

FERRORESONANCE PHENOMENON IN CFE, ITS ORIGIN AND EFFECTS

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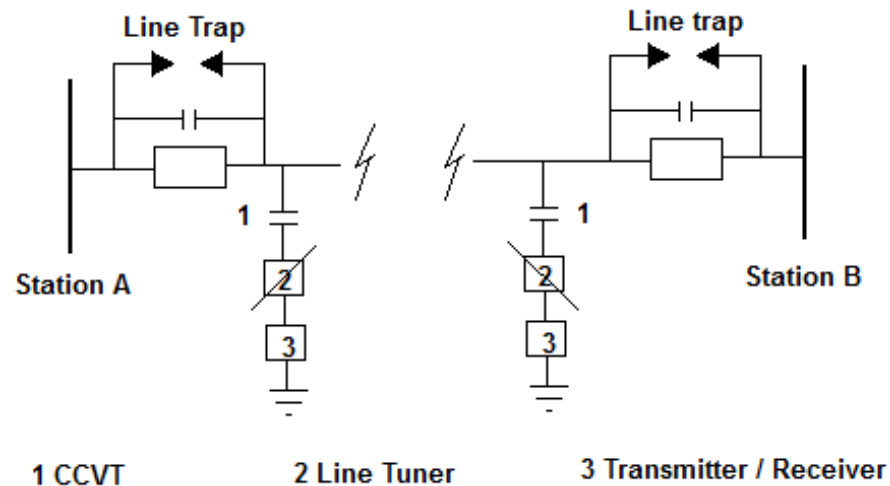
Outline

- 1) Replacement CCVTs by IVTs
- 2) Ferroresonance phenomena
- 3) Ferroresonance in the Mexican Electrical System
- 4) Two study cases : Tecnológico (TEC) and Rio Escondido (REC)
- 5) Ferroresonance mitigation

Conclusions

1) Replacement CCVTs by IVTs

- Power Line Carrier (PLC) and Coupling Capacitor Voltage Transformers (CCVTs) have been used in Mexican Electrical System (MES), operated by the Electrical Mexican Company *Comisión Federal de Electricidad* (CFE)

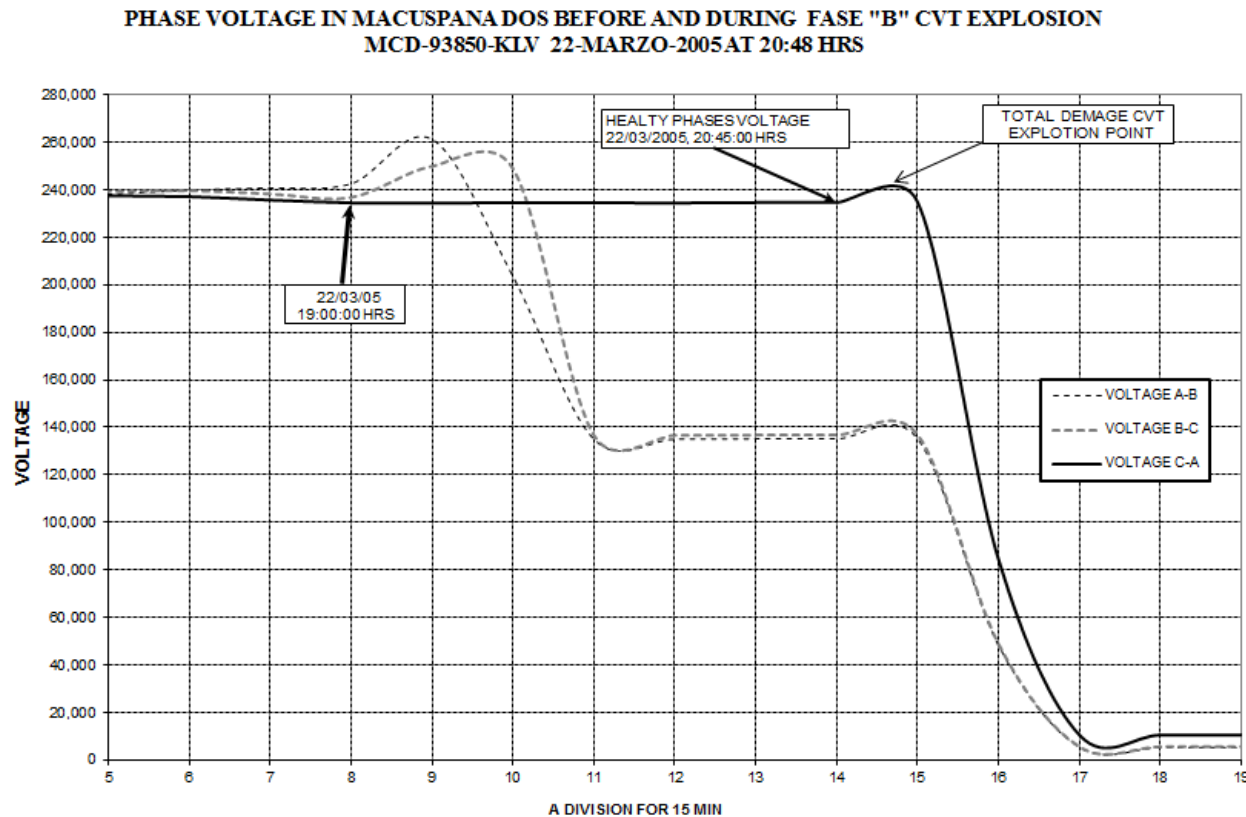


Power Line Carrier diagram

1) Replacement CCVTs by IVTs

Failures due to manufacturing defects and extreme environmental conditions

CCVT Fault Analysis



Based on the above, it was possible to implement alarms / controls for detection of phase voltage imbalance, and replace the CCVT **before** explosion

1) Replacement CCVT's by IVTs

CCVT Failures in Mexican Electrical System (MES)

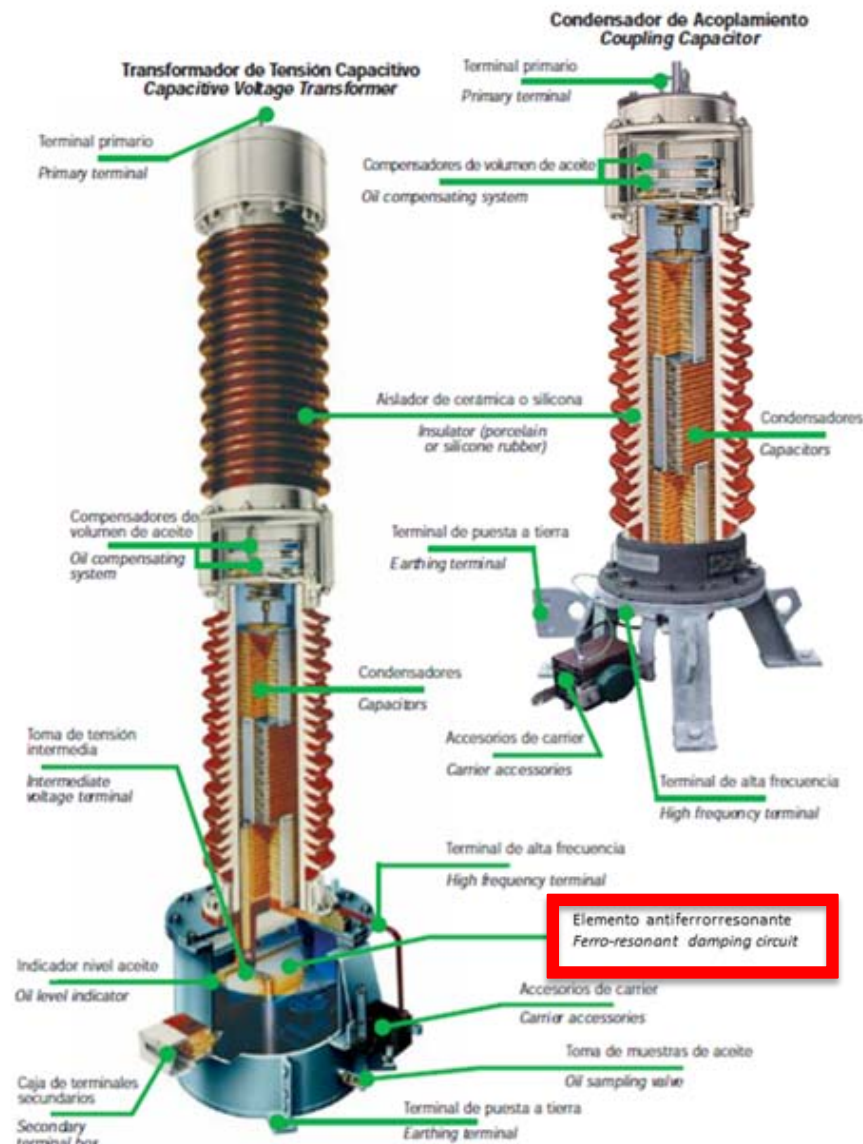
YEAR	400 KV	230 KV	115 KV	TOTAL
2010	1	4	2	7
2009	11	5	2	18
2008	3	4	0	7
2007	15	8	0	23
2006	6	8	5	19
2005	10	18	5	33
2004	4	10	1	15
2003	5	9	0	14
2002	3	4	1	8
2001	2	6	0	8
2000	0	11	3	14
TOTAL	60	87	19	166

1) Replacement CCVTs by IVTs

- CCVT failures and their insufficient measurement accuracy lead to their replacement by Inductive Voltage Transformers (IVTs). At the same time PLC were replaced by fiber optic communications
- However IVTs do not have anti-ferroresonance element, thus ferroresonance cases became frequent

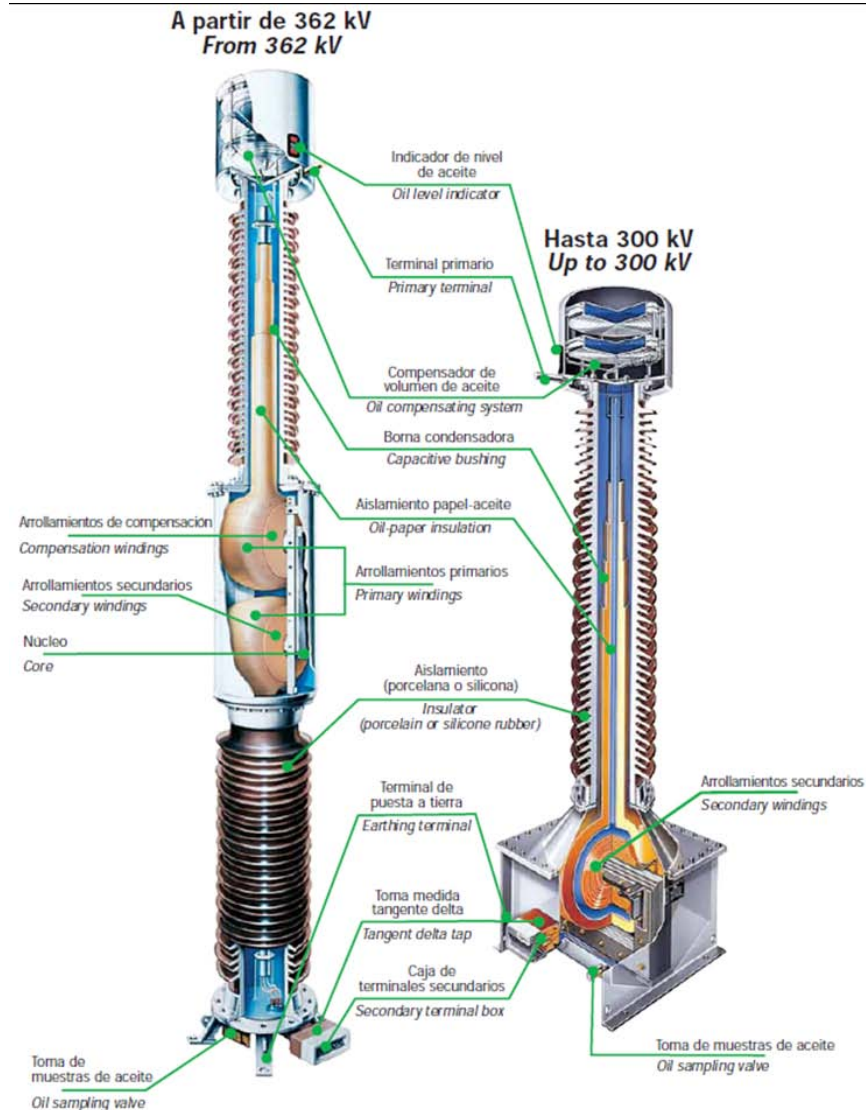
1) Replacement CCVTs by IVTs

CCVT with anti-ferroresonant element



1) Replacement CCVTs by IVTs

IVT without anti-ferroresonant element



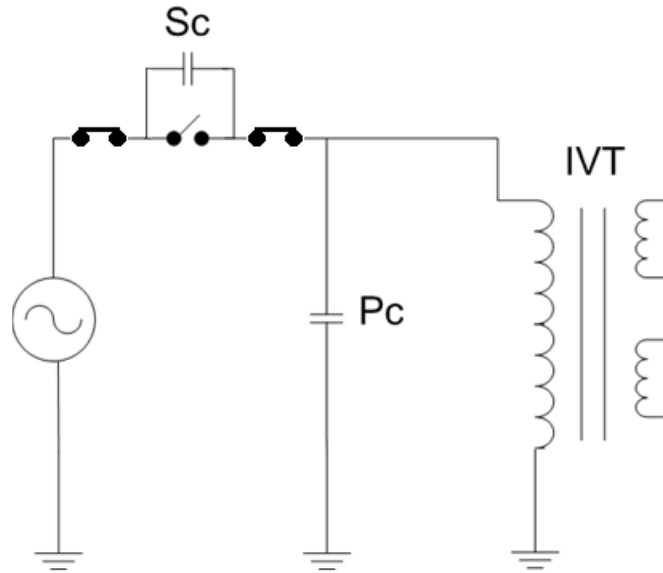
2) Ferroresonance phenomena

Ferroresonance Definition

- Ferroresonance is characterized by a **sudden jump** of voltage and current from one stable operating state to another. The relationship between voltage and current depends not only on the frequency but also on a number of other factors.
- .
- Ferroresonance or nonlinear resonance occurs when a circuit containing a **non-linear inductive** ferromagnetic core is fed from a source with **series and parallel capacitances**, and the circuit is subjected to a disturbance such as opening of circuit breakers.
- Ferroresonance should not be confused with linear resonance that occurs when inductive and capacitive reactances of a circuit are equal. In linear resonance the current and voltage relationship is linear and frequency dependent.

2) Ferroresonance phenomena

Ferroresonant Circuit



Sc Series capacitance

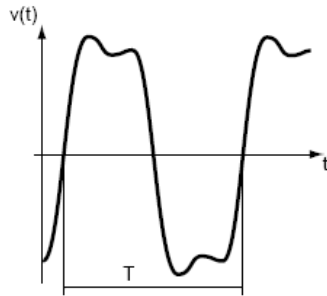
Pc Parallel capacitance

IVT Inductive Voltage Transformer

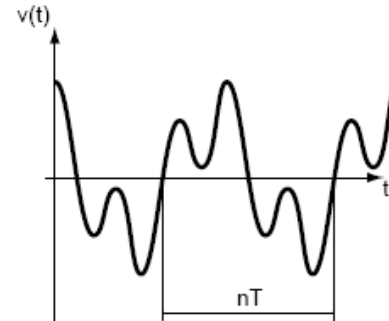
Low voltage

2) Ferroresonance phenomena

Ferroresonant Modes

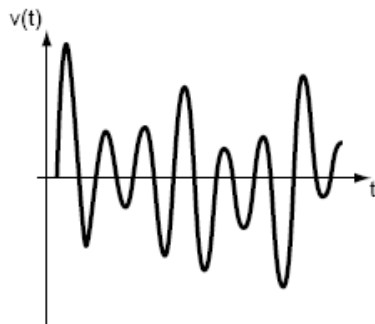


fundamental

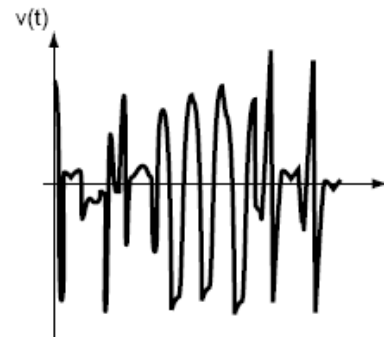


sub-harmonic

periodic



quasi-periodic



chaotic

no periodic

2) Ferroresonance phenomena

Ferroresonance Effects

- Sustained phase-to-phase and phase-to-ground overvoltages
- Sustained overcurrents
- Sustained waveform distortions of currents and voltages
- Transformers heating up
- Electrical equipment damage (thermal or due to insulation failure)
- Loss of protective devices operation
- Overheating of walls and metal parts of the transformer due to dispersion flux and high saturation of the core and internal parts
- Damage in surge arresters, surge suppressors and overvoltage protection devices due to overheating
- Transformers life reduction due to overheating and dielectric stress

2) Ferroresonance phenomena

Ferroresonance Effects in IVTs



China



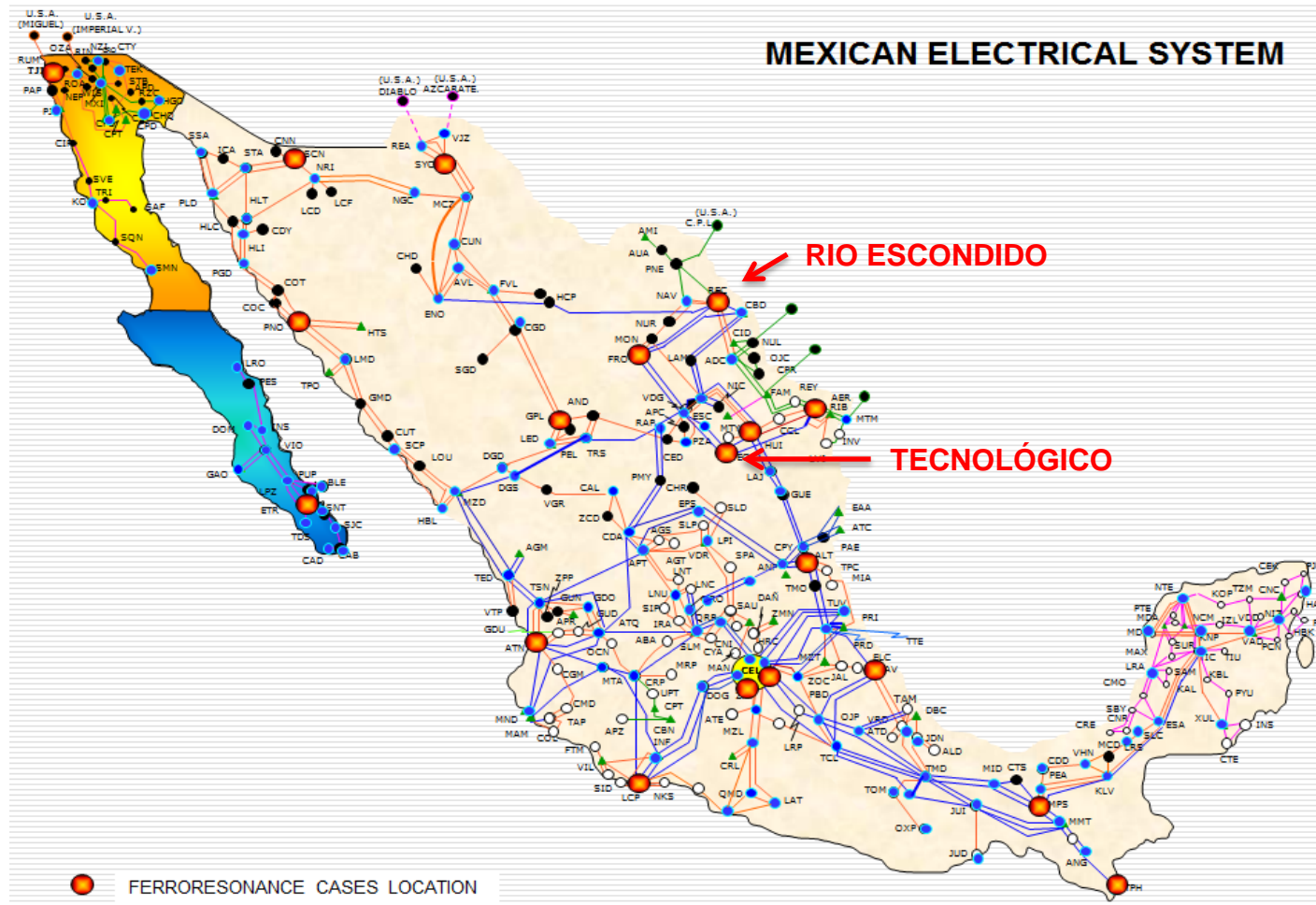
USA



México (Rio Escondido)

3) Ferroresonance in the Mexican Electrical System

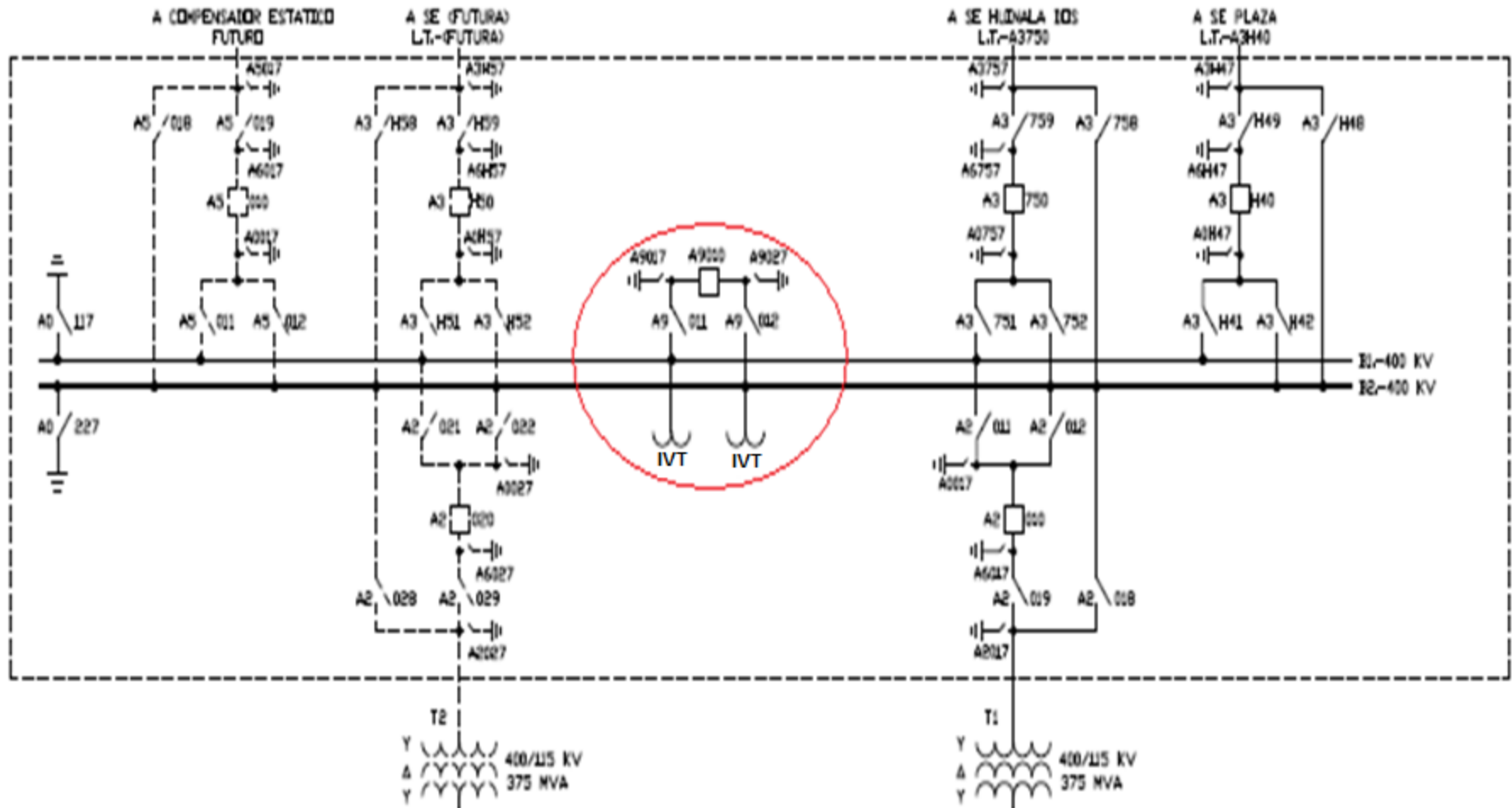
Ferroresonance Cases Registered in MES



Study case 1: Tecnológico substation Study case 2: Rio Escondido substation

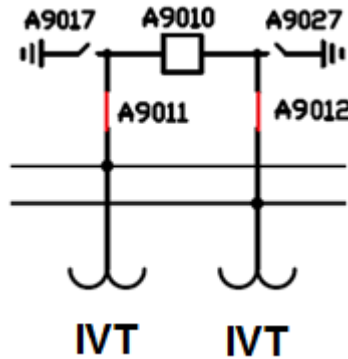
4) Two studies cases: Tecnológico TEC y Rio Escondido REC

Study cases 1: Substation Tecnológico (TEC)



Gas-insulated substation Tecnológico in 400kV
November 4, 2010

4) Two studies cases: Tecnológico TEC y Rio Escondido REC

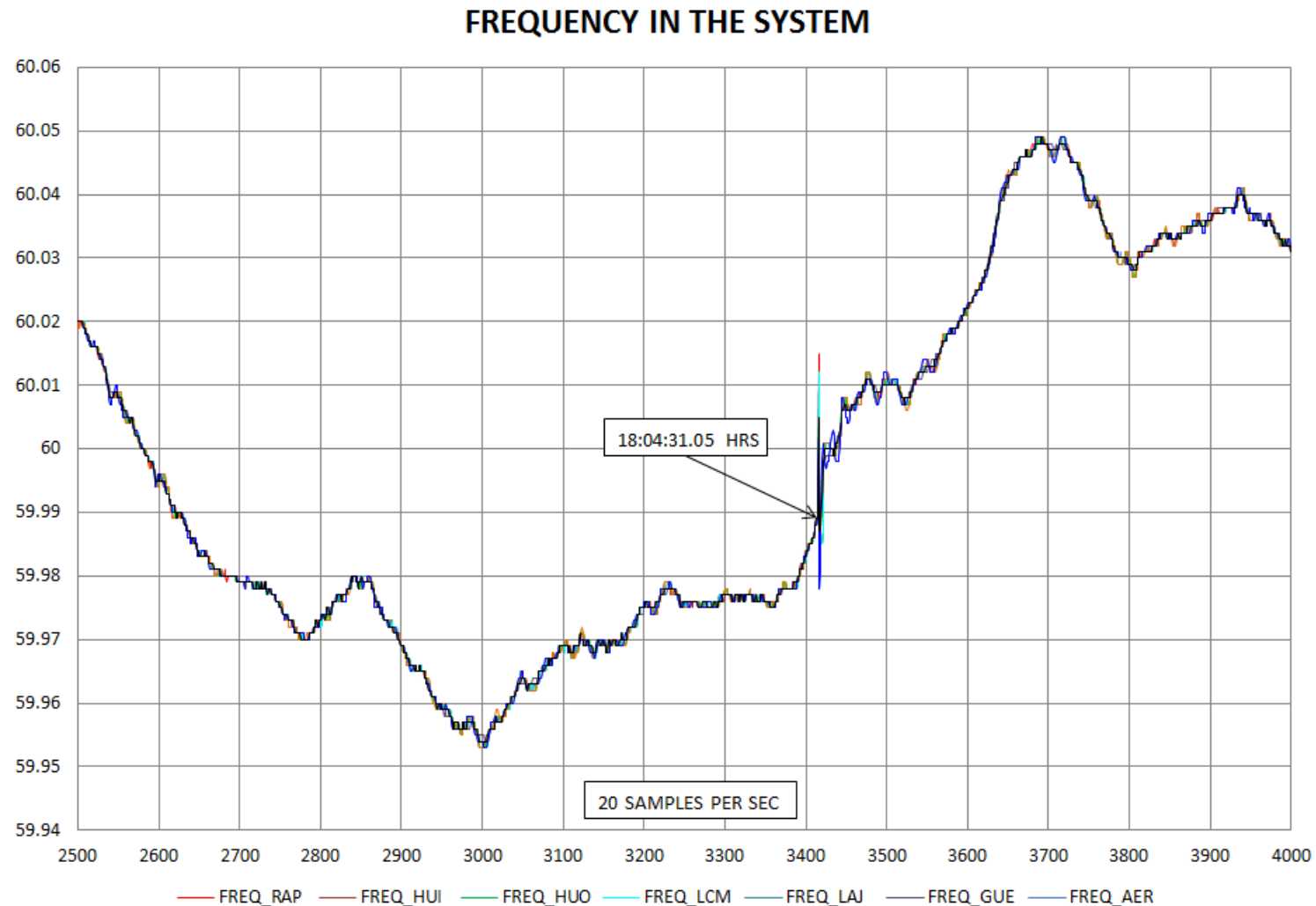


Event description

- On **November 4, 2010 at 15:06 hrs**, the breaker A9010 which links busbar 1 and 2 was out of service for maintenance opening the associated breakers. When all breakers on bus bar 2 were open, ferroresonance event occurred and IVT phase B on bus bar 2 was damaged (strange noise reported by personnel was caused by IVT core vibration).
- On **November 4, 2010 at 18:04 hrs**, when the circuit breaker A9010 got back in service (closed), after completed maintenance work, operated differential protection of bus bar 1 (because of IVT damage), and disconnected all devices connected to bus bar 1. This caused a second ferroresonance event that damaged IVT phase B in bus bar 1.

4) Two studies cases: Tecnológico TEC y Rio Escondido REC

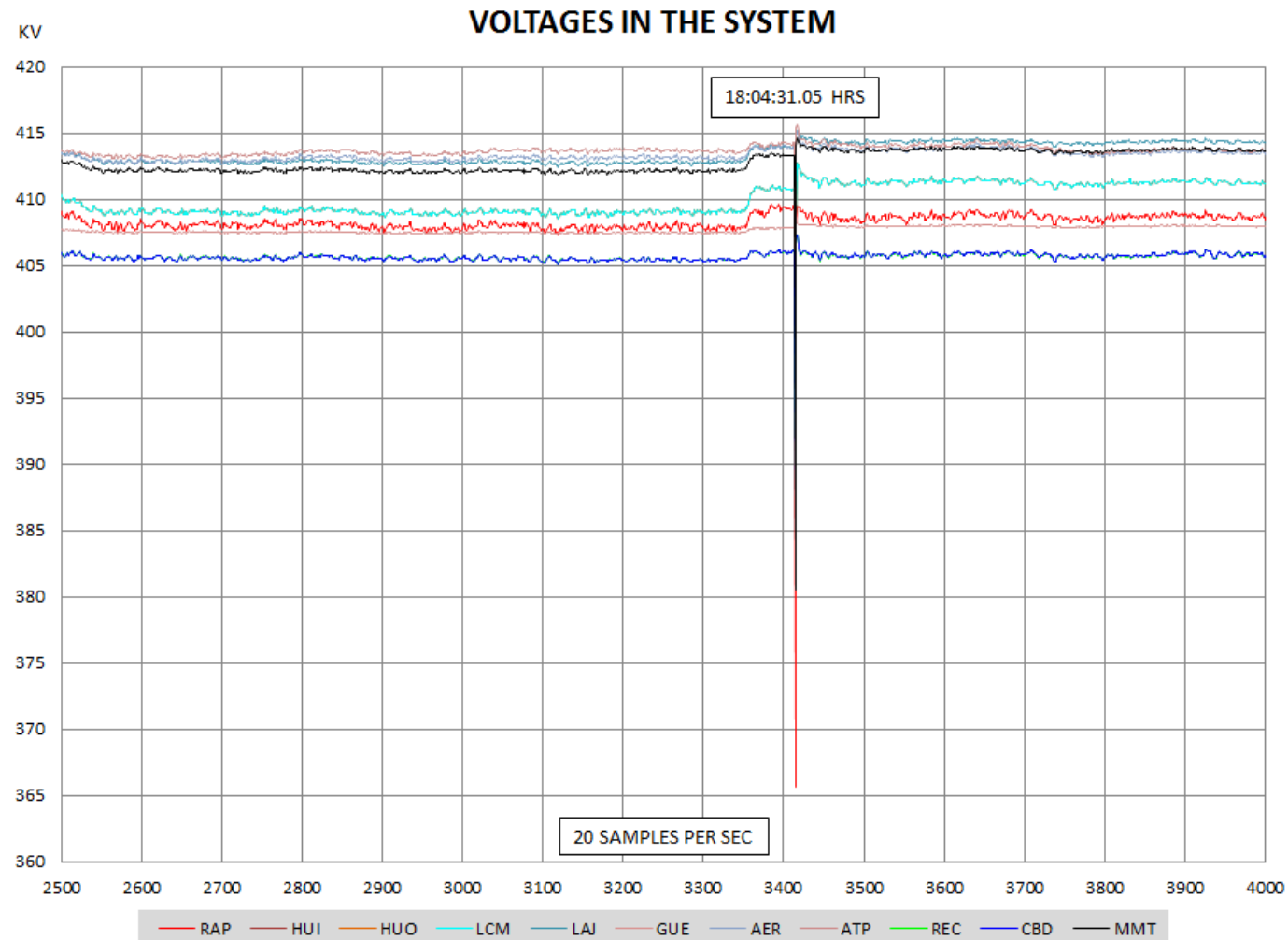
System Frequencies on November 4 2010 at 18:04 hrs



PMU records of MES frequencies during November 4, 2010 event at 18:04 hrs

4) Two studies cases: Tecnológico TEC y Rio Escondido REC

System Voltages on November 4 2010 at 18:04 hrs



PMU records of MES voltages during November 4, 2010 event at 18:04 hrs

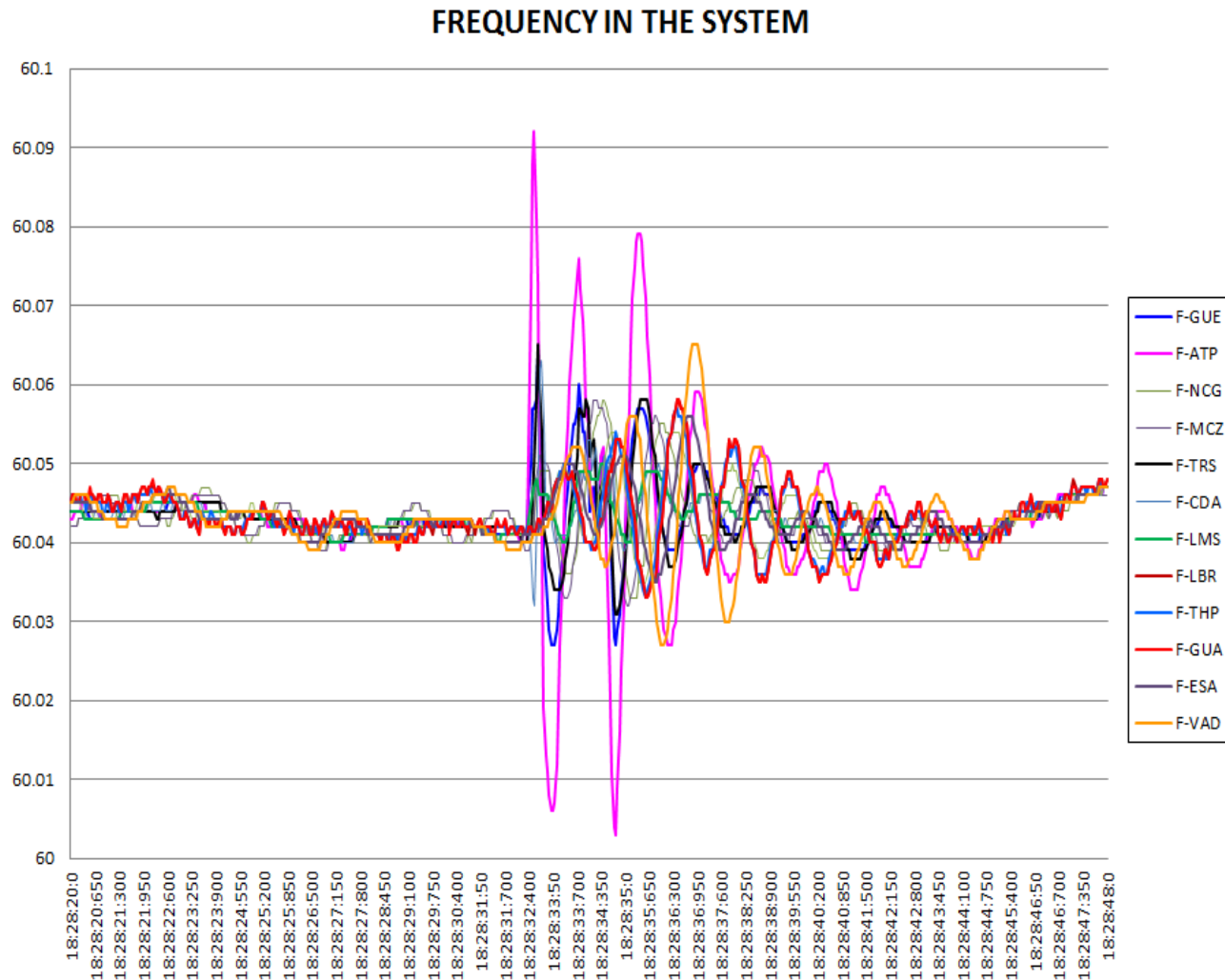
4) Two studies cases: Tecnológico TEC y Rio Escondido REC

Events in Tecnológico (TEC) on November 4 2010 at 18:28 hrs

- At 18:27 hrs after normalizing bus bar 1, it was energized through the line TEC-A3H40-PZA.
- At 18:28 hrs the line TEC-A3750-HUO was connected and circuit breaker PZA-A3H40 was operated due to the fault in the IVT phase B on bus bar 1.
- Circuit breaker TEC-A3750 was closed with the failure still present in the bus bar 1. The protection switch into fault operated and because the circuit breaker did not clear the fault, the Breaker Failure protection 50 BF operated and disconnected all the equipment connected to bus bar.

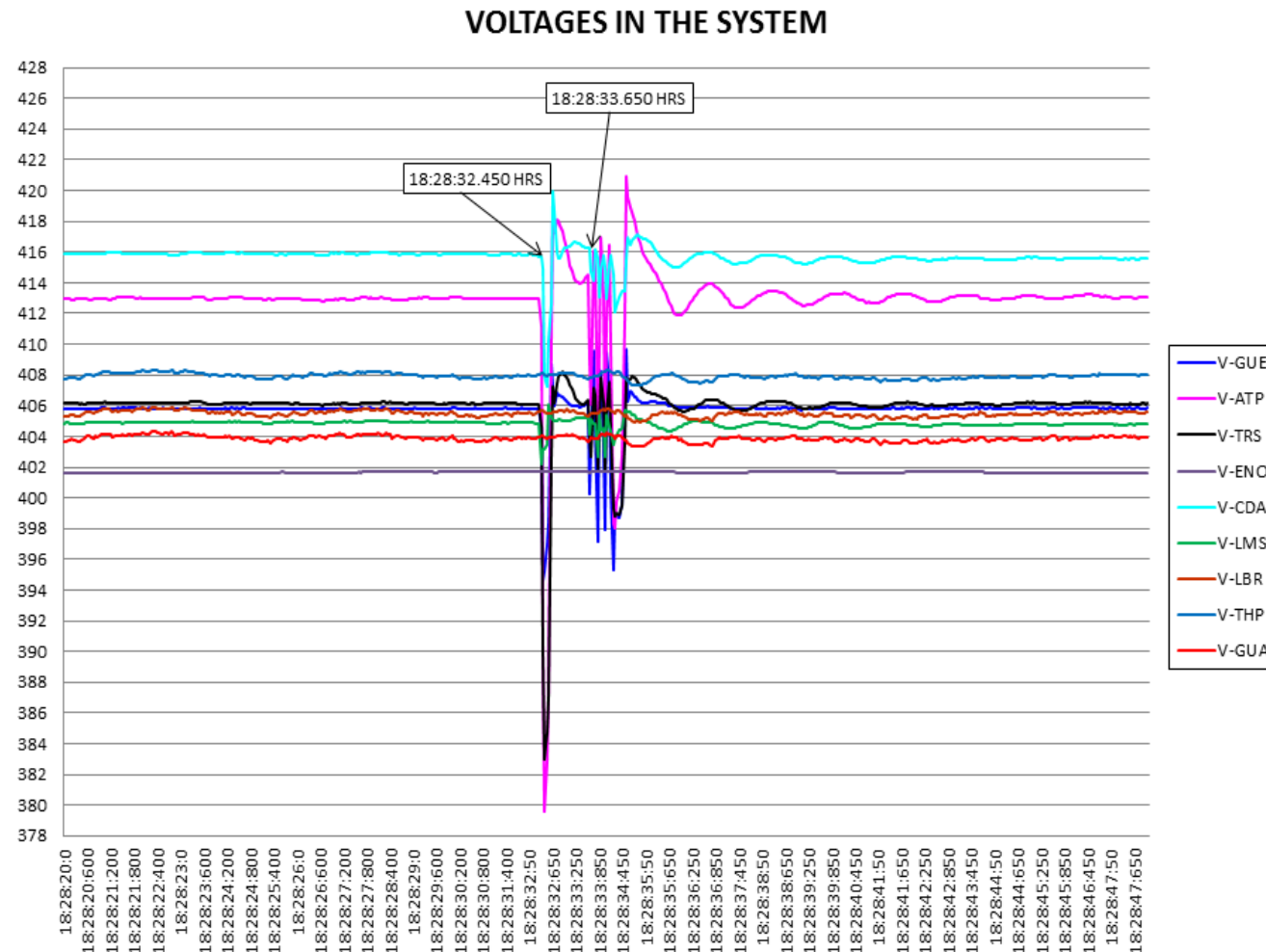
4) Two studies cases: Tecnológico TEC y Rio Escondido REC

System Frequencies on November 4 2010 at 18:28 hrs

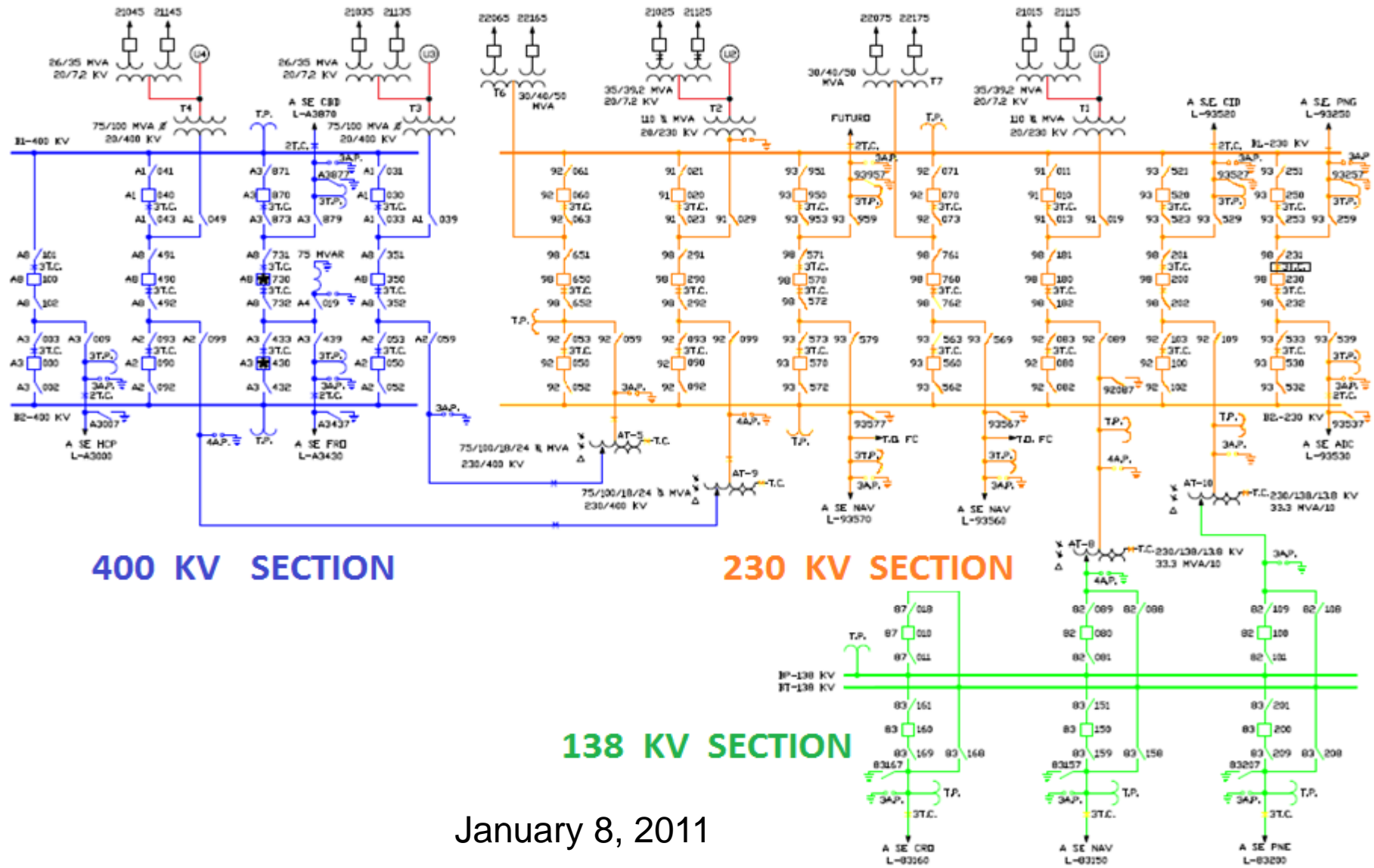


4) Two studies cases: Tecnológico TEC y Rio Escondido REC

System Voltages on November 4 2010 at 18:28 hrs



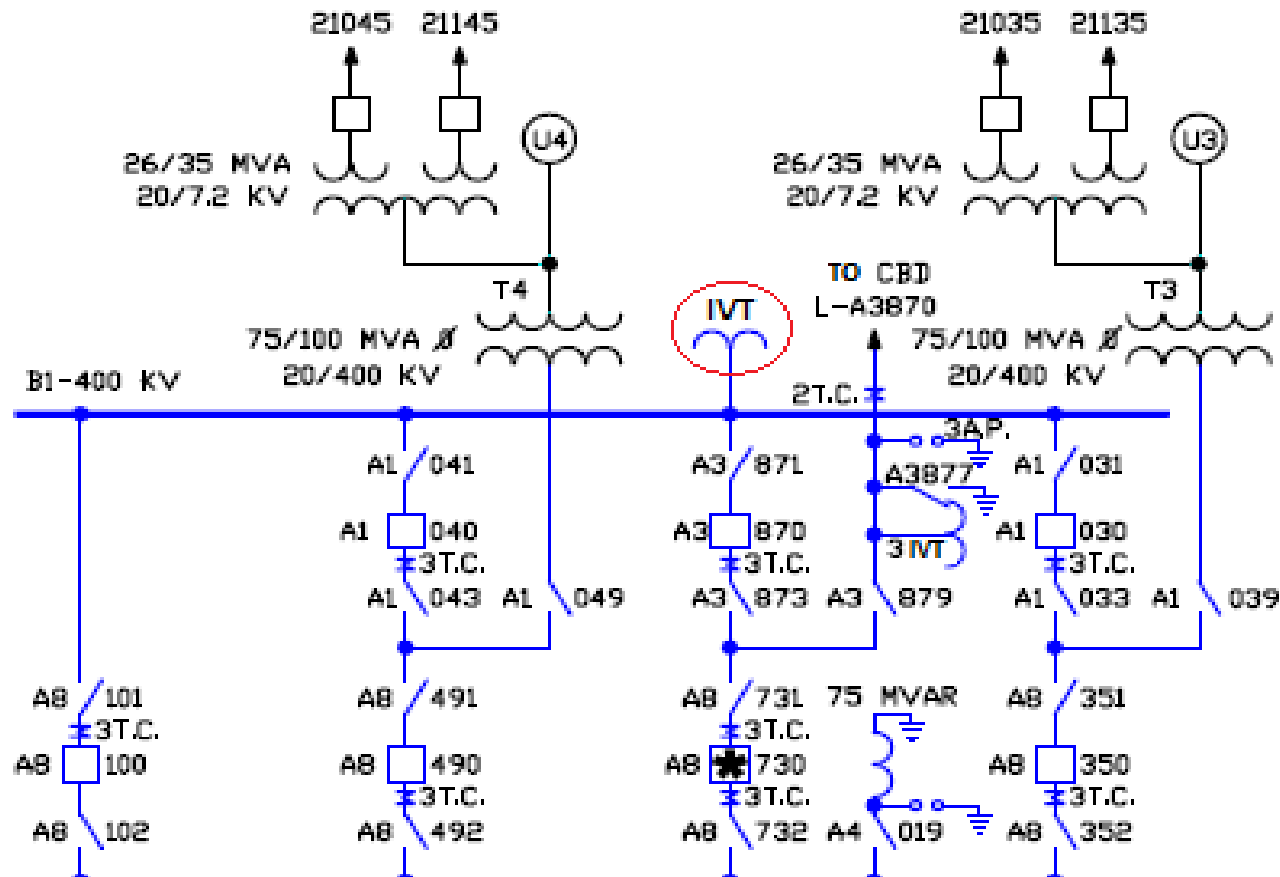
Study case 2: Substation Rio Escondido (REC)



January 8, 2011

4) Two studies cases: Tecnológico TEC y Rio Escondido REC

IVT location in REC

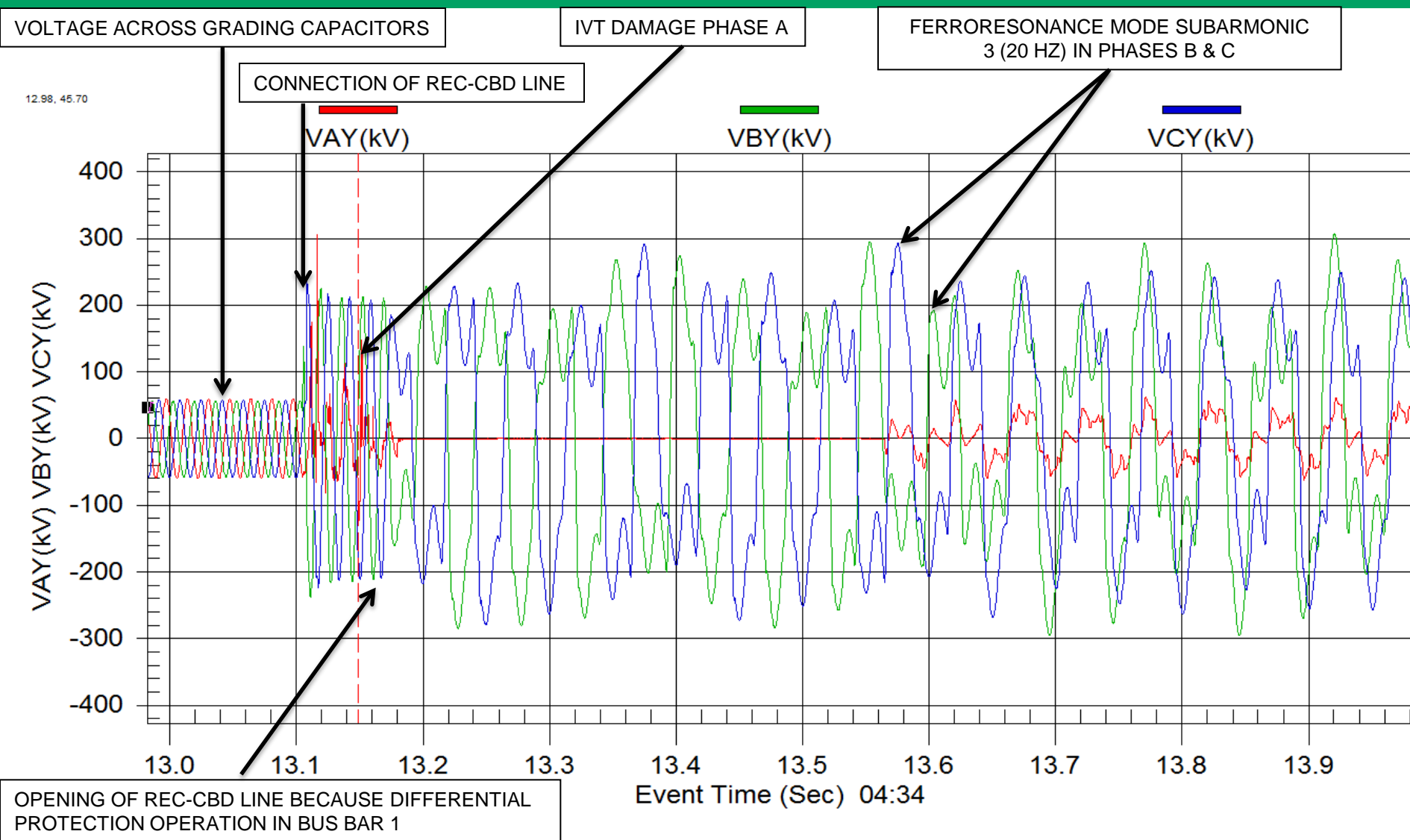


4) Two studies cases: Tecnológico TEC y Rio Escondido REC

Event in Rio Escondido on January 8, 2011

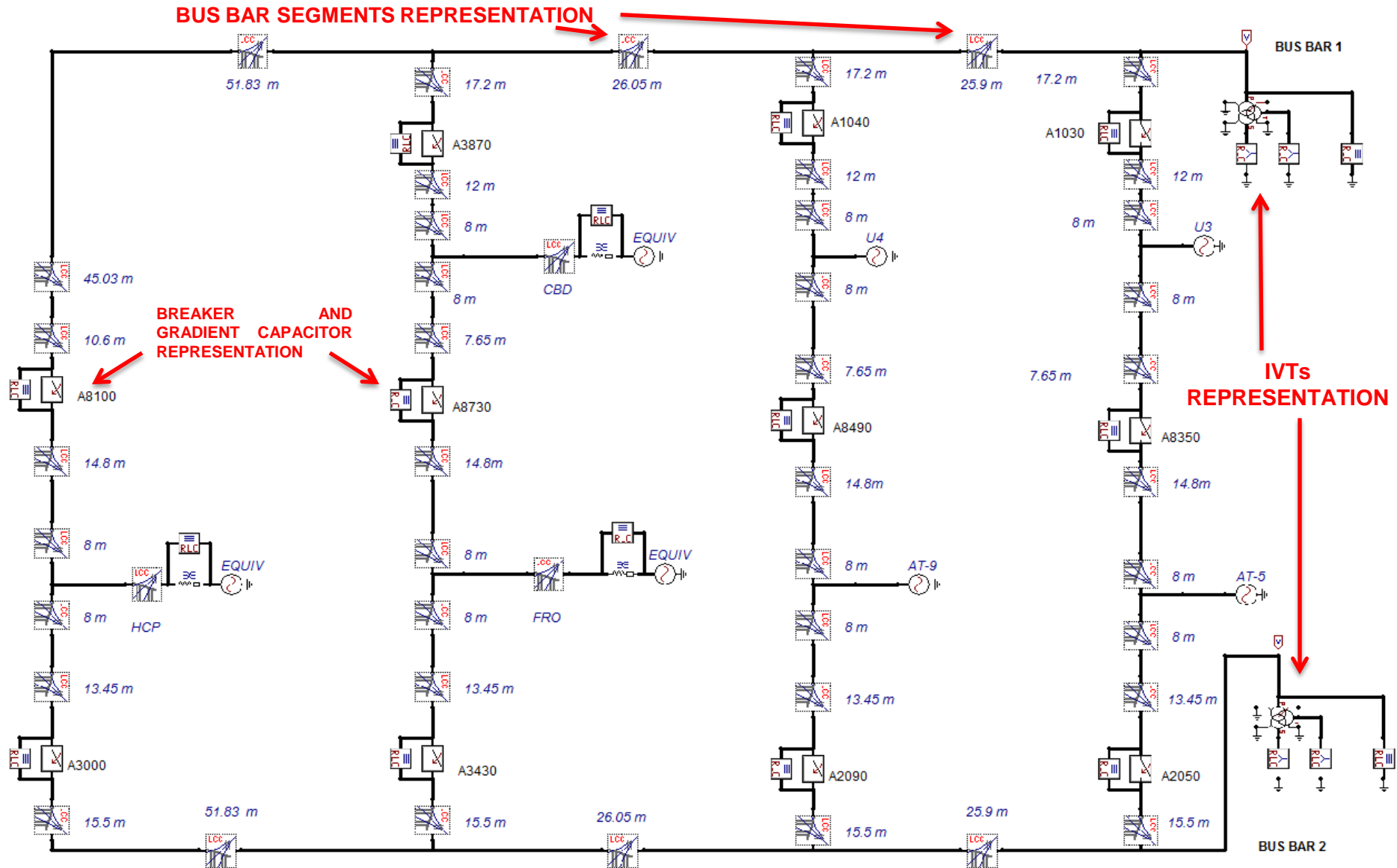
- On January 8, 2011 at 0:57 hrs there was a mechanical failure in Generator 4
- The breaker did not operate to clear the fault, so the Breaker Failure scheme worked and disconnected all equipment connected to bus bar 1. In this moment ferroresonance took place and IVT phase A was damaged.
- At 4:34 hrs when bus bar 1 was trying to restored by closing transmission line REC-Carbon Dos (CBD), exploted IVT phase A of bus bar 1(because previous damage caused for ferroresonance) operated differential protection of bus bar 1. In this moment appears ferroresonance in phases B and C.

Event in Rio Escondido on January 8, 2011 at 4:34 hrs



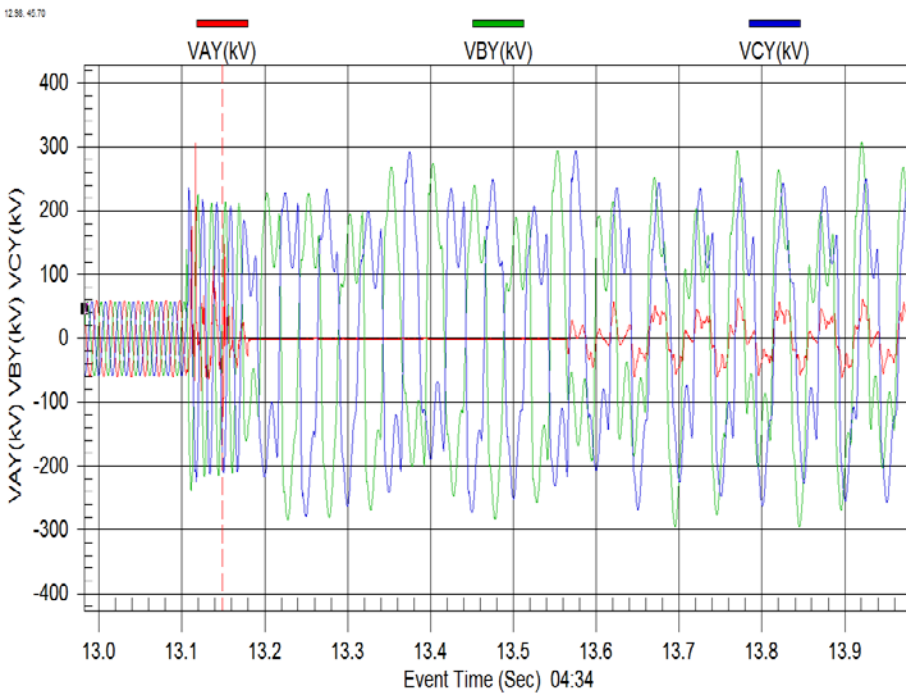
Disturbance Record captured in REC on January 8th, 2011 at 4:34 hrs

Simulation of January 8, 2011 REC Event

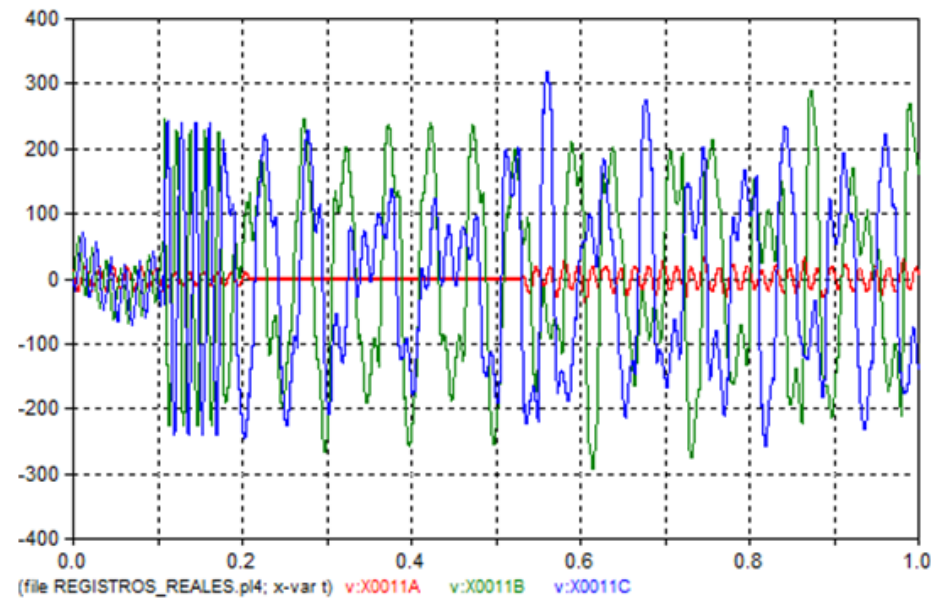


5) Ferroresonance mitigation

Verification of the Event Simulation

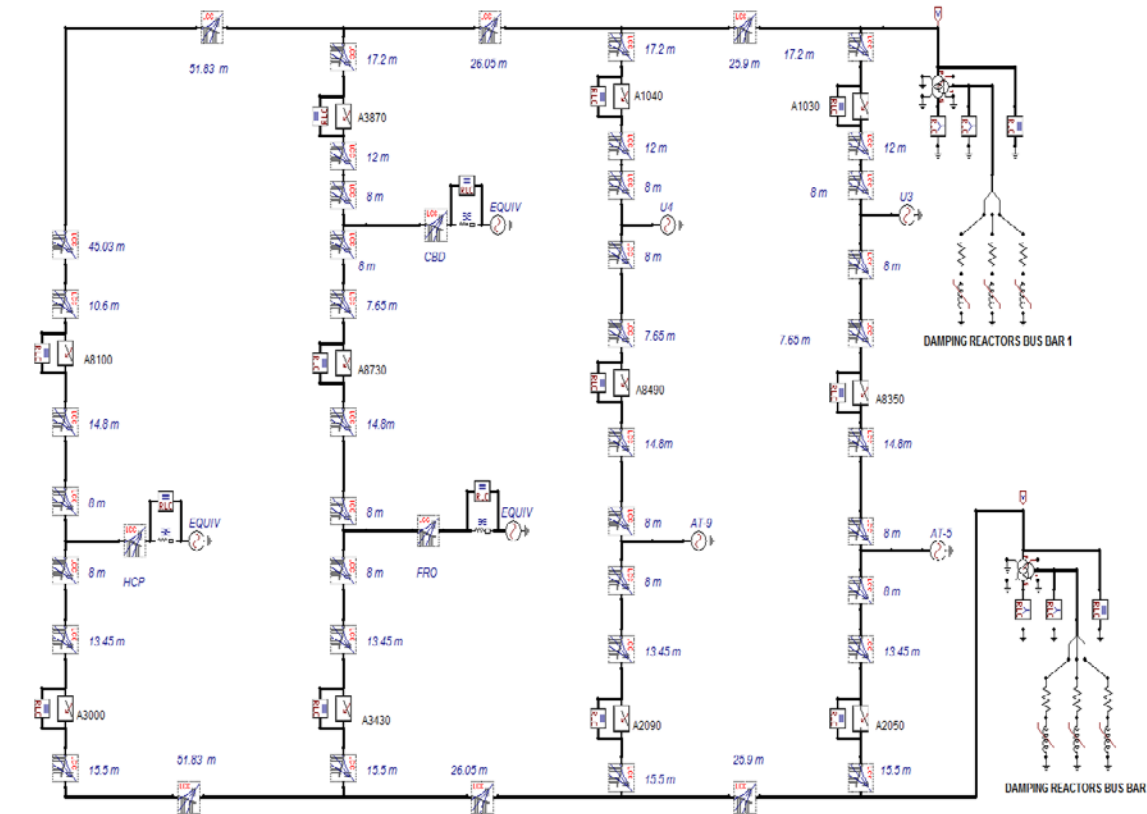


EVENT RECORD



EVENT SIMULATION

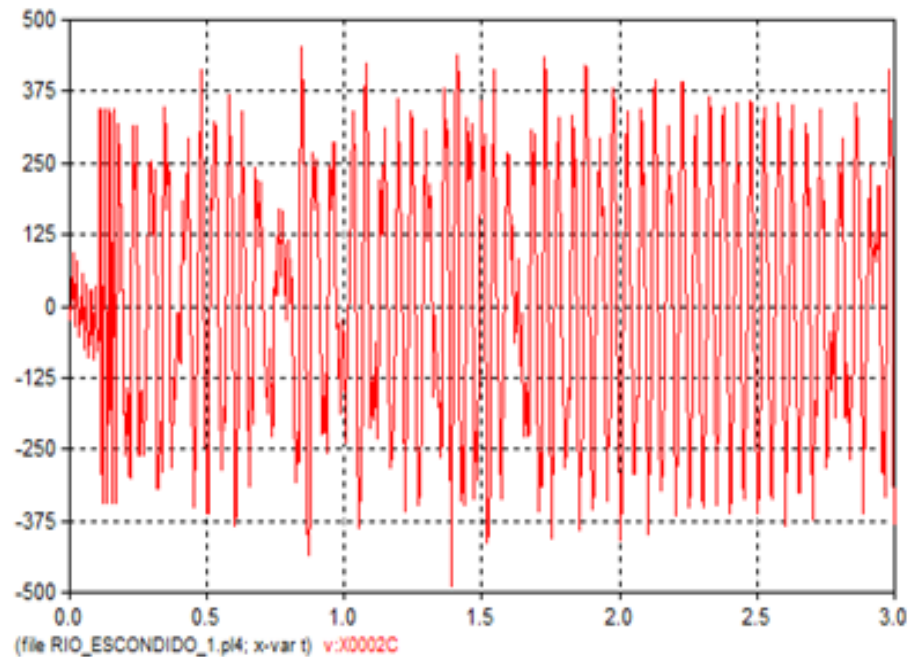
5) Ferroresonance mitigation: Use of Damping Reactors



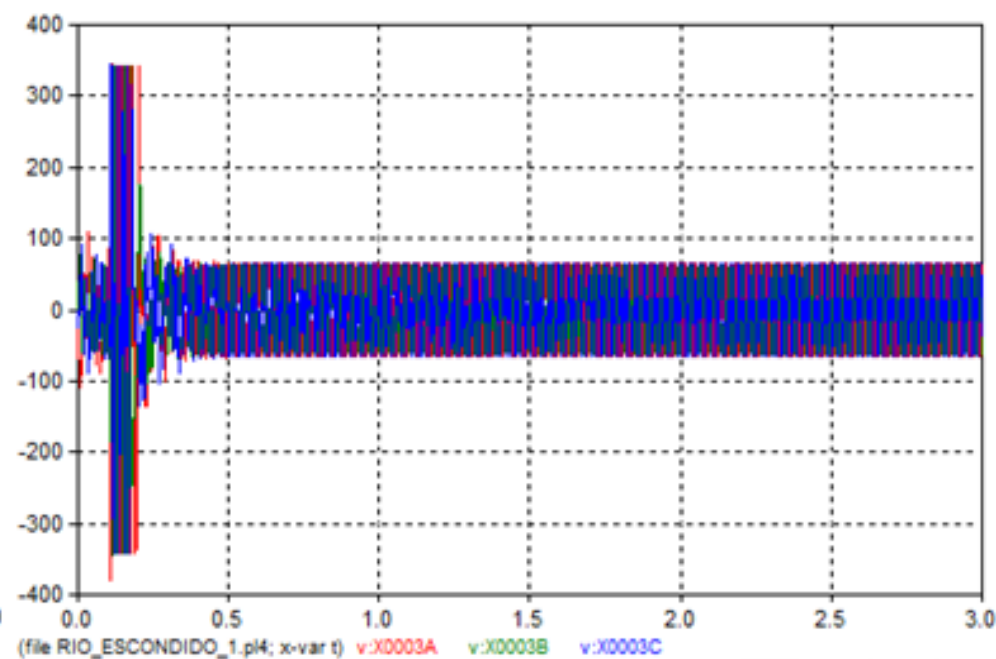
- Investigate Ferroresonance Event (determine mode, etc)
- Calculate parameters of the appropriate **Damping Reactor**
- Damping Reactor
 - It is saturated **before** than the IVT
 - Connects appropriate **resistance** to mitigate

5) Ferroresonance mitigation

Verification of the Damping Reactors Operation



PHASE C SIMULATION WITHOUT
DAMPING REACTOR



PHASES A,B and C SIMULATION
WITH DAMPING REACTOR

Conclusions

- Due to CCVT failures and their lack of measurement accuracy, CCVTs have been replaced in CFE by IVTs.
- Ferroresonance cases increased in CFE because IVTs do not have anti-ferroresonance element.
- Two study cases were presented and analyzed using PMU records (TEC) and disturbance records (REC).
- Ferroresonance is not easy to predict due to the non-linearity of the IVT saturation.
- For avoiding ferroresonance is necessary to use three-phase interrupting device to disconnect the applied voltage. Another approach is to add appropriate anti-ferroresonant device.
- Damping Reactors can be used to mitigate ferroresonance (event investigation, parameters' calculation, simulations and verifications are needed). Therefore, it is necessary to carry out an accurate simulation.
- Since ferroresonance can cause significant damage to personnel and equipment, mitigation techniques are required.