Control and Protection System Tests for a Fixed Series Capacitor

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Background

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- In 2015-2016, a fixed series capacitor (FSC) installation became ready for commissioning.
  - *Purpose: increasing the power transfer capacity of a 275kV line, connecting two arreas.*
- Planning and design studies had revealed potential issues such as sub-synchronous oscillations (SSO) at one of the interconnected systems under certain network configurations and power flow conditions.
  - *Potential Sub-synchronous Resonance (SSR) at a neighbouring thermal power plant*
  - *Potential Sub-synchronous Control Interactions (SSCI) at a neighbouring wind farm with Type-3 machines*

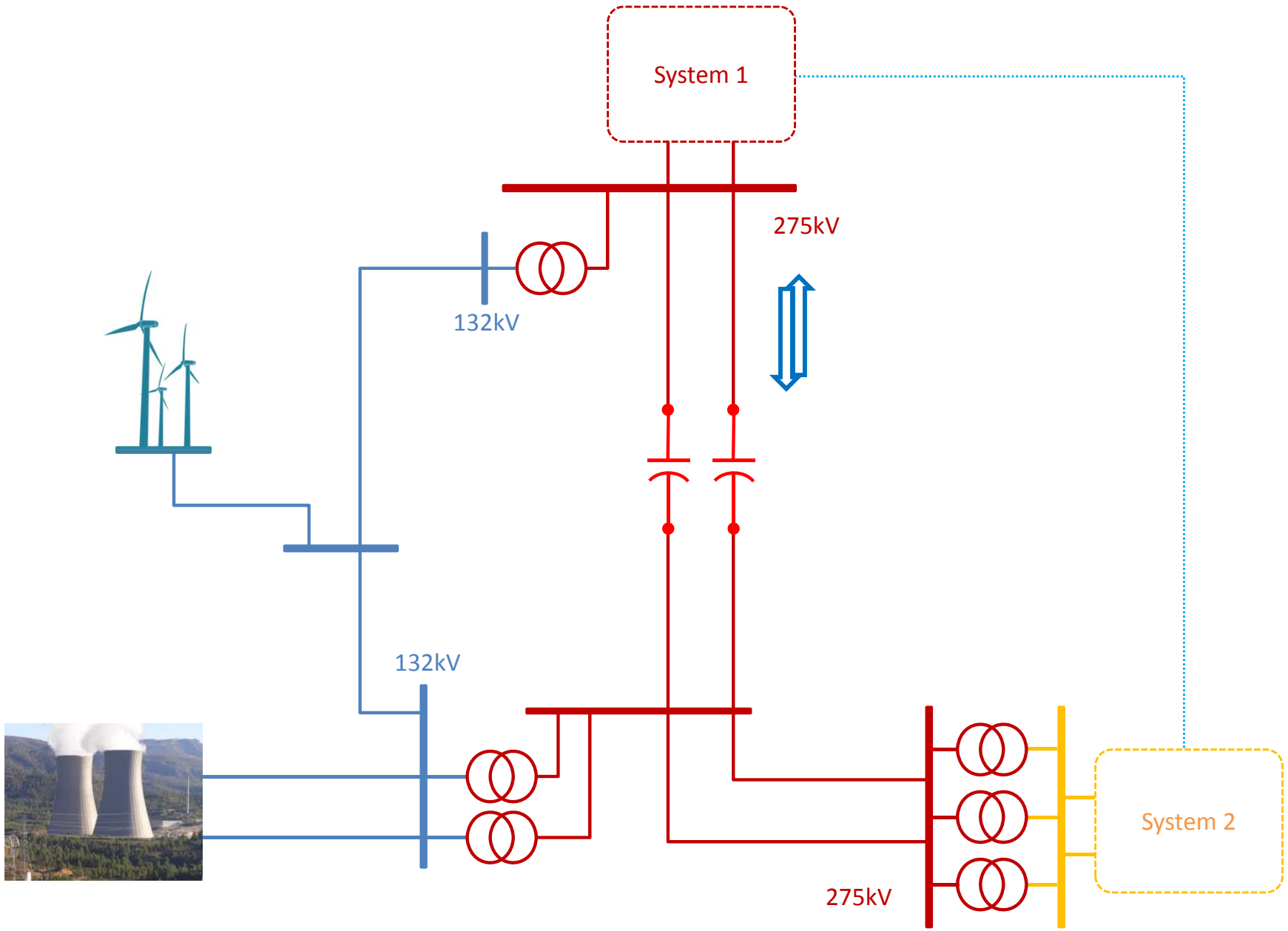
Background

- The FSC vendor had tuned the control and protection (C&P) system based on the system parameters and offline simulation studies .

- Protective relay settings were obtained by the Client's Protection Team.

- In order to verify the correct operation of the relays, hardware-in-the-loop (HIL) tests were conducted using RTDS.
  - The FSC control cubicles were also integrated into the test set-up.

The Interconnected Systems and the Series-Compensated Line



Scope of Work

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Objectives:

- Verifying the performance of the line protective relays
- Factory system tests (FST) for the FSC C&P system, in order to verify its performance prior to installation at the FSC station

Scope of this work:

- Implementing the RSCAD models
  - *Required two racks each with six PB5 processor cards*
- Validation against the PSCAD™/EMTDC™ models used for the planning and design studies
- I/O interfacing preparation
- Setting up the simulation at the RTDS laboratory and participating in the tests

Series Compensated Line: Protections

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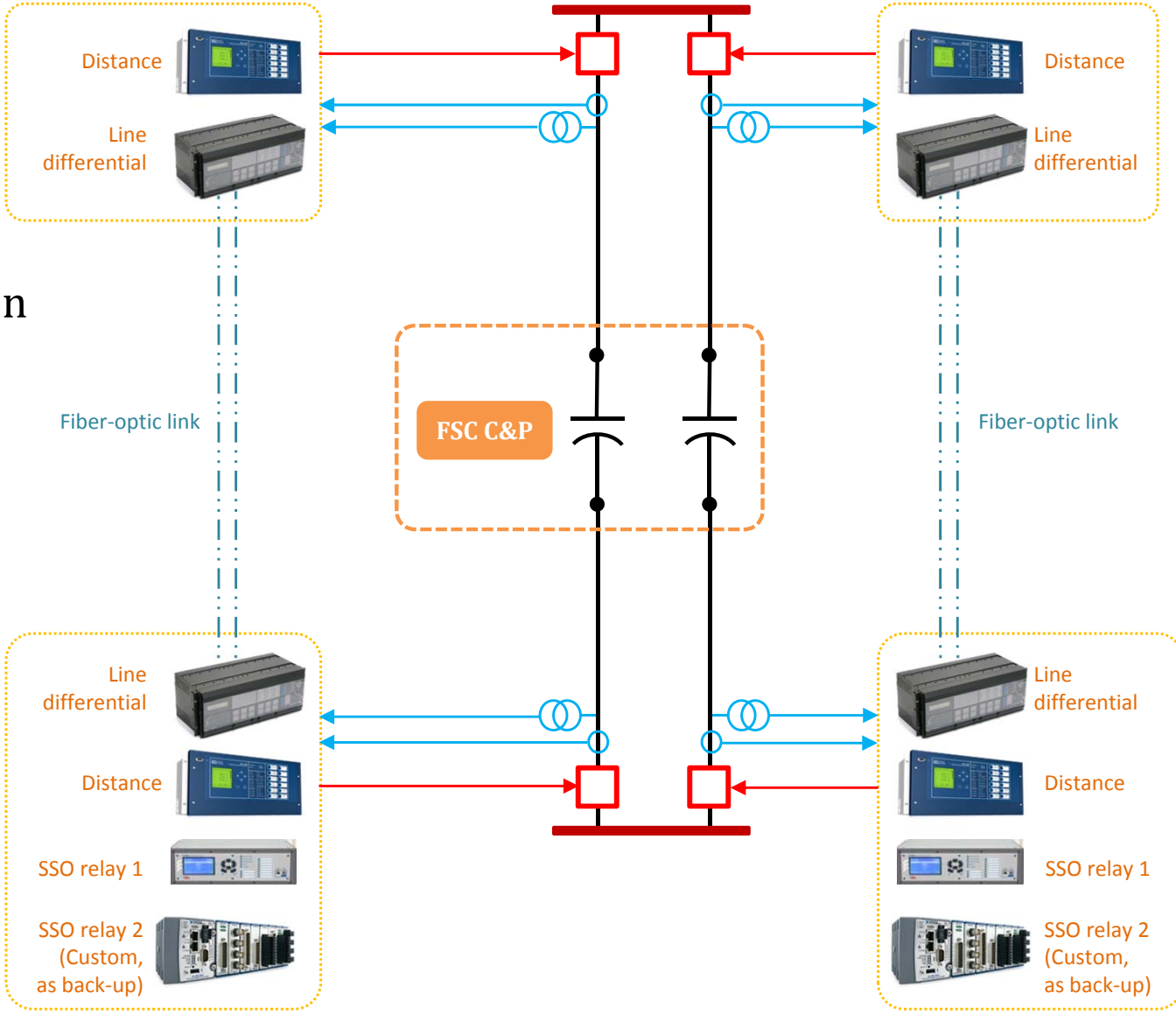
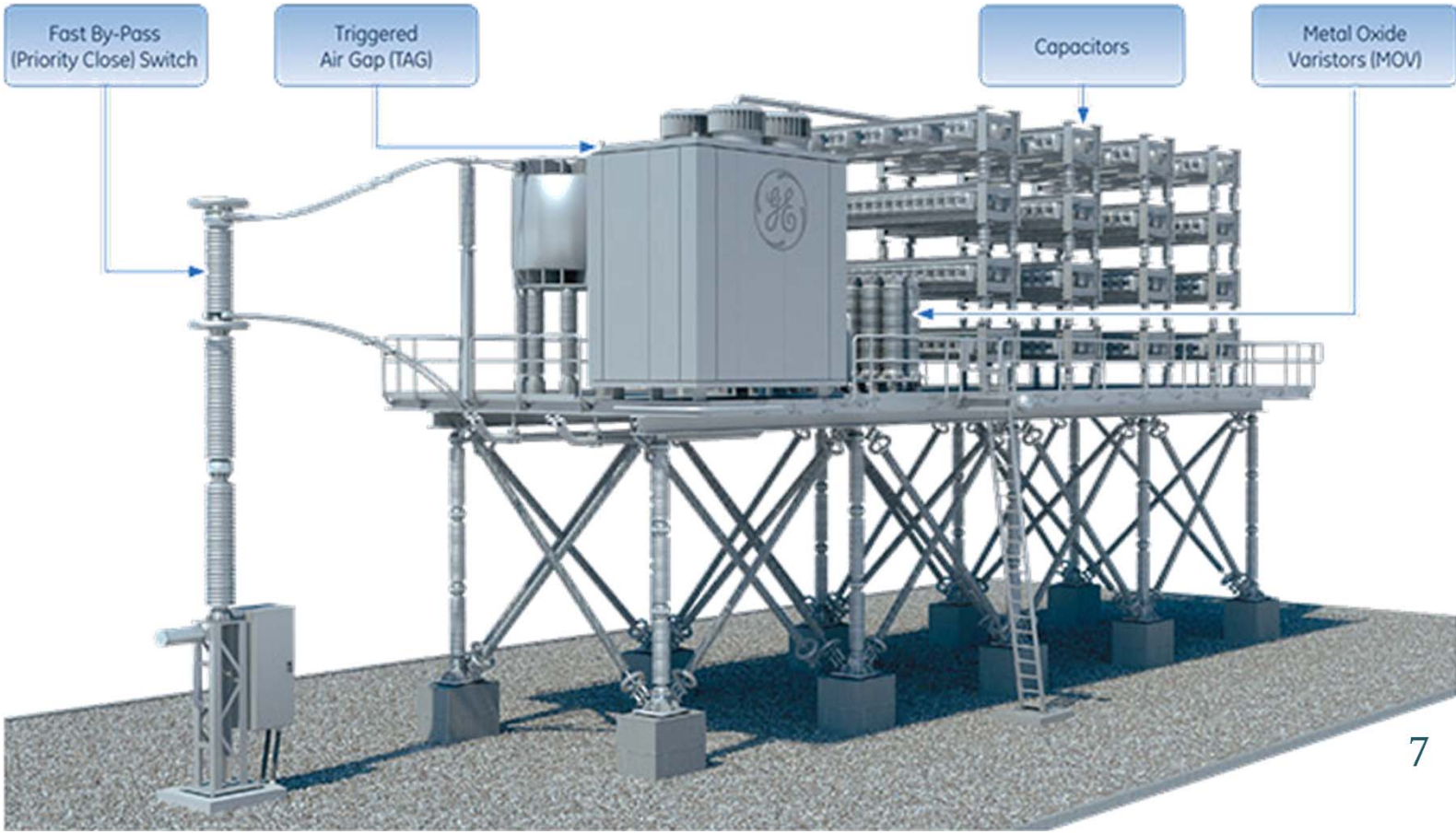
- Line protections:
  - Distance
  - Differential
- Sub-synchronous oscillation protections:
  - Off-the-shelf SSO relay
  - Custom-made SSO relay as back-up
- The FSC had its own protective functions using local measurements.
  - The bypass function could also be triggered remotely, if necessary.



Fixed Series Capacitor Station

- Main components

Images: ge.com
(GE Grid Solutions)



Fixed Series Capacitor Station

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- Per-phase circuit

Image: ge.com
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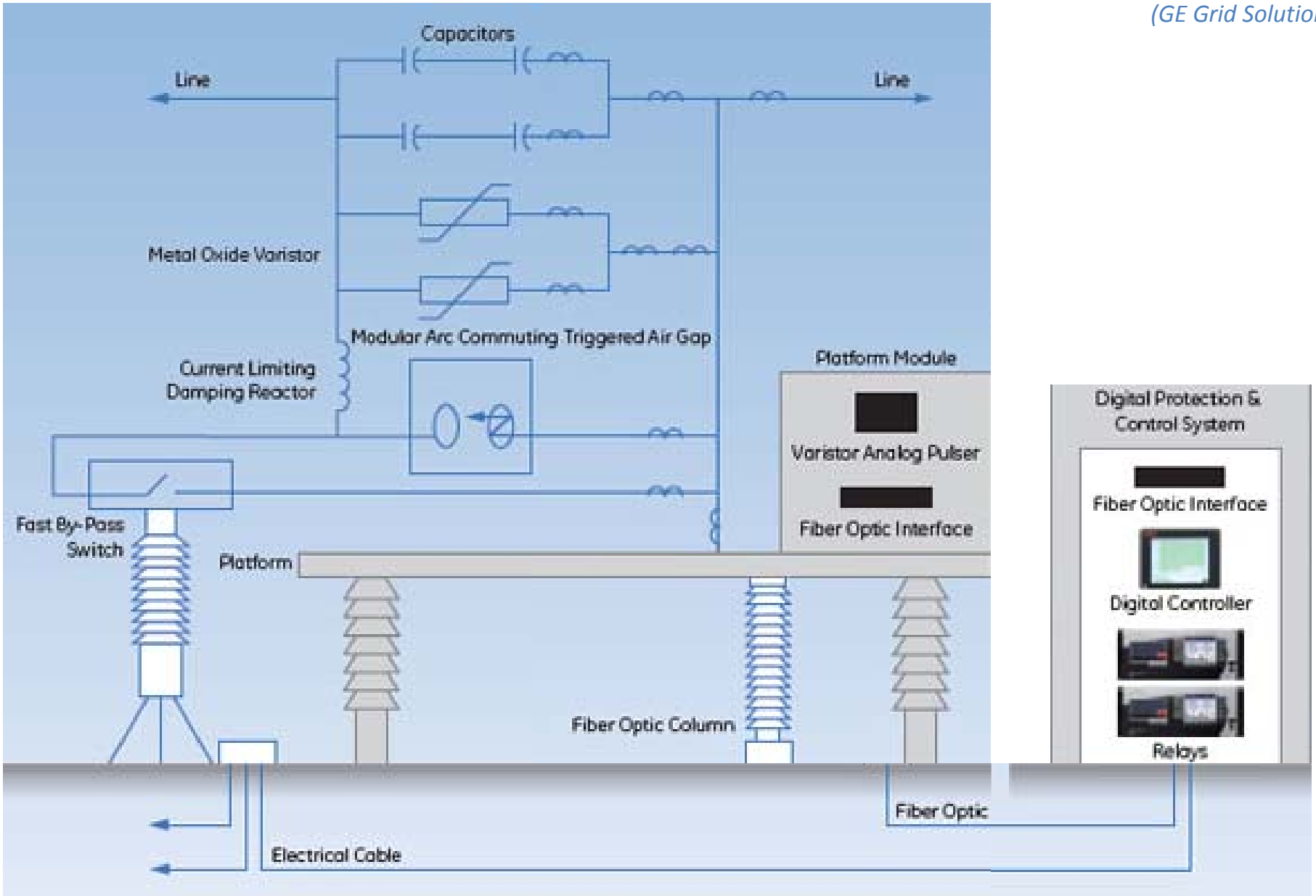

Fixed Series Capacitor Station

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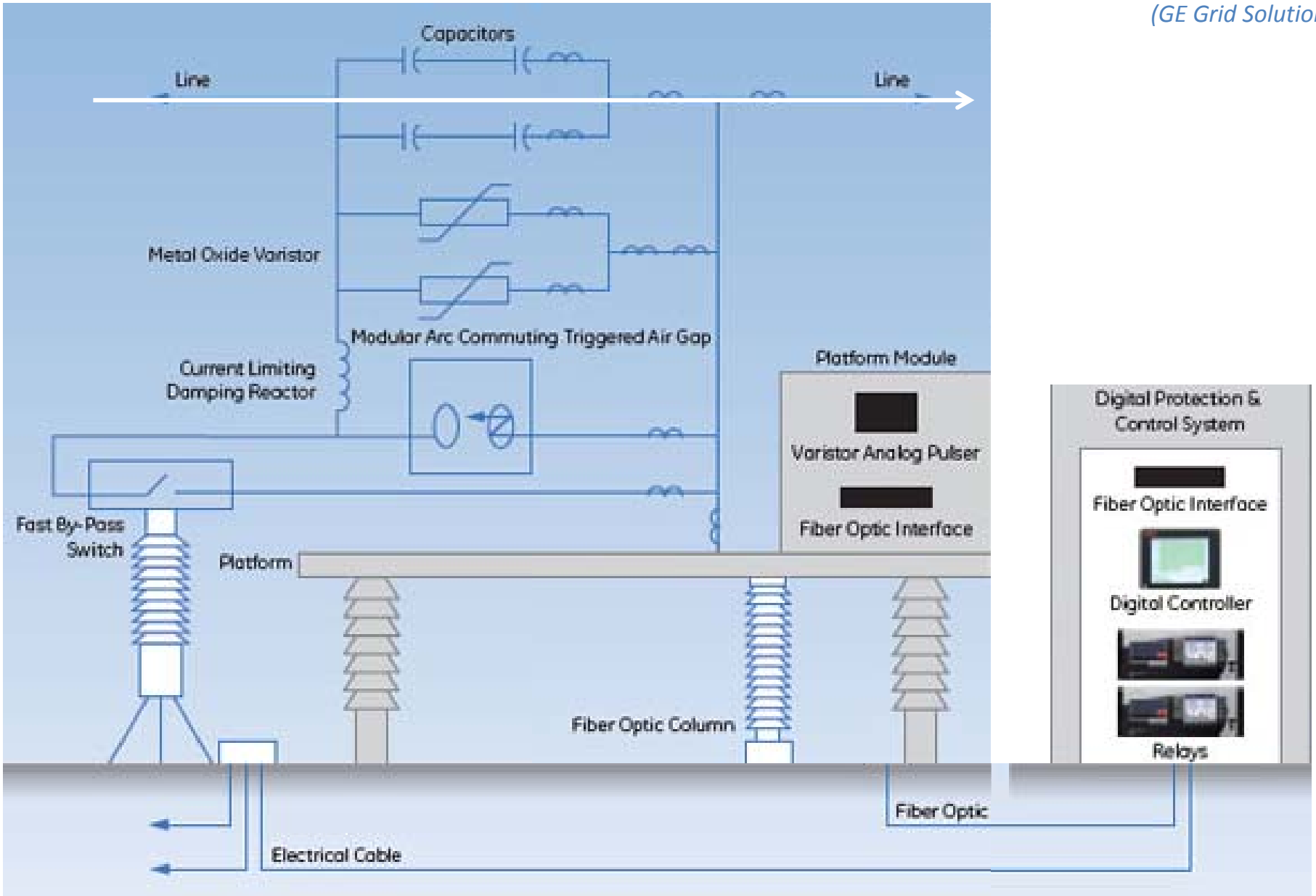
- Normal operation

Image: ge.com
(GE Grid Solutions)



Fixed Series Capacitor Station

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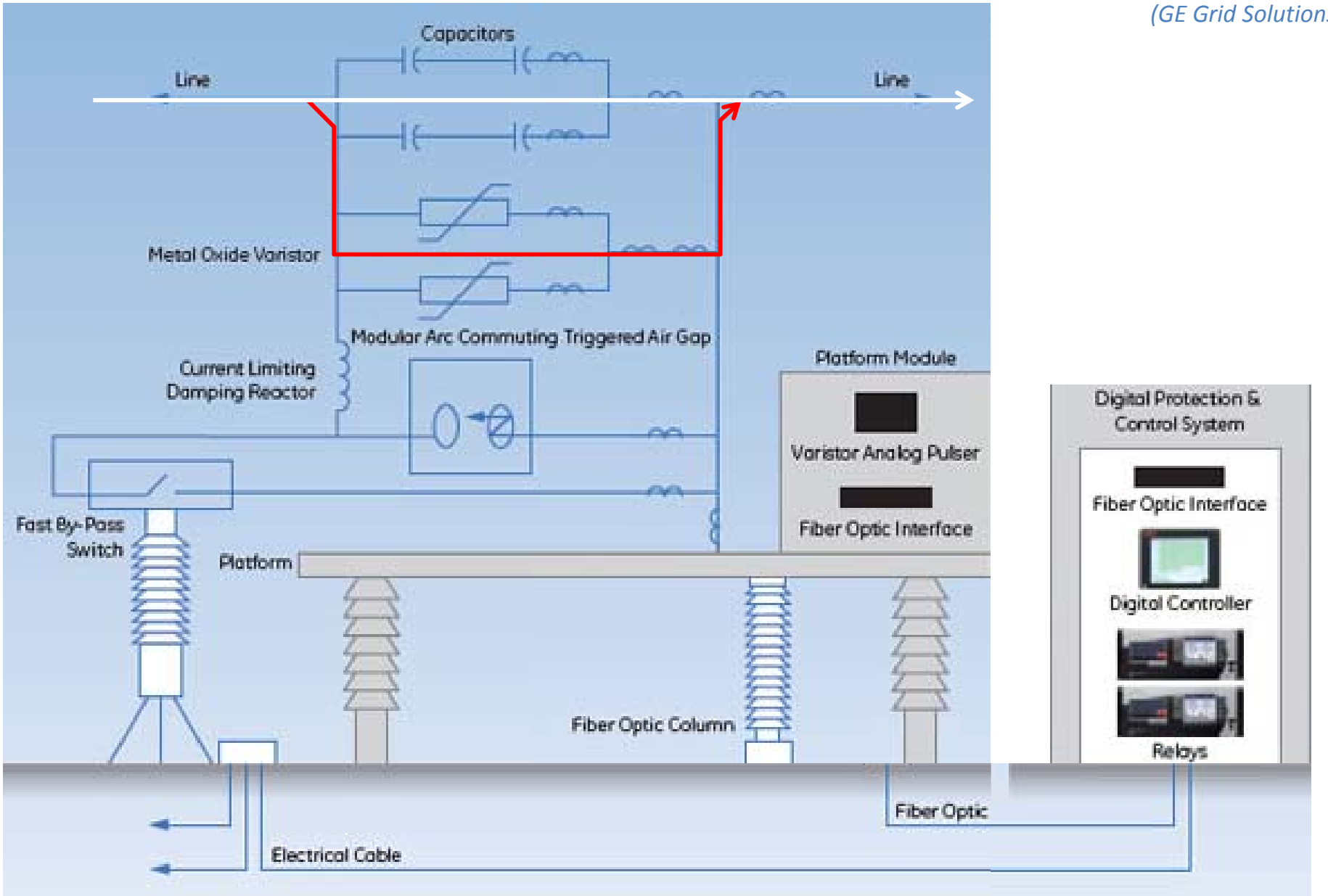
- Faults, sub-synchronous oscillations, etc.

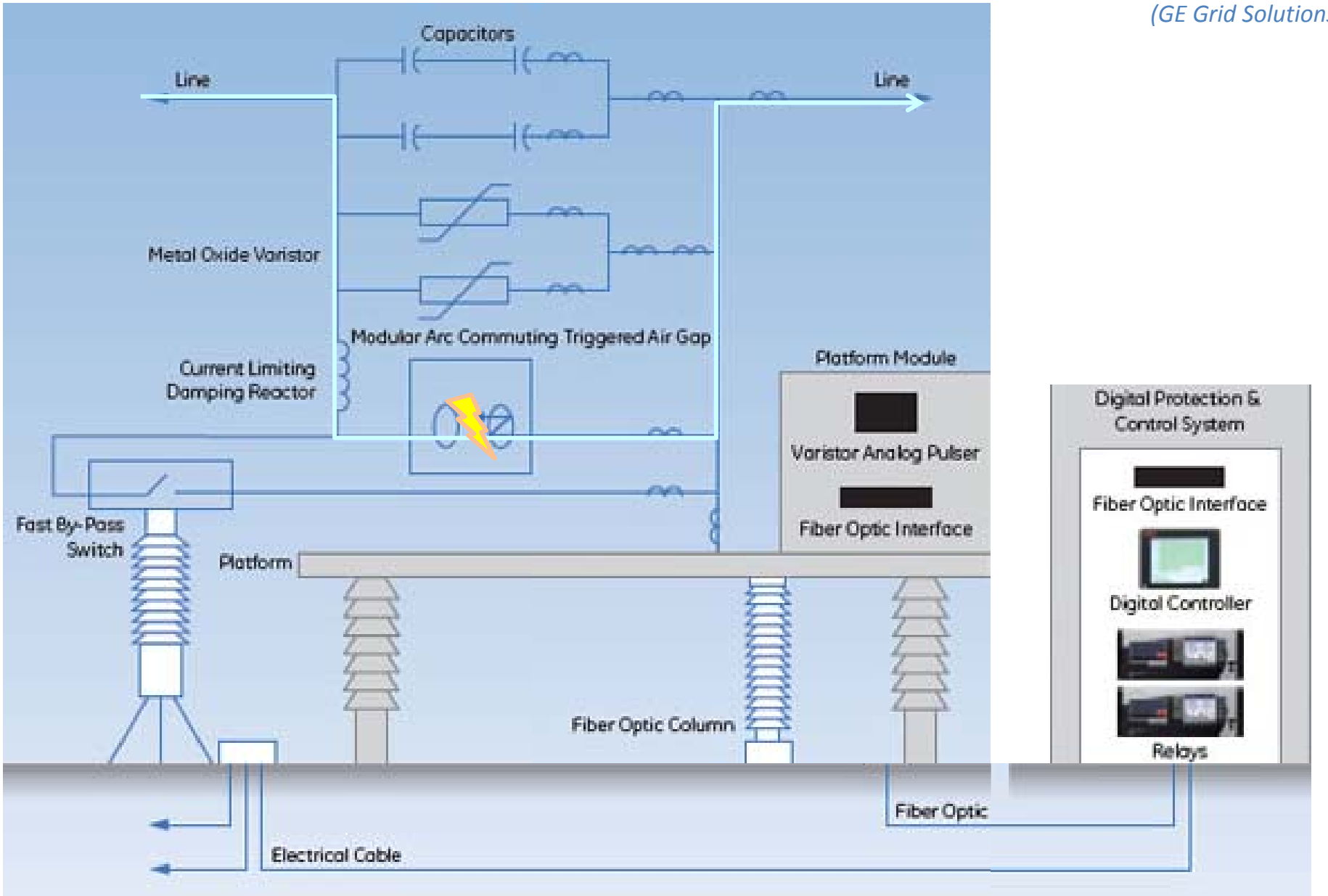
Image: ge.com
(GE Grid Solutions)



Fixed Series Capacitor Station

- Temporary bypass: spark gap triggering

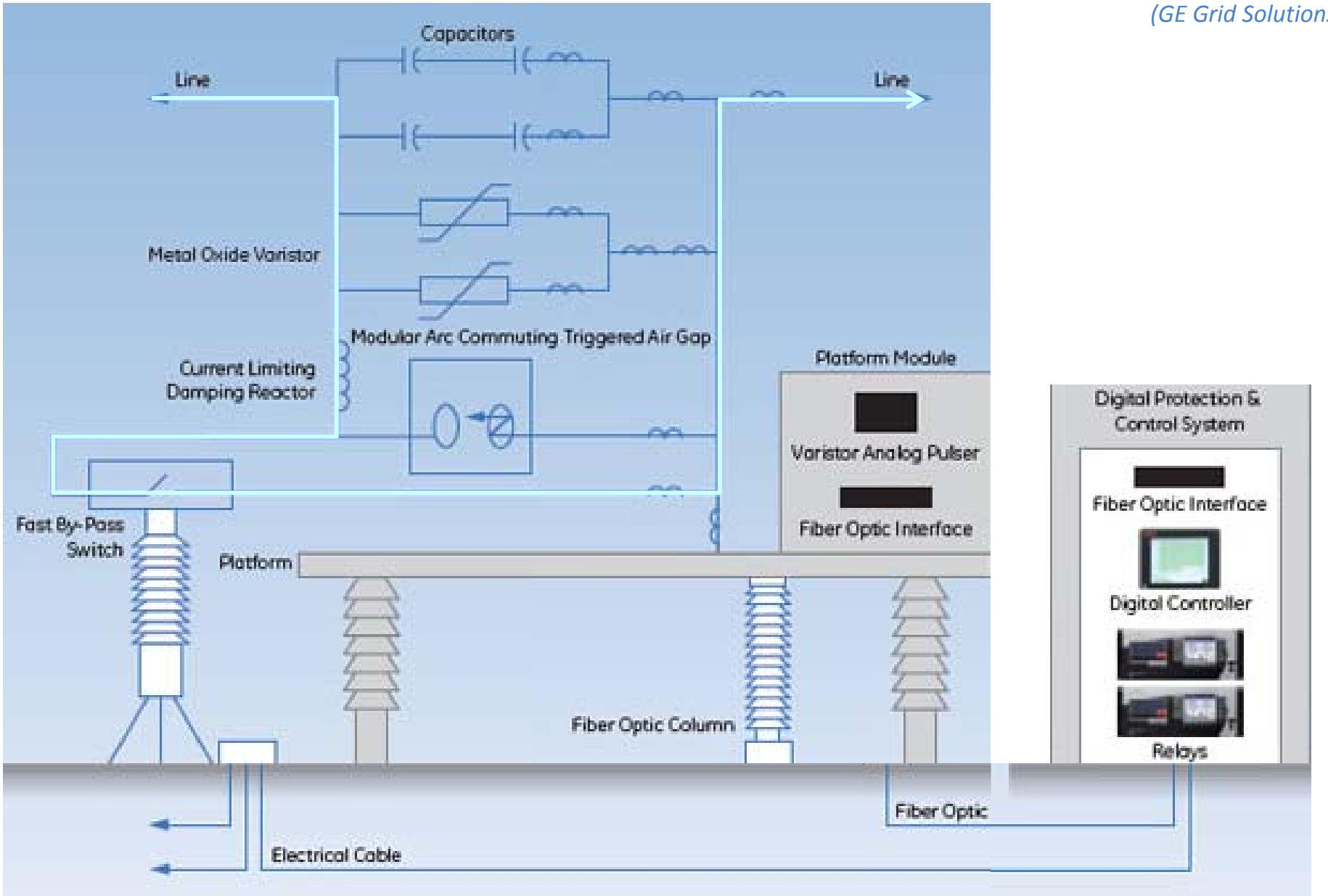
Image: ge.com
(GE Grid Solutions)



Fixed Series Capacitor Station

- Permanent bypass: bypass switch

Image: ge.com
(GE Grid Solutions)



RTDS Laboratory

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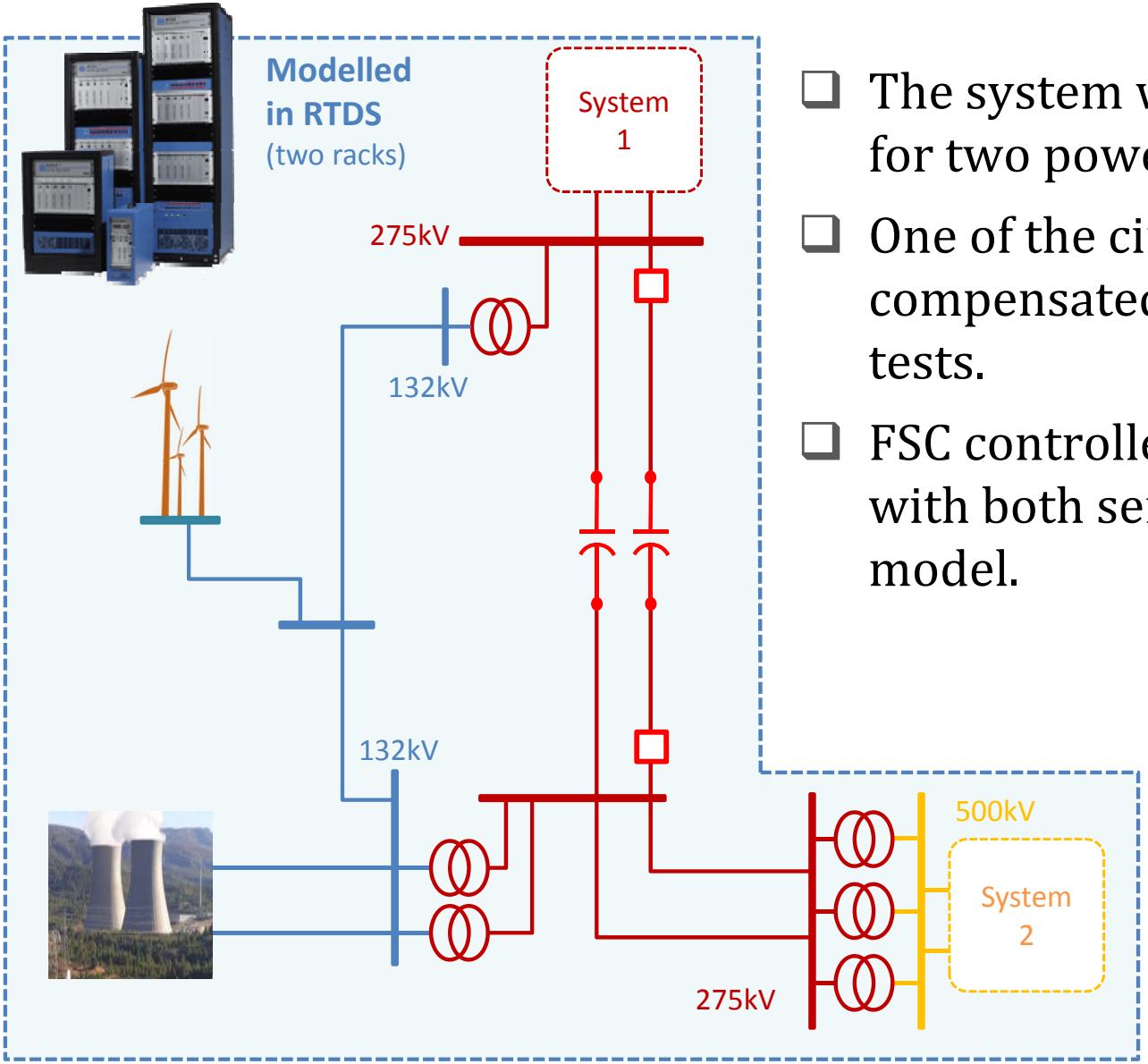
- 18 RTDS racks
  - 90 PB5 cards
  - All equipped with digital and analog I/O interface cards

- 4 amplifiers
  - Each capable of amplifying 3 voltage signals and 3 current signals

Simulation Set-up



- The system was implemented in RSCAD for two power flow conditions.
- One of the circuits of the series-compensated line was selected for HIL tests.
- FSC controller cubicles were interfaced with both series capacitors in the model.

Simulation Set-up and I/O Interfacing

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Modelled in RTDS (two racks)

System 1

275kV

132kV

132kV

275kV

500kV

System 2

To GTFPI

From GTAO

Amplifier

From GTAO

To GTDI

FSC1

FSC2

From GTAO

To GTFPI

Line protection relays

Distance

Differential

Fiber-optic link

Differential

Distance

SSO 1

SSO 2

Test Scenarios

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- Line differential and distance protection tests
  - Faults at different locations
  - Different fault types (single-phase, line-line, etc.)

  - Over 1300 scenarios, applied via RSCAD automation feature
    - Fault types and locations changed via RSCAD scripting

    → *The client's protection team recorded the results and fine-tuned the relay settings where necessary.*

    → *FSC C&P also responded appropriately to the faults by bypassing the FSCs, when necessary.*

Test Scenarios

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❑ SSO protection tests

- SSR: Thermal turbine-generator units in radial configuration with the series-compensated line

  → *The FSC controller successfully detected the undamped SSO and bypassed the series capacitors to suppress the oscillations.*

  → *Both SSO relays successfully detected the SSO condition.*

- SSCI: Type-3 wind farm in radial configuration with the series compensator line

  → *The FSC controller successfully detected the SSCI distortions.*

  → *One of the SSO relays successfully detected the SSCI.*
  SSO relay 2 (back-up) was unable to detect the condition and react.
  Adjustments were required.

Typical Steps in Similar Projects

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- Identifying the appropriate model size that could provide sufficient accuracy, while matching the available RTDS resources

- Validation of the implemented real-time model against offline simulation results obtained from tools such as PSCAD™/EMTDC™

- Preparing the analog and digital input/output signals for interfacing with the hardware being tested
  - Signal conditioning, scaling, etc. should be applied.

Carrying out the Scenarios in a Typical HIL-Based Factory System Test

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- Normally, a list of test scenarios is prepared as a 'Test Outline Report'.
- Tests may involve hundreds of scenarios.
  It may be necessary to automate the simulations using the simulation automation features in RSCAD:
  - *To apply disturbances*
  - *To record the results (where applicable)*

- Results are normally compared with those obtained from tools such as PSCAD™/EMTDC™ during the design stage.
  - *In case of mismatches, the reason for differences should be found.*
  - *Appropriate changes may be required in the hardware.*

Summary

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- Real-time simulation models were implemented for testing the control and protection systems of a series-compensated line.
- Acceptance tests were performed on the control and protection systems for this compensated line through HIL techniques.
- Necessary adjustments were applied to the hardware to ensure proper performance after installation in the field.