JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE	Jaipur Engineering college and research centre, Shri Ram ki Nangal, via Sitapura RIICO Jaipur-302 022.	Academic year-2020-21

DEPARTMENT OF ELECTRICAL ENGINEERING

Syllabus
Power System Protection

III Year - VI Semester: B. Tech. (Electrical Engineering)

1. Introduction: Objective, scope and outcome of the course.

2. Introduction and Components of a Protection System: Principles of Power System Protection, Relays, Instrument transformers, Circuit Breakers.

3. Faults and Over-Current Protection: Review of Fault Analysis, Sequence Networks. Introduction to over current Protection and over current relay co-ordination.

4. Equipment Protection Schemes: Directional, Distance, Differential protection. Transformer and Generator protection. Bus bar Protection, Bus Bar arrangement schemes.

5. Digital Protection: Computer-aided protection, Fourier analysis and estimation of Phasors from DFT. Sampling, aliasing issues.

6. Modeling and Simulation of Protection Schemes: CT/PT modeling and standards, Simulation of transients using Electro-Magnetic Transients (EMT) programs. Relay Testing.

7. System Protection: Effect of Power Swings on Distance Relaying. System Protection Schemes. Under-frequency, under-voltage and df/dt relays, Out-of- step protection, Synchro-phasors, Phasor Measurement Units and Wide-Area Measurement Systems (WAMS). Application of WAMS for improving protection systems.

Power System Protection

UNIT-VI

Modeling and Simulation of Protection Schemes:

The modeling and simulation of Protection Schemes testing and verification of protection devices and arrangements introduces a number of issues. This happens because the main function of protection devices isrelated to operation under fault conditions so these devices cannot be tested under normal operating conditions. This problem is worsened by the growing complexity of protection arrangements, application of protection relays with extensive software functionalities, and frequently used Ethernet peer-to-peer logic. The testing and verification of relay protection devices can be divided into four groups:

- Routine factory production tests
- Type tests
- Commissioning tests
- Occasional maintenance tests

TYPE TESTS

Type tests are needed to prove that a protection relay meets the claimed specification and follows all relevant standards. Since the basic function of a protection relay is to correctly function under abnormal power conditions, it is crucial that the operation is evaluated under such conditions. Therefore, complex type tests simulating the working conditions are completed while products intended for installation with the requirements. Since type testing of a digital or numerical protection relay includes software and hardware testing, the type testing procedure is very complex and more challenging than a static or electromechanical relay.

ROUTINE FACTORY PRODUCTION TESTS

These tests are done to show that protection relays are free from defects during manufacturing process. Testing will be done at several stages during manufacture, to make sure problems are discovered at the earliest possible time and therefore minimize remedial work. The testing extent will be impacted by the relay complexityand past manufacturing experience.

COMMISSIONING TESTS

Commissioning tests are done to show that a particular protection configuration has been correctly used prior to setting to work. All aspects of the configuration are thoroughly verified, from installation of the correct equipment through wiring verifications and operation checks of the equipment individual items, finishing with testing of the complete configuration.

PERIODIC MAINTENANCE VERIFICATIONS

These are needed to discover equipment failures and service degradation, so that corrective action can be taken. Because a protection configuration only works under fault conditions, defects may not be discovered for a substantial period of time, until a fault happens. Regular testing assists in discovering faults that would otherwise stay undetected until a fault happens.

FUNCTIONAL TESTS

When a modern numerical protection relay with many functions is assessed, each of which has to be type-tested, the functional type-testing involved is significant issue. In the case of a recent relay development project, it was found that if one person had to complete all the work, it would take 4 years to write the functional type-test specifications, 30 years to complete the tests and several years to write the test reports. Automated processes and equipment are clearly needed.

RATING TESTS

Rating type tests are completed to make sure that components are used within their defined ratings and that there is no fire or electric shock hazards under a normal load or fault conditions. Also, this is done along with verification that the product follows itstechnical specification.

THERMAL WITHSTAND TESTS

The thermal withstand of VTs, CTs and output contact circuits are done to ensure compliance with the defined continuous and short-term overload conditions. In addition to functional check, the pass criterion is that there is no damaging effect on the relay assembly, or circuit elements, when the product is exposed to overload conditions that may be expected. Thermal withstand is evaluated over a time period of 1s for CTs and 10s for VTs.

RELAY BURDEN TEST

The auxiliary supply burdens, optically isolated inputs, VTs and CTs are measured to determine that the product complies with its specification. The burden of products with a big number of input/output circuits is application specific i.e. it increases according to the number of optically isolated input and output contact ports which are energized under normal power system load conditions. It is typically believed that not more than 50% of these ports will be simultaneously energized in any installation.

RELAY INPUTS

Relay inputs are verified over the specified ranges. Inputs include those for auxiliary voltage, VT, CT, frequency, optically isolated digital inputs and communication elements.

RELAY OUTPUT CONTACTS

Protection relay output contacts are type tested to make sure that they follow product specification. Special withstand and endurance type tests have to be completed using DC, since the normal supply is via a station battery.

ELECTROMAGNETIC COMPATIBILITY TESTS

There are different tests that are completed to check the ability of protection relays to withstand the electrical environment in which they are put. The substation environment is a very severe environment in terms of the electrical and electromagnetic interference that can happen. There are many sources of interference within a substation, some developing internally, others being conducted along the transmission lines or cables into the substation from external disturbances. The most typical sources are:

- system faults
- switching operations
- conductor flashover
- lightning strikes
- telecommunication operations e.g. mobile phones

A whole suite of tests are completed to simulate these types of interference, and they fall under the broad umbrella of what is known as EMC or Electromagnetic Compatibility tests. Broadly speaking, EMC can be specified as: 'The ability of various devices to co-exist in the same electromagnetic environment'. This is not a new topic and has been examined by the military ever since the advent of electronic equipment. EMC can cause severe problems, and does need to be considered when making electronic equipment. EMC tests check the impact on the protection relay under test of high-frequency electrical disturbances. Protection relays produced or intended for application in the EU have to follow Directive 2004/108/EC. To accomplish this, in addition to designing for statutory compliance to this Directive, the following range oftests is completed:

- DC interrupt test
- fast transient test
- AC ripple on DC supply test
- high frequency disturbance test

- DC ramp test
- power frequency interference test
- surge immunity test
- conducted and radiated emissions tests
- electrostatic discharge test
- magnetic field tests
- conducted and radiated immunity tests

D.C INTERRUPT TEST

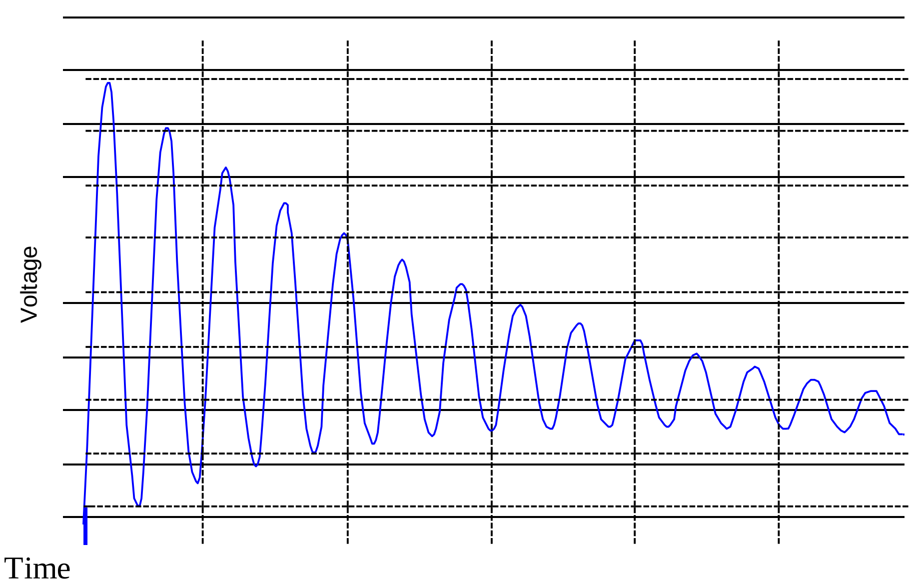
This is a test to check the maximum length of time that the protection relay can withstand an interruption in the auxiliary supply without de-energizing, e.g. switchingoff, and that when this time is surpassed and it does transiently switch off, that no mal operation happens. It models the impact of a loose fuse in the battery circuit, or ashort circuit in the common DC supply, interrupted by a fuse. Another DC interruption source is if there is a power system fault and the battery is powering both the protection relay and the circuit breaker trip coils. When the battery energizes the coils to start the circuit breaker trip, the voltage may decrease below the needed level for operation of the protection relay. For interruptions lasting up to and including 20ms, the protection relay must not de-energize of mal operate, while for longer interruptions it must not mal operate. Many modern devices are capable of staying energized for interruptions up to 50ms.The protection relay is supplied from a battery supply, and both short circuit and open circuit interruptions are completed. Each interruption is applied 10 times, and for auxiliary power supplies with a big operating range, the tests are completed at minimum, maximum, and other voltages across this range, to check compliance overthe complete range.

D.C. RAMP DOWN/RAMP UP TEST

This test models a failed station battery charger, which would end in the auxiliary voltage to the relay slowly ramping down. The ramp up part models the battery being recharged after discharging. The protection relay must cleanly power up when the voltage is applied and not mal operate.

HIGH FREQUENCY DISTURBANCE TEST

The high frequency disturbance test models high voltage transients that result from power system faults and plant switching operations. It comprises a 1MHz decaying sinusoidal waveform, as the interference is applied across each independent circuit (differential mode) and between each independent circuit and ground (common mode) via an external coupling and switching network. The product is energized in both normal (quiescent) and tripped modes, and must not mal operate when the interference is applied for 2 seconds.



POWER FREQUENCY INTERFERENCE TEST

This test models the interference type that is caused when there is a power system fault and very high levels of fault current flow in the primary conductors or the ground grid. This creates 50 or 60Hz interference in control and communications circuits.

Tests are completed on each circuit, with the protection relay in the following operation modes:

- current and voltage applied at 110% of setting, (relay tripped)
- current and voltage applied at 90% of setting, (relay not tripped)
- main protection and communications functions are verified to check the interference effect. The protection relay shall not mal operate during the test, and shall still complete its main functions within the claimed tolerance.

CONDUCTED AND RADIATED EMISSIONS TESTS

These tests come up from the basic protection demands of the EU directive on EMC. These demand that manufacturers ensure that any equipment must not interfere with other equipment. To accomplish this it is necessary to evaluate the emissions from the equipment and check that they are below the prescribed limits. Conducted emissions are evaluated only from the equipment's power supply ports and are to ensure that when connected to a mains network, the equipment does not send interference back into the network which could affect the other equipment installed in the network. Radiated emissions measurements are to make sure that the interference emitted from the equipment is not at a level that could cause interference to other devices.

CONDUCTED AND RADIATED IMMUNITY TESTS

These tests are done to make sure that the equipment is immune to interference levels that it may be exposed to. The two tests, conducted and radiated, come up from the fact that for a conductor to be an efficient antenna, it must have a length of at least ¼ of the wavelength of the electromagnetic wave it is required to transfer. Even with all the cabling attached andwith the longest PCB track length taken into consideration, it would be highly unlikelythat the protection relay would be able to transfer radiation of this frequency.

Hence, the test would have no effect. The interference has to be physically introduced by conduction, therefore the conducted immunity test. Nevertheless, at the radiated immunity lower frequency limit of 80MHz, a conductor length of roughly 1.0m is needed. At this frequency, radiated immunity tests can be completed with the confidence that the protection relay will transfer this interference, through a combination of the attached cabling and the PCB tracks. Even though the test standards state that all 6 faces of the equipment should be exposed to the interference, in reality this is not done. Applying interference to the sides and top and bottom of the protection relay would have little effect as the circuitry inside is effectively screened by the grounded metal case. Nevertheless, the front and rear of the protection relay are not totally enclosed by metal and are therefore not at all well screened, and can be regarded as an EMC hole. Electromagnetic interference when directed at the front and back of the protection relay can freely enter onto the PCBs inside. When completing these two tests, the protection relay is in a quiescent condition, that is not tripped, with currents and voltages applied at 90% of the setting values. This is because for the majority of its life, the protection relay will be in the quiescent state and the coincidence of an electromagnetic disturbance and a fault is believed to be unlikely. Nevertheless, spot checks are completed at chosen frequencies when the main protection and control functions of the protection relay are exercised, to make sure that it will function as expected, should it be needed to do so. The frequencies for the spot verifications are chosen to coincide with the radio frequency broadcast bands, and the frequencies of mobile communications devices used by staff working in the substation. This is to make sure that when working in the vicinity of a protection relay, the staff should be able to operate their radios/mobile phones without fear of protection relay mal operation.

INSULATION WITHSTAND FOR OVERVOLTAGES

The objective of the high voltage impulse withstand type test is to make sure that circuits and their elements will withstand over-voltages on the power system created by lightning. Three positive and three negative high voltage impulses, 5kV peak, are applied between all circuits and the case ground and also between the terminals of independent circuits.

SINGLE FAULT CONDITION EVALUATION

Verification is done to understand if a single fault condition such as an overload, or an open or short circuit, applied to the equipment may cause an electric shock or fire hazard. In the case of uncertainty, type testing is completed to make sure that the product is safe.

ENVIRONMENTAL TYPE TESTS

Different tests have to be completed to show that a protection relay can withstand the environment effects in which it is expected to operate. They consist of the following tests:

- Humidity
- Temperature
- mechanical
- enclosure protection

These tests are discussed in the following paragraphs.

TEMPERATURE TEST

Temperature tests are completed to make sure that a product can withstand extremes in temperatures, both hot and cold, during transit, storage and operating conditions. Storage and transit conditions are specified as a temperature range of –25°C to +70°C and operating as –25°C to +55°C. Many products now claim operating temperatures of +70°C or even higher. Dry heat withstand tests are done at 70°C for 96 hours with the protection relay de-energized. Cold withstand tests are completed at –40°C for 96 hours with the protection relay de-energized. Operating range tests are completed with the product energized, verifying that all main functions operate within tolerance over the defined working temperature range –25°C to +55°C.

HUMIDITY TEST

The humidity test is completed to make sure that the product will withstand and correctly function when exposed to 93% relative humidity at a constant temperature of 40°C for 56 days. Tests are completed to make sure that the product operates correctly within specification after 21 and 56 days. After the test, visual verificationsare done for any signs of unacceptable corrosion.

MECHANICAL TESTS

Mechanical tests model a number of various mechanical circumstances that the product may have to withstand during its lifetime. These fall into two groups:

- disturbances response while energized
- disturbances response during transportation (de-energized state)

Tests in the first category are related with the vibration response, shock and seismic disturbance. The tests model typical in-service conditions for the product. These tests are completed in all three axes, with the product energized in its normal (quiescent) state. During the test, all output contacts are supervised for change using contact follower circuits. Vibration levels of 1g, over a 10Hz-150Hz frequency sweep are applied. Seismic tests use excitation in a single axis, using a 35Hz test frequency and peak displacements of 7.5mm and 3.5mm in the x and y axes respectively below the crossover frequency.

SOFTWARE/HARDWARE INTEGRATION TESTING

Software/hardware integration testing is completed in the target environment, i.e. it applies the actual target hardware, operating system, drivers etc. It is typically completed after software/software integration testing. Testing the interfaces to the hardware is crucial feature of software/hardware integration testing. Test cases for integration testing are usually based on those defined for validation testing. Nevertheless, the focus should be on spotting errors and problems. Completing a dry run of the validation testing usually completes integration testing.

VALIDATION TESTING

The purpose of validation testing (also known as software acceptance testing) is to check that the software meets its defined functional requirements. Validation testing is completed against the software requirements, using the target environment. In ideal conditions, someone independent of the software development completes the tests.In the case of high-integrity and/or safety critical software, this independence is crucial. Validation testing is ‘black box’ in nature. It does not consider the internal software structure. For protection relays, the non-protection functions included in the software are regarded as important as the protection functions. Therefore, they are tested in the same manner. Each validation test should have predefined evaluation criteria that can be used to decide if the test has passed or failed. The assessment criteria shouldbe explicit with no room for interpretation or ambiguity.

SIMULATION HARDWARE

Equipment can now provide high-speed, highly precise power system modeling. The equipment is based on distributed digital hardware under the control of real time software models. Typical equipment is presented in Figure 11. The modules have outputs connected to current and voltage sources that have a similar transient capability and have adequate output levels for direct connection to the protection relay inputs. Inputs are also provided to supervise the protection relay response (contact closures for tripping, etc.) and these inputs can be used as part of the power system model. The software can also accurately model the dynamic response of CTs and VTs. The digital simulator can also be digitally linked to the protection relay(s).

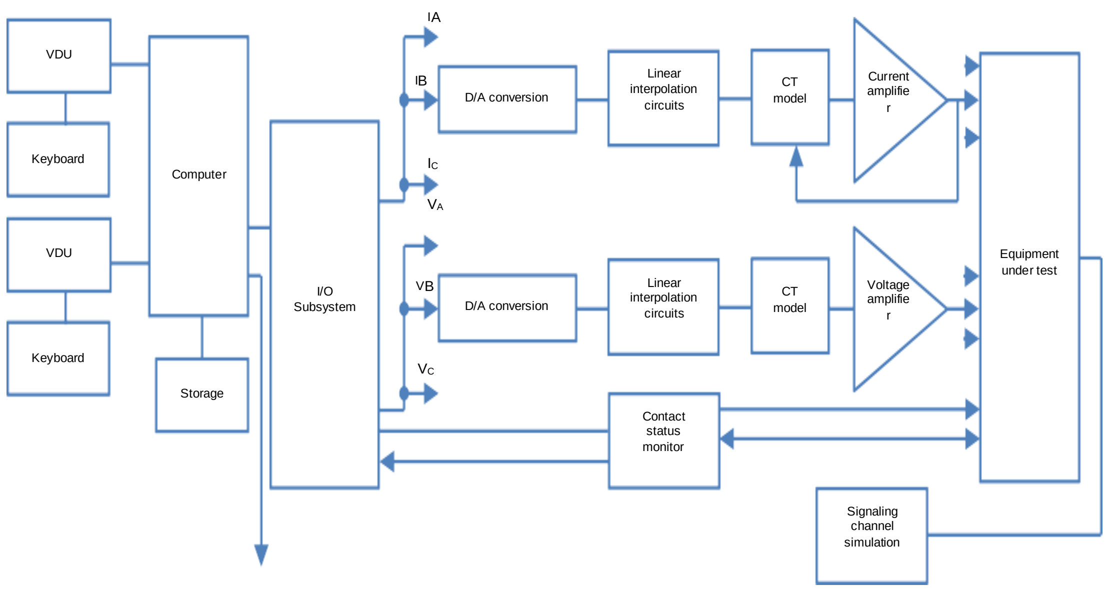
This approach introduces many benefits over traditional test devices:

- the power system model is capable of reproducing high frequency transients such as travelling waves
- saturation effects in CTs and VTs can be simulated
- it is not impacted by the harmonic content, noise and frequency changes in the AC supply
- tests involving very long time constants can be completed
- a set of test routines can be defined in software and then left to run unattended (or with only frequent supervision) to completion, with a comprehensive record

of test results.

- it is capable of representing the change in the current related with generator faults and power swings

A block diagram of the equipment is presented It is based around a computer which computes and stores the digital information representing the system voltages and currents. The computer controls conversion of the digital information into analogue signals, and it supervises and controls the protection relays.



SIMULATION SOFTWARE

Unlike most conventional software used for power systems assessment, the used software is suitable for the fast transients modeling. These transients happen in the first few milliseconds after fault inception. Two very precise simulation programs areapplied, one based on time domain and the other on frequency domain methods. Inboth programs, single and double circuit transmission lines are modeled by fully distributed parameter models. The transmission line parameters are computed from the physical construction of the line, taking into consideration the effect of conductor geometry, conductor internal impedance and the ground return path. It also includes the line parameter frequency dependence in the frequency domain program. The frequency dependent variable effects are computed using Fast Fourier Transforms. Obtained results are converted to the time domain. Conventional current transformers and capacitor voltage transformers can be modeled. The fault can be applied at any system point and can be any combination of line to line or line to ground, resistive, or non-linear phase to ground arcing faults. For series compensated transmission lines, flashover across a series capacitor following a short circuit fault can be modeled. The frequency domain model is not adequate for developing faults and switching sequences. Hence, the widely used Electromagnetic Transient Program (EMTP), working in the time domain, is used in such situations. In addition to these two programs, a simulation program based on lumped resistance and inductance parameters is used. This simulation is used to model systems with long time constants and slow system changes such as power swings.

SIMULATOR APPLICATIONS

The simulator is used for verifying the calibration accuracy and completing type tests on a wide range of protection relays during their development. It has the following benefits over existing test methods:

- 'state of the art' power system modeling information can be used to test protection relays

- freedom from frequency changes and noise or harmonic content of the laboratory's own domestic supply
- chosen harmonics may be laid over the power frequency
- all tests are precisely repeatable
- the protection relay under test does not burden the power system
- wide bandwidth signals can be generated
- a wide range of frequencies can be reproduced
- reproduces fault currents whose peak amplitude changes with time
- transducer models can be included
- two such devices can be linked together to model a system with two relaying points
- the use of direct coupled current amplifiers allows time constants of any length
- capable of simulating slow system changes
- automatic testing removes the likelihood of measurement and setting errors

The simulator is also used for the relay production testing, in which most of the benefits mentioned above apply. As the tests and measurements are done automatically, the testing quality is also highly improved. Also, in situations of suspected relay malfunction under known fault conditions, the simulator can be used to replicate the power system and fault conditions, and complete a comprehensive investigation about relay performance. Finally, complex protection configurations can be simulated, using

both the protection relays intended for use and software models as appropriate for any insulation deterioration. The measured insulation resistance depends on the amount of wiring,its grade, and the site humidity.