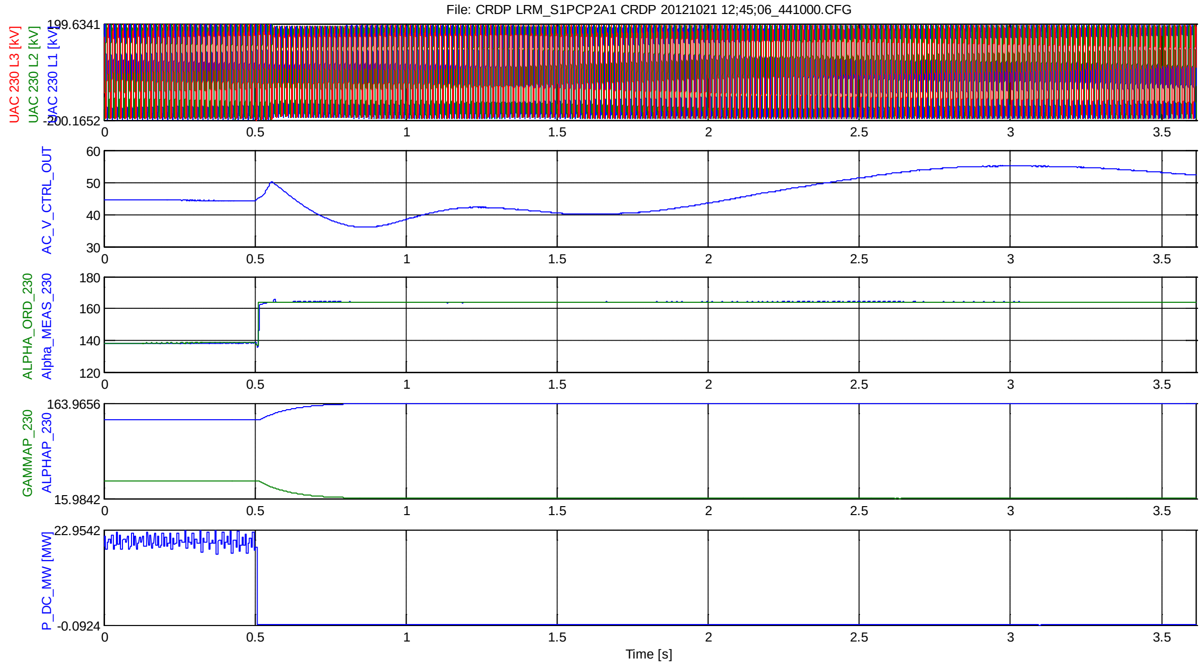

Figure 5: Inverter performance.

It can be seen in the oscillogram, that the rectifier blocking tests results demonstrate appropriate performance. The angles, DC current and DC voltage behave as expected. The DC power interruption is instantaneous and matches the DC current and DC voltage behavior.

Figures 6 and 7 present rectifier and inverter performance for the inverter blocking test.

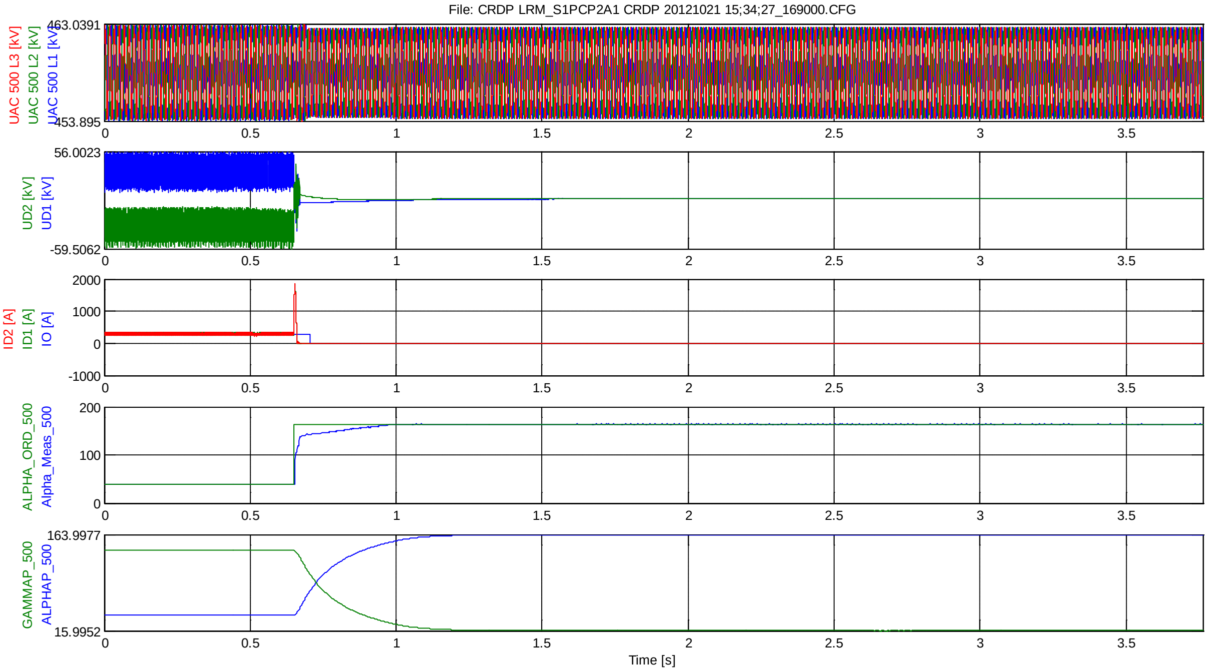

Figure 6: Rectifier performance.

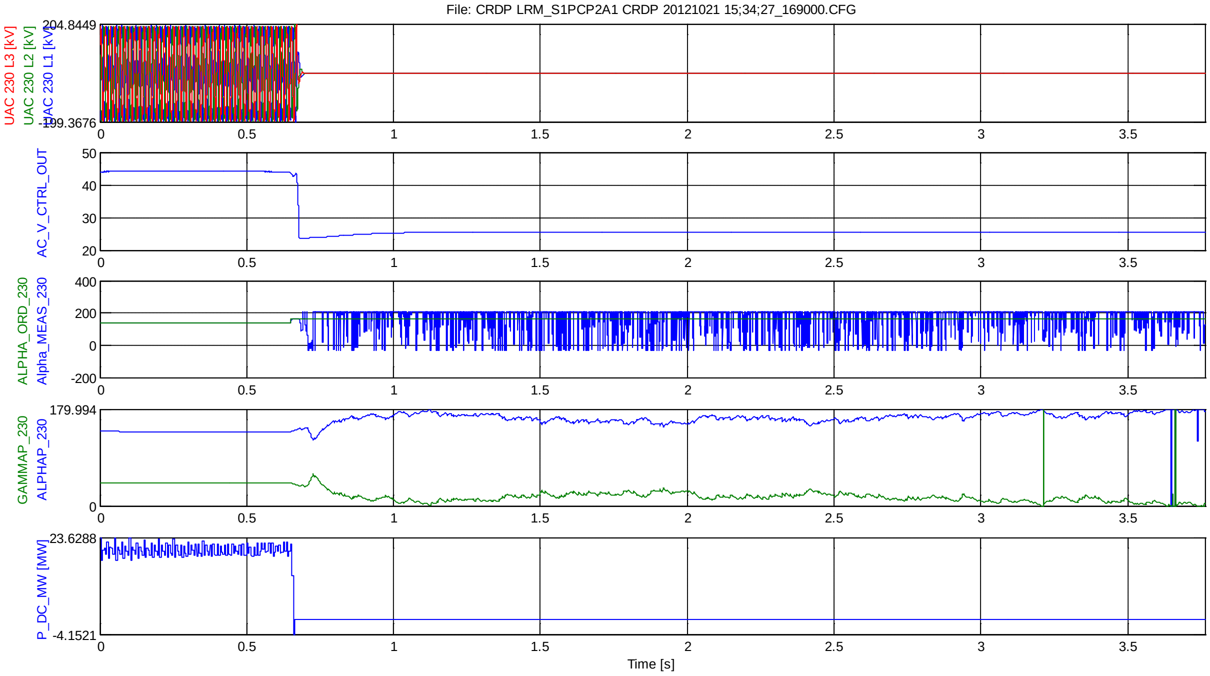

Figure 7: Inverter performance.

In the inverter blocking test recording the observed DC current on rectifier side can be seen rising at the recording blocking instant. This represents rectifier current responses to eliminate the transient caused by the inverter blocking. Fast AC voltage control response following the AC voltage transients on the inverter side demonstrates adequate performance.

2.3.3. DC Current step test

This test considers positive current order steps applied to the rectifier side. Figures 8 and 9 present rectifier and inverter performance for DC current order steps.

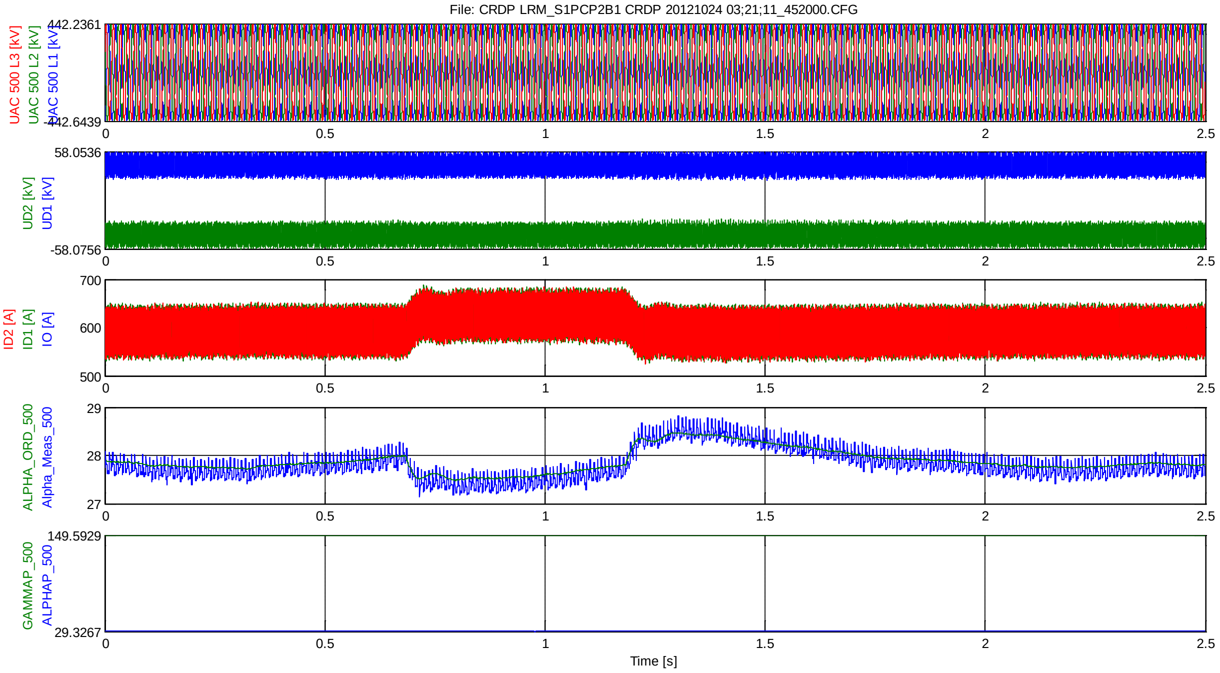

Figure 8: Rectifier performance.

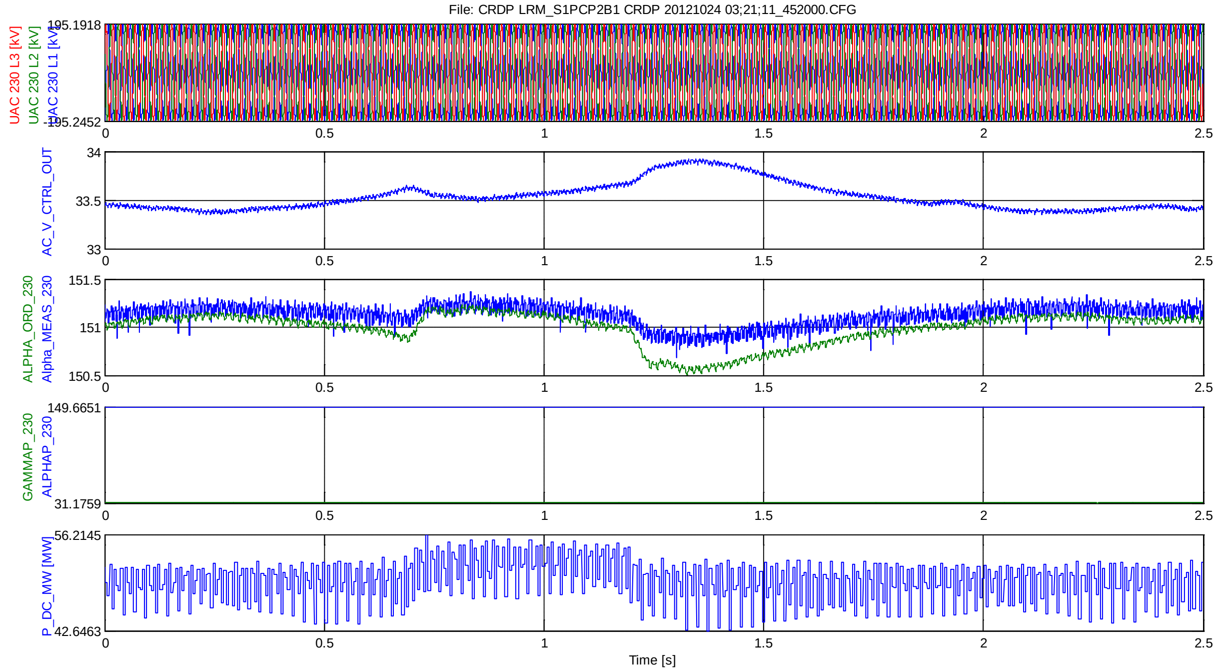

Figure 9: Inverter performance.

It can be observed that the system behaviour in response to DC current order steps is appropritate. The AC voltages on the rectifier and inverter sides have no oscillations. As a consequence of the current order steps, the DC power is incresead in the same proportion and the DC voltage remains constant. The control angle actions also behave properly.

2.3.4. AC Voltage step tests

This test considers a positive voltage step order applied in the voltage control on the 230 kV side. Figures 10 and 11 present rectifier and inverter performance.

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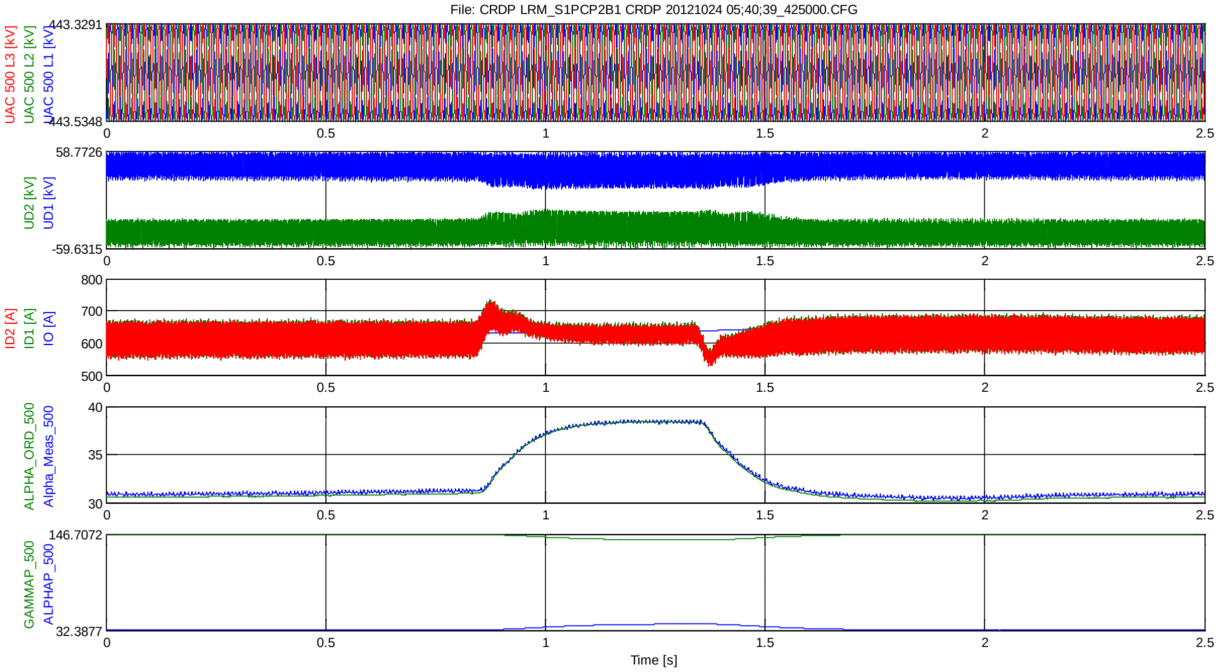

Figure 10: Rectifier performance.

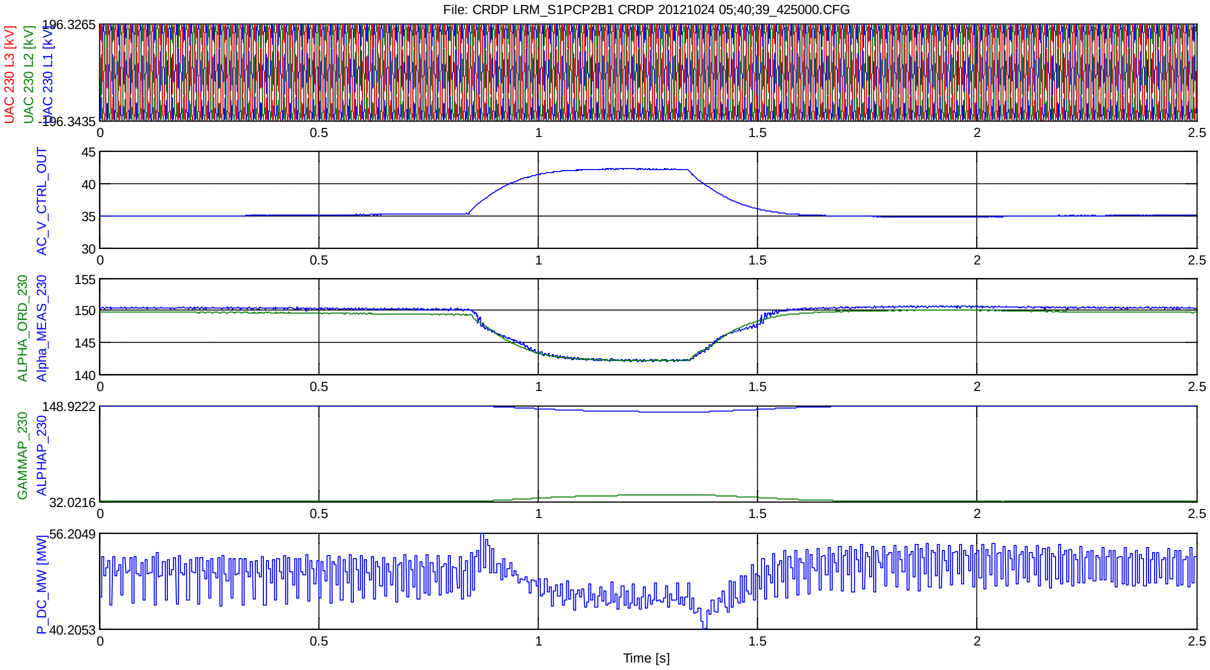

Figure 11: Inverter performance.

It can be observed that the behaviour of the DC voltage, as well as the AC voltage control step responses are appropriate. The AC voltages on the rectifier and the inverter sides have no oscillations. As a consequence of the voltage control order step, the DC power is decresead in the same proportion. Also, the control angle have proper actions to compensate for the voltage variations.

3. Bipole 1 commissioning

Bipole 1 has not been completely commissioned yet. It has already been energized in Araraquara (inverter side) and it is about to be energized for the first time in Porto Velho (rectifier side). Then bipole 1 will be ready to transmit power for the first time. However, many important conditions have to be met to permit power transmission.

First of all, it is important to mention that the hydro power plants are not ready yet. Furthermore, due to the low rating of the bulb turbines with very low inertia, it is necessary to guarantee a minimum amount of generation to be on line, to allow for energization of the AC harmonic filters preventing generator self-excitation. Thus, bipole 1 in Porto Velho can only be energized with at least 12 generators in operation. Considering the urgency of power demand in the southeast of Brazil and the schedule of the hydro power plants, the back-to-backs will be switched off to permit bipole 1 energization in Porto Velho and for power transmission tests.

In addition, with the aim to increase the short circuit level at the bipole connection point in Porto Velho, the existing parallel transformer will be kept connected to the system. The parallel transformer is installed between the two networks (500 kV and 230 kV networks), in parallel with the HVDC back-to-back systems. It was needed to permit generator synchronization and tests in the Santo Antonio hydro power plant. However, it is still considered as a convenient mean to improve the reliability of the system for HVDC equipment and the transmission system tests.

Further, in order to improve the voltage stability, it is recommended to insert a AC harmonic filter connected to the 230 kV network, as well as having the line Jirau reactor connected to the 500 kV busbar. This line reactor is installed to assist with the generator tests in the Jirau hydro power plant.

Last, but not least, Bipole 1 will first be tested as a monopole in the metallic return configuration since the bipole configuration demands a larger amount of connected generators. Considering that only one AC harmonic filter can be connecter to avoid self-excitation it will only be possible to transmit up to 700 MW with 12 generators once the transmission line is ready.

4. Master Control

The Master Controller is a highly important piece of equipment, required to enable the operation of the whole Rio Madeira complex. It is intended to control the power flow from generation to transmission in a smooth and reliable way.

The Master Controller is the top level control system in the Rio Madeira complex. It has direct control interfaces with both the back-to-back systems, bipoles 1 and 2, and the hydro power plants Santo Antonio and Jirau. The interfaces with the hydro power plants are performed by a piece of specific control equipment called the Generation Station Coordinator (GSC).

The Master Controller’s main functions concern responses to outages of equipment, which create active power unbalance between generation and HVDC load, unscheduled trips of generators, and HVDC load rejection due to pole or bipole trips. In the event of a sudden loss of a certain number of generators, due to a fault, the pre-fault active power dispatched by the generator station will be suddenly supplied by a lower number of generators. Without any action, that would cause under-frequency at the 500 kV busbar in Porto Velho and possible over excitation of the remaining machines in operation. In the event of a HVDC load rejection as a consequence of pole / bipole outages or limitations resulting from faults, the generators will see a sudden decrease in the load. Without any action, that would cause over-frequency at the 500 kV busbar in Porto Velho. The Master Controller is designed to take appropriate actions on the transmission and/or generation sides, to prevent power unbalances.

In addition, the number of generators in operation will also be used by the Master Controller to prevent self-excitation of the generators by calculating the maximum possible amount of AC harmonic filters connected at each HVDC component (Bipole 1, Bipole 2 and Back-to-Back).

Last but not least, it is important to mention that bipole 1 will be commissioned before the availability of the GSC in the hydro power plants. As a consequence, temporary additional actions must be taken to avoid self-excitation as well as for equipment protection against large frequency variations in case of transmission or generation outages. In addition, the absence of the GSC will, in spite of those temporary additional actions, limit the amount of possible transmission power to 1200 MW, even if a higher number of generators are available in the system.

5. Conclusion

The Rio Madeira complex is a large project encompassing generation and HVDC transmission in a particular region of Brazil and under particular conditions. As a consequence, the project commissioning is highly complex, demanding a lot of planning and resources.

The commissioning of the hydro power plants has a specific time schedule that does not match that of the HVDC transmission systems. The back-to-back HVDC converters started commercial operation in December 2012. Bipole 1 has already been commissioned in Araraquara side using open line test. Porto Velho energization tests are forecasted for June 2013 for filter and transformer energization, as well as open line test.

Transmission tests are forecasted to be initiated in July 2013. This, however, depends on the completion of the overhead line, which has been delayed because of being in the rainy season, environmental law issues, etc. Once finished, the transmission tests will be performed in monopole configuration with metallic return, transmitting 700 MW from Porto Velho up to Araraquara, more than 2500 km without any intermediate substation; the longest transmission line in the world.

Next step in the Rio Madeira project will be the implementation of the GSCs in the hydro power plants and full automatic control of the Master Controller, expected to be completed in December 2013. This will allow transmission of all available power generation to the southeastern regions of Brazil without control and protection restrictions.

Last but not least, the second bipole will be commissioned and provide significant flexibility to the operation of the Rio Madeira transmission system complex, allowing all of the energy generated in the complex for use by the Brazilian population.