Indigenous technology development: Seismic Switch for Nuclear Reactors

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After Fukushima incident it has become a regulatory requirement to have automatic reactor trip on detection of earthquake beyond OBE level. Seismic Switches that meets the technical specifications required for nuclear reactor use were not available in the market. Hence, on Nuclear Power Corporation of India Ltd (NPCIL's) request, Refuelling Technology Division, BARC has developed Seismic Switches (electronic earthquake detectors) required for this application. Functionality of the system was successfully tested using a Shake Table. Two different designs of seismic switches have been developed. One is a microcontroller based system (digital) and the other is fully analogue electronics (analog) based. These switches are designed to meet the technical requirements of Class IA systems of nuclear reactors. It is also designed to meet other qualification tests such as EMI/EMC, climatic, vibration, and reliability requirements. In addition to nuclear industry seismic switches are having potential use in oil and gas, power plants, buildings and other industrial installations. These technologies are currently available for technology transfer and details are published in BARC website.

This paper describes the requirements, principle of operation, and features and testing of the developed systems.

Introduction

Major earthquakes are known to cause buildings to collapse, dishevel roads, shear pipe lines, disrupt communication, set fires, and inflict injuries which sometimes result in death. While significant advances have been made to reinforce structures against earthquakes, little has been done to reduce non-structural hazards. Toppled furniture, objects thrown off shelves and out of cabinets, broken gas and water lines, damaged electric power lines and equipment, derailed passenger trains and elevators, and catastrophic disruption of industrial processes continue to pose a hazard to people and property during a major earthquake. Injuries aside, serious economic losses result from major earthquakes due to the cost of emergency services, repairs, and clean-up.

In this regard, a reliable seismic switch to detect major earthquakes and activate safety devices would be of benefit. One which initiates safety measures before the onset of the earthquakes most destructive ground motions, would be even more so. A forewarning of a few seconds would be most beneficial by warning people to take cover, latching cabinets closed, deactivating electrical equipment, systematically shutting down pipelines, stopping passenger elevators and trains, and putting industrial plants such as nuclear power stations, refineries and electric power plants on standby so as to safely ride out the earthquake, thereby minimizing damage to persons and property.

After Fukushima incident it has become a regulatory requirement to have Automatic Seismic Trip System (ASTS)

Fig. 1: Photograph of Seismic Switch (digital) and its internal PCB's

in nuclear reactors on detection of earthquake. This is designed to scram the reactor upon the occurrence of a seismic event, before turbine trip or other conditions resulting from the seismic disturbance could cause a scram. The earlier scram could give a lead time between 5 to 20 seconds. This lead time could provide resulting benefits such as reduced loads during the seismic event and, therefore, fewer burdens on the plant systems. It may also reduce the likelihood of a Loss of Coolant Accident (LOCA) or severe transient after a seismic event. ASTS comes under classification as safety Class IA system (reactor protection) and has to meet the relevant standard requirements such as on-line testability, fail safe criteria and other qualification requirements. Since systems available in the market are not meeting these requirements, on NPCIL's request, Refuelling Technology Division, BARC has indigenously developed fully functional prototypes of Seismic Switch. Two different designs of seismic switches have been developed. One is a microcontroller based system (digital) and the other is fully analogue electronics (analog) based. Functionality of these systems was successfully tested using a Shake Table. Photograph of the Seismic Switch is shown in Fig. 1.

Theory of Operation

To mitigate the seismic hazard, an NPP is designed to withstand the effects of vibratory ground motion arising from strong earthquakes. The design basis ground motion (DBGM) for this purpose is evaluated for each site. The DBGM is characterized by Peak Ground Acceleration (PGA), response spectral shape and a time history compatible with response spectrum [1]. PGA and response spectrum are derived based on site specific studies. The DBGM parameters are evaluated for two levels of severity, S1 level earthquake or OBE and S2 level earthquake or SSE. The structures, systems and components (SSC) of the nuclear reactors are designed for either SSE (Safe Shut down Earthquake) Level or OBE (Operation Basis Earthquake) level earth quake.

Triggering Conditions of Seismic Switch

The destructive low frequency vibrations (0.05 to 10 Hz) are characteristic of major earthquakes. The seismic switch continuously measures the accelerations in X, Y (Horizontal) and Z (vertical) from the 3-axis MEMS accelerometer. Acceleration signal from each axis is low pass filtered with 3 db cut-off frequency at 13.5 Hz. The Seismic switch triggers on detecting the acceleration greater than the preset PGA level. The PGA level setting is normally kept as the PGA of the OBE level response spectrum of the respective sites. For example; OBE spectra of Tarapur (Maharashtra) site is having a PGA of 0.100g.

Standardised Cumulative Average Velocity (CAV)

Using PGA as the parameter for detection of earthquake often leads to false alarm. Standardised Cumulative Average Velocity can be used as the parameter for detection of earthquake. CAV is the area under the absolute accelerogram as shown in the following equation..

$$CAV_{total} = CAV_i + \int_{t_{i-1}}^{t_i} |a(t)|\,d(t)$$

a(t)= acceleration values in a one-second interval where at least one value exceeds 0.025g

i = 1 to n equal to the record length in seconds.

Design Features of Seismic Switches

Seismic Switch is housed in an IP66 industrial rated enclosure with a single cable inlet for all connections. Two outputs are provided in the Seismic Switch which are 2 Form C (DPDT) isolated relay contacts. One is called 'Earthquake relay' and other is called 'Status relay'. Activation or triggering conditions of both the relays are defined.

Coils of both the relays are in energized state during normal operation and de-energizes on any fault. This ensures 'fail safe' operation of the system. On-line testability is another important feature in this system which enables the user to manually initiate the self-diagnostics of the system without removing it from the installation.

Self diagnostics feature of the Seismic Switch (digital) involves continuous health monitoring of communication, battery and sensor parameters. This is carried out in every sensor communication cycle. On any error the earthquake relay gets triggered.

Actual testing of sensor by applying known test condition is carried out during Self Test. It can be initiated manually through push button switch. Self test of Seismic Switch (digital) can be initiated from remote software. It is also done automatically at regular time intervals as well as at reset. Seismic switch generally does not require calibration; however, the calibration can be verified on a tilt table. Seismic Switch (Digital) can communicate to a Graphical User Interface Software (GUI) through an RS-485/RS-232 link. Various features of this software include remote reset for automatic levelling, self test, password protected access, saving instrument details in EEPROM, setting trip parameters, display of battery status, real-time plots of accelerations and display of various other system parameters such as voltage and temperature of the sensor. The system can be programmed for having additional triggering conditions such as Cumulative Average Velocity (CAV).

Testing and Qualification

A Six Degrees of Freedom (6DOF) Shake Table available in Engg. Hall 3 of BARC has been utilized for testing and validating the functionality of Seismic Switches. Sinusoidal motion was created on the table on various peak acceleration amplitudes and actuation of earthquake relay on the preset acceleration amplitude was observed. Response spectrum compatible acceleration time history with Peak Ground Acceleration (PGA) of 0.1g was generated on the table in all three directions individually and simultaneously and actuation of Earthquake Relay was observed. Block diagram of the test setup for all functional and qualification tests are as shown in Figure 2.

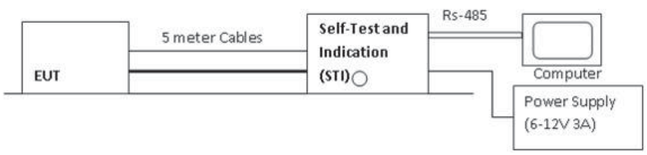

Fig. 2: Test Setup for Seismic Switch.

Seismic Qualification test (Five times Tarapur Spectra with 0.4g PGA on Shake Table) was carried out on the shake table (Figure 3). Visual inspection after the test was carried out and observed that mechanical integrity of the Seismic Switch is intact after the tests.

Seismic switch is designed as a safety critical system for Indian nuclear reactors, which is intended to reliably generate a trip signal to the reactor in the event of an earthquake beyond site specific threshold level. Care has been taken in selection of individual components to have high reliability. Hardware reliability analysis of the Seismic Switch designs have been analyzed as per MIL HDBK 217 PLUS and found to have MTBF values above 75 Years.

Also, it has to avoid generating spurious trips to meet the relevant standards. This requirement is largely addressed by having 2/3 logic in the nuclear installations. In order to qualify for the nuclear reactor use it has to undergo various qualification tests such as environmental (EMI/EMC and Vibration) and climatic (damp heat, dry heat and temperature cycling) tests. Severity levels of various tests are chosen depending on the operating envelop of the seismic switch installations. Possible Disturbance Sources considered are Lightning, switching inductive loads, arcing, welding, mobile phones, walkie-talkie, voltage sag from starting a large motor, equipment failure, relay actuation (arcing) and cable crosstalk.

CONCLUSION

Seismic Switches are required to trip the Nuclear reactor in case of a Seismic event beyond a threshold level specific to the site. Seismic Switches come under reactor protection system (Class-IA) and it is required to have features such as on-line testability, fail safe and calibration methods. Two different designs (Digital and Analog) were designed, developed and tested on a Shake table.

Seismic Switch (analog) is exempted from Software Verification and Validation (V&V). Components used in the systems was carefully chosen for high reliability and has MTBF of above 75 years as per MIL HDBK 217 PLUS. Functional and Seismic qualification tests were conducted and observed satisfactory performance of these systems. Environmental qualifications tests were selected as per the

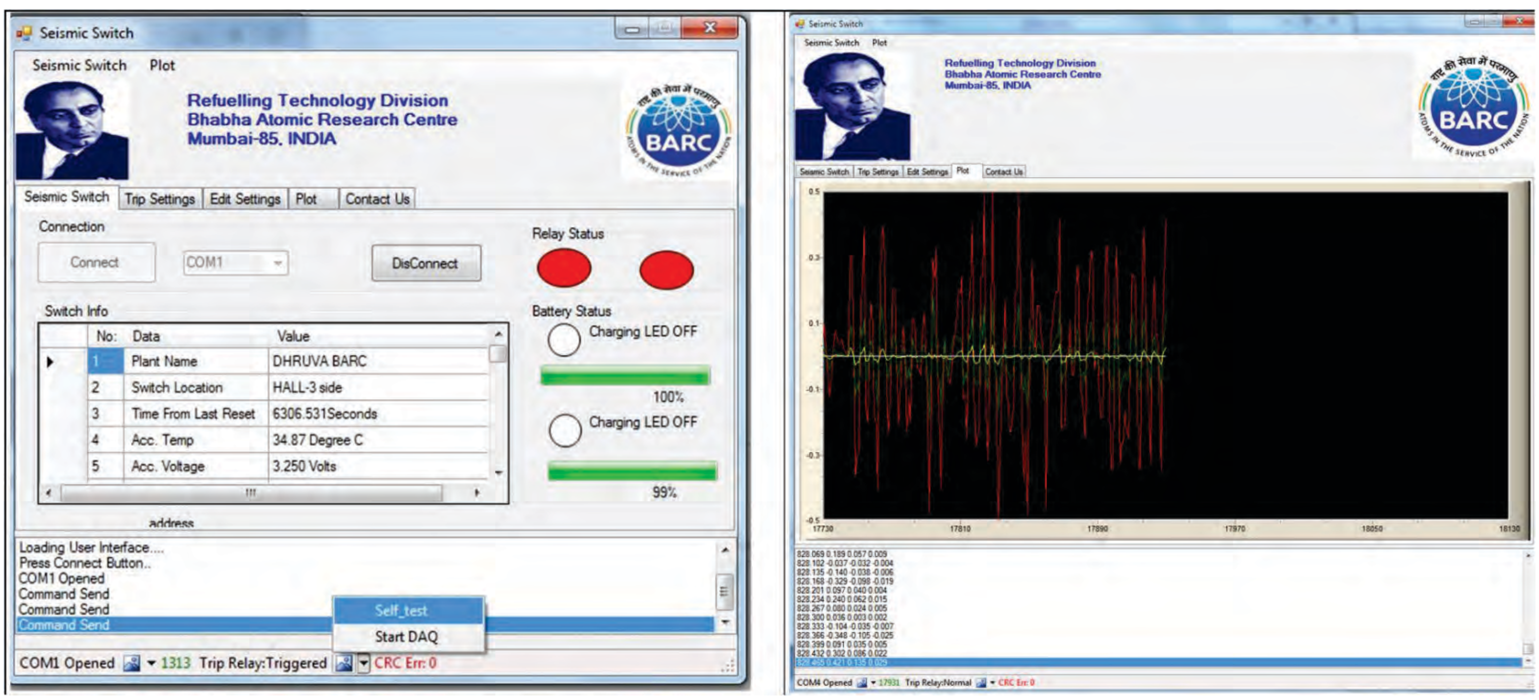

Fig. 3: GUI of the Seismic Switch captured during Seismic qualification testing of the Seismic Switch

operating environment of Seismic Switches. Test setup and procedures have been laid out.

These technologies are currently available for technology transfer and details are published in BARC website.

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