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PROTECTION AND CONTROL OF POWER SYSTEM-A REVIEW.

Patrick I. Obi[1], G. C. Chidolue[1] and Innocent I. Okonkwo[2]

1.Lecturers Anambra State University/Department of Electrical/Electronic, Uli, Ihiala Anambra State, Nigeria Email: patndyobi@gmail.com, chidolue@yahoo.com

2. PhD Scholar, Anambra State University/Department of Electrical/Electronic,Uli,Ihiala Anambra State, Nigeria Email: fins212@gmail.com

ABSTRACT

Modern power systems are being operated closer to their stability margins because of deregulation, competition, and problem of securing capital outlays expansion of existing power system. The conventional method of power system protection and control no longer achieve secured and reliable protection hence given rise for the incorporation of PMU base protection and control which has better wide area monitoring, protection and control. In this paper the protection and control of power system is overviewed, the contingencies obtainable in operational power systems are also overviewed, while the conventional and the most modern state of art of mitigating and controlling of such power system contingencies are explored.

Keyword: power system protection, power system controls, PMU, wide area monitoring, and power system contingencies.

1.0 INTRODUCTION

The task of protection and control in substations and in power grids is the provision of all the technical means and facilities necessary for the optimal supervision, protection, control and management of all system components and equipment in high and medium – voltage power system. The task of the control system begins with the position indication of the HV circuit – breaker and ends in complex systems for substation automation, network and load management as well as for failure and time based maintenance. For all these functions the data acquisition at the switch yard and if applicable, the command execution at the switch yard are part of the network control and management [1].

Modern automation technology provides all the means necessary for processing and compressing at the actual switchgear locations in order to simplify and secure normal routine operation. This allows more efficient use of the existing equipment and quick localization and disconnection of faults in case of troubles, thereby also reducing the load on the communication links and in the network control centers.

Protection devices are required to safeguard the expensive power equipment and transmission lines against overloads damages. Therefore, they have to switch off very quickly short circuits and earth faults and to isolate very selectively the faulted or endangered parts of the power system. They are thus a major factor in ensuring the stability of the power system. While the purpose of power system control as a subdivision of power system management is to secure the transmission and distribution of power in the more and more complex power system by providing each control centre with a continually update and user-friendly overall picture of the entire network. All important information is transmitted via communication links from substations to the control centre, where it is instantly evaluated and corrective actions are taken.

The trend in power system planning utilizes tight operating margins, with less redundancy, because of new constraints placed by economical and environmental factors. At the same time, addition of non-utility generators and independent power producers, an interchange increase, an increasingly competitive environment, and introduction of FACTS devices make the power system more complex to operate and to control, and, thus, more vulnerable to a disturbance. On the other hand, the advanced measurement and communication technology in wide area monitoring and control, FACTS devices (better tools to control the disturbance), and new paradigms (fuzzy logic and neural networks) may provide better ways to detect and control an emergency [2].

Better detection and control strategies through the concept of wide area disturbance protection offer a better management of the disturbances and significant opportunity for higher power transfers and operating economies. Wide area disturbance protection is a concept of using system-wide information and sending selected local information to a remote location to counteract propagation of the major disturbances in the power system. With the increased availability of sophisticated computer, communication and measurement technologies, more "intelligent" equipment can be used at the local level to improve the overall emergency response.

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Decentralized subsystems, that can make local decisions based on local measurements and remote information (system-wide data and emergency control policies) and/or send pre-processed information to higher hierarchical levels are an economical solution to the problem. A major component of the system-wide disturbance protection is the ability to receive system wide information and commands via the data communication system and to send selected local information to the SCADA centre. This information should reflect the prevailing state of the power system.

In this paper the protection and control of power system are overviewed, the contingencies obtainable in operational power systems are also overviewed, while the conventional and the most modern state of art of mitigating and controlling of such contingencies are explored.

2.0 POWER SYSTEM DISTURBANCES

Power systems size and complexity have grown to satisfy a larger and larger power demand. Phenomena, having a system-wide, global nature, endangering the normal operation of power systems have appeared, explicitly [3 – 8].

2.01 Frequency Instability

Frequency Instability - is inability of a power system to maintain steady frequency within the operating limits. Keeping frequency within the nominal operating range (ideally at nominal constant value) is essential for a proper operation of a power system. A maximal acceptable frequency deviation (usually 2 Hz) is dictated by an optimal setting of control circuits of thermal power plants. When this boundary is reached, unit protection disconnects the power plant. This makes the situation even worse – frequency further decreases and it may finally lead to the total collapse of the whole system. Frequency instability is in its nature rather a tracking than truly a stability control problem. Frequency instability occurs due to the mismatch between load and generation caused by tripping of generators and / or rejection of loads giving rise to a sudden change in frequency [7].

2.02 Voltage Instability

Voltage Instability - is the inability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system conditions causes a progressive and uncontrollable drop in voltage. Lack of adequate reactive power support is the main cause for the voltage instability [2]. It could be due to (a) sudden change in the network topology redirecting the power flows, and/or due to (b) gradual increase of power demand in such a way that VAR requirement of some of the buses may not be met locally. Voltage collapse getting initiated from a node/set of nodes could result into wide area voltage instability and can be classified as Transient (varying from 1 to 3 sec.) or Steady-state (varying from tens of seconds to several minutes).

2.03 Transient Angular Instability

Transient Angular Instability (also called Generator's Out-of-step) - is the inability of the power system to maintain synchronism when subjected to a severe transient disturbance. The resulting system response involves large excursions of generator angles and is influenced by the nonlinear power-angle relationship. In case of transient angle instability, a severe disturbance is a disturbance, which does not allow a generator to deliver its output electrical power into the network (typically a tripping of a line connecting the generator with the rest of the network in order to clear a short circuit). This power is then absorbed by the rotor of the generator, increases its kinetic energy, which results in the sudden acceleration of the rotor above the acceptable revolutions and eventually damage of the generator. Transient angular instability caused due to sudden tripping of load/generator [9].

2.04 Small-signal Angular Instability

Small-signal Angular Instability (also mentioned as Generators' Swinging or Power Oscillations) - is the inability of the power system to maintain synchronism under small disturbances. Such disturbances occur continually on the system because of small variations in loads and generation. The disturbances are considered sufficiently small for linearization of system equations to be permissible for purposes of analysis. Local modes or machine-system modes are associated with the swinging of units at a generating station with respect to the rest of the power system. The term local is used because the oscillations are localized at one station or small part of the power system Inter-area modes are associated with the swinging of many machines in one part of the system against machines in other parts. They are caused by two or more groups of closely coupled machines being interconnected by weak ties [8].

3.0 Control and mitigation of system disturbances

Control methods mitigating the listed dangerous phenomena (frequency, voltage, transient, and small-signal instability) and keeping the power system in a secure state are mainly based on the classification of power system states. Explicitly, according to [4], these states are [9], [11]:

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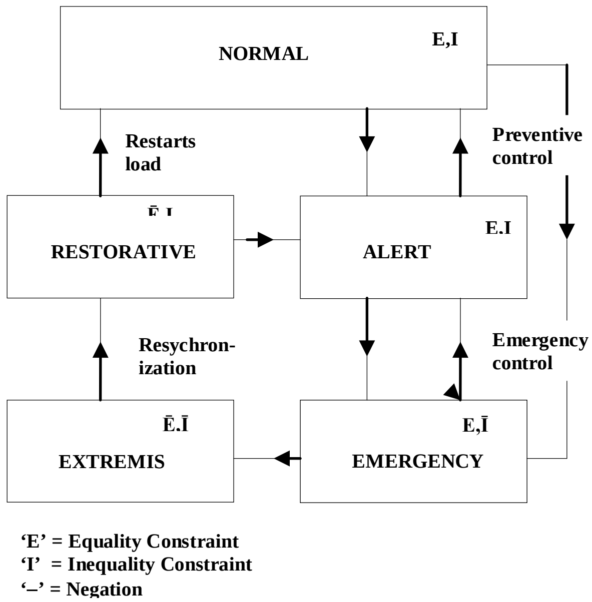

Fig 1: State Transition Diagram

Normal
All system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand a contingency without violating any of constraints.

Alert
All system variables are still within the acceptable range and all constraints
are satisfied. However, the system has been weakened to a level where a contingency may cause an overloading of equipment that places the system in an emergency state.

Emergency
Some system variables are outside of acceptable range (e.g. voltages too low, lines overloaded). If no control changes are introduced, system progresses into In Extremis.

In Extremis
Cascading spreading of system components outages resulting in partial or system-wide blackout (loss of supplied load) are the characteristics of extremis.

Restoration
Energizing of the system or its parts and reconnection and resynchronization of system parts.

With respect to the above categorization of operation states, control approaches for keeping power systems secure are usually applied in two stages namely: Normal and preventive control, this control is applied in the normal and alert state. Its objective is either to stay in or to return into normal state. The other is the Emergency Control, this control is applied in emergency or in extremis state to stop the further progress of the failure and to bring the system into normal or alert state.

3.01 Normal and Preventive Control

Typical representatives of normal and preventive control are:

- Hierarchical automatic control:
  - Frequency control
  - Voltage control
- Centralized manual control based on:
  - Operator judgment
  - Contingency screening

Control measures usually include:

- Change of active power generation set-points, i.e. re-dispatch.
- Change of reference points of flow controlling (FACTS) devices.
- Start-up of generation units.
- Change of voltage set-points of generators and Static VAR Compensators (SVC).
- Switching of shunts elements (reactors, capacitors).
- Change of substation configuration (e.g. splitting of busbars).

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The hierarchical frequency control
Frequency quality control requirements for different operational conditions under undisturbed conditions, the network frequency must be maintained within strict limits in order to ensure operation of control facilities in response to a disturbance. The various disturbances in a power system will cause frequency deviation in the network. Control facilities, which prevent frequency deviation and allow keeping it within strict limits, are primary, secondary and tertiary control [9]. Primary control involves the action of turbine speed governors of generating units, which will respond during the frequency deviation from the frequency set point as a result of imbalance between generation and demand in the network [2]. Its aim is to prevent deep power system frequency decline. With primary frequency control action, a change in system load will result in a steady-state frequency deviation, depending on the governor droop characteristic and frequency sensitivity of the load. All generating units will contribute to the overall change in generation, irrespective of the location of the load change. Restoration of system frequency to nominal value requires supplementary control action, which adjusts the load reference set point. As system load is continually changing, it is necessary to change the output of generators automatically. This is done by so called secondary control.

The function of secondary control in a given control area is as follows:

- the maintenance of scheduled power exchange program between the areas and all other interconnected zones;
- the secondary control reserve will only be activated in the control area where the imbalance appeared;
- the restoration of the synchronous system frequency to its set point value.

In some countries functions of secondary control are fulfilled by centralized control system – automatic generation control (AGC). The primary objectives of automatic generation control are to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values [9], [12].

Tertiary frequency control refers to manual and automatic changes in the dispatching and commitment of generating units. This control is used to restore the primary and secondary frequency control reserves, to manage congestions in the transmission network, and to bring the frequency and the interchanges back to their target value when the secondary control is unable to perform this last task [13 – 14].

The hierarchical voltage control

The hierarchical voltage control has been implemented only in a few countries (e.g. France, Italy). Two additional higher levels – Secondary Voltage Regulation (SVR) and Tertiary Voltage Regulation (TVR) enrich primary voltage regulation. National TVR shall coordinate SVRs that control the areas voltage profiles. The objective here is to create a system-wide voltage profile minimizing the transmission of reactive power over longer distances and maximizing the reactive power generation reserves [9]. Larger reactive power generation reserves mean that they can be activated in case of a disturbance, i.e. the system is made more robust.

Hierarchical frequency and voltage control concepts are usually fully automated, i.e. the control loop is closed and does not involve any human intervention. Possible negative interactions among layers are minimized by appropriate selection of their time constants, e.g. primary layer dynamics is in order of seconds, secondary layer in tens of seconds to minutes and tertiary layer minutes to hour.

Security assessment

In this control scheme, the main objective is to keep the power system in a secure state, expressed by the compliance with N-1 criterion. That means that a possible outage of any single component shall not create an unacceptable stress of other component(s) or instability problem. In most power systems, a procedure called Security Assessment is employed for this purpose. Security Assessment is usually implemented as a program belonging to the Energy Management System (EMS) processing present state information given by State Estimation. Security Assessment is then done in a continuous cycle, typically every 5 or 15 minutes, or it is initiated by operator. The consequences of possible component outages, which are then examined, are components operated outside their limits (line overloads and (undervoltage or overvoltage), voltage instability, transient instability). Usually, each type of consequences is analyzed by a separate software package, independently of others (i.e. there is a package for voltage instability analysis, a package for components overloads etc.). Security Assessment is often executed in two steps:

1. Complete set of possible contingencies is processed using fast (sometimes only approximate) static analysis, neglecting system dynamics. This procedure is often referred to as Contingency Screening.
2. Reduced set of contingencies, identified as possibly most severe ones in the Contingency Screening, are analyzed in detail in form of time domain simulation considering all relevant dynamics aspects. For checking of unacceptable components stresses, employment of purely static methods (i.e. Contingency Screening) is sufficient and the whole Security Assessment is then referred to as Static Security Assessment (SSA) [9].

Essentially, for each assumed contingency a power flow computation is done, followed by a simple comparison of computed post-contingency state and components operational limits. When a time-domain simulation is involved, the term Dynamic Security Assessment (DSA) is used. The relation between the active power consumed in the monitored area and the corresponding voltages is expressed by so called PV-curves (often referred as "nose curves"). The increased values of loading are accompanied by a decrease of voltage. When the loading is further increased, the maximum loadability point is reached, from which no additional power can be transmitted to the load under those conditions. In case of constant power loads, i.e. loads whose power consumption is independent of the voltage magnitude, the voltages in the nodes become uncontrollable and rapidly decrease, resulting in voltage collapse.

However, the voltage level close to this point is sometimes very low, what is not acceptable under normal operating conditions, although it is still within the stable region. But in emergency cases, some utilities accept it for a short period. There are also other alternative graphical representations, e.g. QV-curves (amount of needed reactive power to keep a certain voltage at a given active power loading). PV-curves (or QV-curves) starting from actual system state are computed for considered set of contingencies. If any of the resulting PV-curves indicates that the system would be unstable (or would have an unacceptably low voltage profile) after a

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contingency, the operator takes preventive measures, such as switching shunt capacitors, generation redispatch etc.

3.02 Emergency Control
Typical representatives of emergency control in today power systems are:

- Protection based systems:
  - Under frequency load shedding (UFLS) schemes
  - Under voltage load shedding (UVLS) schemes
  - System Protection Schemes (SPS)
- Damping control

Emergency control measures may include:

- Tripping of generators
- Fast generation reduction through fast-valving or water diversion
- Fast HVDC power transfer control
- Load shedding
- Controlled opening of interconnection to neighboring systems to prevent spreading of frequency problems
- Controlled islanding of local system into separate areas with matching generation and load
- Blocking of tap changer of transformers
- Insertion of a braking resistor

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The main challenge in emergency control is the urgency, in which it has to be applied. Since historically very high demands for high performance communication system and control decision logic could not be met, emergency control strategy relies on devices reacting to their local measurements based on their setting determined off-line by simulations of assumed dangerous scenarios.

Under frequency load shedding (UFLS) schemes
Local devices used for UFLS schemes are UFLS relays. UFLS schemes and relays might be sorted in various categories, but their functionality is essentially the same. They are usually triggered when frequency drops to a predefined level and/or with a predefined rate of frequency change. Their action is disconnection of the load in several steps (5 - 20 % each) from the feeders they supervise. However, their effectiveness is strongly dependent on their careful tuning based on pre–studies, since there is no on-line coordination between them.

Under voltage load shedding (UVLS) schemes
Under voltage load shedding relays are a conventional local solution to prevent voltage instability The criterion triggering the load shedding action is a predefined voltage level in the supervised node (For example 88 % and 86 % of the nominal voltage in one particular isolated network.).

System Protection Schemes (SPS)
SPS are defined as: a protection scheme that is designed to detect a particular system condition that is known to cause unusual stress to the power system and to take some type of predetermined action to counteract the observed condition in a controlled manner. In some cases, SPSs are designed to detect a system condition that is known to cause instability, overload, or voltage collapse. The action prescribed may require the opening of one or more lines, tripping of generators, ramping of HVDC power transfers, intentional shedding of load, or other measures that will alleviate the problem of concern. Common types of line or apparatus protection are not included in the scope of interest here.

SPS differ from UFLS and UVLS schemes and relays essentially in two aspects:
1. SPS use in addition to (or instead of) measurements also a particular topology change (i.e. contingency) information to detect a dangerous system state.
2. SPS consist of several relays, which often use information from a remote location (e.g. measurement taken by one relay is sent to other relay, which processes it and executes a control action).

Damping Control
Some power systems lack a ”natural” damping of oscillations, which may occur, and they would be unstable when subjected to any minor disturbance and sometimes even under normal operation conditions if no measures increasing the damping were introduced. A traditional way of introducing an additional damping in the system is using of Power System Stabilizer (PSS) 1, which modulates the output voltage of the generator. Besides generators, PSS can be installed and used for modulation of FACTS devices control. The coordinated tuning of PSSs is a complex task, since they should be robust - work in the wide range of operation conditions and provide the best possible performance. This process is done off-line. Data needed for tuning of PSSs are usually obtained by modal analysis of power system model linearized around its operating point.

3.03 Restoration
After the contingency being cleared, the restoration actions help the power system get to a secure operating point or to re-connect components which have been disconnected from the network may be because it is impossible to operate the original network in synchronism or due to overload of some components cannot be reduced. It is necessary to make the frequency control system during power system restoration be more effective, which requires the location and the magnitude of all generations and loads. During power system restoration, both generation and load profiles are

constantly changing however the conventional approaches for frequency control and protection have only one set point for all scenarios. Offline power generators' loading optimization is a common practice for electric power utilities in order to prevent dangerous imbalance between load and generation and strong frequency deviations during power system restorations. Major drawback of conventional approaches for frequency control during power system restoration is that local protection devices do not have a system view, and, therefore, they are not able to take optimized and coordinated actions [15]. Even in the case of frequency control and monitoring, in which the frequency itself is a system index, the actions are taken locally on predefined design rules. Carrying out improper actions during power system restoration, especially in the early stages, will prolong the overall process. Generators' loading is one of the most important parameters should be managed considering power system operational constraints, load characteristics, and so forth. Offline scheduling of generators' load pickup could not guarantee that the actions will not cause further problems.

3.04 Problem of conventional protection and control system

Power system reliability, the security monitoring and control function of the control center is actually the second line of defense. The first line of defense is provided by the protective relay system. For example, when a fault in the form of a short circuit on a transmission line or a bus occurs, measurement devices such as a current transformer (CT) or potential transformer (PT) pick up the information and send it to a *relay* to initiate the tripping (i.e., opening) of the appropriate circuit breaker or breakers to isolate the fault. The protective relay system acts in a matter of one or two cycles (one cycle is 1/60 of a second in a 60-Hz system). The operation of the protective relay system is based on local measurements. The operation of security monitoring and control in a control center, on the other hand, is based on system-wide (or wide-area) measurements every 2 s or so from the SCADA system [16]. The state estimator in EMS then provides a snapshot of the whole system. Different time scales driving the separate and independent actions by the protective system and the control center lead to an information and control gap between the two. This gap has contributed to the missed opportunity in preventing cascading outages, such as the North American blackout and the Italian blackout of 2003. In both cases, protective relays operated according to their designs by responding to local measurement, whereas the control center did not have the system-wide overall picture of events unfolding. During that period of more than half an hour, control actions could have been taken to save the system from a large-scale blackout. The security monitoring and control functions of today's control center, such as state estimation, contingency analysis, etc., are based on steady-state models of the power system. There is no representation of system dynamics that govern the stability of a system after a fault in control center's advanced application software. The design philosophy for security control is that of preventive control, i.e., changing system operating conditions before a fault happens to ensure the system can withstand the fault. There is no analytical tool for emergency control by a system operator in a control center. All of these are the result of limitations imposed by: 1) the data acquisition system and 2) computational power in conventional control centers.

4.0 Modern protection and control system (smart grid)

The new data acquisition systems, such as PMUs that provide measurements in the order of milliseconds, offer new opportunities for dynamic security assessment and emergency control that would greatly enhance system reliability. Online monitoring and analysis of power system dynamics using real-time data several times a cycle will make it possible for appropriate control actions to mitigate transient stability problems in a more effective and efficient fashion [17]. Other system dynamic performance, including voltage stability and frequency stability, can also be improved with the assistance of PMUs [18 – 20]. A comprehensive "self-healing power grid" framework for coordinating information and control actions over multiple time-scales ranging from milliseconds to an hour employing distributed autonomous intelligent agents has been defined in [21].

Another function in control centers that has developed rapidly in the last couple of years and will become even more important in the future is the visualization tools to assist power system operators to quickly comprehend the "big picture" of the system operating condition [22 – 23]. As technology progresses, more and more data will become available in real time. The human-machine aspect of making useful information out of such data in graphics to assist operators comprehend the fast changing conditions easily and timely and be able to respond effectively is crucial in a complex system such as the power system as long as human operators are still involved.

4.01 Self healing protection and control system

The self-healing concept is a natural extension of traditional power system monitoring, control, and protection philosophies—but taken to the next level with automation through advanced theory and technology. For example, a self-healing grid will frequently utilize a network design that links multiple loads and energy sources. Sensors and analytic programs will detect patterns that are precursors to faults, providing the ability to correct conditions before disturbances actually occur [24].

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One key aspect of a smart, self-healing electrical grid is that it will know a great deal about problems affecting its operation. Fault location, voltage and power-quality problems, emerging dynamic instabilities, and other grid abnormalities will be quickly discovered and corrected. Advanced simulation models combined with new visualization tools will reveal congestion issues, overlays of failure probabilities, and resulting threat levels. In addition, the self-healing grid will also have an improved ability to recognize high-risk situations. When forecasted atmospheric extremes and/or real-time contingency analyses are incorporated into a probabilistic model, grid operators will better understand the risks of each decision, as well as ways to minimize those risks.

Effective presentations and related decision support tools will help operators quickly grasp system conditions, and enhance the situational awareness that is the key to safe and secure grid management while advanced sensing, analysis, protection, and control are important elements of a self-healing grid, so too is a robust transmission and distribution (T&D) infrastructure. High-capacity interconnections, joining major regional transmission organizations (RTOs), allow for inter-regional power flows during an emergency. But if this power transfer capability is not adequate, then upgrades to higher capacity or the construction of new tie lines is required. This infrastructure improvement also results in more robust energy markets, allowing less expensive remote generation to flow to areas of high-cost local supplies. The smart grid will act to reduce the number and duration of outages, minimize restoration times, and reconfigure the grid to produce optimum reliability and quality of service. All these features are rolled up under a common term—the "self-healing" characteristic—of the smart grid.

4.02 Current State of Today's Transmission Grid

Today's transmission grid was designed with many self-healing features. Auto-reclosing and auto-sectionalizing are common techniques employed to maintain service under adverse conditions. The mesh network design of the transmission system is inherently self-healing due to its built-in redundancy and such protective relaying features as high-speed reclosing and single-phase tripping. System planners have historically modeled the transmission system to verify that, under a normal system configuration, assumed loads could be met even during expected peak conditions. In addition, planners ensured that these same loads could be met even with the failure of single, and in some cases, multiple lines or components. Sophisticated protective relaying schemes are in place to monitor system conditions and take corrective action should specific parameters exceed limits. Transmission lines and equipment are relayed out (opened) when conditions require. Most loads normally are not impacted by a single transmission line fault because the system can tolerate such a contingency. Substation automation and new intelligent electronic devices have taken transmission protection to the next level. Some of today's special protection systems and remedial action schemes (SPS/RAS) are obvious precursors of the intelligent agents that will be deployed throughout the grid. Their effectiveness is expected to be improved by frequent tuning from a higher level, as well as through better local analyses. The design of the current transmission system has actually incorporated the notion of self-healing for many years by implementing new technologies, processes, and techniques as they became available. Significant advances in digital control, protection, and communications technologies, correctly applied, will continue to improve this self-healing capability.

4.03 Look-Ahead Features

In no doubt, the future protection and control system will expected to have the following features,

- Analytical computer programs, using many new and timelier system measurements, will identify challenges to the system, both actual and predicted, and take immediate automatic action to prevent or mitigate problems. Where appropriate, and when time allows, these algorithms will also provide options for the system operator to manually address such challenges.
- Probabilistic risk analysis will identify threats to the system under projected normal operating conditions, single failures, double failures, and out-of-service maintenance periods.
- Load forecasting will be greatly improved. These models will cover various time horizons— minutes, hours, and days in support of operations; monthly, quarterly, and annually to support operations and maintenance (O&M) planning activities; and longer range to support investment decisions.
- Fast simulation & modeling (FSM) will enable look-ahead capabilities to anticipate power system disturbances, while continually optimizing grid performance. FSM will:
  - ✓ Provide faster-than-real-time simulations to avert previously unforeseen disturbances
  - ✓ Perform what-if analysis for large-region power systems
  - ✓ Integrate market, policy, and risk analysis into system models, and quantify their effects on system security and reliability.

Monitoring Features

- Numerous intelligent sensors and communication devices will be integrated with power system control. Real-time data acquisition, employing advances in

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communication technology and new, lower-cost smart sensors, will provide a significantly larger volume and new categories of data, such as wide-area phasor measurement information. This dramatic increase in the volume of real-time data, combined with advanced data processing and visualization techniques, will give system operators a rapid grasp of the power delivery system's health. Advanced metering infrastructure (AMI) systems will provide an additional new source of relevant distribution status information, including loadings, voltage profiles, harmonics, and outage conditions.
- By analyzing equipment condition data, such as high-frequency emission signatures, condition monitoring technologies will provide additional perspectives on the probability and consequences of potential equipment failures.
- System state estimators will take advantage of advanced measurement and data acquisition technologies and powerful computers will enable them to solve problems in seconds or less. The availability of phasor information will make state estimators faster and more accurate.
- Command and control centers at the regional level for transmission operations, and at more local levels for distribution operations, will serve as hubs for many new self-healing features.

Protection and Control Features
- Advanced relaying will be employed to communicate with central systems and adapt to real time conditions. Line current differential relaying, enabled by high speed communications between high voltage (HV) stations, will increasingly replace older impedance schemes, providing more secure and reliable protection of transmission lines
- Due to their "uncontrolled" nature, real and reactive power flows are often smaller than can be thermally accommodated, reflecting an underutilization of some transmission paths. Power transfer is governed by line impedance, voltage magnitude, and phase angle difference across a transmission corridor. Improved utilization of transmission lines will be realized through the broad deployment and dispatching of flexible AC transmission systems (FACTS) devices that can control each of these steady state flow parameters.
- High-speed switching, throttling, modulating, and fault-limiting devices will dynamically reconfigure the grid. This will include faster isolation and sectionalization, as well as rapid control of power flows in response to dynamic system challenges.
- Intelligent control devices, such as grid-friendly appliances, will modulate load requirements in response to changing grid conditions.
- Broadband communications between stations and from stations to control centers will allow wider areas to be protected as an integral unit. System integrity protection systems (SIPS), remedial action systems (RAS), and other wide area protection and control (WAPC) concepts will be more widely deployed as integral features of the new transmission smart grid. In particular, extensive phasor monitoring will provide cycle by cycle assessment of the grid's dynamic performance.
- The computing and communication systems of the self-healing grid will employ a multitude of embedded processors scattered throughout the system that will communicate via standardized interfaces. They will employ control cycles that match relevant power system time constants, such as:
  - ✓ 1-hour cycles that assure adequacy of resources and reveal system bottlenecks;
  - ✓ 5-minute cycles that manage reliability and efficiency;
  - ✓ 2-second cycles that implement steady state area controls;
  - ✓ 100-millisecond cycles that address developing system instabilities; and
  - ✓ 10-millisecond cycles that trigger intelligent protection actions (load-shedding, generation rejection, system separation).

5.0 CONCLUSION

Modern protection and control of power system have been made more robust than the conventional type through the use of pmu which has reduced the time lag between the measured system state and the time these system states are sent to the control centers for procession. The incorporation of PMU has to the adaptation of real time self healing system which has definitely easy off some of the operator's control job with great improvement in speed and precision. The dynamic system assessment which in this modern protection and control are been done on – line rather than offline simulation and have led to operation of power system closer to their limits with its attendant economical advantage especially in this modern world embraced with deregulated power system environment. The time stamped PMU data other known as synchronized PMU data offers opportunities for more efficient wide area protection and control as such some stubborn protection like the protection of series compensation lines and likes are better handled in this new protection and control dispensation.

The incorporation of PMU in modern protection and control has clearly shown to improve the modern protection and control especially in the area of local protection and more generally in the control and mitigation of contingencies that are wide area in nature. The future protection and system is envisaged to be better

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than the present PMU base type as there is every day to day improvement especially in the communication which had been the backbone of system wide protection and control and also had been the bane of conventional power and control. A future more decentralized and integrated protection and control system will thus be the result of such advancement in communication system.

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