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Modern Substation Design

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Abstract

A Modern Substation equipped with enhanced safety features, accurate and precision measurements, and fast protection relays is the need of the hour for the fast developing India. In coming decade, the power sector in India is destined to witness a growth of many folds. As substations are the back bone of electrical power system, we shall be direly in need of substations equipped with sophisticated equipments adorned with latest technology in coming years. In recent years Electrical Engineers and Technologists have put in lots of effort to develop new technologies to replace old-fashioned and slow acting equipments requiring abundance of space in installing a substation. In this paper, I elaborate my contribution in designing and developing a Modern Substation.

1. Introduction

A substation comprises of two types of equipments: Primary Equipments, and Secondary Equipments. The Primary Equipments consists of Transformers, Circuit Breakers, and Instrument Transformers. Whereas, the Secondary Equipments include Measurement, Display, Communication, Protection, and Control devices. A Modern Substation should incorporate state of the art information, automation and interactive characteristics.

In order to realize digitized substation information, networking communication platform and standardized information sharing, a modern substation must use the advanced, reliable, integrated, low-carbon and environmentally friendly intelligent equipments to automatically achieve information collection, measurement, control, protection, metering, monitoring and other basic functions. The Transformer, a key primary element must possess intelligent features. It should occupy less space than the older ones. In modern substation, a transformer is protected from impulse, surge voltage by metal oxide surge arresters. The On Load Tap Changing feature is controlled automatically by a microprocessor based controller. The temperature of winding and oil is measured online by sensors. Temperature is controlled by digital temperature controller by switching ON/OFF the cooling fans. Dissolved gas analyzer is used to generate alarm in case of any dissolved gas is detected in the transformer oil. Nitrogen fire detection and protection system is provided to safeguard transformer against any fire hazard.

Gas Insulated Switchgear using SF-6 gas is used in modern substation. GIS requires less space even for higher rating and extra high voltage isolation and interruption. It also protects its internal accessories from environmental impact. It facilitates remote observation, operation, and control. Current transformers (CTs), Potential Transformers (PTs) or Voltage Transformers (VTs), also called instrument transformers, are used to measure current and voltage signals.

A current transformer (CT) produces a reduced current at the secondary side proportional to the current in the primary circuit, which can be used to conveniently connect measuring and recording instruments. A current transformer also galvanically isolates the measuring instruments. The current/voltage transformer is one of the most important interfacing sensors for measurement and relay protection subsystem. Traditional current/voltage transformer, which is still widely used in power system, is based on magnetic circuits. This may create series of problems such as measured signal bandwidth limitation, magnetic saturation, etc.

A Modern substation needs to overcome these challenges and use Gas Insulated CT (PT), Oil-minimum current transformers, Magneto-Optic Current Transformer, optical CT and PT, etc. The Secondary equipments, which should include a Substation Automation System, support a series of advanced functions such as sequence control, intelligent alarm, fast protection relays, analysis, and report generation. Compared with traditional substations, a modern substation achieves the intelligent management of substation equipments by advanced data analysis processing methods based on advanced automation technologies. The integration of primary and secondary equipments is realized through intelligently reforming traditional primary equipments with electronic instrument transformers and condition-based monitoring technologies. Key equipments such as transformers and switches with intelligence components are to achieve the integration of condition-based monitoring, measurement, protection, control and other functions.

2. Site Considerations

Suitable site selection is one of the most critical factors in the design of a substation. Otherwise, it may result in excessive investment in the number of substations and associated transmission and distribution facilities. Following factors should be evaluated when selecting a substation site:

- Location of present and future load center.
- Location of existing and future sources of power.
- Availability of suitable right-of-way and access to site by overhead or underground transmission and distribution circuits .
- Location of existing distribution lines .
- Nearness to all-weather highway and railroad siding, accessibility to heavy

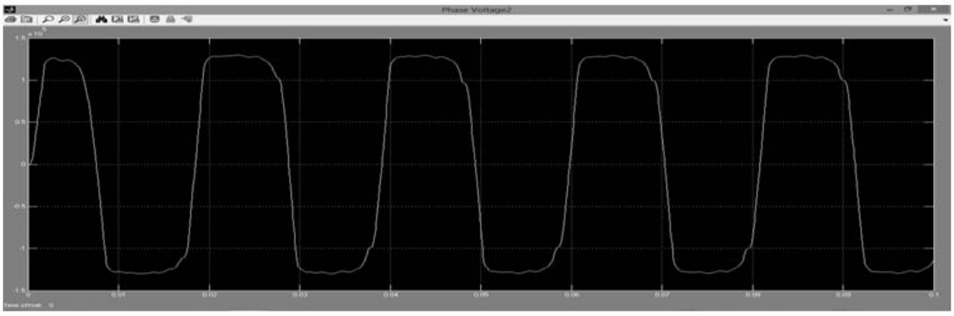
equipment under all weather conditions, and access roads into the site.
- Soil resistivity.
- Space for future expansion.

3. Safety Considerations

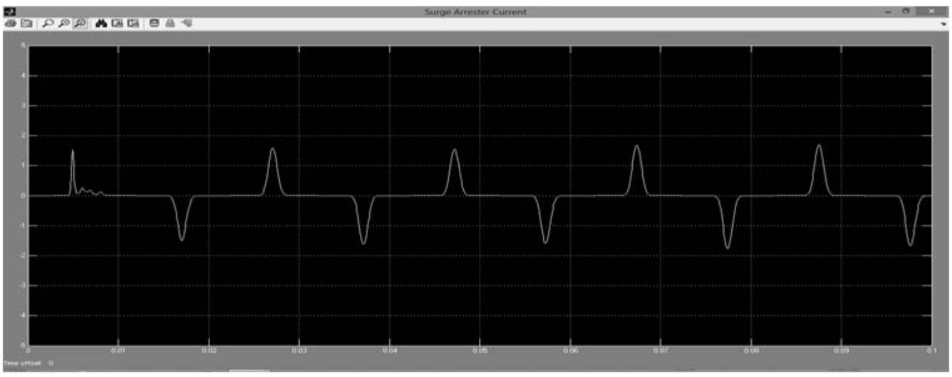
A substation should be safe for the general public and for operating and maintenance personnel. Practical approaches include the employment and training of qualified personnel, appropriate working rules and procedures, proper design, and correct construction. The safeguarding of equipment also needs to be considered in a substation design.

4. Direct Stroke Protection and Surge Protection

The effect of a direct lightning stroke on a substation may prove devastating. Hence, a substation should be designed keeping in mind protecting its equipments from direct lightening stroke. Direct stroke protection normally consists of shielding the substation equipment by using lightning masts, overhead shield wires, or a combination of these devices. The Protection against impulse voltage and surge voltage is provided by surge arresters. The types and arrangements of protective schemes used are based on the size and configuration of the substation equipment.



Substation Incomer Voltage – Impact of Surge Arrester



Surge Arrester Current during Surge Voltage

5. Primary Equipment

A modern substation should have primary equipments that possess some intelligence. Their status can be observed from a remotely located control room with the help of sophisticated measuring and communication means. Advanced sensor technology and condition-based monitoring technology are used to impart intelligent features to the primary equipments.

Through inside or outside monitoring sensors, the condition-based monitoring technologies can achieve the condition monitoring and visualization of important primary equipments, such as transformers, switchgears, lightning arresters, etc.

6. Power Transformer

The primary function of a power transformer is to transform system voltage from one nominal level to another. The transformer has to be capable of carrying the power flow for its particular location in the system under various operating conditions and contingencies. A power transformer needs some adequate means of cooling. There are various methods of transformer cooling depending upon rating and size of the transformer. The type of cooling used is based on the requirements of the specifications, the size of the transformer, and the manufacturer’s standard design. Because of their great importance and complexity, power transformers require special care in their application, specification, and procurement. A modern substation transformer should have online measurement facility for following parameters:

- Oil Temperature
- Winding Temperature
- Dissolved gas
- Inside pressure
- Oil level
- Voltage
- Current

All measured parameters are communicated to a Supervisory Control And Data Acquisition System located in a control room. SCADA provides real time monitoring, trending, report generation, and alarm generation features. The temperature of the power transformer is also remotely controlled by microprocessor based automatic controller by generating signals for turning ON/OFF the cooling fans.

6. Gas Insulated Switchgear

For a system at 33kv level and above GIS circuit breakers have become a necessity. It needs less space than required by a conventional metal clad circuit breaker. A GIS provides isolators, interrupters, earth switches, and bus bars all enclosed in SF-6 chambers having requisite gas pressure. The deterioration of equipments due to environmental impact is slowed down by the GIS. The intelligence of Gas Insulated Switchgear can be realized by additionally installing state variable sensors and intelligent components. GIS not only realizes the monitoring and control of substation operation, but also realizes the collection and processing of GIS status information. Use of GIS enhances the personnel safety at the substation. Moreover, application of intelligent components reflects the functional integration.

7. Electronic Instrument Transformer

Compared with electromagnetic instrument transformer, the advantages of electronic instrument transformer include small size, strong anti-saturation capability, good linearity, etc. Electronic instrument transformers can avoid inherent problems such as ferroresonance, insulating oil explosion, SF6 leaks, and have better economical efficiency in high voltage level through saving a lot of iron core, copper and other metal materials.

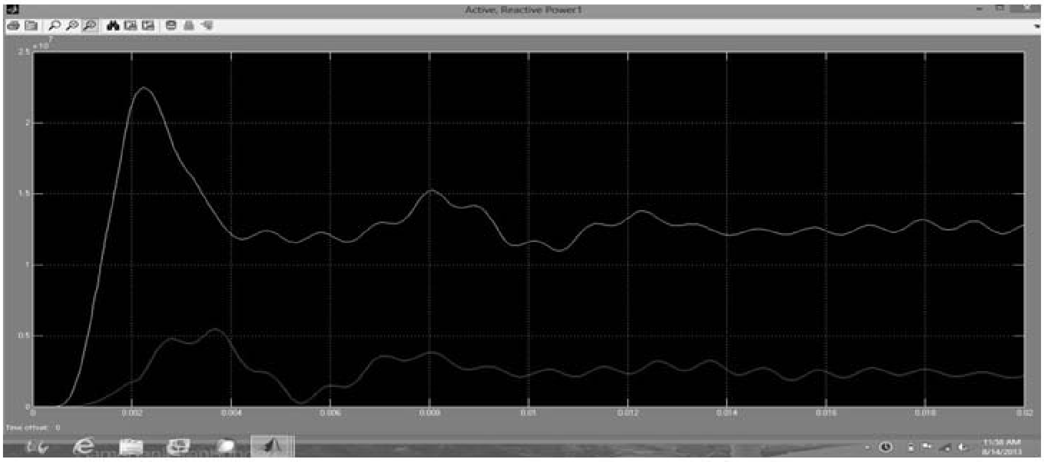
8. Substation Voltage Regulator

Substation voltage regulators are one of the primary means, along with load-tap-changing power transformers, shunt capacitors, and distribution line regulators, for maintaining a proper level of voltage at a customer's service entrance. A very important function of substation voltage regulation is to correct for supply voltage variation.

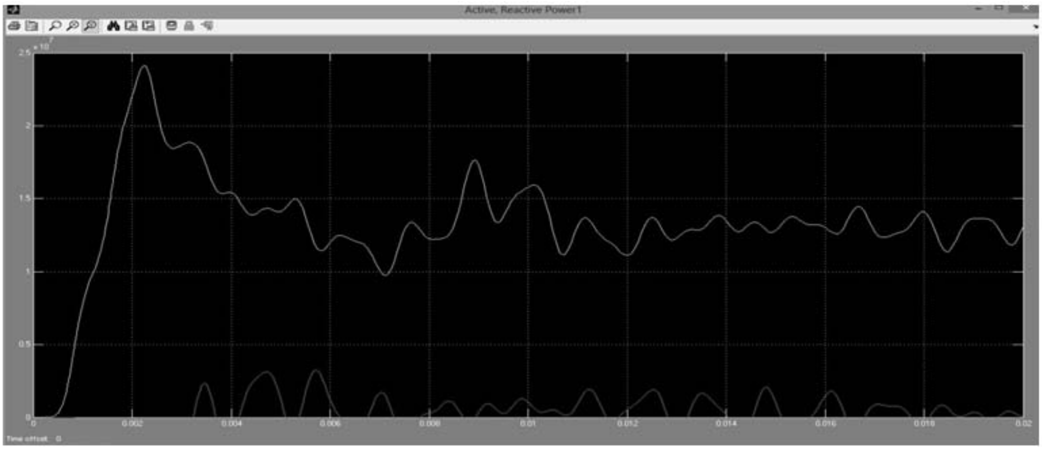
With the proper use of the control settings and line drop compensation, regulators can correct for load variations as well. A properly applied and controlled voltage regulator not only keeps the voltage at a customer's service entrance within approved limits but also minimizes the range of voltage swing between light and heavy load periods.

9. Shunt Capacitor Bank

Shunt capacitor banks at substations improve power factor and voltage conditions by supplying leading Mvars to transmission and distribution systems. A capacitor bank of a given size and voltage rating may be made up of a number of series and parallel groups. Use of capacitors with the highest possible voltage rating results in a bank design with the fewest number of series groups, which provides for the most economical design and greatest sensitivity for unbalance detection schemes. The maximum and minimum number of capacitor units in parallel per series group is limited by capacitor unit design considerations regarding permissible overvoltages and avoidance of case rupture. It is important in any capacitor installation to ensure that the maximum operating voltages do not exceed 110 percent of the rated voltage of any capacitor. Because of this, the number of parallel capacitor units in each series section is selected so that the loss of any one unit in any series section will not result in such overvoltage.



Active and Reactive Load



Reactive Power control by Capacitor Bank

10. Problems faced in Modern Substation

The integration of multiple technologies by the modern measuring, communication, control devices leads to the stability and reliability problems of equipments. Due to sensors' life being shorter than the life of primary equipments, we should further consider and research the effects of sensors embedded in devices, their performance stability, sampling accuracy in future. The stability and reliability of electronic instrument transformers needs be improved and enhanced further.

11. Protective Relaying

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 initiate 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.

12. Instruments, Transducers, and Meters

They play a very significant role in a modern substation design. An instrument is a device for sensing the magnitude of a physical quantity. It is calibrated or programmed to indicate or record this magnitude based on a known standard. The instrument may be indicating or recording. A transducer is a device that converts a physical quantity to a proportional low- level dc signal. Electrical transducers typically change amperes, watts, volts, and VARs to millivolt or milliampere signals. Transducer outputs can be used to operate local instruments or can be employed in data acquisition systems. An electric meter is a device that measures and registers the integral of an electrical quantity with respect to time. The term “meter” is also used in a general sense to designate any type of measuring device including all types of electrical measuring instruments.

13. Integrative Secondary System

Based on IEC 61850, a modern substation achieves the “ One World, One Standard” goal, unifies the communication interface for all substation devices, and realizes the interoperability and extendibility between equipments reserving interface for distributed energy source’s access.

IEC 61850 defines the basic three-layer architecture of integrative secondary system in smart substation. Three-layer consists of station layer, bay layer and process layer. Station layer network use the communication protocol based on manufacturing message specification (EMS) between station layer and bay layer. Process layer network is composed of generic object oriented substation event (GOOSE) network and sample value (SV) network. The advantage of this architecture furthest meets the information sharing leading to flexible function distribution and consumes fewer fibers. The disadvantage of this architecture is that due to protection depending on network switches and GPS, the failure of a single device could cause a wide range of protection fault. This architecture doesn’t require process layer switches, and can’t increase the range of station layer, and then has the characteristic of simplest network structure and minimum GOOSE networking model is the future development direction of a modern substation.

14. Condition-based Maintenance

Based on online monitoring technologies, the maintenance strategy of substation equipments would be changed from “periodic maintenance” manner for traditional substation into "condition-based maintenance" manner for a modern substation.

Condition-based maintenance makes equipment maintenance more scientific and feasible, and ensures safe and reliable operation of electrical equipments, and achieves immense economic and social benefits.,

15. Conclusion

In this paper, I tried my utmost to provide a guideline for new substation design and installation in coming years in India. The sum and substance of a modern substation design is to utilize new automation technologies to monitor, operate, and control the substation equipments. Besides, a modern substation should provide greater level of operational safety and better ergonomic condition to the operation and maintenance personnel. SCADA and DCS are becoming inevitable for a modern substation.

Acknowledgement

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