On-Site RTDS Testing of the FSC Units: Application of RTDS Technologies in Transmission System

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Contents

Scope of the Work

The design studies and analysis reports prepared by the manufacturer/contractor have been reviewed.

The materials used for the FSCs by the manufacturer/contractor have been evaluated.

The adequacy and compliance of the technical data and specifications provided by TEİAŞ to the manufacturer/contractor with international standards have been evaluated.

TOV, TRV, and SSR analyses for the FCSs have been conducted in the PSCAD environment.

Feedback has been provided regarding past failures and fault reports.

Real-time simulation (RTDS) tests have been conducted at 2 substations.

Network Structure

- FSC at substations 1 and 2 substation have a reactance of 33 Ω and a rated current of 2000 A.

Line Name	Line Length	Total Reactance	Compensation Factor
Feeder 1	210 km	55,65 Ω	%59
Feeder 2	203 km	53,79 Ω	%61
Feeder 3	266 km	70,49 Ω	%46
Feeder 4	266 km	70,49 Ω	%46

Table 1 – Substation 1

Line Name	Line Length	Total Reactance	Compensation Factor
Feeder 1	266 km	70,49 Ω	%46
Feeder 2	217 km	57,50 Ω	%57
Feeder 3	168 km	44,52 Ω	%74

Table 2– Substation 2

Structure of the FSC

- The FSCs at substations are structured in an H-bridge connection, consisting of a total of 180 units, arranged in 5 series and 9 parallel connections.

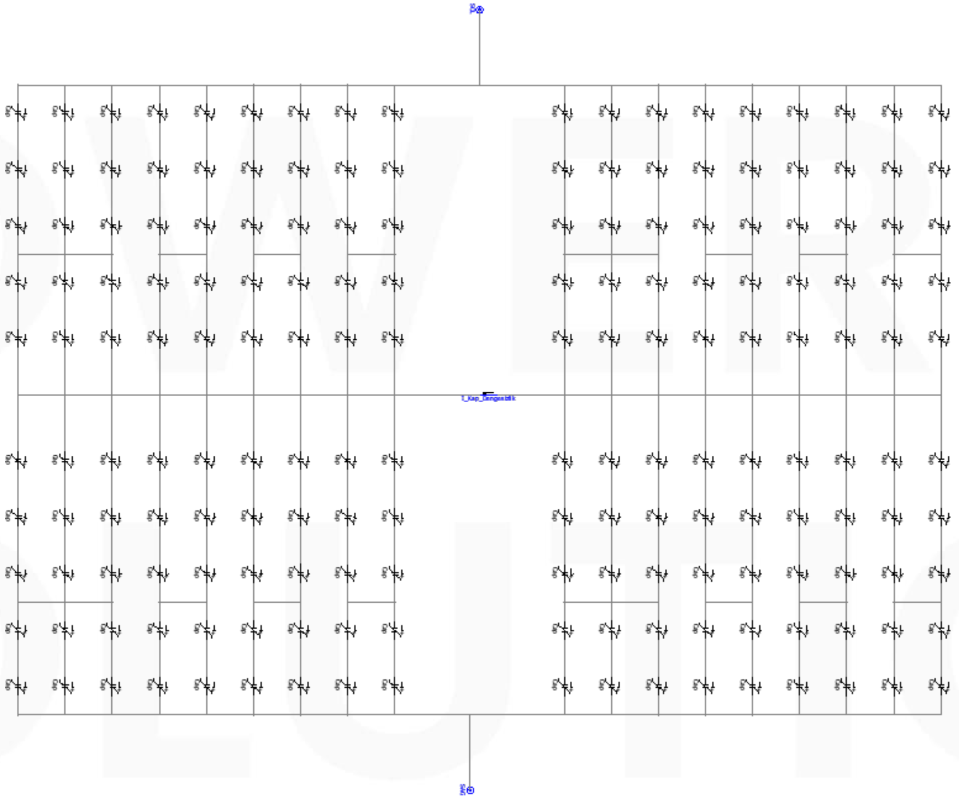

Figure 3 –Connection structure of FSC

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Technical Specification

- The technical specification prepared by TEIAS for the FSCs at substation has been reviewed, taking into account international standards and specifications from similar applications abroad.
- The technical specification and data prepared by TEIAS are considered to be defined in accordance with the scope and objectives of the project. However, some updates have been recommended to protect TEIAS's rights in similar future projects.
- It is recommended that open source EMT and RMS models of the system to be installed in future projects be prepared and submitted to TEIAS.
- It is recommended that RTDS tests be conducted and each unit be tested individually before on-site installation in future applications.
- It is recommended that important aspects of the analysis and design studies be clearly stated in the technical specification.

FSC Unit Structure

- The FCSs are classified as M2 type (MOV + Spark Gap) overvoltage protection, as defined in the IEC60143-1 standard.
- The protective voltage level determined by the manufacturer is U_{pl} 2.3 pu which is equivalent to 214,6 kV.

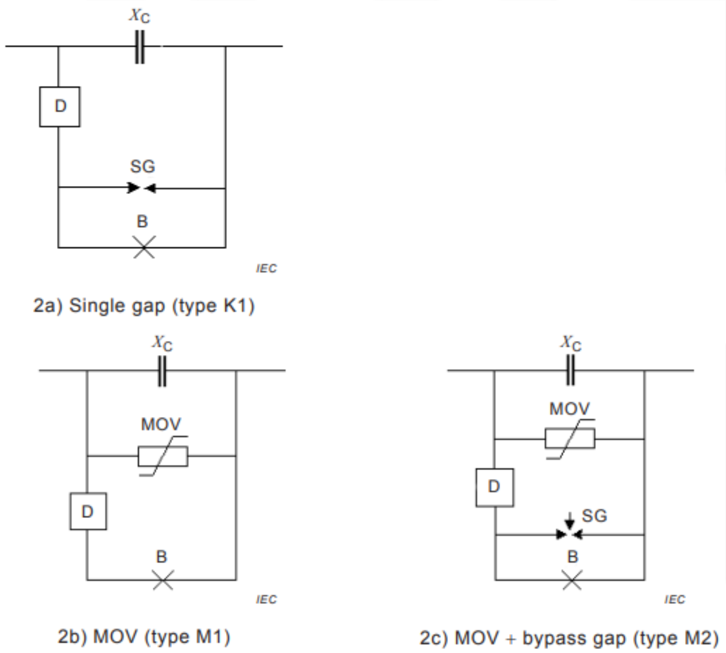

Figure 4 – IEC60143 Type Definitions of FSC

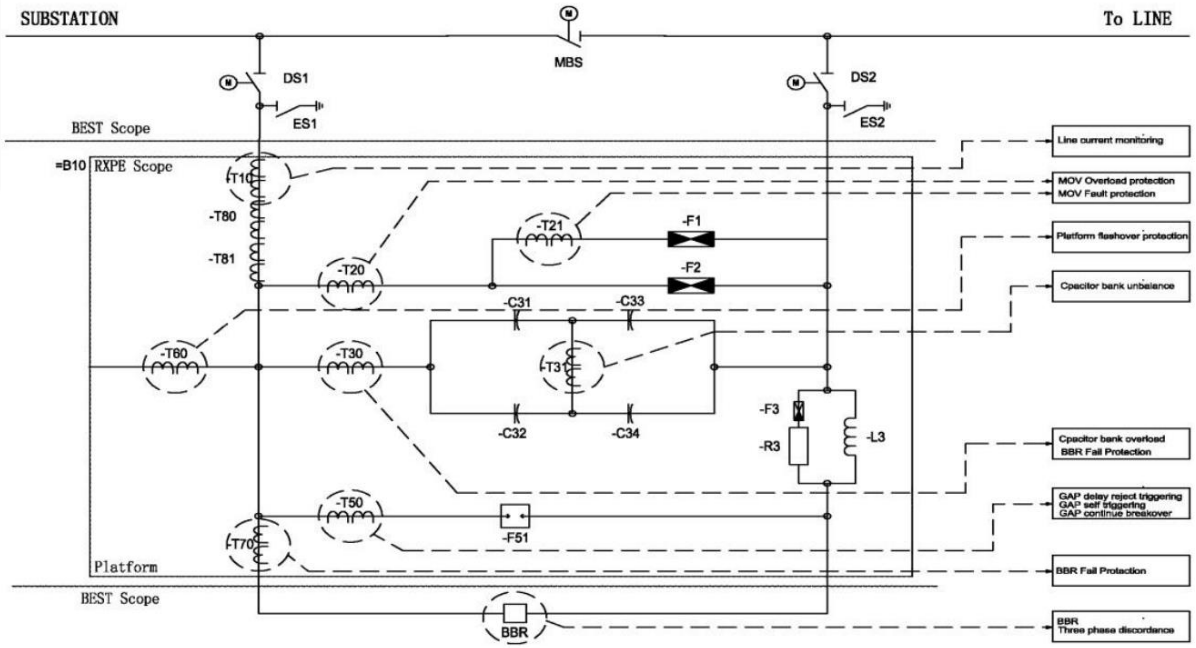

Figure 5 –Structure of FSCs

Protection Functions

Function	Alarm Level	Bypass	Lockout	Temporary block insertion	Reinsertion
Capacitor overload	X	X		X	X
Varistor overload		X		X	X
Sub-harmonic protection	X	X		X	X
SSR protection	X	X			
Line current supervision				X	
Capacitor unbalance	X	X	X		
Flashover to platform protection		X	X		
Varistor failure		X	X		
Bypass gap failure		X	X		
Bypass switch failure protection : close failure		X	X		
Bypass switch failure protection : open failure		X	X		
Bypass switch pole disagreement protection		X	X		
Disconnector pole disagreement protection		X	X		
Protection and control system failure		X	X		
Flashover to platform		X	X		

Figure 9 – IEC60143 Typical FCS Protection Functions

Capacitor overcurrent protection
Capacitor unbalance overcurrent protection
MOV overcurrent protection
MOV high temperature gradient protection
MOV over temperature protection
MOV unbalance overcurrent protection
Spark gap self triggering protection
Spark gap delayed trigger protection
Spark gap trigger rejection protection
Spark Gap long term transmission protection
Line trip protection
Platform Flash over protection
Bypass breaker opening fault
Bypass breaker closing fault
Bypass switch pole disagreement protection

Table 3 – Protection Functions Used in FCSs

RTDS Reports from the Manufacturer

- RTDS tests should be conducted on the equipment to be installed on site. Even if the equipment has the same or similar structure, the same tests should be repeated for each piece of equipment that will be installed in different locations.
- In the RTDS test report shared by the manufacturer, it was observed that the tests were conducted on a single bank, despite the fact that each of the 7 feeders had different threshold values.

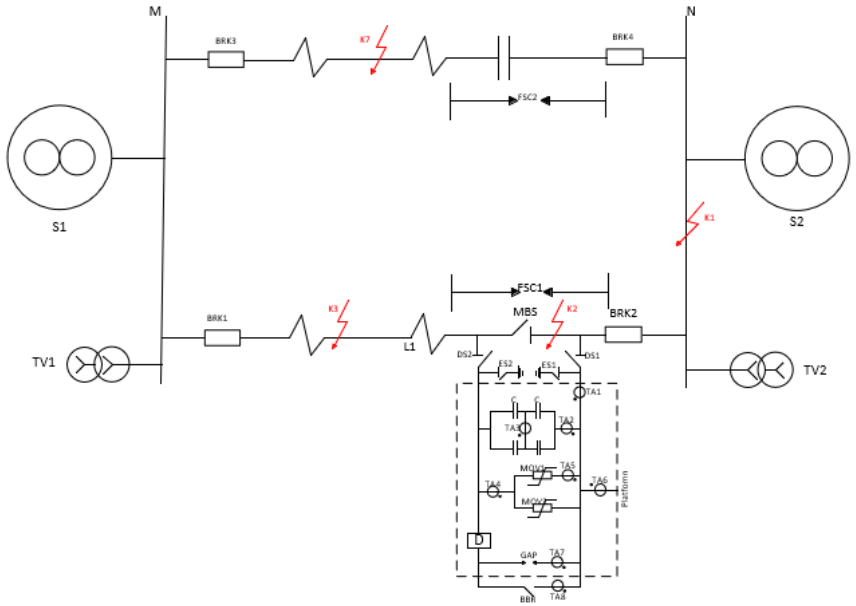

Figure 10 – RTDS Test Reports

RTDS Tests Vs. System Operation

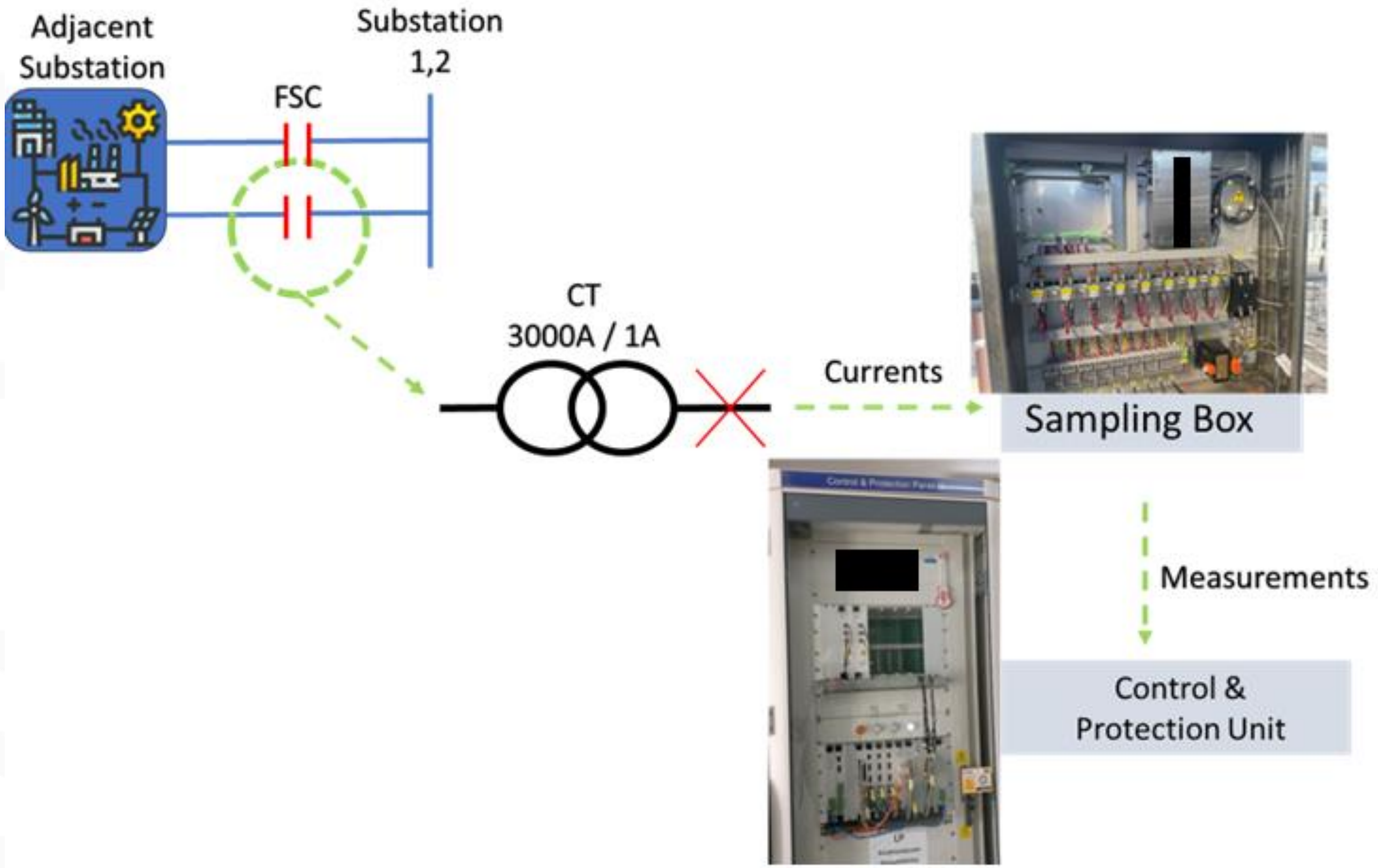

Figure 15 – FSC connections to the network during system operation Vs. RTDS tests

RTDS Test Configuration

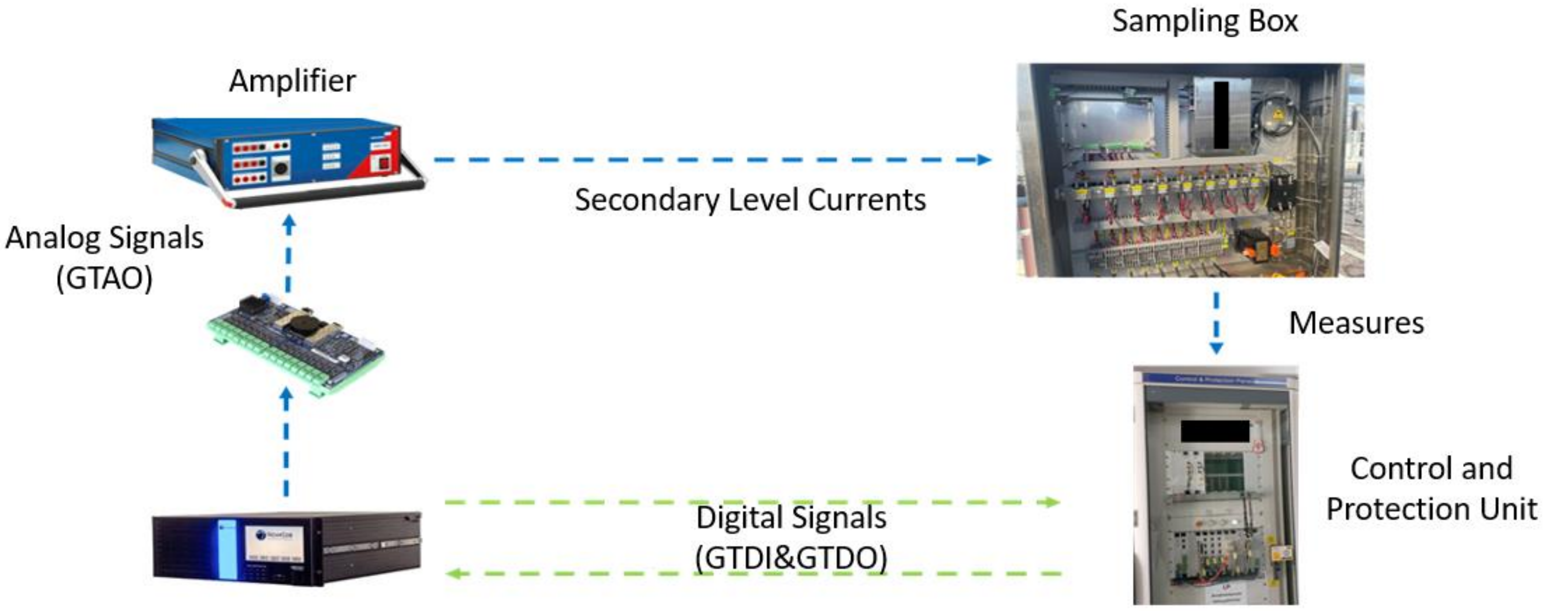

Figure 16 – RTDS Test Configuration

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RTDS Test Configuration

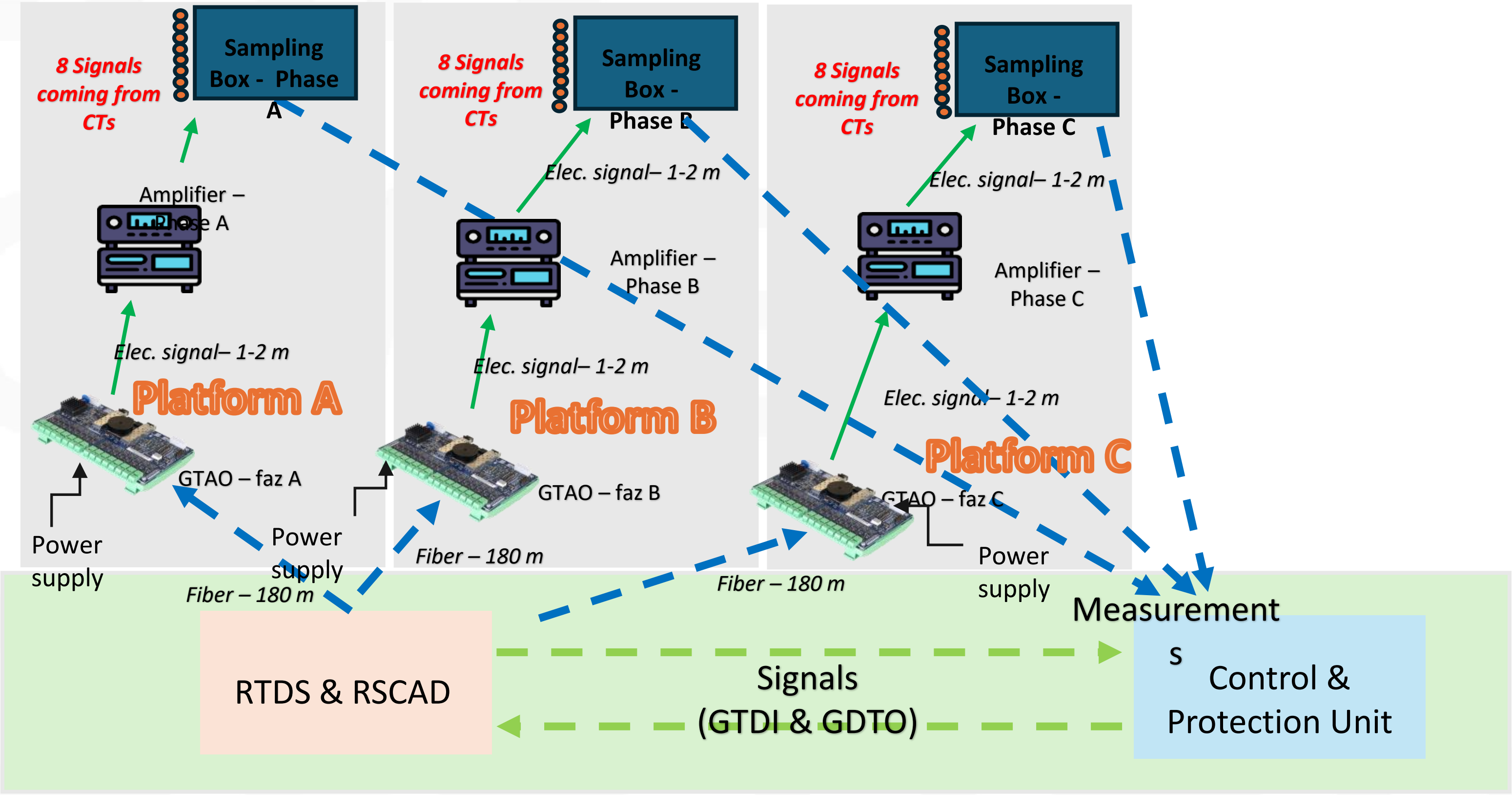

Figure 17 – On Site Test Connection Setup

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RTDS Test

- Control and protection system of the FSCs operates under normal operating conditions through current transformers T10, T20, T21, T30, T31, T50, T60, and T70.
- Behavior of the protection and control system was examined by supplying secondary level current through the GTAO card and amplifier via RTDS/RSCAD.

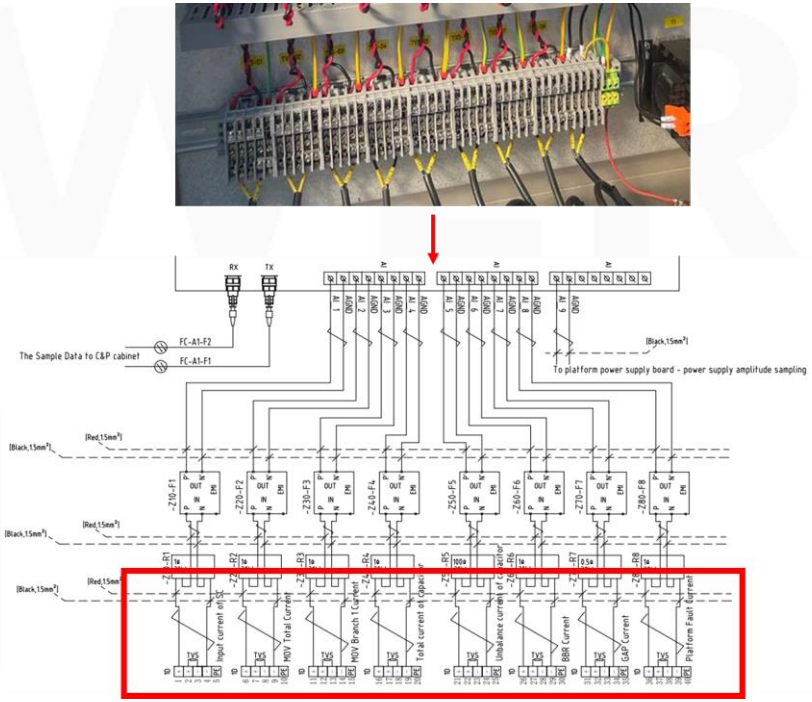

Figure 18 – Sampling Box Current Transformer Connections

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RTDS Test Configurations

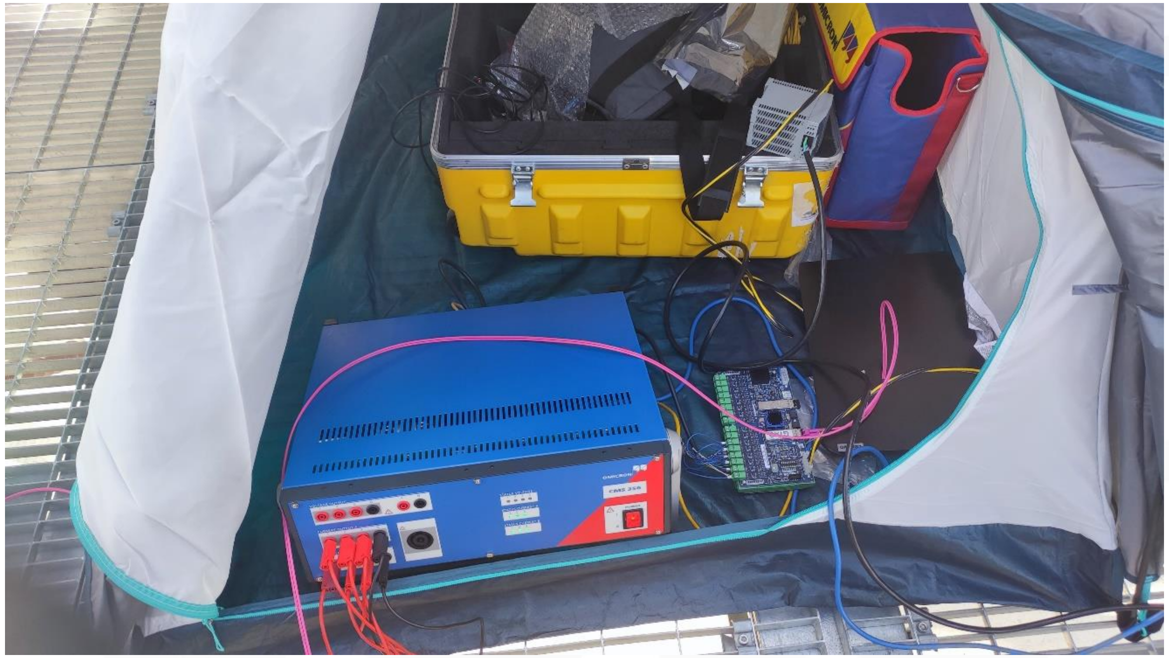

Figure 19 – RTDS, GTAO ve Amplifier Connection

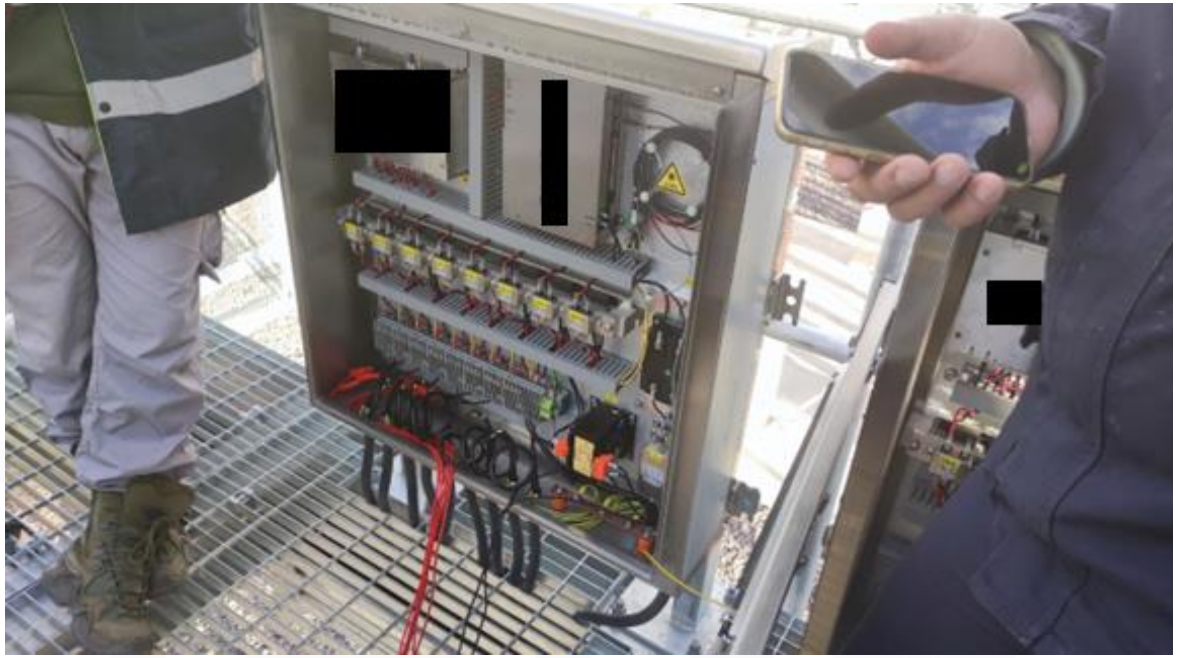

Figure 20 – Amplifier ve Sampling Box Connection

RTDS Test Configuration

- In the electromagnetic transient model created in the RSCAD interface, various scenarios, such as normal operation and fault conditions, can be analyzed.

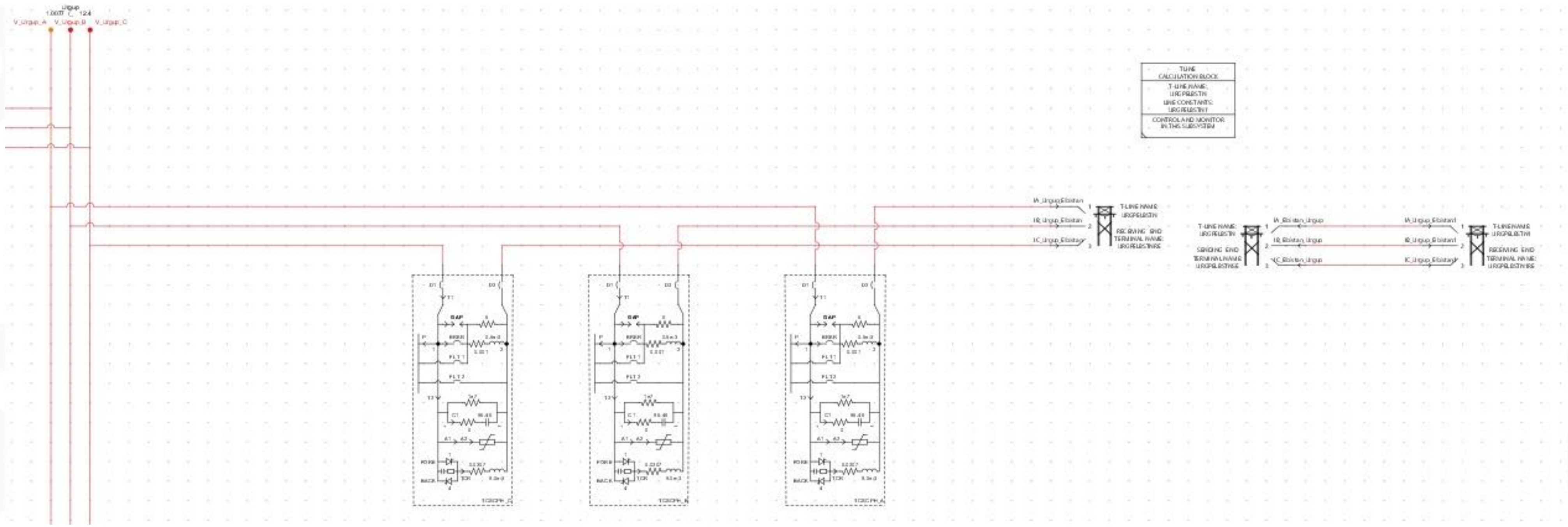

Figure 21 – RSCAD Model

Sampling Card Temperature

- Due to previous issues with faulty bypass and noise related to high ambient temperatures in the substations FCSs, the sampling cards were heated to 70 degrees during RTDS tests.

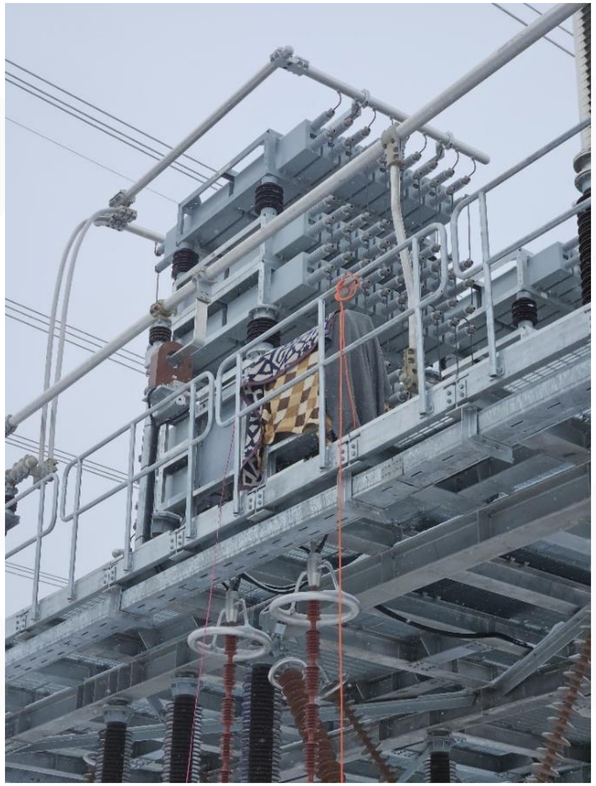

Figure 22 – Heating Sampling Box

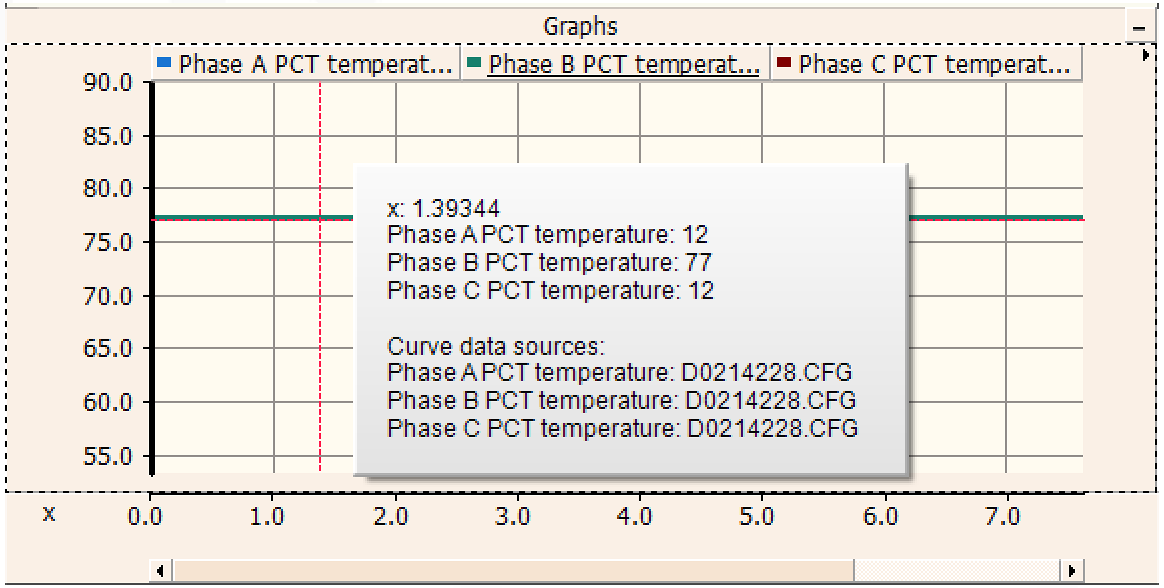

Figure 23 – PCT Temperature

RTDS Test Results

- The behavior of the protection and control system is recorded in COMTRADE format via RTDS/RSCAD. These records can be obtained from the TFR computer and analyzed in the ENERPLOT environment. System A and System B have been tested separately for each feeder.

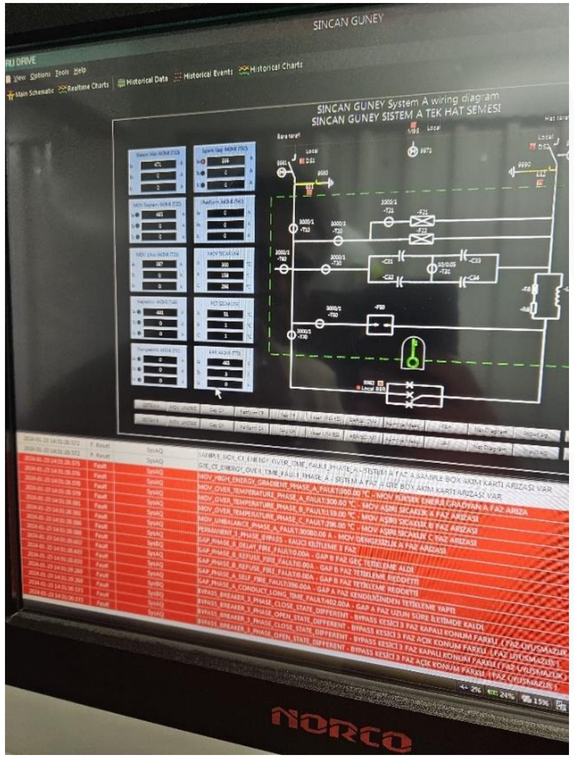

Figure 24 – CP Panel SOE Records

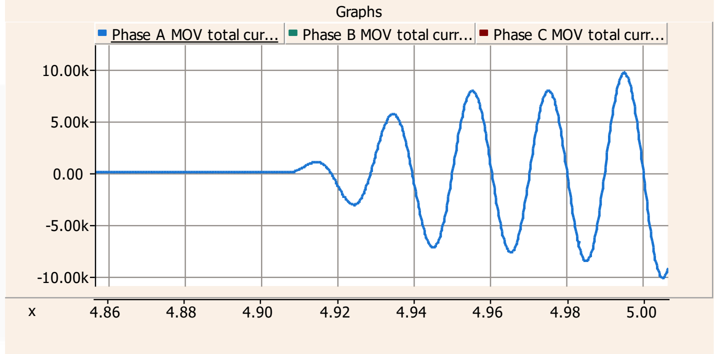

Figure 25 – MOV Total Current Record

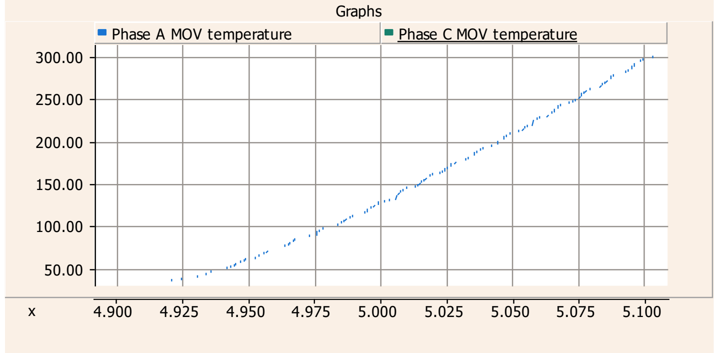

Figure 26 – MOV Temperature Record

RTDS Test Results

- Additionally, high temperature tests were conducted with the old version sampling cards on System B of the Kayabasi Substation Deceko Feeder.
- When the PCT temperature reached 40 degrees, distortions (noise) began to appear in the current measurements for Phase C. As the temperature approached 50 degrees, the level of these distortions increased, leading to currents being observed on connections that were not carrying current during the test (such as the spark gap and bypass circuit)
- Finally, when the temperature reached 52 degrees, while no current was applied to the system, the protection system produced a self-triggering protection signal for the C phase Spark Gap. When the system was reset, the same signal continued to appear repeatedly, leading to the termination of the tests conducted with the old cards.

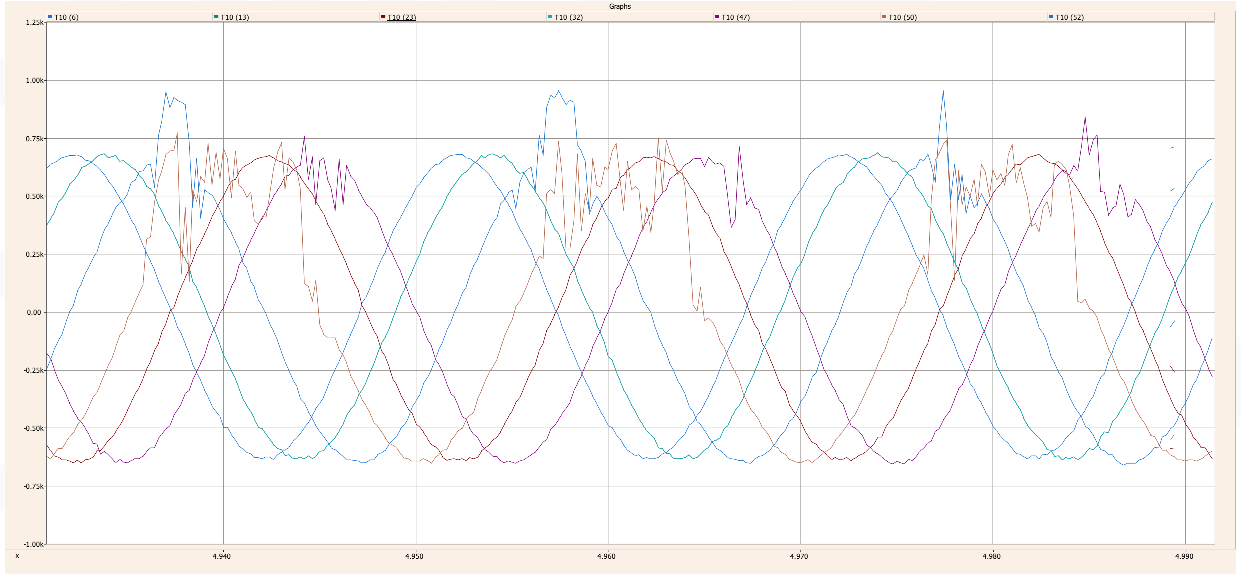

Figure 27 – Phase C T10 Currents at Different Temperatures

RTDS Test Results

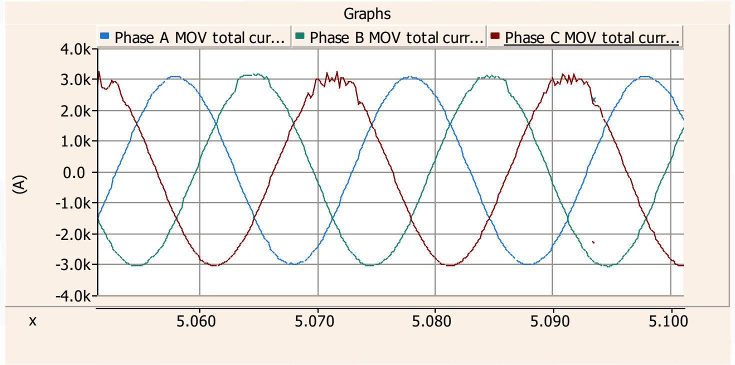

Figure 28 – MOV Total Current (Phase C PCT Temperature 35, 36, 41)

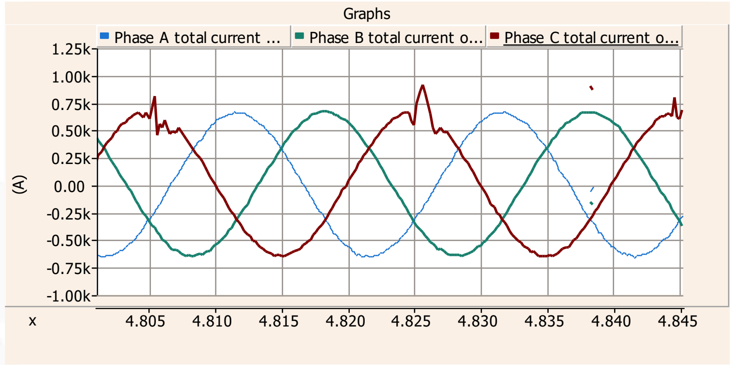

Figure 30 – Deceko Line Current (PCT Temperature 36, 37, 47)

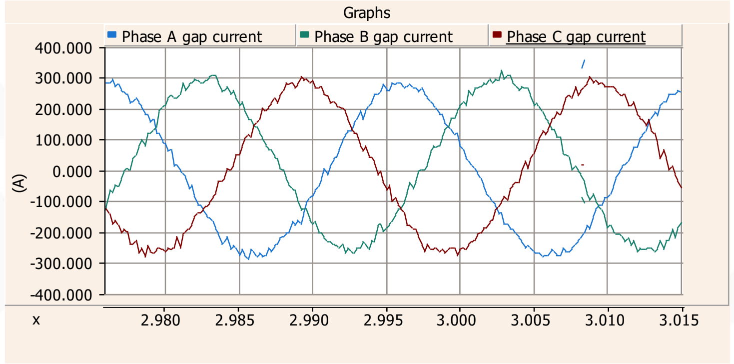

Figure 29 – Gap Current (PCT Temperature 36, 36, 42)

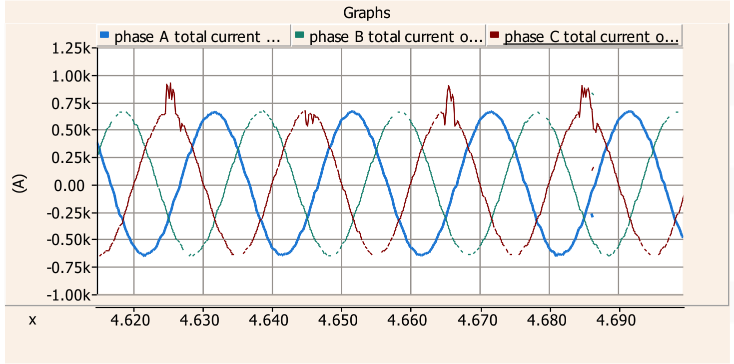

Figure 31 – Deceko Capacitor Current (PCT Temperature 36, 37, 47)

RTDS Test Results

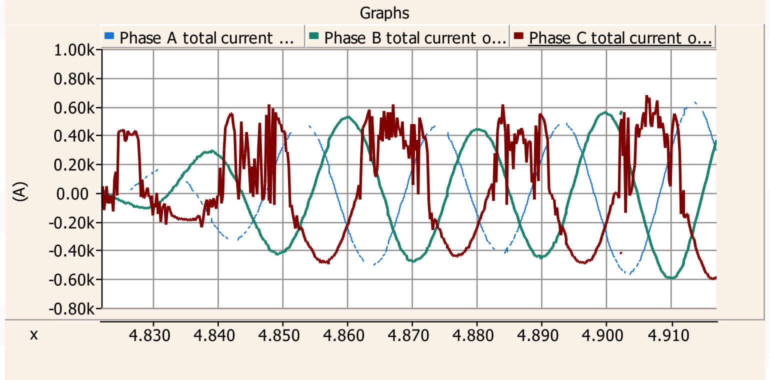

Figure 32 – Deceko Line Current (PCT Temperature 30, 33, 52)

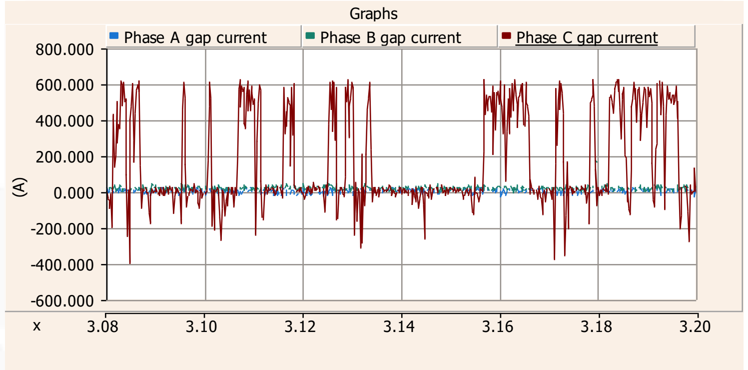

Figure 34 – Deceko Spark Gap Current (PCT Temperature 30, 33, 52)

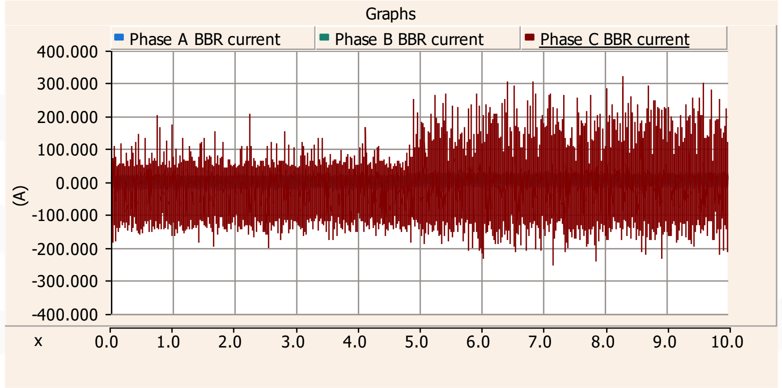

Figure 33 – Deceko Bypass Breaker Current (PCT STemperature 30, 33, 52)

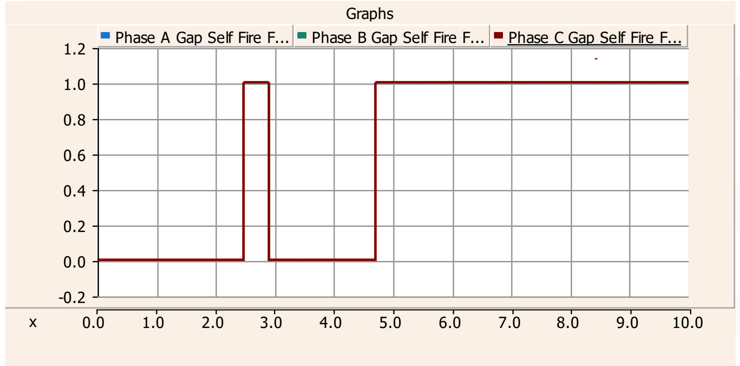

Figure 35 – Gap Self Triggering Protection (PCT Temperature 27, 31, 52)

RTDS Test Results

- During the pulse current tests conducted on the Kayabasi substation Kursunlu Feeder System A, a positive current pulse applied to the T10 connection was recorded as negative in phases A and B.
- It is believed that the cause of this issue is that the measurement connection taken from the current transformer was connected with reversed polarity at some point in the system. The on-site manufacturer/contractor team has been informed about the matter and has conducted checks. However, the cause of the problem could not be determined. In System B, no issues were observed.
- For this reason, since the sinusoidal graphs for phases A and B were measured multiplied by -1, this situation appears as a phase shift. When past records are checked, it is understood that this issue is not new.

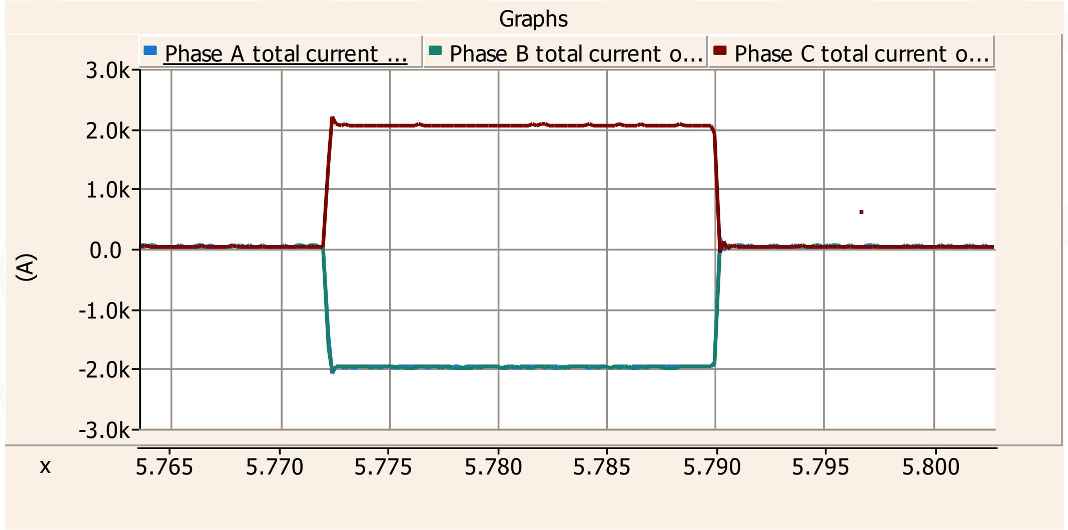

Figure 36 – Pulse Current Applied to T10 Connection

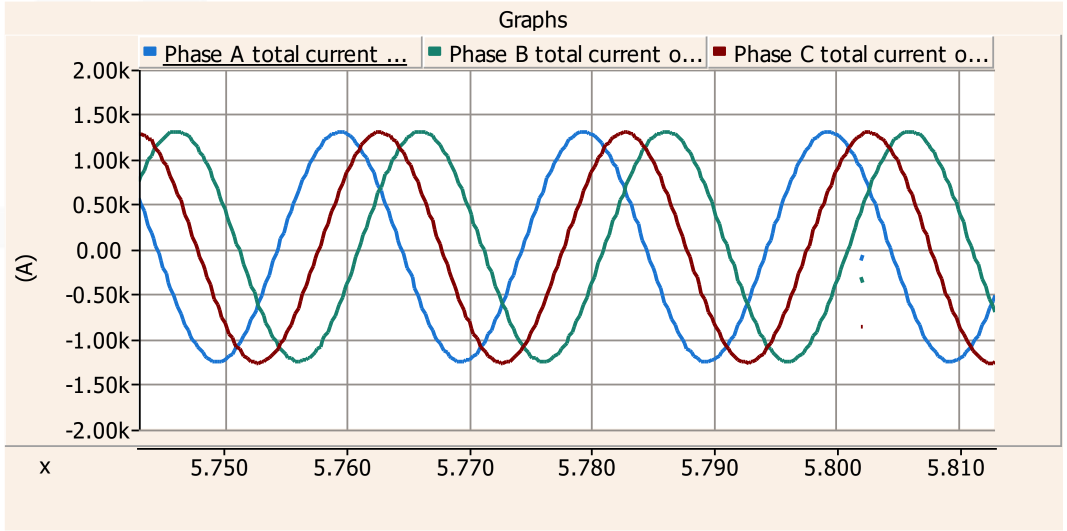

Figure 37 – T10 Connection in Continuous Operation

Conclusion and Recommendations

- The compensation rate can be set at any value between 20% and 80%. However, as the compensation percentage increases, the risk of subsynchronous resonance and equipment costs also rise.
- To prevent unbalanced load flows in parallel lines, the compensation rate should be chosen equally. However, in some cases, if there is an unbalanced load flow in the current situation, different compensation rates can be chosen between two parallel lines to balance the load distribution.
- In transposed lines, since the inductive reactance of each phase is approximately equal, the compensation rate or capacitive reactance value selected for each phase should be the same. This minimizes negative sequence currents.
- If the line length and current are sufficiently high, the desired compensation rate can be achieved by applying two capacitor banks (on both sides of the line). When two banks are applied on the line, it is also possible to obtain a different compensation rate by bypassing one of the banks, although this increases costs.
- The compensation rate for the capacitor bank does not necessarily have to be determined only for the current system structure, such as nominal current or fault currents. These values can also be specified in specifications based on the planned future grid structure and the anticipated load flow.

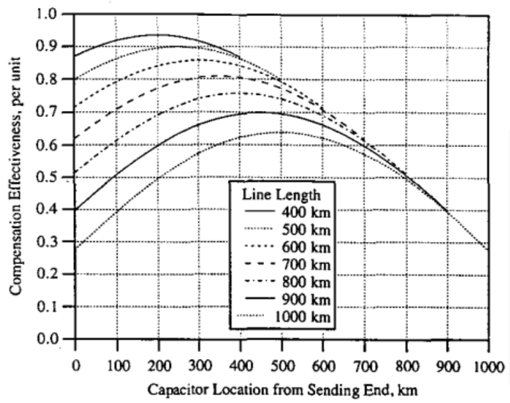

Figure 55 – The Effect of FSC on Compensation at Different Locations of the Line

Conclusion and Recommendations

- If the preferred compensation rate for the line carries a resonance risk, the compensation rate should be adjusted, or measures should be taken for the generation plants that pose a resonance risk. Additionally, as the compensation rate increases, the resonance point also shifts toward the system's nominal frequency.
- The risk of subsynchronous resonance is critically important for series capacitor applications when the following conditions occur:
  - A series capacitor is located on the load flow path, which is the only connection between the turbine generator and the rest of the system (radially connected)
  - The mechanical oscillation frequency of the turbine generator is approximately equal to the system's electrical resonance frequency (after compensation), and at this frequency, the mechanical oscillation interacts with the electrical system through the generator.
- As a result of the frequency scan conducted for Urgup and Kayabasi substations, negative damping was observed in the generation units at Afsin Elbistan A TPP, Afsin Elbistan B TPP, Tufanbeyli TPP, and Kangal TPP transformer substations

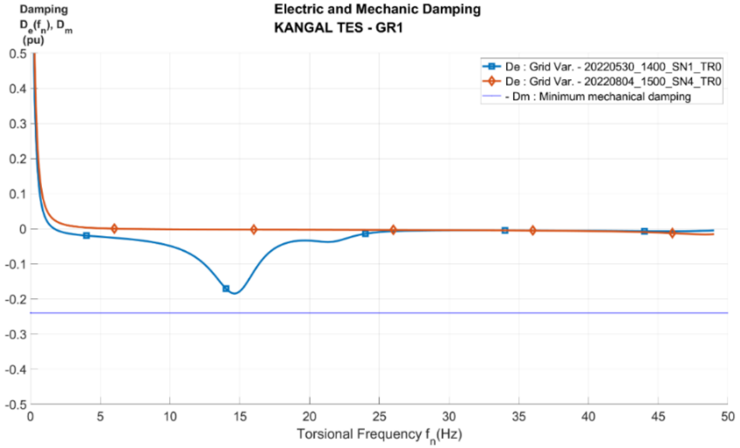

Figure 56 – Kangal TES GR1 Frequency Scan

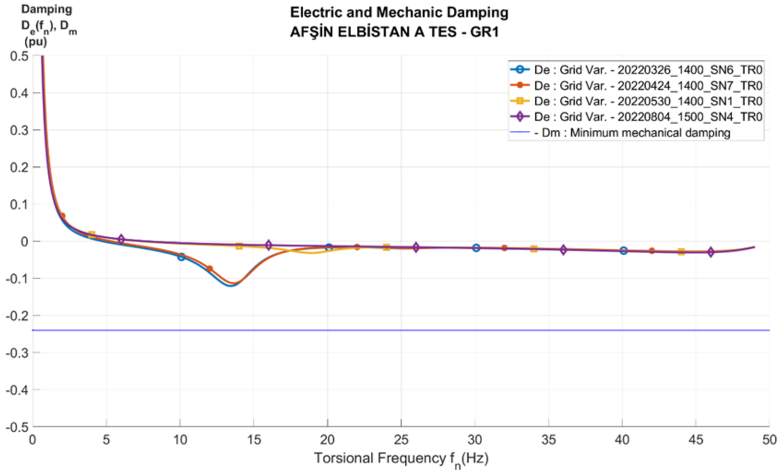

Figure 57 – Elbistan A TES GR1 Frequency Scan

Conclusion and Recommendations

- If sub-synchronous resonance risk is detected, methods such as reducing the compensation rate to around 35% or implementing selective bypass protection functions for predetermined system topologies (such as when a thermal power plant remains radially connected to a series-capacitor line) can be considered.
- In addition, thyristor-controlled series capacitors, equipped with an appropriate control and protection system, can also be preferred.
- In addition to these, another simple countermeasure is to integrate a protection function that continuously monitors the torsional movements of the turbine generators and armature currents, and trips the generator to disconnect it when the relevant threshold value is exceeded.

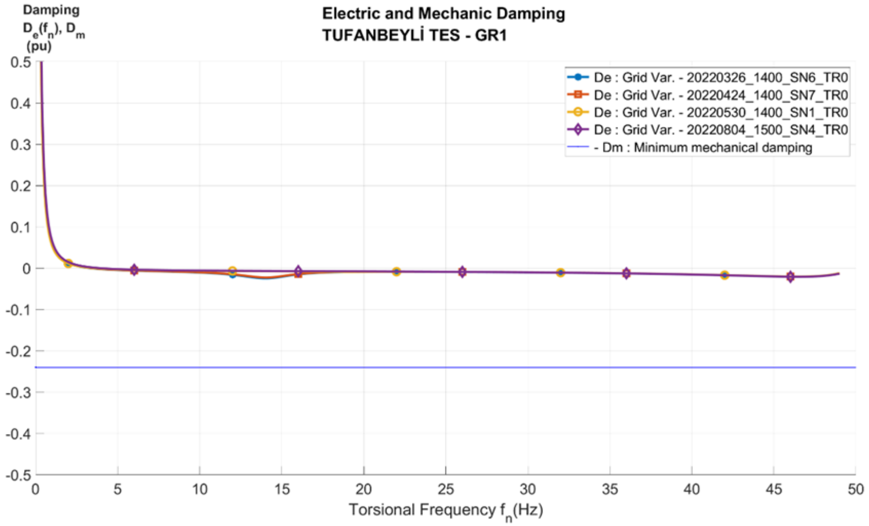

Figure 58 – Tufanbeyli TES GR1 Frequency Scan

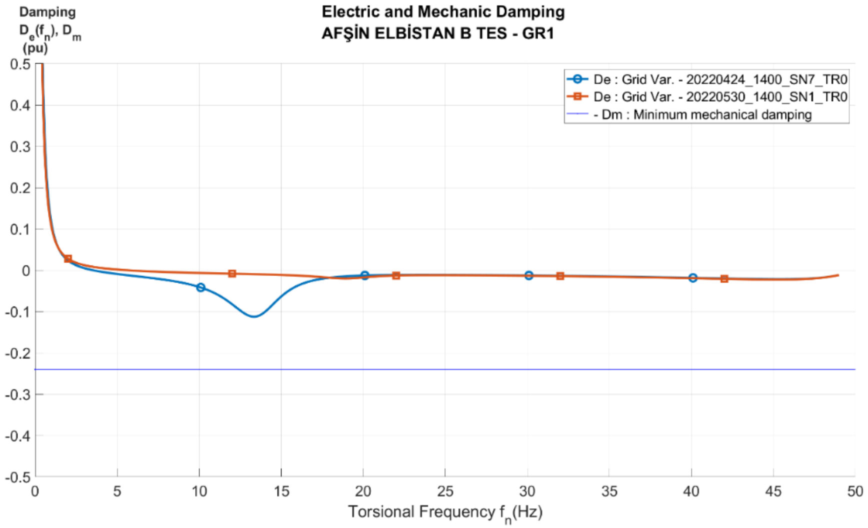

Figure 59 – Elbistan B TES GR1 Frequency Scan

Conclusion and Recommendations

- During RTDS dynamic performance tests, it was observed that the series capacitor banks (FCSs) generated a bypass signal in external faults.
- It was confirmed in the tests conducted at the substations that the older version of the sampling cards were affected by high temperatures (faulty measurements begin around 40 degrees). In the high temperature tests conducted with the new version of the cards, no faulty measurements or bypass issues were encountered.
- However, when reviewing past fault records, it was observed that faulty signals (inconsistent with design documents) were generated in some cases, independent of temperature. It is believed that this issue was resolved through changes made to the protection system software or functions

Thanks!