System Planning and Protection Engineering – An Overview

by

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**System Planning and Protection Engineering – An Overview**

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**Abstract**—System planners are responsible for future planning of system and substations/protection engineers are responsible for the protection system and design. An engineer with an experience of both planning and protection can plan and design an adequate system and protection for the future. This paper aims to provide a comprehensive reference document to the practicing engineers, researchers, and academicians of fast growing developing countries about the system planning and protection engineering techniques and tools practiced in North American Power System, which is one of the largest and most advance power systems.

**Keywords**—Planning; Load Flow; Planning; Power Systems; Protection

**I. OVERVIEW OF NORTH AMERICAN GRID**

The Federal Energy Regulatory Commission (FERC) of USA is an independent agency that regulates the interstate transmission of electricity, natural gas, and oil. NERC Corporation was certified as the “electric reliability organization” by the FERC on July 20, 2006. NERC’s mission is to improve the reliability and security of the bulk power system in North America. To achieve that, NERC develops and enforces reliability standards; monitors the bulk power system; assesses future adequacy; audits owners, operators, and users for preparedness; and educates and trains industry personnel. NERC works with eight Regional Reliability Councils to improve the reliability of the bulk power system. These entities account for virtually all the electricity supplied in the United States, Canada, and a portion of Baja California Norte, Mexico. NERC’s proposal to delegate enforcement authority to eight regional entities is pending before the FERC. Founded in 2003, the ISO/RTO Council (IRC) is an industry organization comprised of 10 Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs) in North America. These ISOs and RTOs serve two-thirds of electricity consumers in the United States and more than 50 percent of Canada’s population. The IRC works collaboratively to develop effective processes, tools, and methods for improving competitive electricity markets across North America. The IRC’s goal is to balance reliability considerations with market practices, resulting in efficient and robust markets that provide competitive and reliable service to electricity users. As wholesale competition for electricity was established, groups of utilities and their regulators began forming ISOs, to ensure equal access to the power grid for new, non-utility competitors. ISOs and RTOs provide a sound framework to reduce costs, promote private investment in electric resources, and better manage consumption to achieve reliable and reasonably priced electricity for consumers.

**II. SYSTEM PLANNING**

System planning study may include expansion study, generation interconnection, transmission service request etc. System planners study the power system model (using PSS/E or PSLF) and add the future load/generation and study the power system models for present and future (e.g. 5 years from now, 10 years from now). Based upon the best available information, all the future loads, approved generation and system upgrades such as transmission lines, transformers and new substations are also modeled. The system is studied for the light load and peak load cases for summer and winter.

A typical planning study may involve:
- Transmission service request
- Generation interconnection
- System Upgrade/ New Facility

Various studies required to be performed by the system-planning and protection engineer are Load Flow/ Power Flow, Short Circuit, Motor Starting (Static and Dynamic), Transient Stability Analysis, Insulation coordination, Ground Grid Analysis, Cable Ampacity Analysis, PF, Switching, Harmonic Analysis, Arc-Flash, Relay Coordination.

Generation interconnection study is typically required if new generation is planned, e.g. some Independent Power Producer (IPP) decides about the new generation. This study may require evaluation of 6-8 sites (or more) for generation and study the transfer of power to selected locations. The site selection is based upon many factors such as permitting, gas or coal, generation and transmission cost per MW, losses/MW, equipment and lines upgrades cost, load growth, environment etc. The study is than reviewed by the regional council for accuracy and based upon the more accurate future information and model study is performed in details for one or two sites. At this stage transient stability and breaker failure study is also performed to compare the two options. Before the final site selection, a load flow, PQ and stability study will be required.

The study should also be performed for the future years. The system upgrades are also analyzed and studied. System upgrade study may be required to evaluate the effect of any transmission, generation or transformer upgrade e.g. any existing facility is planning to add some generation and adding new lines or transformers.

For the new facilities and refineries, it will be required to perform the load flow, motor starting, cable ampacity, and transient stability. For the new EHV substation equipments switching studies are required for the Transient Over-Voltage (TOV) study. This study will decide the location of surge arresters. There are many factors that can result in TOV including the capacitor banks.

Example: An IPP is planning to build connect new Gas turbine to Location A. He will approach the utility where he wants to connect the generation. Utility will perform the pre-feasibility study to have preliminary investigation for the site for the transmission congestion. PSS/E, PSLF and MUST can be used to perform this analysis. For the system planning point of view, transmission planning includes the power flow and stability analysis and study N-1 and N-2 contingency analysis for power flow and stability. Protection and system operators will come up with the possible scenarios. The analysis depends upon...
the correct future model with respect to the future generation and load growth and considering the right amount of generation and load for the area of interest and nearby areas. A reasonable amount of power flow on the tie lines is also considered. Good overview and knowledge of future planning is required to make this decision. For the new generation, a combustion turbine or any generation proposed by customer, which is usually a costly generation, is turned off.

From this analysis list of problems, solutions and upgrades are suggested. In some cases generation or load back off may be required. At this point it is also important to perform PQ analysis. If Var support is not available, that can be corrected by the additional capacitors or SVC. In some cases, Remedial Action Scheme (RAS) is proposed and different solutions may be required for different seasons. RAS can be programmed using the automation solution by Schweitzer Engineering Laboratories (SEL) or others [1], [2].

Once the system upgrade is planned and approved, all the substation equipments at least two buses away from the new generation site should be evaluated for the fault on the system. If any breaker is already marginal on fault duty, and any other substation equipment is running near the limits, it should be included in the analysis. It is possible that if the breaker fault duties are already marginal, replacement of breakers and other protective equipments may be required. This task is to be performed by the protection engineers who will review the adequacy of the system depending upon the approved system upgrades. The system for new lines is also similar. Siemens PTI PSS/E and GE PSLF software can perform these tasks. Siemens PTI software MUST is utilized to perform quick system analysis to review the system adequacy for any transfer. The studies usually performed are Load Flow, Transient Stability and PV analysis. Load flow and PV analysis will confirm the thermal capability of the system. Reactive power analysis confirms in which areas reactive power compensation is required. Transient stability analysis will determine the adequacy of breaker failure time and system stability. In certain cases, it may be required to identify the critical cases, which will require some remedial actions. Complete analysis of these remedial schemes is also required. If it is a new system a pilot scheme or faster breaker may be a solution.

Protection engineer will focus its study on a particular substation and at least one substation forward and one substation reverse. Because of zone 3 requirements, it is better to check the coordination up two substations in each direction. Protection engineer will review the protection settings for this revised configuration. Many software analysis tools are available for the analysis e.g. PSS/E, ASPEN, PTW SKM, ETAP, CAPE, EDSSA etc. In addition to the relay settings, all the equipments should be adequate for the revised fault current and ground grid design should also be reviewed for the revised fault current if there is a significant change in the fault levels.

III. LOAD FLOW STUDY

Load flow studies [3]-[5] are an excellent tool for system planning. A number of operating conditions can be evaluated, including contingency conditions (such as the loss of a generator, a transmission line, a transformer, or a load), which will alert the user to conditions that may cause equipment overloads or poor voltage levels. Some of the uses of load flow studies are to determine the optimum size and location of capacitors for power factor improvement, Component or circuit loadings, Steady-state bus voltages, Reactive power flows, capacitor in/out of service, Transformer tap settings, System losses, Generator exciter/regulator voltage set performance under emergency conditions.

As the load distribution, and the network, will vary during different time periods, it may be necessary to obtain load flow solutions representing different system conditions such as peak load, average load, or light load. Load flows form the basis for determining both when new equipment additions are needed and the effectiveness of new alternatives to solve present deficiencies and meet future system requirements. The load flow model is also the basis for several other types of studies such as short-circuit, stability, motor starting, and harmonic studies as it supplies the network data and an initial steady-state condition for these studies.

A. Load Flow Data Input

The input of data to the program may either be in per unit or in physical units, depending on program convention. Selection of the base kVA and base voltage specifies the base impedance and current. Bus Data: The data includes Bus number, Bus name, Bus type, Load, Shunt, Per unit voltage and angle, and Bus base kV. The bus number is normally the primary index to the information about the bus. Typically, the four bus types are Load bus (define P, Q), Generator bus (define P, V), Swing bus (define V, δ), and Disconnected bus. Load is normally entered in MW and MVar at nominal voltage. Load can be selected constant MVA, constant current or constant admittance as required. Care must be taken to ensure the proper sign convention is used to distinguish reactors from capacitors as defined for the particular load flow program being used. Generator Data: Generator data is entered for each generator in the system including the system swing generator. The data defines the generator power output and how the generator controls voltage. The data items normally entered are Real power output in MW, Maximum/ Minimum reactive power output in MVar (i.e., machine maximum/ minimum reactive limit), and Generator in-service/out-of-service code. Other data items that may be included are the generator MVA base and the generator's internal impedance for use in short-circuit and dynamic studies. Some programs may allow a generator to regulate a remote bus voltage. Branch Data: Data is also entered for each branch in the system. Here the term "branch" refers to all elements that connect two buses including transmission lines, cables, series reactors, series capacitors, and transformers. The data items include Resistance, Reactance, Charging susceptance (shunt capacitance), Line ratings (Rating A, B, C), Line in-service/out-of-service code, Line-connected shunts, and Multi sections lines that include series capacitor at the ends. A series reactor, series capacitor, or transformer would not have a charging susceptance term. The modeling of the charging susceptance is often ignored for short overhead lines and industrial plant systems. Transformer Data: This usually includes Tap setting in per unit, Tap angle in degree, Maximum tap position, Minimum tap position, Scheduled voltage range with tap step size or a fixed scheduled voltage using a continuous tap approximation. The organization of transformer tap data requires an understanding of the tap convention used by the load flow program to ensure the representation gives the correct boost or buck in voltage. Transformers whose rated primary or secondary voltages do not match the system nominal (base kV) voltages on the terminal buses will require an off-nominal tap representation in the load flow (and possibly require corresponding adjustment of the transformer impedance).

B. Solution Tools

Many types of software are available for Load Flow. Transmission planners in North America use PSS/E from PTI Siemens and PSLF software from GE for system impact study. In addition software MUST software from PTI or similar software from GE software is also utilized for system planning. FCITC using PTI software MUST can be used to determine the line rating upgrade required for the amount of power required for transfer.
IV. SHORT CIRCUIT STUDY

Short-circuit studies [3], [6-9] are done to determine the magnitude of the prospective currents flowing throughout the power system at various time intervals after a fault occurs. The magnitude of the currents flowing varies with time until they reach a steady-state condition. During this time, the protective system is called on to detect, interrupt, and isolate these faults. The duty imposed on this equipment is dependent upon the magnitude of the current, which is dependent on the time from fault inception. This is done for various types of faults at different locations throughout the system and the information is used to select fuses, breakers, and switchgear ratings in addition to setting protective relays.

Short-circuit studies can be performed at the planning stage in order to help finalize the system layout, determine voltage levels, and size cables, transformers, and conductors. For existing systems, fault studies are necessary in the cases of added generation, installation of extra rotating loads, system layout modifications, rearrangement of protection equipment, verification of the adequacy of existing breakers, relocation of already acquired switchgear in order to avoid unnecessary capital expenditures, etc. The great majority of short-circuit studies in industrial and commercial power systems address one or more from the four kinds of faults namely three-phase fault, single line-to-ground fault, line-to-line fault (any two phases shorted together), and double line-to-ground fault.

Three-phase short circuits often turn out to be the most severe of all. It is thus customary to perform only three phase-fault simulations when seeking maximum possible magnitudes of fault currents. However, important exceptions do exist. For instance, single line-to-ground short-circuit currents can exceed three-phase short-circuit current levels when they occur in the vicinity of solidly grounded synchronous machine, and auto and three winding transformer with delta tertiary, wye winding grounded and in these cases, it is advisable to perform a single line-to-ground fault simulation. The fact that medium- and high-voltage circuit breakers have 15% higher interrupting capabilities for single line-to-ground faults compared to three phase. Ground fault should be taken into account, if elevated line-to-ground fault currents are found. Line-to-line or double line-to-ground fault studies is also required for protective device coordination requirements. It should be noted that, since only one phase of the line-to-ground fault can experience higher interrupting requirements, the three-phase fault will still contain more energy because all three phases will experience the same interrupting requirements. Other types of faults are series faults, which may include one line open, two lines open or three lines open.

Fault current includes the AC and DC component. Industry standards dictate certain analytical techniques that adhere to specific guidelines, suited to address the questions of ac and dc decrement in multi-machine systems in compliance with well-established, industry-accepted practices. Typical standards are the North American ANSI and IEEE C37 standards and recommended practices, the international standard, IEC 60909 (1988) and others, such as the German VDE 0102-1972 and the Australian AS 3851-1991.

Three types of short-circuit currents, depending on the time frame of interest taken from the inception of the fault, are defined as:

- First cycle currents – momentary or 1/5 cycle
- Interrupting currents – 3–5 cycles
- Time delayed currents – steady state fault current

Typical data is required for the short circuit study. Start from the load flow case and enter the required information for the Short circuit study, which are Utility system equivalent and X/R ratio, Synchronous machine size, subtransient, transient reactance, Induction motors size and locked rotor current, Transformer size, sequence impedances, X/R ratio, Transmission lines and cables sequence impedances.

For the short circuit solutions may require replacing the switchgear, reorganizing the system, adding series reactor or delay the tripping in a rare cases (tripping during the steady state). Many software’s namely PSS/E, PSLF, ASPEN, CAPE, ETAP etc. can be used for the short circuit analysis and produce reports in various formats.

V. MOTOR STARTING STUDY

During the motor starting period, the starting motor appears to the system as small impedance connected to the bus. It draws a large amount of current from the system about six times (vary depending upon the locked rotor current) the motor rated current, which may result in the voltage drop and results in disturbance for other operating loads. Since the motor acceleration torque is dependent on the motor terminal voltage, in some cases motor may not be able to reach to the rated speed due to low acceptable voltage and may stall.

Motor starting study [3], [4], [7], [8] will determine whether the largest motor can be started successfully for the worst system conditions. In some cases multiple motor needs to be started at the same time due to process requirement. Worst case should be considered. The voltage dip should also be monitored and should be acceptable. According to the IEEE standard 399, a motor starting study should be performed if the motor horse-power exceeds approximately 30% of the supply transformer base KVA rating if no generators are present. If only generators are present, a study is required if the motor horse-power exceeds 10 to 15% of generator KVA rating. Different methods are available for motor starting i.e. series impedance starting, auto-transformer starting, wye/delta starting, soft start etc.

Two types of motor starting can be performed static and dynamic. Typical data required is:

- Motor nameplate, inertia constant, LR current etc.
- Utility and generator impedances and size
- Transformer - refer IEEE C37-010-1979 for typical transformer data and X/R ratio if actual information is not available
- Cables - number, size, shielding, conductor material etc.
- Load - type (constant current, constant impedance or constant MVA), power factor, load factor and inrush characteristics
- Motor and Load - speed torque curve, detailed test report of motor, motor equivalent circuit parameters, detail about single cage, double cage, starting time and Wk2 (inertia) including motor and load

Many software such ETAP, SKM and PSS/E can perform both the static and dynamic motor starting studies also. Detailed library about the motor models is also available in these software.

VI. TRANSIENT STABILITY STUDY

For years, system stability was a problem almost exclusively to electric utility engineers. Small IPPs and co-generation (co-gen) companies were treated as part of the load and modeled casually. However with generation and synchronous motors available now with IPPs, it is important to study transient stability of these systems to avoid system/grid failures [3]-[5], [10].

System disturbances that can cause instability are short circuits, loss of a tie circuit to a public utility, loss of a portion of on-site generation, starting a motor that is large relative to a system generating capacity, switching operations, impact loading on motors, abrupt decrease in electrical load on generators, and protection mal-operation or equipment failure.
A. Solution to Stability Problems

System design primarily affects the amount of synchronizing power that can be transferred between machines. Two machines connected by a low impedance circuit, such as a short cable or bus run, will probably stay synchronized with each other under all conditions except a fault on the connecting circuit, a loss of field excitation, or an overload. The greater the impedance between machines, the less severe a disturbance will be required to drive them out of step. For some systems, the dynamic stability problems could be resolved by the construction of new connecting circuits.

Selection of rotating equipment and control parameters can be a major contributor to improving system stability. Most obviously, use of induction instead of synchronous motors eliminates the potential stability problems associated with the latter. However, economic considerations often preclude this solution. Where synchronous machines are used, stability can be enhanced by increasing the inertia of the mechanical system. Since the H constant (stored energy per rated kVA) is proportional to the square of the speed, fairly small increases in synchronous speed can pay significant dividends in higher inertia. A further possibility is to use synchronous machines with low transient reactance that permit the maximum flow of power that can be transferred between machines. Two machines run, will probably stay synchronized with each other under all conditions except a fault on the connecting circuit, a loss of field excitation, or an overload.

Voltage regulator and exciter characteristics affect stability because, all other things being equal, higher field excitation requires a smaller rotor angle. Consequently, stability is enhanced by a properly applied regulator and exciter that respond rapidly to transient effects and furnish a high degree of field forcing.

The PSS installation has been widely used in the power industry to improve the system damping. The basic function of a PSS is to extend stability limits by modulating generator excitation to provide damping to the oscillation of a synchronous machine rotor. To provide damping, the PSS must produce a component of electrical torque on the rotor that is in phase with speed variations.

The data is required for the study is System data, Impedance (R + jX) of all significant transmission lines, cables, reactors, and other series components, For all significant transformers/auto-transformers, kVA rating, impedance, voltage ratio, winding connection, available taps and tap in use, For regulators and load tap-changing transformers (regulation range, tap step size, type of tap changer control), Short-circuit capacity of utility supply, KVar of all significant capacitor banks, Description of normal and alternate switching arrangements, Load data (real and reactive electrical loads on all significant load buses in the system).

Rotating machine data required is Mechanical and/or electrical power ratings (kVA, hp, kW, etc.), speed, Real and reactive loading, if base-loaded generator, Inertia constant H or inertia Wk2 of rotating machine and connected load or prime mover, Speed torque curve or other description of load torque, Direct-axis and quadrature-axis subtransient, transient, and synchronous reactance, Direct-axis and quadrature-axis subtransient and transient time constants, Saturation information, Damping data, Excitation system type, time constants, and limits, Governor and steam system or other prime mover type, time constants, and limits.

For major induction machines or groups of machines data required is Mechanical and/or electrical power ratings, inertia, speed, Positive-sequence equivalent circuit data (e.g., R1, X1, Xm) and Negative-sequence equivalent circuit data (e.g., R2, X2), Load speed-torque curve, Description of reduced-voltage or other starting arrangements, if used

Disturbance data required is General description of disturbance to be studied, including (as applicable) initial switching status; fault type, location, and duration; switching operations and timing; manufacturer, type, and setting of protective relays; and clearing time of associated breakers, Limits on acceptable voltage, current, or power swings.

Study parameters used for monitoring and system performance evaluation are Duration of study, integrating interval, output printing interval and data output required, Rotor angles, torques, and speeds of synchronous machines, Real and reactive power flows throughout the system, Voltages and voltage angles at all buses, Bus frequencies, Torques and slips of all induction machines.

For the analysis of stability study, it may be required to model the under/over voltage, under/over frequency and other protections on the major equipments near to the area of study, to make sure that study is done correctly. For the stability studies typically a slack machine or swing machine with very big generation is considered to be reference machine. The machine angles of other machines are studied during various fault conditions and breaker failure conditions for various load flow conditions. The critical clearing angle is determined for various fault conditions. Protection engineers will plan the protection scheme accordingly.

Transmission planners in North and South America use the Siemens PTI software PSS/E and GE software PSLF for the transmission planning studies. For the islanded and refineries OTI software ETAP and SKM Powertools is used. In some cases where very small system is under study, RTDS, EMTP and EMPT RV can also be used for stability analysis, where real time testing of the system is also required.

VII. INSULATION COORDINATION

The purpose of the insulation coordination study [3], [11] is to determine the selection of the dielectric strength of equipment in relation to the voltages which can appear on the system for which the equipment is intended and taking into account the service environment and the characteristics of the available protective devices. IEEE Std 1313.1-1996 identifies classes and shapes of different types of over-voltages. There are many possible causes for each of the different types of over-voltage. Some of the common over-voltages are:

- Temporary over-voltages that are caused by faults, load rejection, line energizing, resonance conditions, Ferro-resonance, or by some combination of these factors
- Switching (slow-front) over-voltages that are caused by switching operations, fault initiation, or remote lightning strokes
- Lightning (fast-front) over-voltages that are caused primarily by lightning strikes but can also be caused by some switching operations or fault initiation
- Very fast-front over-voltages that are the result of switching operations or faults and are usually associated with high voltage disconnect switch operation, GIS, and cable connected motors

Degree and duration of phase-ground and longitudinal over-voltages for two types of substations are described below:

System substation: In a moderately extended system, for a full load rejection, the temporary over-voltage is usually less than 1.2 pu. The duration depends on the voltage control operation and may be up to several minutes. In extended systems, the over-voltages may reach 1.5 pu or even more when Ferranti effects or resonance occur. The duration may be in the order of seconds. The longitudinal over-voltage across a switching device is usually equal to the phase-ground over-voltage unless motors or generators, connected to the rejected side, produce phase opposition.
Generator station: For a full load rejection, the over-voltage at the substation may reach up to 1.5 pu. The duration may be up to 3 s depending on the generator characteristics and control. The longitudinal temporary over-voltage is the difference between the phase-ground operating voltage at one terminal and the phase-ground temporary over-voltage on the other terminal. In the case of phase opposition the longitudinal over-voltages could be as high as 2.5 pu.

Switching over-voltages may have times-to-crest from 20-500 μs and time to half value of less than 20000 μs. They are generally a result of the line energization, faults and fault clearing, load rejections, or switching of capacitive or inductive currents.

Switching studies are also required to study the breaker requirement for the TRV, capacitance and transformer switching. Lightning study can be used to determine the surge arresters and transmission line ground wire requirement in addition to the insulation requirement for transmission lines, transformers and others EHV equipments. RTDS from RTDS technologies, EMPT RV, PSCAD and ATP can be used for this analysis.

VIII. GROUND GRID ANALYSIS

The purpose of the ground grid analysis [12]-[14] is to limit the ground to the neutral voltage, present during ground fault, an average person can withstand. IEEE-standard 80 is the primary document for the ground grid design. The grounding system must be designed to limit:
- Ground potential rise of the substation ground mat to acceptable value
- Touch step and transfer voltages to acceptable limits

For GIS substation, special care should be taken as the Grid size is small, and all the equipments are housed in the pipe, which is insulated. GIS manufacturer should be consulted about the design of switchgear before any study.

For this study following parameters are required:
- Soil resistivity in the vicinity of earth grid
- Ground grid area and geometry
- Structure, parameters of interconnected system such as power system transformers connection, ground wires, transmission lines and types, tower grounds, ground rods, counterpoises, cables and grounding. Any ungrounded connection should also be observed and analyzed properly

CDEGS, ETAP, SKM Powertools or CYME can be used to model the power system connected to the substation and ground grid of the substation. The analysis can be performed to analyze the ground grid for limits as suggested in IEEE-80. The possible solutions to limit the potential hazard may include crushed rocks, more ground rods, counterpoise and/or denser ground grid. In some extreme cases it will be required to modify the connection of power system, modify the system grounding to limit the ground fault current, interconnection of nearby grids etc.

The typical study procedure requires Perform soil resistivity using Wenner method, Analyze soil resistivity and prepare soil model using software, Data collection and model of interconnected power system, Preliminary analysis and analysis of results, including step and touch potentials, Perform iterative solution to arrive at safe and cost effective solution, In some cases it may be required to propose two or three solutions with the cost comparison. This will give better understanding of the system,

The ground grid study can be extended to do the EMF study to analyze the effects of power lines that run in parallel to the pipelines and communication lines. Many states in USA and other parts of world require investigation of electric and magnetic field strengths. Many software tools are available to do this study. Typical data requirement is transmission line configuration, identifying the right of way, pipelines model, transmission lines crossing or in parallel to the right of way.

IX. CABLE AMPACITY STUDY

With the advancement of cables and new insulations, cables are also becoming popular for transmission of power at higher voltages specially for shorter distances. Ampacity is defined as "the current in amperes a conductor can carry continuously under the surrounding medium in which the cables are installed without exceeding its temperature rating." Cable ampacity study [3], [15] is the calculation of the temperature rise of the conductors in a cable system under steady-state conditions. The operating voltage determines the dielectric insulation requirement and the conductor sizes are dictated by the ampacity rating.

The cables are designed as per the characteristics defined by National Electrical Code® (NEC). The NEC procedure is based upon the Neher-McGrath method [15]. Typical cable installation may be, directly buried in the ground, underground submarine cables, underground cable using ducts or concrete encasing, low or high-pressure oil or gas filled etc. If multiple cables are installed next to each other, temperature rise of one cable may results in temperature rise of others also. The important factor in regards to the cable ampacity are the ambient temperature, thermal characteristics of the surrounding medium, heat generated by the conductor due to its own losses, and heat generated by adjacent conductors.

Information required for the cable ampacity analysis is System data including system voltage, frequency and ambient temperature, Duct bank/ conduit location including the cable locations, Conduit and pipe data including dimensions, Conductor data including conductor type, conductor size, resistivity, dielectric constant, dissipation factor, types and thickness of insulations, sheath information etc., Number of circuit in duct banks, number of conductors in pipe, operating current, and voltage, current per phase etc.

Many software packages also provide the comprehensive library about the cable models. Software’s such as ETAP, SKM, and CAPE etc. can be used for steady state cable ampacity and duct banks analysis.

X. FLICKER, PF CORRECTION, HARMONIC ANALYSIS

The reactive power fluctuations caused due to the arc furnaces, traction loads and motor starting, can be mitigated using the Static var compensators, Harmonic filters, motor generator sets, and super conducting magnetic energy storage (SMES). For flicker analysis, the performance characteristic of load, arc furnace transformer tap, real, reactive power, MVA, PF of arc furnace at various operating loads and system impedance data is required [11], [16].

For correcting the PF of the system, capacitor placement and sizing studies are required. Most of the utilities use capacitor banks to correct the PF. Other studies are required, if capacitor sizing is required. For this, power system model is required and for the steady state analysis load flow programs are used to analyze the size and location of capacitor bank. The capacitor bank is selected to maintain normal system voltage during all the contingencies. The capacitor banks switching may be required in stages, to eliminate the over-voltages during the various operating conditions.

For the switching study, system model in the software like EMTP is required. For the harmonic analysis, frequencies scan study is required, which can be performed using EMTP RV, ETAP or others. For harmonic analysis it is also important to verify the total...
harmonic distortion (THD) and total demand distortion (TDD) as per the IEEE standard 519.

Voltage magnification is also of importance if the capacitor banks are installed very close such as high side and low side of transformers and resonance frequencies are almost equal. For back-to-back capacitor bank switching series reactors may be required to limit the inrush. It may be required to perform analysis to size the reactors to limit the inrush and outrush currents. TRV’s are the voltages measured across the breaker poles after opening. The severity depends upon the magnitude and rate of rise of voltage across the contact. Based on ANSI C37.90, the breaker switching capability is tested at the maximum TRV of 2.5 p.u.

RTDS from RTDS technologies, EMPT RV, PSCAD and ATP can be used for this analysis. ETAP and SKM Powertools can also perform harmonic analysis. However if the study requires studying any complex project including HVDC, Power Electronics, Wind farm etc., and analysis using PSCAD or EMTP will be required.

XI. ARC-FLASH STUDY

Arc-Flash studies estimate incident energy exposure from potential arc sources [17]-[19]. Arc-flash studies are defined as per the IEEE 1584 2003, and NFPA 70E 2004 to calculate incident energy, and personnel protective equipment (PPE). The Arc-flash study should be performed for the maximum and minimum fault levels. The solution to reduce Arc-flash may require changing the relay settings, using correct PPE, and installing a faster protection scheme i.e. differential and high-speed bus protection. PPE labels should be installed to make people aware of the PPE requirement. SKM Powertools and ETAP can be used for Arc flash study.

XII. RELAY COORDINATION STUDY

Protective devices are used to protect the system in the event of fault. The protective devices in addition to the discrimination disconnect the minimum system. Relay coordination study [6], [20] is required for the protective devices selection and settings. For this study system model is required including equivalent power system, generator, transformer, line, cables and loads including the motors. The system model case used for short circuit study can also be used for this study. Existing relays and new relays are modeled with the settings and coordination is verified for the various operating conditions. PSS/E, ASPEN, ETAP, SKM, CYME or CAPE is some of the tools that can be used for this analysis.

A typical substation or generating station may include transformer, reactor, capacitor bank, circuit breakers, CT, CCVT, bus, transmission line, generator, motor wave trap, surge arrester. For the new substation/generating station and system expansion, substation engineer and protection engineer will decide about the substation layout and switchgear. Study will be required such as load flow, short circuit, motor starting, switching, insulation coordination, ground grid, lightning, stability studies and harmonic analysis etc. depending upon the system and customer requirement.

Protection engineer may require protection setting for the generator protection, transformer/reactor protection, line protection, bus protection, motor protection, and shunt capacitor bank. Planning department and substation engineers perform the future expansion and substation design studies. Based upon the study and system requirements, switchgear is selected and approved. This may require knowledge and understanding of protection system i.e. CT, PT selection and adequacy of system analog signals for the protection scheme and relays proposed, existing protection schemes in the nearby substations and existing system relay coordination problems.

Protection engineer will select the protection scheme based upon the system planning report and will subsequently prepare the relay coordination of the new relays with the existing relays, prepare relay settings, and also perform testing and commissioning of relays and protection scheme. With the modern digital relays, controls like HMI and SCADA can be performed from remote to monitor and control.

XIII. SUMMARY

This paper provides an overview of North American power map, procedures for system planning and protection studies. This paper also provides various studies, recently developed sophisticated techniques and software tools for system planning and protection, practiced and available in the North American power sector, and also indicates the studies for which engineer with the understanding of both protection and system planning is preferred. North American Power System is one of the biggest, very advance and sophisticated system and most of the latest techniques and power engineering practices find their practical implementation there. With current expansion of power infrastructure going on world wide, especially in the developing countries, with very high economic growth rate, like India and China, we sincerely believe the present overview paper documenting the latest system planning and protection practices prevalent in North American power system will come up as an excellent reference document for practicing power engineers, academicians and researchers in developing countries and will be of immense help in increasing their horizon of knowledge in these areas.

REFERENCES

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