Power Systems Automation - The Impacts of Protective Relaying Development in Nigeria

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Abstract: *This paper analyses the impacts of protective relaying development in the Nigeria power system automation. Protective relaying has progressed from electromechanical (EMR) through solid-state (SSR) to microprocessor-based (MPB) relays.*

Analysis of substation automation in power system protections has been conducted. This is accomplished by obtaining real-time information from the system, having powerful local and remote control applications and advanced electrical protection. The core ingredients of a Substation Automation system are local intelligence, data communications and supervisory control and monitoring.

The implementation of MPB relays in substation automation, improved performance over EMRs, eliminate the need to manually read meters, and provide the utilities with more precise load data, ability to share and communicate more information over a wider area, integrate protection, and enhance sophisticated automation and control functions. Metering and measurements are automatically forwarded to central system operating offices over communication system; it also provided system operators with control of substation devices, and switching commands which could be operated remotely. It's faster, accurate and reliable protection in power substation automation.

Keywords: *Protective Relaying, SCADA, EMR, SSR, MPBs, Substation Automation, Data Communications, Human Machine Interface.*

I. Introduction

In power systems, substations play an important role in determining the stability of the grid and they execute right action as soon as possible to keep the whole grid running normally even if some faults happen. In the past, substations were usually controlled by the operators, but today it is not enough to deal with such complex functions just by the operators. Substations are always monitored and controlled to take necessary precautions accurately and timely. Owing to the development of automation technology, more automatic equipment is used in substations to bring about substation automation. IEEE standard 100-2000[1] defined supervisory control and data acquisition (SCADA) as a system operating with coded signals over communication channels so as to provide control of remote equipment. The supervisory system may be combined with a data communication channels to acquire information about the status of the remote equipment for display or for recording functions.

Nowadays, substation automation usually includes a SCADA system, which enables a cost-effective remote control system that is capable of monitoring real time operating conditions and controlling the performance of substations.

1.1 Protective Relays

Protective relay is a device, which operates to disconnect a faulty part of the system, thereby protecting the remainder of the system from further damage. In fact, power protection has the following five main functions as its levels of discipline and functionality, as shown in order of priority to:

Ensure safety of personnel; Safeguard the entire system; Ensure continuity of supply; Minimize damage and; Reduce resultant repair costs. All of these requirements make it necessary to ensure early detection, localization, and rapid isolation of electrical faults and additionally prompt and safe removal from service of faulty equipment.

Relay can be divided into five functional categories [2]

a)   **Protective Relay**, which detect defective lines, defective apparatus, or other dangerous or intolerable conditions. These relays can either initiate or permit switching or simply provide an alarm.

b)   **Monitoring Relays**, which verify conditions on the power system or in the protection system. These relays include fault detectors, alarm units, channel-monitoring relays, synchronism verification, and network phasing. Power system conditions that do not involve opening circuit breaker during faults can be monitored by verification relays

c)   **Programming Relays,** which establish or detect electrical sequences. Programming relays are used for reclosing or synchronizing.

d) **Regulating Relays,** which are activated when an operating parameter deviates from pre-determined limit. Regulating relays function through supplementary equipment to restore the quantity to the prescribed limits.

e) **Auxiliary Relays**, which operate in response to the opening or closing of the operating circuit to supplement another relay or device. These include timers, contact multiplier relays, scaling units, receiver relays, lock-out relays, closing relays and trip relays.

The following characteristics are related with good performance of a relay in a power system.

- **Reliability:** The reliability of a relay is directly in correspondence with the concepts of dependability and security.
- **Selectivity:** Selectivity is the ability that a relay has to only open those breakers that isolate the faulted element.
- **Speed:** In the occurrence of a fault, the greater the time in which the fault is affecting the power system, the greater is the risk that the power system falls into an unstable operation point.
- **Stability:** This term refer to the ability of the system to remain inoperative to all load conditions and faults external to the relevant zone.
- **Simplicity:** Simplicity in a protective relay system is always the hallmark of good design. Major economics are possible with a complex relay system that uses a minimum number of circuit breakers.
- **Sensitivity:** The relay is said to be sensitive if the relay operates to the minimum value of faulted input signals [3, 4].

Normally, CBs and switches, which are applied to switching the power transmitted along the transmission lines on and off, are directly controlled by relays.

II. Description

Relay technology application for protection of power systems date back nearly 100 years ago. Since then, the technology employed to construct relays have improved dramatically in relay size, weight, cost and functionality. Based on the technology employed for their construction, relays can be chronologically classified as electromechanical, solid-state, and microprocessor-based relays.

(a) Electromechanical Relays:

The first relays employed in the electric power system were electromechanical relays (EMR) and have been used for almost 100 years and most typical utilities still have several throughout their power system. They work on the principles of a mechanical force causing the operation of the relay contact in response to a fault situation. The mechanical force was established by the flow of a current that reflected the fault current through windings mounted in magnetic cores. Due to the nature of its principle of operation, electromechanical relays are relatively heavier and bulkier than relays constructed with other technologies. Figure 1 demonstrates the basic connections of a traditional EMR. The EMR is used to control the trip coil of the CB which controls the transmission lines.

The Over current relay in Figure.1 has an operating coil which is connected to the CT secondary winding, and a set of contacts. When short circuit fault current (Isc) exceed a specified ''pickup'' value, the operating coil causes the normally open contacts to close. When the relay contact close, the trip coil of the circuit breaker is energized, which then cause the circuit breaker to open the transmission line under protection.
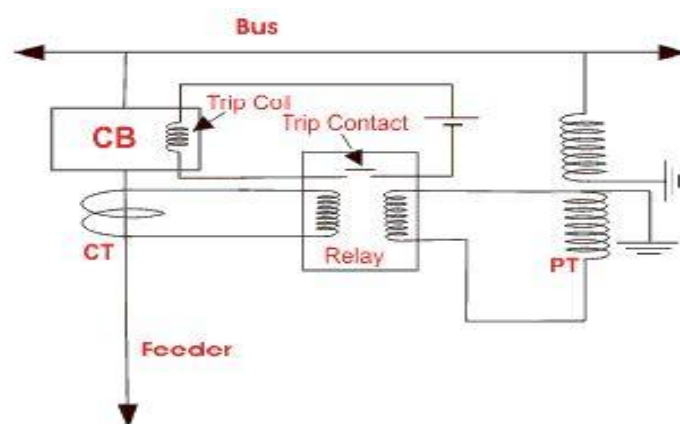

Figure 1: Electromechanical Overcurrent Relay Protection Circuit

(b)   Solid State Relays

With the advances on electronics, the electromechanical technology presented in the relays of the first generation started to be replaced by static relays in the early 50's. Solid state relays use low power components with rather limited capability to tolerate extremes of temperature and humidity, or over voltages and over currents. Solid-state relays are more accurate; not affected by vibration or dust, and often require less mounting space, and need not be mounted in a particular orientation. As shown in figure 2; the input current I, is pass through the resistive shunt R, full-wave rectified by the bridge rectifier B filtered to remove the ripple by the R-C filter and applied to a high-gain summing amplifier A., the other input of the summing amplifier is supplied with an adjustable reference voltage e_r. When the input of the summing amplifier exceeds the reference setting, the amplifier output goes high, and this step change is delay by a time-delay circuit, in order to provide immunity against spurious transient signals in the input circuit. The advantages of static relays over electromechanical relays are reduced size, weight and electrical burden.

By comparison with EMRs, SSRs have the following main features:

*   Anti-shock, anti-vibration; and long life;
*   Absolute electrical insulation;
*   Switching without causing arc;
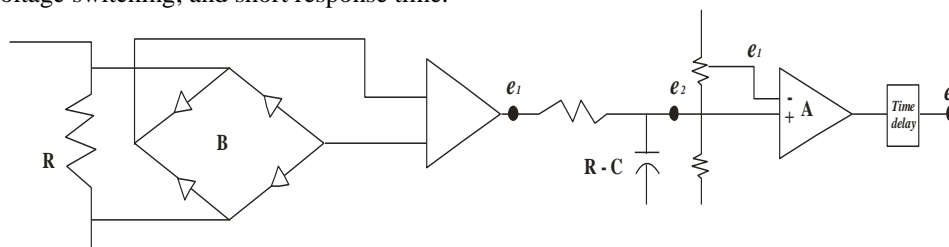*   Zero voltage switching; and short response time.

Figure 2: Simplified block diagram of a Static Relay

Advantages
1.   Absence of moving contacts and associated problems of arcing, contact bounce, erosion replacement of contacts etc.
2.   Quick Response, long life, shock proof, fewer problems of maintenance, high reliability and a high degree of accuracy.
3.   There is no effect of gravity on operation of static relays and therefore they can be installed in vessels etc.
4.   Ease of providing amplification enables greater sensitivity to be obtained.
5.   Use of printed or integrated circuits avoid wiring errors and facilitate rationalization of batch production.

Disadvantages
1.   The reliability of the system depends upon a large number of small components and their electrical connections
2.   Sensitive to voltage spikes or voltage transients
3.   Semi conductor components are sensitive to electrostatic discharges
4.   The characteristics are influenced by ambient temperature and ageing
5.   They are not robust in construction and easily affected by surrounding interference.

(c)   Microprocessor-Based Relays:

Incorporating microprocessor into the architecture of relay to implement relay and logic functions started happening in the 80's. Microprocessor-based relays (MPBRs) incorporated analog-to-digital converter (ADC) to sample the analog signals incoming from instrument transformers, and used microprocessor to define the logic of the relay. MPBRs presented an improvement in accuracy and control over incoming signals, and the use of more complexes relay algorithms, extra relay functions and complementary task. MPBR provides fast, accurate, reliable, compactness and flexibility. A block diagram of MPBR is shown in Figure 3. The three-phase ac quantities received from the power system through CTs and PTs are sampled simultaneously at uniform time intervals. They are then converted into the digital form through an A/D converter and transferred to Digital Signal Processor (DSP). The DSP compares the dynamic inputs and generate trip/alarm signal to the output device.
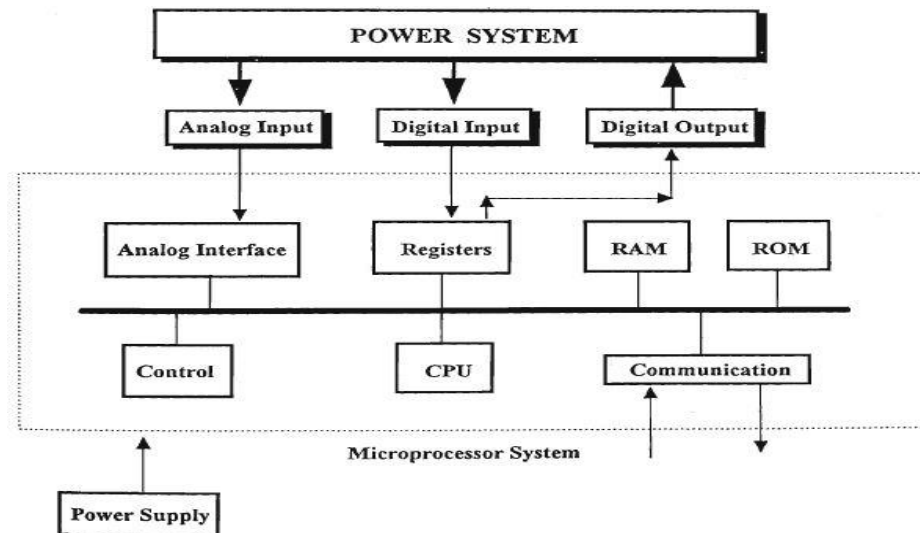
Figure 3: Basic Microprocessor – Based Relay Block diagram

Microprocessor-based relays offer many advanced features and functions in addition to their basic protection functions, Some examples of additional features now commonly available on relays are Event Reporting, fault locating**,** Disturbance Recorders (DR), metering data, targets, status information, measurement functions and power quality monitoring. Therein, the fault locating function has become a standard feature in nearly all the microprocessor-based relays. This function may greatly improve the working efficiency and may also be used to evaluate the faulty area in the transmission lines in terms of the real time values of fault current and impedance. Next, the event recording function provides data about internal relay element operation and the real time waveforms of current and voltage. The event data obtained by this function is of importance in evaluating the performance of the relays and the whole system.

This data is accessed through relay communications parts, local displays, or other human machine interface (HMI). Many individuals within a utility organization use the data. For example, operators may need to know targets and fault location for a particular electrical disturbance. Planning engineers may which to analyze load demand data collected from a feeder relay. Relay engineers may need to analyze an event report to explain a fault on a line that serves a critical customer load. Microprocessor-based relays can also provide networks load flow and switching information to SCADA systems, and uses sophisticated communication for signaling other remote relays. MPB relays have embedded automatic self test functions, which verify the correct operation of the relay. Virtually everything in the relay is subject to self tests except the analog inputs and contact input and output circuitry.

MPBRs, however, provide many advantages over the schemes using discrete components. The overall scheme takes up less panel space, easier design and wiring. Furthermore, the number of components as well as the installation testing and maintenance testing is also greatly reduced.

Attributes of Microprocessor-based Relays
Some of the major beneficial characteristics of microprocessor-based relays include the following [2, 5]
➢ Improved accuracy and a wider range of characteristics.
➢ The equipment's designs based on digital technology use fewer parts connections.
➢ Event-recording capability with local and remote reporting.
➢ Built-in logic for control and automation.
➢ Self-checking capability.
➢ Reduced engineering and drafting requirements.
➢ Capability for remote interrogation and setting application,
➢ Ability to change settings automatically based on system conditions.

The relay have metering functions that reduce or eliminate the need for panel meters and transducers and provide remote targeting and fault location information to assist operators in the restoration of electrical services.

Disadvantages

Some disadvantages of using microprocessor-based relays include the following:

➢ Single failure may disable many protective functions,
➢ Excessive input data required for settings logic,
➢ Frequent firmware upgrades – create tracking and documentation problems,
➢ Instruction manuals are complicated and difficult to understand,
➢ Difficulty in matching input software with relays, especially when relays have been field modified.

III.   Automation System Implementation

(i)   **SCADA** integration is a system operating with coded signals over communication channels so as to provide control of remote equipment. The supervisory system is combined with a data acquisition system, by adding the use of coded signals over communication channels to acquire information about the status of the remote equipment for display or for recording functions. The basic SCADA system consists of three components: remote terminal units (RTUs), a master station with host computers, and communication infrastructure. SCADA system functions, in general, include data acquisition, data processing, status estimation, statistical analysis and failure warning etc. As shown in Figure 4, the master station located in a control center is responsible for controlling all the substations within its range. The function of controlling each substation is performed by the RTUs in the substations. At first, the RTUs send real time data to the master station via a high-speed communication channel, and then the master station, after receiving and analyzing the data, may give commands to the RTUs to determine what action should be performed in case of faults, for example, open a circuit breaker (CB). Next, the RTUs send signals to the relays which perform associated action on the CBs and switches [6,7,8]. In practice, the relays belong to significant protective relaying equipment that directly carries out the control over the CBs and Switches.
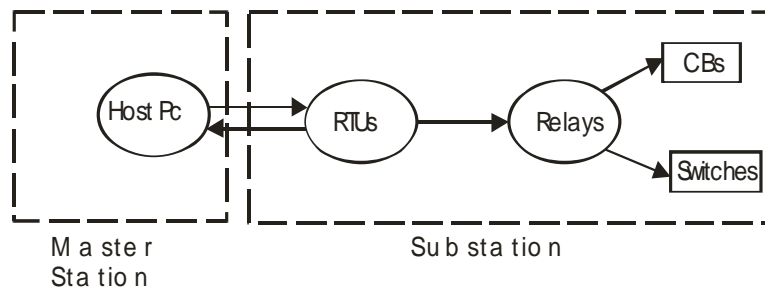

Figure 4:   Basic Structure of SCADA Systems.

The communication flexibility of substation devices represents significant advantages to SCADA environments on a number of fronts. With microprocessor-based hardware based on an open platform, utilities can perform upgrades more cost-effectively, preserve their initial technology investment, and substantially reduce long-term implementation costs. Any authorized user within the utility can easily access information from devices on the network from their desktop, without the usual complexity and expense of building SCADA 'extensions' to engineering planning and other departments that need the information; in order words, it enables employees to have the data base within easy access whether they are sitting in the head offices or working at remote substation in the field.

(ii)   Substation Automation is a system for managing, controlling and protecting a power system. This is accomplished by obtaining real-time information from the system, having powerful local and remote control applications and advanced electrical protection. Power system Automation refers to the use of intelligent device for making decision, data communications and supervisory control, monitoring, and implementing related action to automatically control the operation of power systems [8, 9, 10].

IV.   Results And Discussions

Substation automation schemes possessed the following features:

• Control and monitoring of all substation electrical equipment from a central point
• Interface to remote SCADA system
• Control and condition monitoring of substation electrical equipment in a bay locally
• System database and energy management

The automated processes for making control decisions lie within the computers, intelligent instrumentation, and control devices as presented in Figure 5. Substation Automation, by definition, are made of Electrical Protection, Control, Measurement, Monitoring and Data Communications.

a)   Electrical Protection

Electrical Protection is still one of the most important components of any electrical switchgear panel, in order to protect the equipment and personnel, and to limit damage in case of an electrical fault. Electrical protection is a local function, and should be able to function independently of the Substation Automation system if necessary, although it is an integral part of substation automation under normal conditions. The functions of electrical protection should never be compromised or restricted in any substation automation system.

Figure 5: Functional Structure of Substation Automation

b)   Control

The topology of a substation control system is the architecture of the computer system used. The functionality of such a system is the complete set of functions that can be implemented in the control system. All computer control systems utilize one of two basic topologies: **a).** Centralized and **b).** Distributed topologies. The basic concepts of each are illustrated in Figure 6. Early substation automation used the centralized concept, due to limitations in technology, both of processor power and communication techniques. The distributed architecture uses the microprocessor based relays to link the multidrop serial link to a local processor. The local processor then controls one or more bays in a substation. All of the local processors are, in turn, connected to a Human Machine Interface (HMI), and to a local or remote SCADA system for overall network monitoring /control.
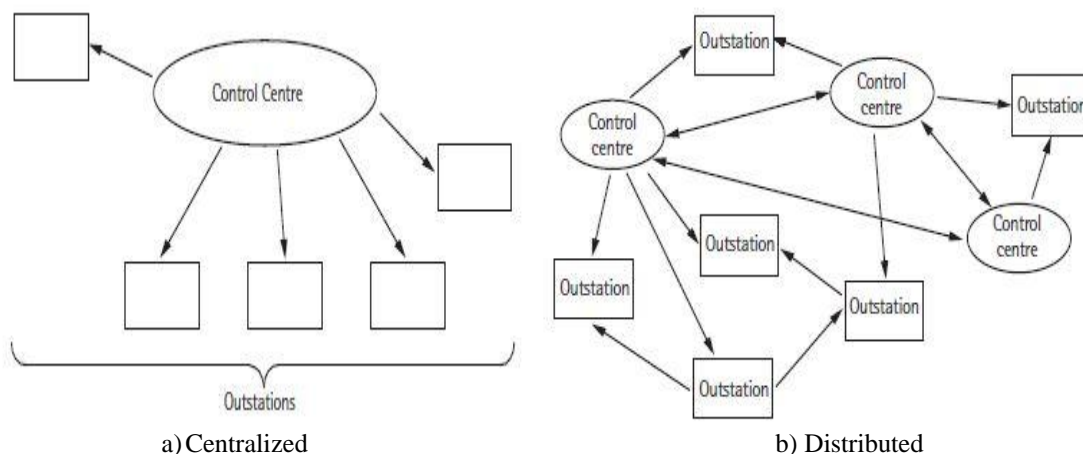

a) Centralized   b) Distributed
Figure 6: Substation Automation System Topologies

A safer working environment is created for personnel, and huge production losses may be prevented. In addition, the operator or engineer at the SCADA terminal has a holistic overview of what is happening in the power network throughout the plant or factory, improving the quality of decision-making.

c)   Measurement

A wealth of real-time information about a substation or switchgear panel is collected, which are typically displayed in a central control room and/or stored in a central database. Measurement includes:

- Electrical measurements - voltages, currents, power, power factor, harmonics, etc.
- Other analog measurements, eg. Transformer and motor temperatures,
- Disturbance recordings for fault analyze.

This makes it unnecessary for personnel to go to a substation to collect information, again creating a safer work environment and cutting down on personnel workloads.

The huge amount of real-time information collected can assist tremendously in doing network studies like load flow analyzes, planning ahead and preventing major disturbances in the power network that may causing huge production losses.

d) Monitoring

Status and condition monitoring, includes Sequence-of-Event Recordings, maintenance information, relay settings, etc. This information can assist in fault analyzes, determining what happened when, where and in what sequence. This can be used effectively to improve the efficiency of the power system and the protection. Preventative maintenance procedures can be utilized by the condition monitoring information obtained.

e) Data Communication

Data communication forms the core of any Substation Automation system, and is virtually the glue that holds the system together. Without communications, the functions of the electrical protection and local control will continue, and the local device may store some data, but there can be no complete Substation Automation system functioning. The form of communications will depend on the architecture used, and the architecture may, in turn, depend on the form of communication chosen. In a new substation, all of the elements of the automation system will normally use the same communications bus or busses, to obtain cost-effectiveness. Where a substation automation system is being retrofitted to an existing substation, it may be necessary to use existing communications busses to communicate with some existing devices.

In the past, majority of power system control were accomplished manually at the site of switchgear and control devices. Major substations were often manned on a continuous basis. Substation personnel would report and record meter reading at the substation and perform switching as required. MPB relays delivered a wealth of new functions built-in digital recording, sequential event recording, metering, multiple setting groups, easier adaptivity to change system conditions, HMI, fault location and digital communications, to name only a few. These devices are designed for guaranteed performance under a variety of activity patterns in any of the respective functional areas. Self-monitoring is an inherent advantage of the MPB technology. With the development and implementation of MPB protective relays in substations, information, metering and measurements are now automatically forwarded to central system operating offices over communication system; it also provided system operators with control of substation devices, and switching commands which could be operated remotely. Thus, creating safer work environments, and cutting down on personnel workloads.

V. Conclusions

The implementation of the substation automation is an effective approach to ensure the stability of the power system. One of the key parts in the substation automation is protective relaying equipment which directly controls CBs and switches. Protective relays are significant protection equipment with a long history. From EMRs, through SSRs, to MPB relays; they are developed towards high reliability and multi-function. Application of microprocessor-based relays in systems automation eliminate the need to manually read meters, provide the utilities with more precise load data, fault location, event recording and allows customers to take advantage of various types of rate incentives as a result of reduced outage times. It is expectable that microprocessor-based relays will be the main protective equipment that will be widely apply to the substation automation with high reliability, flexibility and intelligence.

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