Substations - Volume XI: Relaying

An Online Continuing Education Course for Engineers

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Substations - Volume XI: Relaying

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Preface

This course is one of a series of thirteen courses on the design of electrical substations. The courses do not necessarily have to be taken in order and, for the most part, are stand-alone courses. The following is a brief description of each course.

Volume I, Design Parameters. Covers the general design considerations, documents and drawings related to designing a substation.

Volume II, Physical Layout. Covers the layout considerations, bus configurations, and electrical clearances.

Volume III, Conductors and Bus Design. Covers bare conductors, rigid and strain bus design.

Volume IV, Power Transformers. Covers the application and relevant specifications related to power transformers and mobile transformers.

Volume V, Circuit Interrupting Devices. Covers the specifications and application of power circuit breakers, metal-clad switchgear and electronic reclosers.

Volume VI, Voltage Regulators and Capacitors. Covers the general operation and specification of voltage regulators and capacitors.

Volume VII, Other Major Equipment. Covers switch, arrestor, and instrument transformer specification and application.

Volume VIII, Site and Foundation Design. Covers general issues related to site design, foundation design and control house design.

Volume IX, Substation Structures. Covers the design of bus support structures and connectors.

Volume X, Grounding. Covers the design of the ground grid for safety and proper operation.

Volume XI, Protective Relaying. Covers relay types, schemes, and instrumentation.

Volume XII, Auxiliary Systems. Covers AC & DC systems, automation, and communications.

Volume XIII, Insulated Cable and Raceways. Covers the specifications and application of electrical cable.

Chapter 1: Protective Relaying Overview

Protective relays are used to detect defective lines or apparatus and to initiate the operation of circuit-interrupting devices to isolate the defective equipment. Relays are also used to detect abnormal or undesirable operating conditions other than those caused by defective equipment and either operate an alarm or initiate operation of circuit-interrupting devices. Protective relays protect the electrical system by causing the defective apparatus or lines to be disconnected to minimize damage and maintain service continuity to the rest of the system.

The design objectives of a protective relaying are to minimize the effects of a system disturbance and to minimize the possible damage to power system equipment. A good protective relaying system will address dependability, security, speed, and simplicity.

Dependability is the certainty of correct operation in response to system troubles. Dependability includes the reliable operation of the relay system operating when it is supposed to and selectivity of the relay system operating to isolate the minimum amount of the system necessary to provide continuity of service. *Security* is the ability to avoid misoperations between faults. Every relay system has to be designed to either operate or not operate selectively with other systems. *Speed* means clearing all faults in the shortest possible time with all due regard to dependability and security. A relaying system should be no more complex than is required for any given application. Adding more equipment into a scheme than is necessary for good coverage adds to the possibility of equipment failure and misoperation.

A *short circuit* is an abnormal connection of relatively low resistance between two or more points of differing potential in a circuit. If one of these points is at ground potential, it is referred to as a *ground fault*. If ground potential is not involved, it is referred to as a *phase fault*. Phase faults cause excessive currents and low voltages. Ground faults may or may not cause excessive currents or abnormal voltages, depending on whether the system is normally ungrounded, high- or low-resistance grounded, or effectively grounded.

A few of the abnormal system conditions that occur in electrical substations include,

- Excessive Heating
- Overvoltage
- Undervoltage
- Unbalanced Phase Conditions

- Reverse Phase Rotation
- Abnormal Frequency
- Overspeed
- Abnormal Pressure
- Abnormal Impedance
- Out-of-Step Conditions
- Excessive System Phase Angles

Below is a brief discussion of each of these conditions.

Equipment is designed to deliver full-rated capacity with the temperature maintained below a value that will not be damaging to the equipment. If operating temperature becomes excessive, the life of the equipment (generator, motor, transformer, etc.,) will be reduced. Excessive heating may be caused by overloading, high ambient temperatures, improper cooling, or failure of cooling equipment.

Equipment is designed for normal operating voltages as stated on its nameplate with a slight allowance (usually about 5 percent) for normal overvoltage. *Abnormal overvoltage* may cause:

- Insulation failure
- Shortening of the equipment life
- Excessive heating as a result of greatly increased excitation currents where electromagnetic devices are used
- Excessive heating in resistors used in controls
- Failure of transistors and other electronic devices

Continued *under-voltage* will likely cause overheating of motors and dropping out of contactors, and lead to the failure of electrical equipment.

On balanced three-phase systems with balanced three-phase loads, a sudden unbalance in the current or the voltages usually indicates an open or a partially shorted phase. An unbalanced voltage condition is especially serious for three-phase motors because negative sequence currents can lead to considerable overheating within the motor. On balanced three-phase systems with single-phase loads, the loading on each phase may normally vary, depending on the magnitude of each single-phase load. However, it is desirable to keep this unbalance to a minimum to maintain balanced voltages for three-phase loads. Unbalanced conditions, which include single-phase and double-phase faults with or without ground, can be detected with the use of negative and zero sequence relay elements.

Reversed phase rotation can occur after circuit changes have been made or during an open phase condition. Reversed rotation of motors may cause considerable damage to the facility driven by the motors, such as a conveyor.

Abnormal frequencies can occur when the load does not equal the generation. The frequency may be above or below the system normal frequency. Many facilities such as electric clocks, synchronous motors, etc., are frequency sensitive.

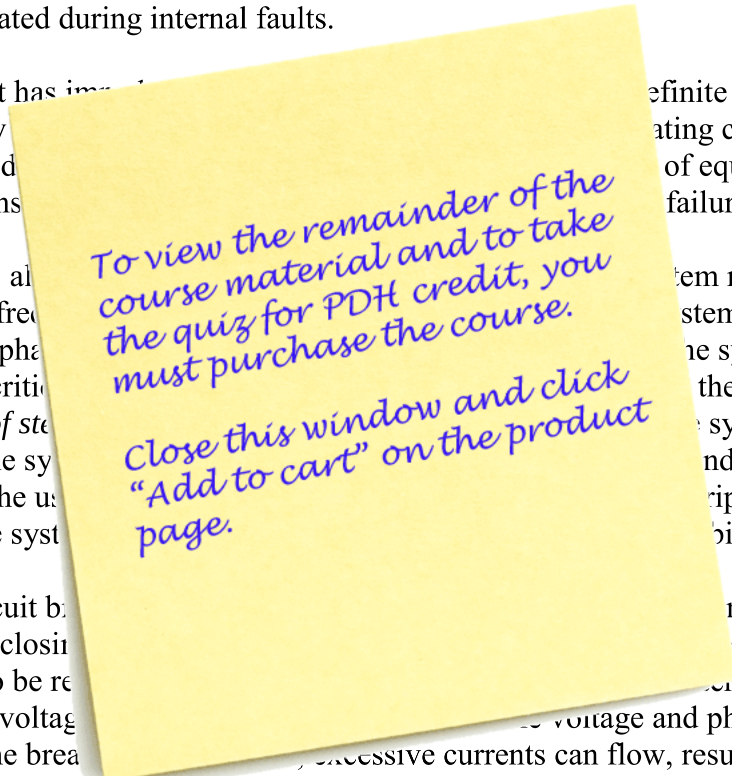
Considerable mechanical damage can be done to generators and motors because of over-speed. Excessive over-speed may cause parts of the generator or motor to be thrown for considerable distances, which is dangerous to personnel as well as to other facilities. Generators or series-connected motors may reach dangerous over-speeds when loads are suddenly removed.

In electrical equipment, such as transformers, that use liquid as an insulating fluid, high internal pressures can be created during internal faults.

Electrical equipment has im… …efinite known values or values that may vary … …ating conditions. These values are normally d… …of equipment. Substantial deviations … …failure of the equipment.

In the United States, al… …tem rotate at an RPM to maintain a 60 hertz fre… …stem maintains a relative position, or pha… …he system. Once a machine exceeds a criti… …the system. It is said to have moved *out of ste*… …system and resynchronized to the sy… …nditions are typically monitored through the us… …rip of breakers in order to segment the syst… …bility studies.

The closing of a circuit b… …n either side of the circuit breaker. The closi… …e and phase angle across the breaker to be re… …m to the other to equalize the system voltag… …oltage and phase angle differences across the brea… …excessive currents can flow, resulting in a disturbance to the system, possibly damaging the breaker or adjacent rotating equipment. Typically, the voltage and phase angle across the breaker are compared to confirm the systems are within proper limits before the breaker is closed.



Fundamental Considerations

A *phasor* is a complex number used to represent electrical quantities. In protective relaying systems, phasors are used to aid in applying and connecting relays and for analysis of relay operations after faults. Phasor diagrams have to be accompanied by a circuit diagram. The phasor diagram shows the magnitude and relative phase angle of the currents and voltages, while the circuit diagram shows the location, direction, and polarity of the currents and voltages.

The relative *polarities* of a current transformer's primary and secondary terminals are identified either by painted polarity marks or by the symbols "H1" and "H2" for the primary terminals and "X1" and "X2" for the secondary terminals. The convention is that, when primary current enters