Effects of Poor Power Quality on Reliability and Security

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Abstract- Reliability is a key aspect of power system design and planning. The success of an electric utility in today's competitive business environment depends in part on overall service quality, a key element of which is system reliability. Electrical distribution reliability is affected by many factors including fault incident rate, adequate maintenance, and system design. PQ and reliability have many different definitions and they are often confused by end-users. The term reliability is used to indicate the ability of a system to continue to perform its intended function. Power system reliability is measured in terms of the ability of the power system to provide electricity to end-user, it is usually measured as the service to the end-users, and tracked by average frequency and duration indices that are reported to Regulators and Commissions. To maintain the reliability of power systems and the profitability of the utility companies the evaluation of the power system and, in particular, the distribution system reliability is an important task. It enables utilities to predict the reliability level of an existing system after improvements have been achieved through restructuring and improved design and to select the most appropriate configuration among various available options. This paper addresses the impact of poor power quality on reliability. The paper discusses about the reliability indices and Degradation of reliability and security due to poor power quality including the effects of harmonics and inter-harmonics on the operation of over-current and under-frequency relays, electromagnetic field (EMF) generation, corona in transmission lines, distributed generation, cogeneration, and frequency/voltage control.

Key words- Power Quality, Reliability, Security, Reliability Indices, DMS.

I. INTRODUCTION

Electrical Distribution reliability is the ability of the distribution system to perform its function under stated conditions for a stated period of time without failure. Distribution reliability is becoming significantly important in the current competitive climate because the distribution system feeds customers directly. Transmission and generation events can cause interruption to customers but events on these systems are much less likely to affect customers than those on the distribution system. Many utilities across the world today use reliability indices to track the performance of the utility or a region or a circuit. Regulators require most investor-owned utilities to report their reliability indices. The regulatory trend is moving to performance-based rates where performance is penalized or rewarded based as quantified by reliability indices. Some utilities also pay bonuses to managers or others based in part on reliability achievements. Some commercial and industrial customers ask utilities for their reliability indices when planning to find a location for their facility. To understand distribution reliability, consider a basic distribution feeder. There are many protective devices (fuses, reclosers, sectionalizes, breakers), overhead and/or underground line segments, three-phase and single-phase line elements, several different distribution voltage levels, and in general many places for failure of components. Distribution systems generally consist of radial feeders, which are not looped. The consequence of radial feeders is that many customers can be affected by the failure of any single component. Modified radial system designs with normally open tie points have become popular to minimize the reliability impact of radial design. The distribution system is greatly affected by weather and vegetation. Lightning is also a major cause of interruption in service. Utilities typically track weather such as wind, rain, lightning, snow, salt accumulation and tornadoes in order to predict the performance of the distribution network and for planning purposes. Tree branches are by large one of the most common causes for distribution system interruptions. Better reliability performance can be achieved with better tree-trimming schedules, regular maintenance schedules, effective crew placement, better design schemes which can include the use of expensive equipment (i.e. reclosers), and distribution automation such as sensors, monitors and advanced technologies for condition monitoring. Utilities which feed only urban centers can achieve the highest reliability performance because they can feed their customers via a looped underground network rather than overhead radial feeds. Hence designing and maintaining a system which is as impervious as possible to failure can improve reliability. The utilities with the most reliable systems are those that have mastered the art of juggling the above-mentioned factors which affect reliability. There are several ways to define the reliability or the quality of the electric supply. The approach described here extends the traditional utility measures of reliability to include short-duration power quality events. The two main ways used to quantify the reliability of the electric supply (they are also used to quantify the reliability of many other systems) are based on:

1. Frequency – The rate of interruptions of the electric supply is often quantified in terms of the mean time between failures (MTBF). The failure rate is often denoted by λ in units of average failures per unit of time ($\lambda = 1/\text{MTBF}$).
2. Duration – An interruption of the electric supply can be quantified as the availability or as the unavailability. Availability (and also unavailability) can be specified in per unit or percent. Even though the unavailability is a unit-less quantity, it is often referred to in units of time such as minutes per year. The unavailability is $r\,\lambda$, where r is the repair time and λ is the failure rate. A common way of defining reliability is in terms of customer- and load-based indices.

Reliability Indices:

Reliability indices defined are not absolute measures, but they provide relative information based on the comparison of alternative solutions. The set of reliability Indices can be divided into four categories:

A. *Load-point indices:* average failure (fault) rate (I), average outage time (r), annual outage time (U), repair time *(tr),* and switching time (ts).
B. *Customer-oriented system indices:* system average Interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), and system average rms (variation) frequency index (SARFI).
C. *Load-oriented system indices:* average service availability index (ASAI), average service unavailability index (ASUI), energy not supplied (ENS), and Average energy not supplied (AENS).
D. *Economical evaluation of reliability:* composite customer damage function (CCDF), customer outage cost (COC), and system customer outage cost (SCOC).

II. LITERATURE REVIEW

New technical and legislative developments shape the electricity market, whereby the reliability of power systems and the profitability of the utility companies must be maintained. To achieve these objectives the evaluation of the power system and, in particular, the distribution system reliability is an important task. It is worth noting that the reliability indices as defined in the literature [1-4] are not absolute measures, but they provide relative information based on the comparison of alternative solutions. The reliability evaluation of power systems is concerned besides traditional approaches [4] with the impact of automation on distribution reliability [2, 3, 4,]. The reliability and security of power systems is impaired by natural and man-made phenomena. Although before the advent of interconnected systems lightning strikes [5], ice storms [6-12], and component failures were mainly a concern. The effects of non sinusoidal voltages and currents on the performance of static under-frequency and over current relays are experimentally studied in [17]. Power-line carrier applications are described in [18-23]. They consist of the control of nonessential loads (load shedding) to mitigate under voltage conditions and to prevent voltage collapse. Renewable energy sources such as solar and wind power plants have an intermittent power output. Nevertheless it is desirable to operate them at maximum power output, for example, employment of peak-power tracker for photovoltaic plant [31]. U.S.-Canada blackout is analyzed in [36] and recommendations are given for prevention of similar failures in the future. Reliability questions are addressed in [1, 37].

III. FACTORS AFFECTING RELIABILITY PERFORMANCE

Reliability performance varies dramatically from one system to another and this is not necessarily an indication that one system has poor performance. Many factors influence the expected reliability at a particular location or for an entire system. Reliability indices that reflect reliability performance differ with data definitions and data classifications. Most utilities define separate indices for planned and unplanned events. Interruption data may or may not be considered in reliability performance because interruptions generally occur due to a major event like a storm, forest fire or a blizzard, which the Utility has least control over. Distribution and transmission events are considered separately for reliability performance evaluation, due to the data classes. Utilities could use different reliability indices for transmission and distribution due to the nature of the events and the type of data. Various studied parameters are as follows.

A. *Single-Time and Non-periodic Events*: The reliability and security of power systems is impaired by natural and man-made phenomena. Both types change in their severity as the power system protection develops over time. There are single-time, periodic, non periodic, and intermittent events. Although before the advent of interconnected systems lightning strikes, ice storms, ferroresonance, faults, and component failures were mainly a concern, the fact that interconnected systems are predominantly used gave rise to the influence of sunspot cycles on long transmission lines built on igneous rock formations, sub-synchronous resonance through series compensation of long lines, nuclear explosions, and increase of the ambient temperature above T amb = 40˚C due to global warming.
B. *Harmonics and Inter-harmonics Affecting Over-current and Under-Frequency Relay Operation*: The effects of non-sinusoidal voltages and currents on the performance of static under-frequency and over-current relays are increment in operating time due to voltage harmonics from 0 to 15 % of the Fundamental. Under-frequency relays are very sensitive to inter-harmonics of the voltage because of the occurrence of additional zero crossings within one voltage period. In case of Over-current Relays, it is self-contained and can have short time, long time, instantaneous, and ground protection on the options selected. Current harmonics cause the over-current device in the worst case to pick up at (100% + 10%) of the nominal RMS value based on a sinusoidal wave shape. Similar studies reveal that the same over-current relay has changed the time delay, for a given pickup RMS current setting up to 45% shorter and up to 26% longer than the nominal time delay with no harmonics. The long-time delay pickup current value is reduced for most harmonics by 20% and increased for certain harmonics by 7%. An electromechanical relay, subjected to similar tests as the solid-state relay, performed in a similar manner as the latter. With regard to the instantaneous pickup, RMS current harmonics cause the over-current relay to pick up in the worst case at (100% + 10%) of the nominal RMS value based on a sinusoidal wave shape. With regard to the time delay for given pickup RMS current values, harmonics cause the hinged armature over-current Relay to pick up in the worst case.
C. *Power-Line Communication*: Power-line carrier applications consist of the control of non-essential loads (load shedding) to mitigate under voltage conditions and to prevent voltage collapse. High-frequency harmonics, inter-harmonics caused by solid-state converters, and voltage fluctuations caused by electric arc furnaces can cause interferences with power-line Communication and control.
D. *Electromagnetic Field (EMF) Generation and Corona Effects in Transmission Lines*: The minimization and mitigation of electromagnetic fields (EMFs) and corona effects, e.g., radio and television interference, coronal losses, audible noise, ozone production at or above 230/245 kV high voltage transmission lines, is important.
E. *Distributed, Cogeneration, and Frequency/Voltage Control*: Renewable energy sources such as solar and wind power plants have an intermittent power output. Nevertheless it is desirable to operate them at maximum power output, for example, employment of peak-power tracker for photovoltaic plant. With such peak-power and intermittent-power constraints it is impossible to operate a power system with distributed generation (DG) sources only because the drooping characteristics which are responsible for load sharing require that at least one plant can deliver the additional power as requested by the utility customers, thus serving as base-load plant with spinning reserve capability.

IV. VARIOUS MEASURES TO OVERCOME THE DEGRADING EFFECTS POOR POWER QUALITY

Apart from the remedial actions taken against the factors discussed in section III, a new approach is described here. The traditional approach to utility planning with its narrow focus on utility-built power plants is no longer adequate. A new paradigm for utility resource planning has been promoted. The new approach should account for the availability of DSM (Demand-Side Management) and renewable-energy technologies and the public concern with environmental qualities. A crucial part of any DSM program is electrical load monitoring. Most utilities rely on revenue meters at the point of electrical entrance service to individual buildings or group of buildings. Some DSM programs may require the installation of additional meters for individual electricity-consuming devices such as lighting systems, ventilation fans,or chillers. With these additional meters, controls of targeted equipment can be performed. To make implementation of DSM programs cost-effective, there is an increased interest in monitoring techniques that allow detection and separation of individual loads from measurements performed at a single point (such as the service entrance of a building) serving several electricity-consuming devices.

A. To minimize the effects of Single-Time and Non-periodic Events, It is interesting to note that utilities install ice monitors on transmission lines and make an attempt to melt ice through dielectric losses Ferro resonance can be avoided by employing gas (SF6)-filled cables for distribution systems above 20 kV. The effect of sunspot cycles and those of nuclear explosions can be mitigated through the use of three-limb transformers with a large air gap between the transformer iron core and the tank. The increase of the ambient temperature will necessitate in a revision of existing design standards for electric machines and transformers, and an ambient temperature of 50°C is recommended for new designs of electrical components.

B. As per the issue discussed in III B, above inter-harmonics should be limited from this point of view to less than 0.5%. The long-time delay pickup current value is reduced for most harmonics by 20% and increased for certain harmonics by 7%.

C. SCADA equipment such as RTUs and PLCs are applications of telecommunications principles. Interdisciplinary telecommunications programs (ITPs) combine state-of-the-art technology skills with the business, economic, and regulatory insights necessary to thrive in a world of increasingly ubiquitous communications networks. ITPs are served by faculties in economics, electrical engineering, computer science, law, business, telecommunications industry, and government. They address research in wireless, cyber-security, network protocols, telecom economics and strategy, current national policy debates, multimedia, and so forth. Security and reliability of utility systems addressing a range of security-related issues on physical and information security as well as vulnerability assessment and management. With the advent of distributed Generation, the controls of power systems will become more complicated due to the limited short-circuit capability of renewable sources and their non-sinusoidal voltage and current wave shapes.

D. The minimization and mitigation of electromagnetic fields (EMFs) and corona effects, e.g., radio and television interference, coronal losses, audible noise, ozone production at or above 230/245 kV high voltage transmission lines, is important. After addressing the generation of electric and magnetic fields, mechanisms leading to corona, the factors influencing the generation of corona, and its negative effects are explained. Solutions for the minimization of corona in newly designed transmission lines and reduction or mitigation of corona of existing lines are well known but not, however, always inexpensive. Active Shielding or Cancellation/Compensation of EMFs. Active shielding is possible through compensation of electric and magnetic fields by suspending several transmission-line systems on the same towers (e.g., reverse-phased double circuit). Through the capacitance of a cable, this is required for inducing ferro-resonant currents.

E. Intentional Islanding, Interconnected, Redundant, and Self-Healing Power Systems: The present interconnected power system evolved after 1940 and represents an efficient however complicated energy generation, distribution, and utilization network. It is reliable but also vulnerable to sabotage, economic issues, distributed generation, and regulations. This problem of distributed control for complicated power networks is closely related to the same problem in communications, biological, economic, political, and many other systems. In the case of distributed generation with renewable energy sources (e.g., wind, solar) additional constraints enter the control approach where the renewable sources are operated at near 100% capacity by imposing droop characteristics with steep slopes. The intermittent operation of renewable sources requires that peak-power plants are able to take over when the renewable sources are unable to generate power. In order to minimize peak-power generation (e.g., spinning reserve) capacity it will be advisable to also rely on energy storage plants (e.g., hydro, compressed air, super capacitors).

V. CONCLUSION

The well-established reliability indices are reviewed, and their application to frequently occurring feeder configurations within a distribution system are addressed. An estimation of electric and magnetic fields generated by transmission lines and their associated corona effects are important from an environmental and from a power quality point of view, respectively. Distributed generation (DG)- where renewable sources are a significant (e.g., 20-30%) part of the generation mix- may lead to frequency and voltage control problems. This is so because renewable sources will be operated near their maximum power range and cannot deliver large transient currents during non-steady-state conditions; that is, renewable sources such as solar and wind-power plants contribute to the properties of a weak generation system. This in turn makes a power system that consists of only intermittently operating renewable plants inoperable because they are operated at their maximum output powers and cannot deliver additional power when demanded by the loads. In other words, the drooping characteristics of intermittently operating renewable sources have a large slope R, whereas base load plants such as coal fired, natural-gas, or storage plants can have droop characteristics with small slopes. The droop characteristics with small slopes guarantee that additional power demand can be covered, through spinning reserve, as requested by the loads. This aspect is important when in the case of severe faults or terrorist attacks the interconnected power system must be separated into several independently operating power system regions where each and every part has its own frequency and voltage control resulting in intentional islanding operation. To maintain a stable operation of each independently operating power region, each one must have sufficient spinning reserve. The maximum error and uncertainty principles are introduced to estimate to total measurement error as applied to power system components. Reliable measurement errors are important for the decision making of dispatch and control centers. Fast switches and current limiters play an important role for the stable operation of a utility system because the faulty part of an interconnected system can be isolated before a domino effect sets in, which may bring down the entire system. In systems with distributed generation- based on renewable intermittently operating energy sources larger than 20-30%, storage plants become important to augment the spinning reserve. This is not fast enough, however, to replace the output of wind-power plants, which may reduce as much as 60 MW per minute. Thus the concept of spinning reserve is important, where the delivery of electric energy can be increased within a few cycles. Lastly, various demand-side management (DSM) programs can play an important role in maintaining the reliability and security of a distribution system. These appear to be very effective with rate increases or decreases in managing peak-power conditions without requiring additional generation.

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