Subsynchronous Oscillation Detection Using Microprocessor Relays

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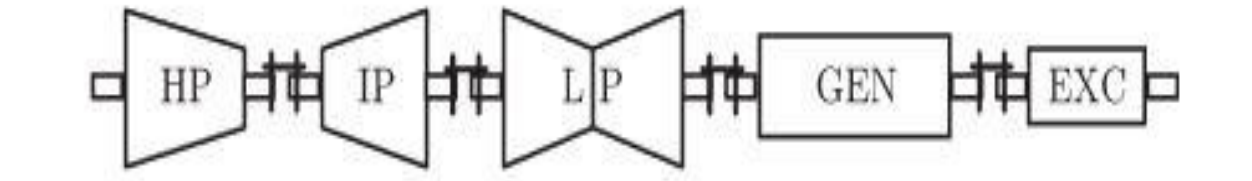
History

- 1970’s Mohave Generator plant turbine generator failure
  - Caused by near coincidence of the first torsional mode of oscillation of the turbine generator and the electrical resonance of the series capacitor and 500kV transmission network
- 1980’s Square Butte generators and a nearby HVDC terminal observed subsynchronous torsional interaction
- Recently, a related phenomena has been associated with modern wind turbine generator technologies.

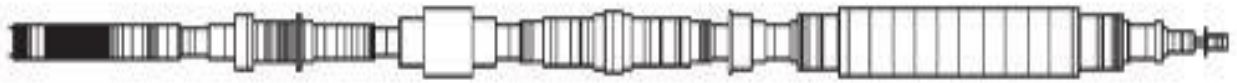
Agenda

- Subsynchronous Phenomena
- SSO Definitions
- Previous Approaches
- Detection of SSO
- Field Observations
- SSO Element
- Conclusions

Subsynchronous Phenomena



(a) Sketch of shafts



(b) Shafts model

Model of 200 MW turbo-generator shafts

With n masses, n-1 modes of oscillation

Oscillation modes

- Perturbations of mechanical system stimulate these modes
- Perturbations come from :
  - Sudden changes of input torque from actions of governor system
  - Sudden changes in electrical torque caused by faults or sudden load changes

SSO Phenomena

Energy put into the mechanical system will exchange between the Kinetic (mass-speed) and potential energy(shaft twist–spring)

Masses oscillate against each other at the natural frequencies of the mechanical system.

These natural modes of oscillation modify the generator speed resulting in currents at the new frequencies

SSO Phenomena

$$f_{ssr} = f_{rated} \pm f_{mechanical}$$

or

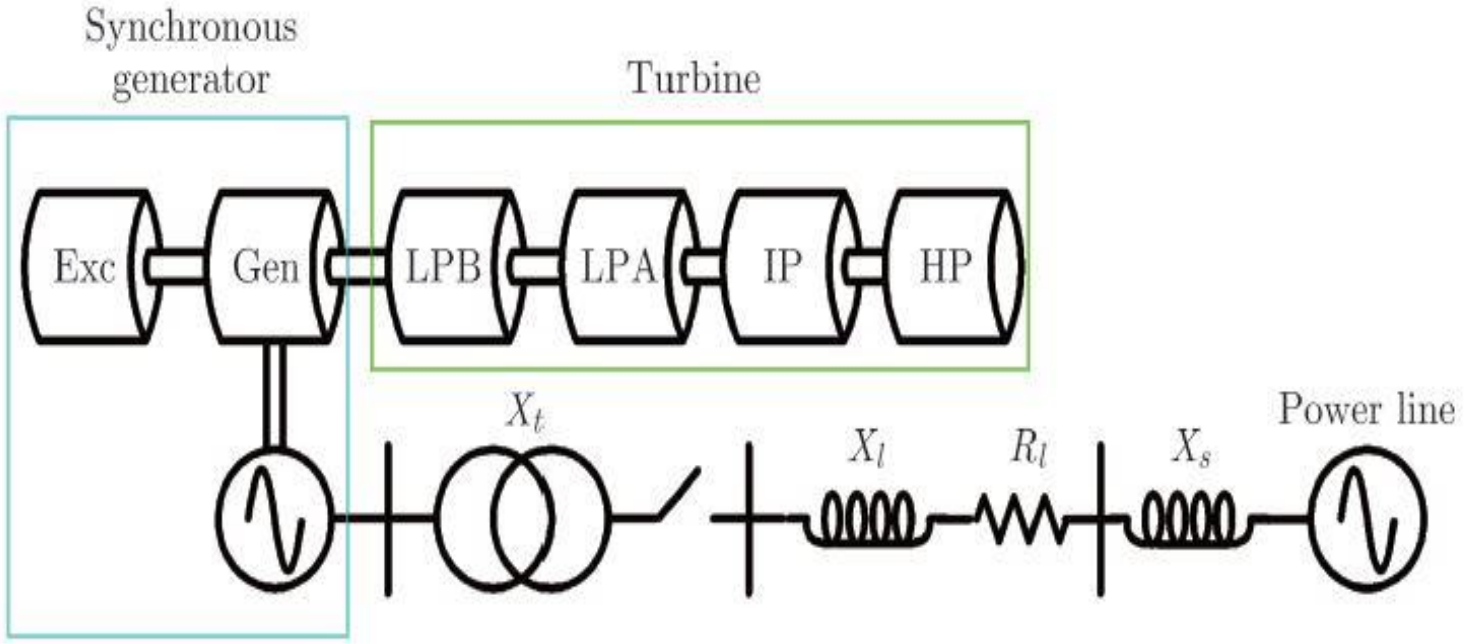
$$f_r = f_0 \pm f_{er}$$

Where: f_0 is the average synchronous frequency

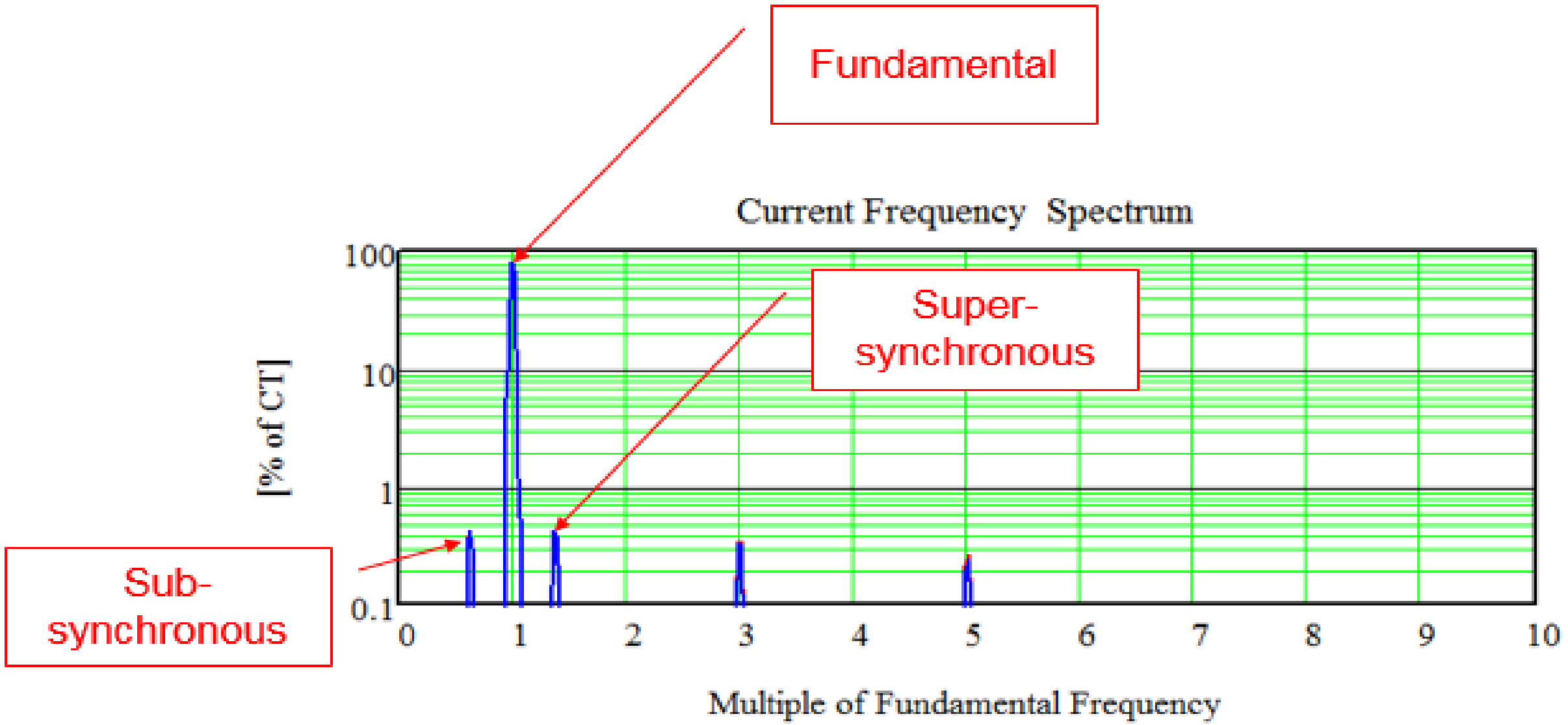
f_{er} is the resonant frequency of the electrical system

f_r is the frequency of the rotor current as a result of f_{er}

Electromechanical Power System



Current Frequency Spectrum



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SSO Categories

- **Induction Generator Effect (IGE)**
- **Torsional Interaction (TI)**
- **Torque Amplification (TA)**
- **Subsynchronous Control Interaction (SSCI)**

IEEE PES Subsynchronous Resonance Working Group - 1985

Induction Generator Effect

- An electrical phenomena that results from an electrical resonance between a series capacitor and a generator

Subsynchronous Torsional Interaction

- Occurs when the electrical system operation results in mechanical damping at the generator that is negative and sufficiently large to exceed the inherent mechanical damping of the shaft at a natural torsional frequency of the mechanical system

Subsynchronous Torsional Interaction

- Can occur because of a resonance with a series capacitor
- Can occur because of the control action of devices such as HVDC converters, SVC/s and STATCOM’s

Torque Amplification

- Occurs when the resonance between a series capacitor and a machine results in shaft stresses following a disturbance that are higher than would be without resonance

Subsynchronous Control Interaction

- A related phenomena concerning the interaction of the series compensated line and the fast acting controls used in HVDC systems, FACTS systems, and some power electronic based wind turbine generators

Effects of SSR

- Rotor damage due to excessive shaft torques
- High torque Levels
  - Steel has reached the yield point
  - Resulting in shaft deformation can result in shaft misalignment
  - Lateral bending could lead to shaft failure
- Low torque levels
  - Where endurance limit has been exceeded
  - Cyclic torque causes fatigue in the shaft
  - Life expended is calculated using stress life or S-N Curve

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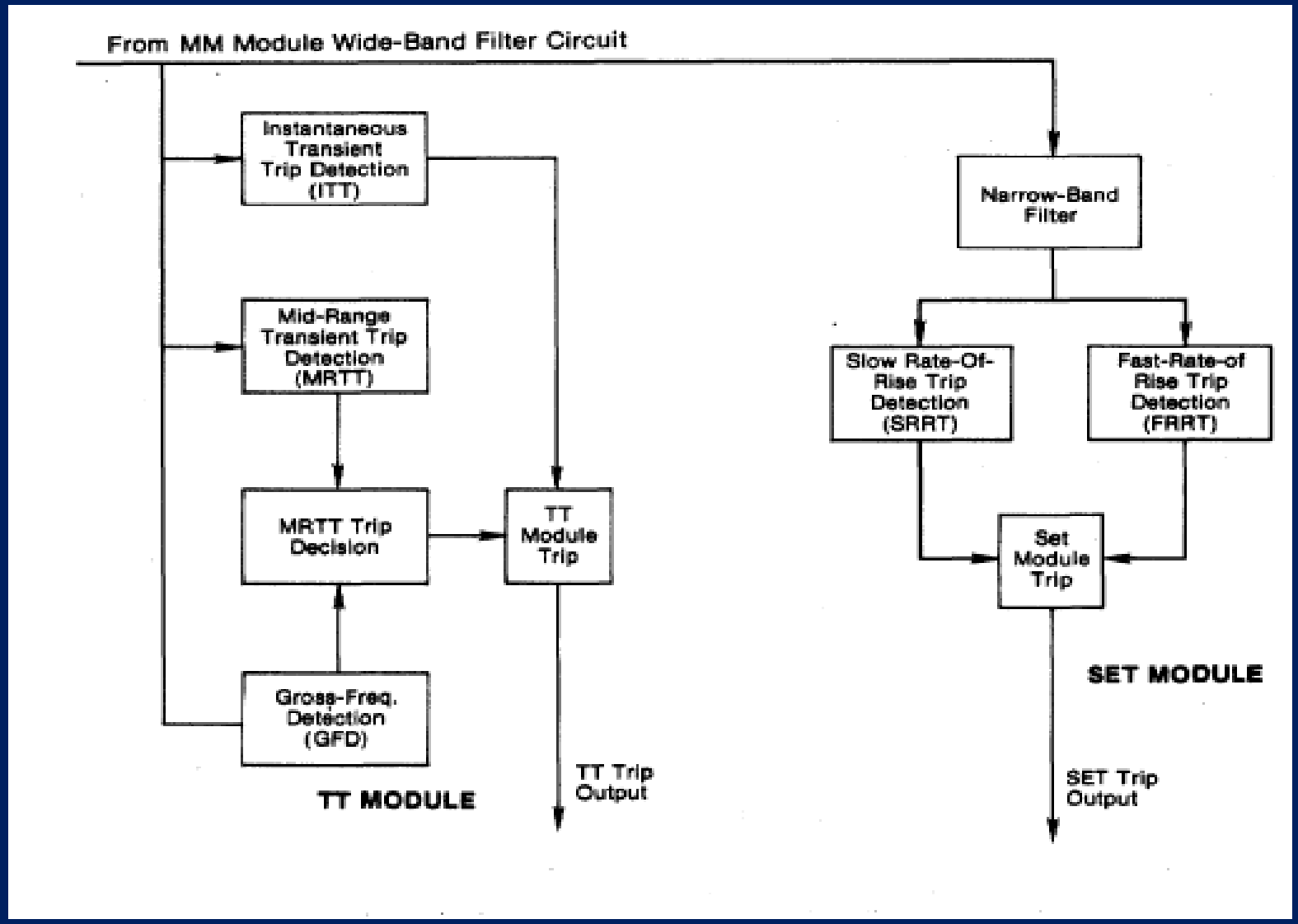
SSO Relay partial block diagram



SSO Relay

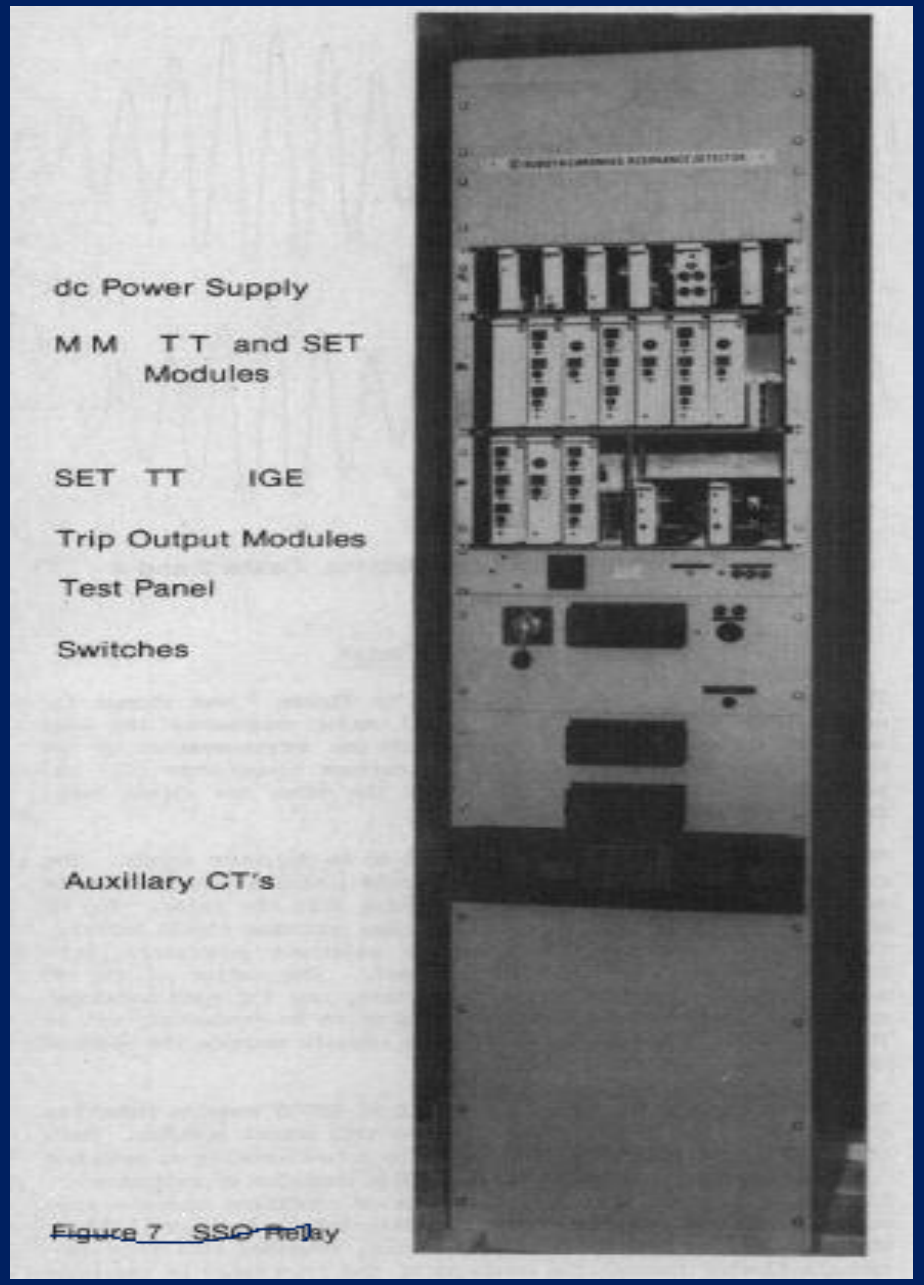
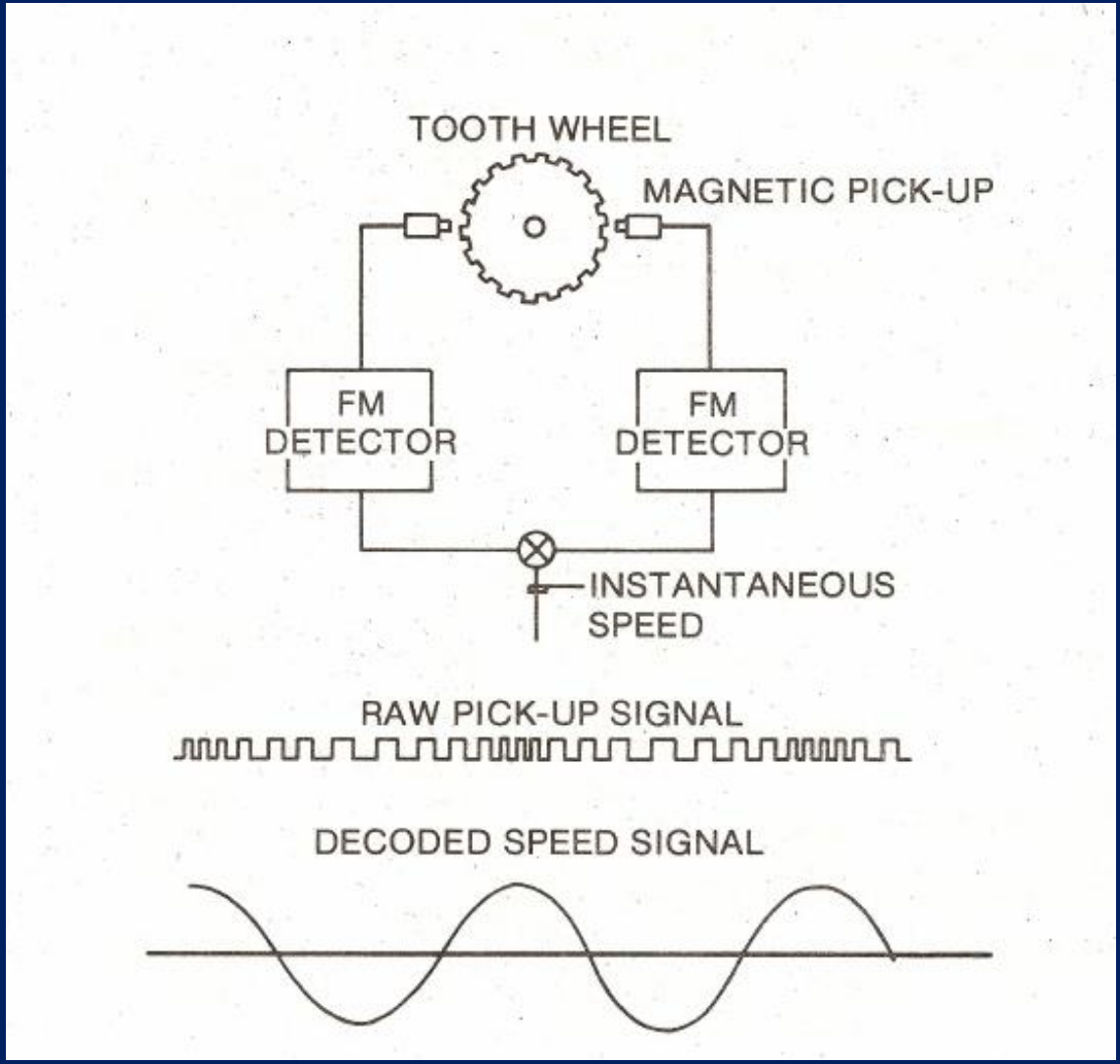
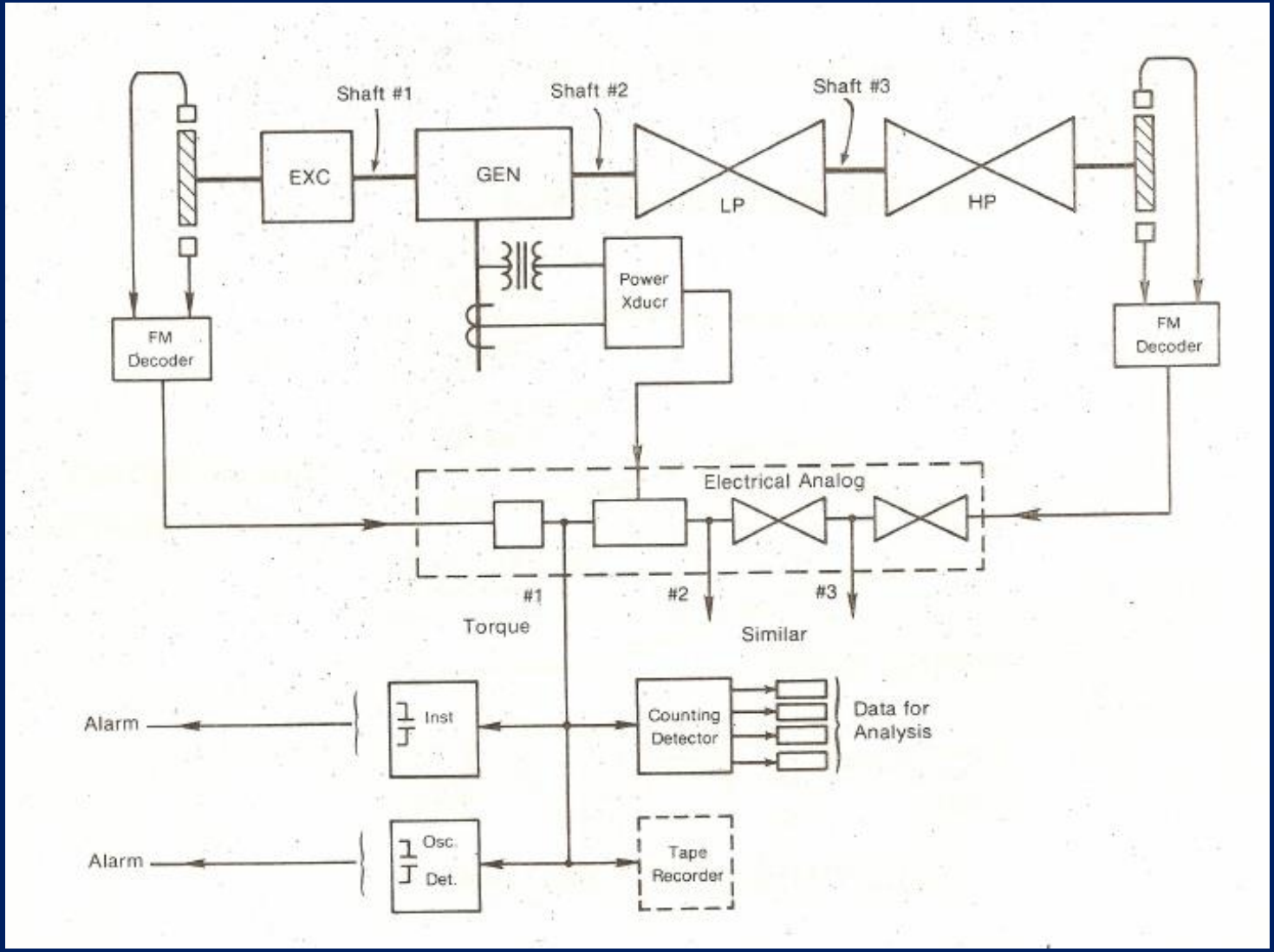


Figure 7 SSO Relay

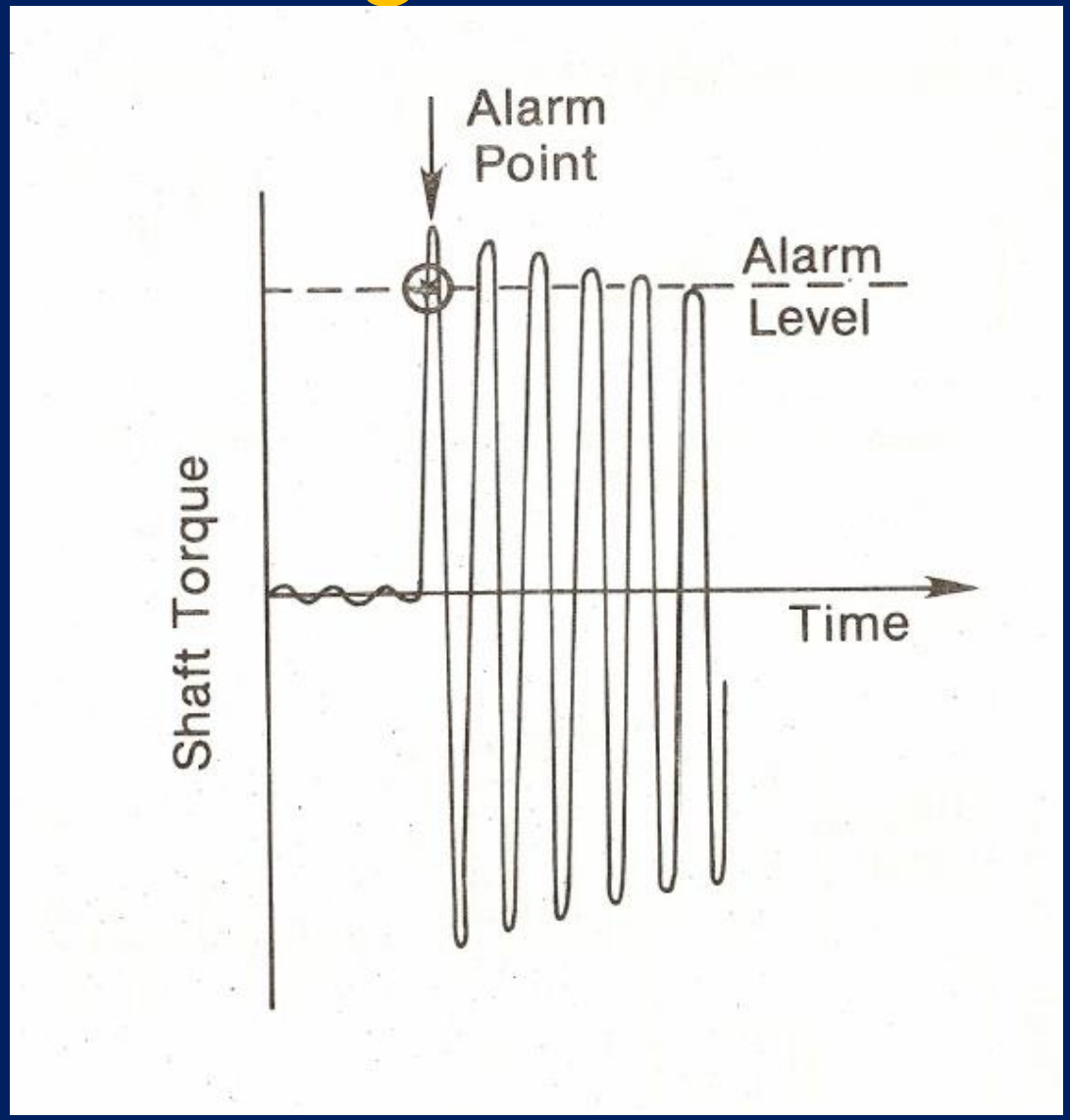
Torsional Monitoring



Torsional Monitoring Block Diagram



Torsional Montioring



Torsional Monitoring

- Expensive Installed cost
- Calibration Maintenance

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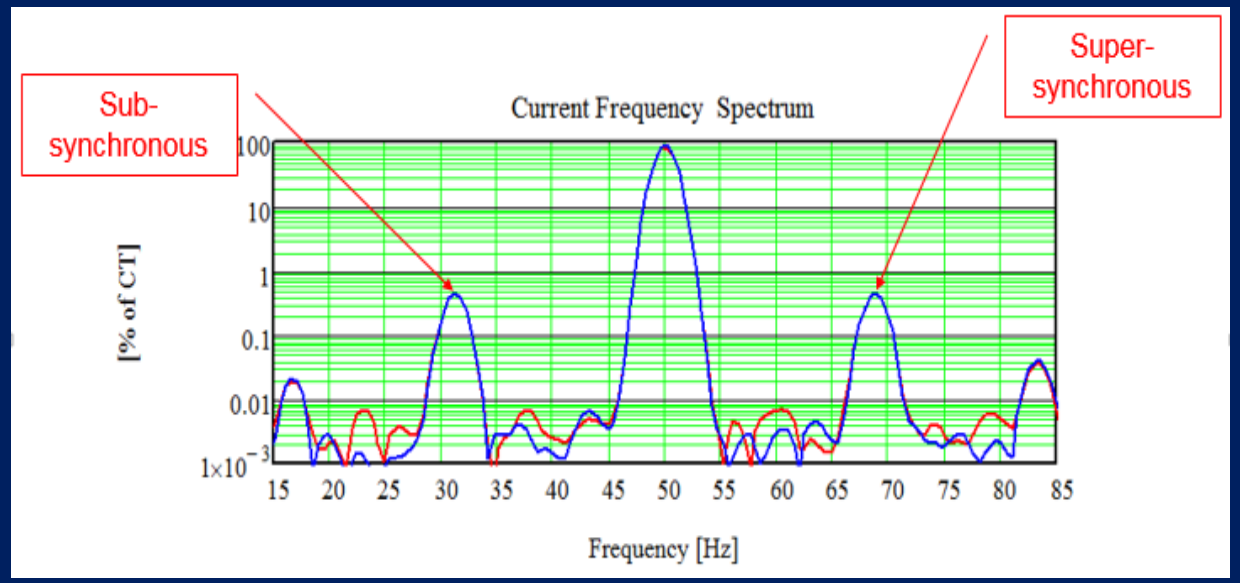
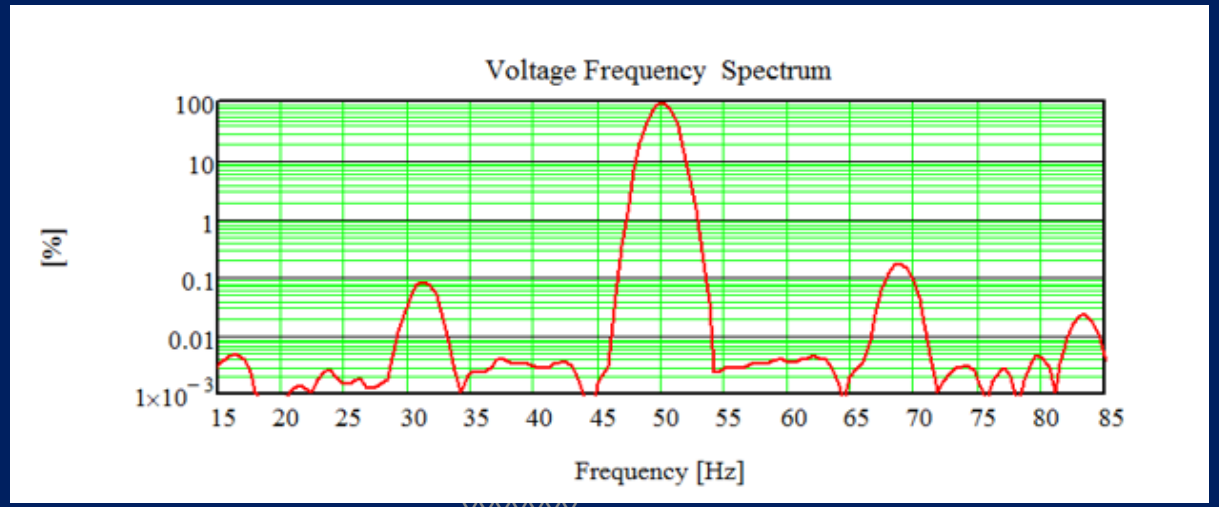
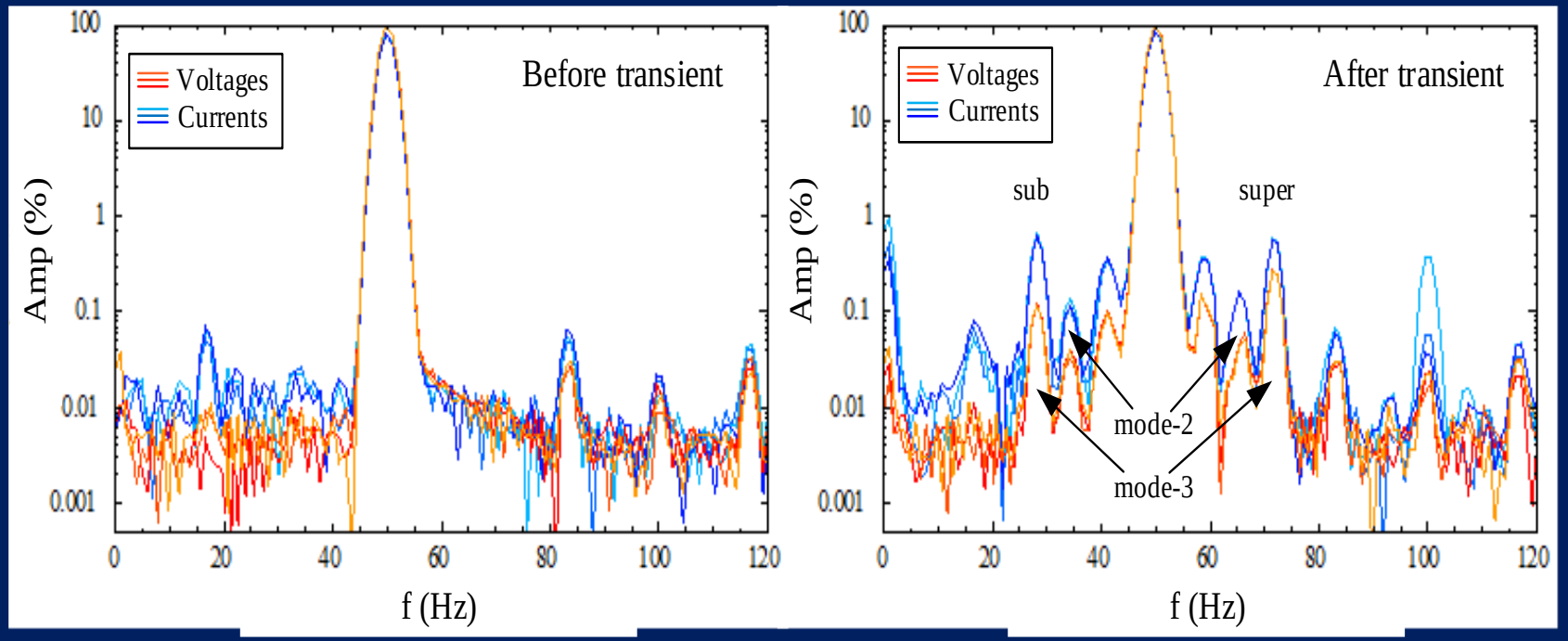
SSR Event Frequency Spectrum





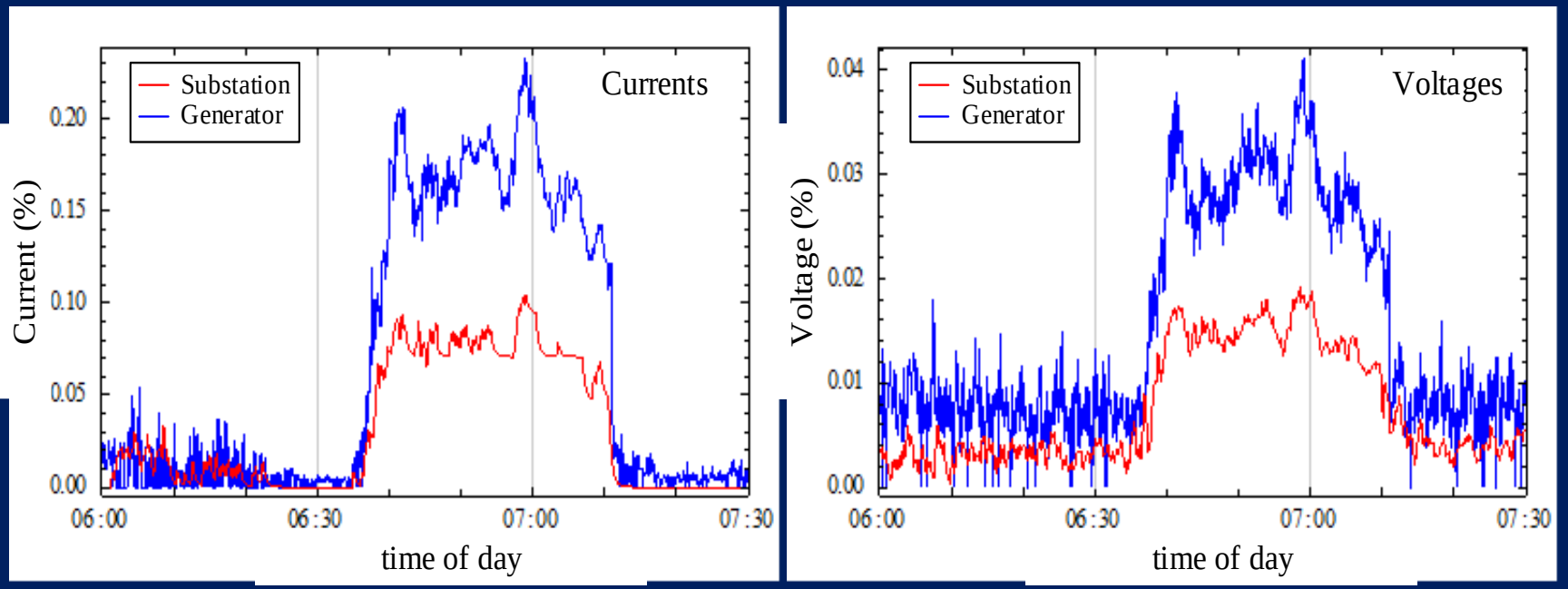
Frequency Spectrum for transient



1250 MWe Nuclear Unit Caused by quick ramp down for HVDC link

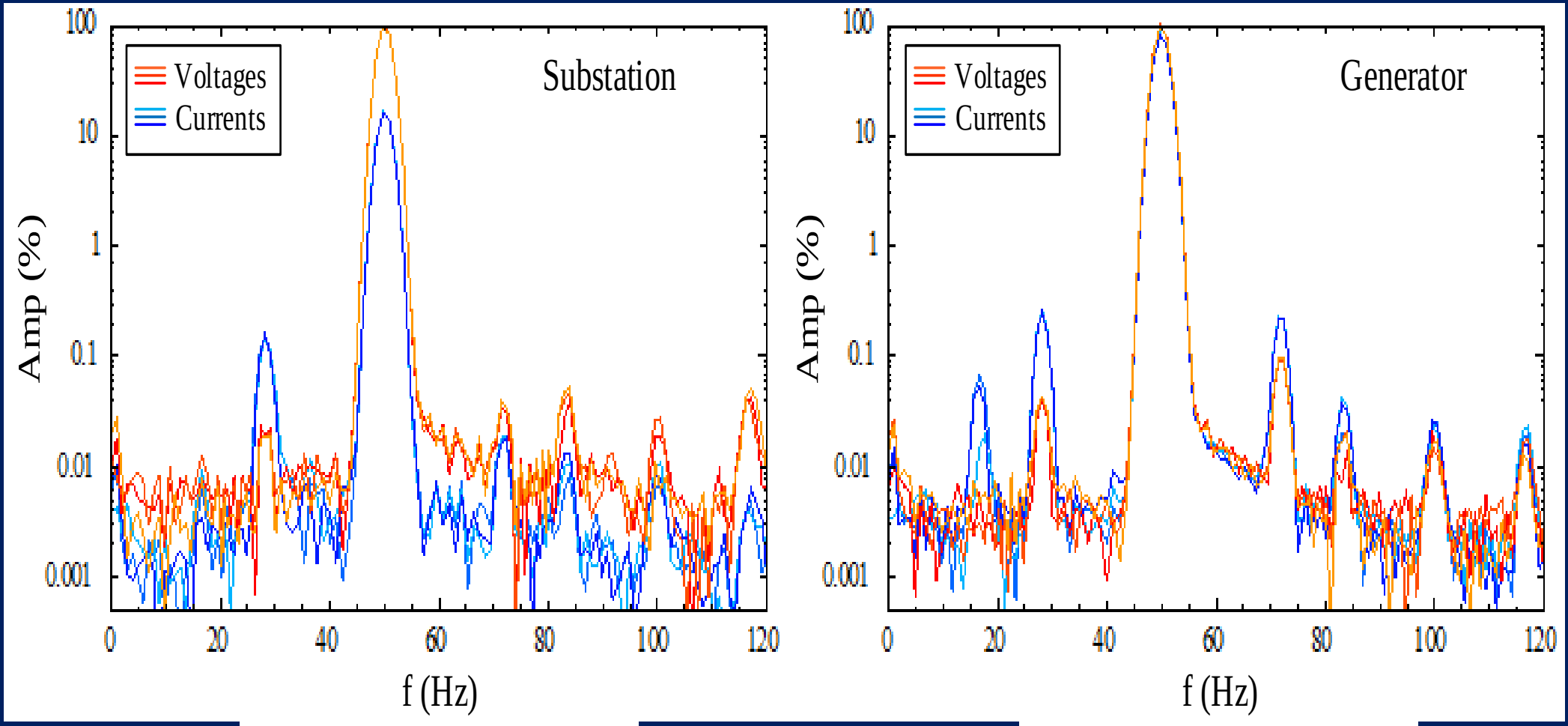
Peaks at 17, 83, and 117Hz caused by Swedish railway system

Voltage and Currents at Generator and 400kV substation



Sustained 30 minute transient with no clear indication of initiating transient or why it ended

Prolonged SSR Event



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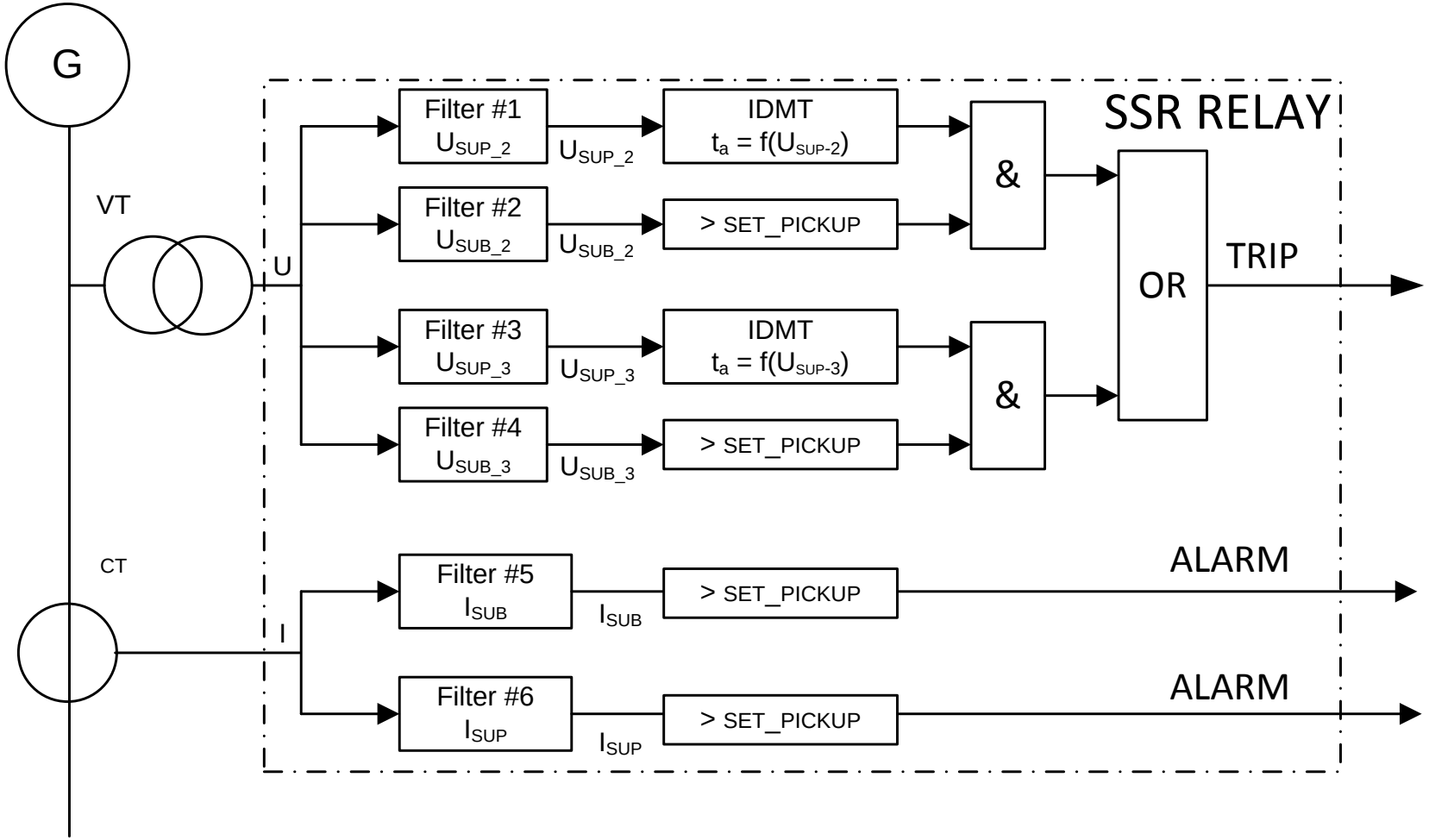
Logic for new SSR Relay



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Conclusions

- **SSO historically involved the interaction between the thermal turbine generator modes of oscillation and the electrical system resonance.**
- **SSR events have both subsynchronous and super-synchronous components**

Conclusions

A new relay algorithm has been developed that uses a very accurate filter to detect both subsynchronous and super-synchronous frequencies.

The Appian way