Design Of Subsynchronous Resonance Protection And Reduction Of Torsional Interaction In Power Systems

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Abstract-An SSR problem has been noticed and caused repeated triggering of the protection. A study indicated that SSR conditions might appear for some network configurations. Thyristor Controlled Series Capacitor (TCSC) was found to eliminate the problem. The paper discusses the problem and introduce different types of protective relays for mitigation of SSR.

Key words: SSR, TCSC, SVR, Protective Relays, Schematic Diagram

I. INTRODUCTION

Sub synchronous Resonance (SSR) is a condition that can exist on a power system where the network has natural frequencies that fall below the fundamental frequency of the generated voltages and produce subsynchronous oscillation of the steam turbine and generator shaft. The oscillation are caused by the electrical resonance of the synchronous generator and the capacitor compensated transmission lines [1].

Turbine-generators are increasingly subject to electrical environments that react with turbine-generator shafts to produce resonance (torsional vibrations) at shaft natural frequencies. These torsional vibration cause cumulative fatigue damage when they exceed material fatigue limits and result in reduced component life of parts such as shafts, buckets (blades), retaining rings, and rotors. In some severe cases, these adverse interaction have led to growing oscillations and shaft damage, including twisted couplings and broken shafts.

There are several ways in which the system and the generator may interact with subsynchronous effects. A few of these interaction are basic in concept and have been given special names [2].

A. Induction Generator Effect

This phenomena is caused by self-excitation of the electrical network. The resistance of the generator to sub synchronous current, viewed looking into the generator at the armature terminals, is a negative resistance over much of the sub synchronous frequency range. If the negative resistance of the generator is greater in magnitude than the positive resistance of the network at one of the network natural frequencies, growing subsynchronous currents can be expected.

B. Torsional Interaction

When a torsional oscillation occurs to the turbines and generator rotating system at a subsynchronous frequency, while the generator field winding itself on the rotor is rotating at an average speed corresponding to the system frequency, there will be voltages and currents induced in the generator armature three phase winding at frequency of subtract of them. If this frequency coincide or be very close to an electrical resonance frequency of the generator and transmission system, the torsional oscillation and the electrical resonance will be mutually excited or reinforced resulting is SSR.

C. Transient Torques

Transient torques are torques that result from large system disturbance, such as faults. System disturbances cause sudden changes in the network, resulting in sudden changes in currents with components that oscillate at the natural frequencies of the network for networks that contain series capacitors, the transient currents will contain one or more oscillatory frequencies that depend on the network capacitors.

II. APPLICATION OF TCSC FOR MITIGATION OF SUBSYNCHRONOUS RESONANCE

The introduction of series compensation improves the transmission system behavior with respect to voltage stability and angular stability. However, under adverse conditions, at the same time electrical resonance might be introduced in the system. Experience has shown that such electrical resonance may under certain circumstances interact with mechanical torsional resonance in turbine-generator shaft systems in thermal generating plants. This phenomenon is known as Sub Synchronous Resonance (SSR). Today the SSR problem is well understood and taken into account when series compensation is planned and designed. Sometimes, however, SSR conditions may limit the degree of compensation wanted for better power system performance [3]. The use of Thyristor-Controlled Series Compensation (TCSC) based on
state of the art high power electronics will help to alleviate such constraints and thereby offer a superior option, from technical, economic and environmental points of view.

Consequently, a transition of the virtual reactance of the TCSC from inductive to capacitive outside the subsynchronous frequency band is achieved by means of a reactance controller, providing a controllable capacitive reactance around the power frequency (Fig.2).

To summarize, the SVR approach offers the elimination of SSR risk throughout the potential subsynchronous frequency range [4].

III. UNIT RELAYING

A protective relay is a good method against SSR that can detect the problem and trip the unit before shaft fatigue has accumulated to a significant level. Most of the other countermeasures are designed to make sure that there is good damping of subsynchronous oscillations and to shield the turbine-generator unit from experiencing these oscillations, insofar as possible. Despite all precaution, there may be occasion when a generation unit will be exposed to subsynchronous oscillations. There is always the possibility that conditions are not ideal. The countermeasures in service may not be working correctly, or may be disabled. Should such an unforeseen event occur, it is not an acceptable risk that generating unit should be caused to sustain long or growing subsynchronous oscillation. Therefore, SSR relays are usually installed to make sure that the unit life is preserved, even under conditions that are extremely rare. In some cases, where the risk of SSR damage is limited or the dangerous conditions are rare, the relay may be the only SSR countermeasure required.

IV. PROTECTIVE RELAYS

There different types of SSR relays have been provided to meet the requirements of detection of potential damaging oscillations and removal of the unit. Two of the relays are based primarily on the monitoring of the frequency content of the generator currents. The third relay models the mechanical behavior of the turbine-generator shaft, each of these relays will be briefly described.

A. Armature Current SSR Relay

Negative-sequence relays protecting the generating units issued alarms, indicting the presence of negative-sequence currents. This indicated that the negative-sequence relay design might be sensitive to subsynchronous frequencies. Laboratory tests of a similar relay confirmed this characteristic, in fact, the negative-sequence relay produced a signal at 30 hertz, even without the presence of any negative-sequence current. This concept became the basis for the design of a new SSR relay, that was later designated the TEX relay, by the addition of suitable band-pass and blocking filters. The TEX relay has the following design features [5]:

- Detects positive-sequence currents in the 20–40 hertz range.
- Provides two subsynchronous current level detectors that are separately adjustable,
- Is relatively insensitive to low system frequency operation,
- Is relatively insensitive to generator negative-sequence current, and
- Has sufficient time delay to override SSR currents associated with normal system operation, such as system faults and series capacitor switching.

A schematic diagram of the TEX relay is shown in Fig.3. The three-phase currents enter the relay at terminals 3, 5, and 7 and level at terminals 4, 6, and 8. A voltage is developed between terminals 15 and 17 that is dependent on the phase current frequency, magnitude, and sequence of phase rotation. Current level detectors, D1 and D2 are contained in the full wave rectifier, which is connected across terminals 16-17. The relay has three filters, designated F1, F2, and F3. F1 is a dual tuned filter that is designed to bypass the 60 hertz components of positive and negative-sequence currents and also to block any subsynchronous current components, thereby forcing the subsynchronous currents through the level detector circuits. F3 is a synchronous rejection filter, which with F1 to ensure high subsynchronous current detection sensitivity and low response to both positive and negative-sequence currents at or near synchronous frequency. F2 is a harmonic band-pass filter that is added to ensure that higher harmonics will not interfere with the relay operation.

TEX relays have been installed at a number of location and were the primary protection at some locations at the time they were first designed. Since that time, newer designs have been developed and these newer devised have begun to replace the TEX installations.

B. Torsional Motion Relay

This relay is designed to detect any of the following conditions.

- Generator self-excitation
- Torsional interaction
- Torque amplification

These three processes are quite different and require unique approaches to their detection. The principal variables required for detection are shown in Fig.4.

When electrical self-excitation occurs, the method of detection requires the use of only electrical quantities, as noted in Fig.4 (a). Each self-excitation event will generate a component of generator voltage and current at a frequency below 60 hertz that is superimposed on the normal 60 hertz quantities, and that increases with time. The TEX relay recognizes self-excitation, but the device is frequency dependent in the frequency range of interest (usually 30-60 hertz) and the sensitivity deteriorated as the frequency approaches 60 hertz. This is the opposite to the required sensitivity under self-excitation conditions [5].

The digital tripping logic, shown in block diagram form in figure, includes four features: the detection of single modal amplitude response, the modal stability, the dual mode response, and the transient response. The modal tripping is directed by 16 level detectors, four for each modal filter, which drive all but the transient protection logic.

These relays have been installed at many locations where there is possible hazard to turbine-generator shafts due to either series compensated transmission lines or to nearby HVDC converter station. Over a decade of experience has been accumulated with these relays and a number of unit trips have resulted due to stresses on unit shafts that would have caused excessive damage.
C. Subsynchronous Current Relay.

The subsynchronous current relay utilizes a special technique to detect very low values of subsynchronous current and employs a special logic to determine if these currents represent a potential danger to the turbine generator. A schematic diagram of the relay detection system is shown in Fig.6 [5]. It is important to note that the subsynchronous frequency components of armature current are directly related to both the magnitude and frequency of the electrical torques and the resultant mechanical stresses in the turbine-generator shafts. The stator currents of frequency \( f_{er} \) interact with the machine flux to produce air-gap torques that cause the generator rotor to oscillate at a frequency \((f_0 - f_{er})\). These air-gap torques decay at the same rate as the transient currents. If, however, the air-gap torques should correspond to a torsional natural frequency \( f_n \) of the turbine-generator shaft, growing oscillation will result.

The system shown in figure is the signal extraction circuit. Phase current measurements are modulated by positive-sequence phase voltages for phase locking. The output of these multipliers will typically include a dc component plus other components that oscillate at frequencies of \((f_0 + f_{er})\) and \((f_0 - f_{er})\) where \( f_{er} \) is the positive-sequence subsynchronous frequency component of the phase current and \( f_0 \) is the system fundamental frequency. This doubling of the frequency components provides an excellent opportunity for filtering out any dc component as well as the super synchronous components, leaving only the required subsynchronous components. This filtering is performed by the wide band filter, shown in Fig.6. These filtered signals are directed to three different types of circuits:

- The self-excited trip detection (SET) circuits
- The transient trip detection (TT) circuits
- The induction generator effect detection (IGE) circuits

IV. COMMENTS ON SSR RELAYS

It is noted that armature current SSR relay (TEX relay) was not considered an adequate nor permanent solution to the need for generating unit protection against unforeseen subsynchronous currents that could be damaging to a unit [5]. Having recognized that need, the industry has developed two relays that are specifically designed to recognize and respond to potentially damaging subsynchronous currents. The two relays, the torsional motion relay and the subsynchronous current relay, operate on different principles to provide the kind of protection that is considered necessary.

V. TECHNICAL SPECIFICATIONS OF A TYPICAL SYSTEM.

In the K.R.E.C network in Iran, there isn’t very long transmission lines, but we wont to study using TCSC for a typical 400kv transmission line. Namely Ghaen-Tabas 400kv line is considered in this study that located in south of khorasan province and almost is 200km [6]. Using the SVR approach for control of TCSC, SSR risk throughout the potential subsynchronous frequency range decrease. The digital protective this relays are made by GE. Required relays for this project and main data of TCSC are described as follows:

- Maximum System Voltage: 400kv
- Nominal Reactive Power: 125Mvar
- Rated Current: 1200 A
- Physical Capacitor Reactance/phase: 15.5 Ω
- Degree of Compensation: 45%
- Boost Reference Value: 1.3
- Turbine-Generator Torsional Stress Relay (TSR)
- Line Distance Protection System (D60 or D30)

A. Turbine-Generator Torsional Stress Relay (TSR)

The torsional stress relay (TSR) is a digital protective relay designed to continuously monitor the turbine-generator’s shaft for torsional oscillation, and provide trip output contacts when shaft fatigue reaches predetermined levels. Two separate trip output circuits are provided, each with separate setting [7]. The standard TSR is configured to protect a single turbine-generator. A vision of the TSR is available that can economically protect up to three turbine-generator units in certain combined cycle plants.

1. TSR Hardware Overview

The standard TSR is a cabinet, suitable for generating station relay room, control room, or other room with a reasonably controlled environment. Its main component is a GE RC2000
digital transducer and control assembly, programmed to monitor shaft speed from toothed wheel transducer inputs and to issue trip outputs when shaft torsional vibrations exceed allowable criteria.

The RC2000 hardware is based on GE’s digital turbine, excitation system, and motor drive controller, which is manufactured in high quantity. The unit contains four microprocessors that cooperate to perform the application tasks, and support extensive standard features including diagnostics and self checking. Because of the motor drive heritage and multiple processor design, the RC2000 has bandwidth in excess of typical power system controllers. It is well suited for torsional protection application requiring high reliability.

2. Available Options

The optional Event Recorder (ER) provides a digital fault recorder built into the TSR cabinet. When high torsional stress is detected, the ER is triggered and it records the response of the turbine-generator during the event.

A TSR can be augmented with a Torsional Stress Analyzer (TSA) to provide detailed analysis of each torsional event. Using data captured by the TSR’s optional Event Recorder, the TSA calculates the mechanical torque for each shaft section and determines the loss of life due to fatigue.

B. D60 & D30 (Line Distance Protection System)

The D60 and D30 line distance protection system are a microprocessor-based relay that protect transmission lines of any voltage level for there pole and single pole tripping applications [7].

The D30 can be used as primary distance protection for subtransmission grids and as back up protection of transmission lines, generators and power transformers. As part of the universal relay (UR) family, the D30 provides superior protection and the D60 offers advanced protection and control features one of these applications is related to series compensated lines.

The D60 and the D30 can be safely used on or near series-compensated lines. The relay depends on memory polarization for directional integrity, using an offset on polarizing voltages for accurate ground directional overcorrect functions. The relay can be set for a non-compensated line and an adaptive mechanism built into the distance function can adjust the reach accordingly. This ensures security despite sub-synchronous oscillations and the effect of series capacitors on the apparent impedance.

VI. CONCLUSION

The studies reveal that the TCSC technology can be advantageously used to improve the SSR condition.

To conclude the TCSC technology permits the full use of series compensation to a degree desired from a system point of view disregarding earlier experienced restrictions due to the risk of SSR.

Also Paper introduce two digital protective relays that are specially designed to recognize and respond to potentially damaging subsynchronous currents.

VII. REFERENCES