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A PRAGMATIC ANALYIS OF POWER SYSTEM STABILITY AND RELATED DIMENSIONS

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ABSTRACT

Successful operation of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to the loads. This means that both voltage and frequency at all loads must be held within acceptable tolerances so that the consumer's equipment will operate satisfactorily! In order to achieve that two requirements are necessary; directly, the system generators should run synchronously in step and with adequate capacity to meet the load demand. Secondly, J the integrity of the power network should 'be maintained to ensure continuity of service. Power systems occasionally suffer perturbations. These perturbations may be small originating from random changes in loads or they may be severe arising out of a fault on the network, a sudden application of 8 major load, or loss of a line or a generating unit. These perturbations may cause the power system to go from one equilibrium state (operating condition) to another. Continued successful operation of the system depends upon a staple transition to the operating condition. The study of the behavior of the system in transition period is described as power system stability analysis. The transient following the system perturbation is oscillatory In nature. If the system is stable, these oscillations will be damped toward either: (a) the original operating condition if there is no net change in power or (b) new operating condition if there is any unbalance between the supply and demand due to this perturbation. In either case all interconnected synchronous machines should maintain in synchronism if the system is to remain stable.

Keywords - Power System Stability, Electrical Power Management, Power Optimization

PREAMBLE

Steady state stability refers to the stability of a power system subject to small and gradual changes in loads - the system remains stable with conventional excitation and governor controls.

Dynamic stability refers to the stability of a power system subject to a relatively small and sudden disturbance : the system can be described by linear differential equations. Typical examples are the low frequency oscillations of interconnected large power systems and the torsional oscillations of a steam electric power plan.

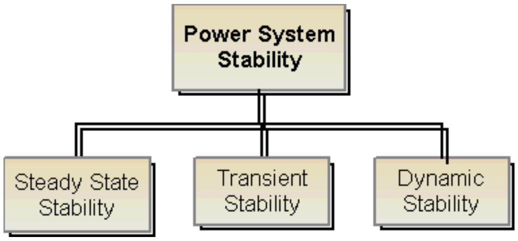

Figure 1 - Power System Stability

Transient stability refers to the stability of a power system subject to a sudden and severe disturbance. For this definition to apply the system must be described by differential equations which may be nonlinear. Typical examples resulting in transient stability analysis include a fault on the network, sudden application of a major load, or loss of a time or generating unit.

POWER SYSTEM STABILITY PROBLEM

By nature, a power system continually experiences two types of disturbances: event disturbances and load disturbances (Anderson and Fouad, 2003; Balu et al., 1992). Event disturbances include loss of generating units or transmission components (lines, transformers, and substations) due to short circuits caused by lightning, high winds, failures such as incorrect relay operations or insulation breakdown, or a combination of such events. Event disturbances usually lead to a change in the configuration of power networks. Load disturbances, on the other hand, are the sudden large load changes and the small random fluctuations in load demands. The configuration of power networks usually remains unchanged after load disturbances. To protect power systems from damage due to disturbances, protective relays are placed strategically throughout a power system to detect faults (disturbances) and to trigger the opening of circuit breakers necessary to isolate faults. These relays are designed to detect defective lines and apparatus or other power system conditions of an abnormal or dangerous nature and to initiate appropriate control actions. Due to the action of these protective relays, a power system subject to an event disturbance can be viewed as going through network configuration changes in three stages: the prefault, the fault - on, and the postfault systems.

CLASSIFICATION OF STABILITY

Power system stability is a single problem; however, it is impractical to study it as such. Instability of a power system can take different forms and can be influenced by a wide range of factors. Analysis of stability problems, identification of essential factors that contribute to instability, and formation of methods of improving stable operation are greatly facilitated by classification of stability into appropriate categories.

These are based on the following considerations:

- The physical nature of the resulting instability
- The size of the disturbance considered
- The devices, processes, and time span that must be taken into consideration in order to determine stability
- The most appropriate method of calculation and prediction of stability.

As a practical necessity, the classification has been based on a number of diverse considerations, making it difficult to select clearly distinct categories and to provide definitions that are rigorous and yet convenient for practical use. For example, there is some overlap between mid-term long-term stability and voltage stability. With appropriate models for loads, on-load transformer tap changers and generator reactive power limits, mid-term long-term stability simulations are ideally suited for dynamic analysis of voltage stability. Similarly, there is overlap between transient, mid-term and long-term stability: all three use similar analytical techniques for simulation of the nonlinear time domain response of the system to large disturbances. Although the three categories are concerned with different aspects of the stability problem, in terms of analysis and simulation they are really extensions of one another without clearly defined boundaries. While classification of power system stability is an effective and convenient means to deal with the complexities of the problem, the overall stability of the system should always be kept in mind. Solutions to stability problems of one category should not be at the expense of another. It is essential to look at all aspects of the stability phenomena and at each aspect from more than one viewpoint. This requires the development and wise use of different kinds of analytical tools. In this regard, some degree of overlap in the phenomena being analyzed is in fact desirable.

HISTORICAL REVIEW OF POWER SYSTEM STABILITY

Power system stability is a complex subject that has challenged power system engineers for many years. A review of the history of the subject is useful for a better understanding of present-day stability problems.

The stability of power systems was first recognized as an important problem in 1920. Results of the first laboratory tests on miniature systems were reported in 1924; the first field tests on the stability on a practical power system were conducted in 1925. Early stability problems were associated with remote hydroelectric generating stations feeding into metropolitan load centers over long-distance transmission. For economic reasons, such systems were operated close to their steady- state stability limits. In a few instances, instability occurred during steady-state operation, but it occurred more frequently following short-circuits and other system disturbances.

The stability problem was largely influenced by the strength of the transmission system, with instability being the result of insufficient synchronizing torque. The fault clearing times were slow, being in the order of 0.5 to 2.0 seconds or longer.

The methods of analysis and the models used were dictated by developments in the art of computation and the stability theory of dynamic systems. Slide rules and mechanical calculators were used; hence, the models and methods of analysis had to be simple. In addition, graphical techniques such as the equal-area criterion and circle diagrams were developed. Such techniques were adequate for the analysis of the simple systems that could be treated effectively as two-machine systems. Steady-state and transient stability were treated separately. The former was related to the slope and peak of the power-angle curve; it was taken for granted that damping was positive. As power systems evolved and interconnections between independent systems were found to be economically attractive, the complexity of the stability problems increased. Systems could no longer be treated as two-machine systems. A significant step towards the improvement of stability calculations was the development in 1930 of the network analyzer (or the ac calculating board). A network analyzer is essentially a scaled model of an ac power system with adjustable resistors, reactors and capacitors to represent transmission network and loads, voltage sources whose magnitude and angle can be adjusted to represent generators, and meters to measure voltages, currents, and power anywhere in the network. This development permitted power-flow analysis of multi machine systems; however, the equation of motion or the swing equation still had to be solved by hand using step-by-step numerical integration. The theoretical work carried out in the 1920s and early 1930s laid the foundation for the industry's basic understanding of the power system stability phenomena. The principal developments and knowledge of power system stability in this early period came about as a result of the study of long-distance transmission, rather than as an extension of synchronous machine theory. The emphasis was on the network; the generators were viewed as simple voltage sources behind fixed reactances, and loads were considered as constant impedances. This was a practical necessity since the computational tools available during this period were suited for solution of algebraic equations, but not differential equations. Improvements to system stability came about by way of faster-fault clearing and continuous-acting voltage regulators with no dead band. The benefits of an excitation system with a high degree of response for increasing steady-state stability were in fact recognized in the early 1920s; however, initially this region of "dynamic stability" was not recommended for normal operation but was treated as additional margin in determining operating limits. With the increased realization of the potential benefits of faster-responding excitation systems in limiting first-swing transient instability as well as increasing steady-state power transfer limits, their use became more commonplace. However, the use of high-response exciters in some cases resulted in decreased damping of power swings. Oscillatory instability thus became a cause for concern, while steady-state monotonic instability was virtually eliminated. These trends required better analytical tools. Synchronous machine and excitation system representation had to be more detailed and simulations had to be carried out for longer time periods.

In the early 1950s, electronic analog computers were used for analysis of special problems requiring detailed modelling of the synchronous machine, excitation system, and speed governor. Such simulations were suited for a detailed study of the effects of equipment characteristics rather than the overall behavior of multi machine systems. The 1950s also saw the development of digital computers: the first digital computer program for power system stability analysis was developed about 1956. The models used in the early stability programs were similar to those of network analyzer studies. It was soon recognized that digital computer programs would allow improvements over network analyzer methods in both the size of the network that could be simulated and the modelling of equipment dynamic characteristics. They would provide the ideal means for the study of stability problems associated with growth in interconnections between formerly separate power systems. In the 1960s, most of the power systems in the United States and Canada were joined as part of one of two large interconnected systems, one in the east and the other in the west. In 1967, low capacity HVDC ties were also established between the east and west systems. At present, the power systems in the United States and Canada form virtually one large system. While interconnections result in operating economy and increased reliability through mutual assistance, they also contribute to increased complexity of stability problems and increase the consequences of instability. The northeast blackout of November 9, 1965 made this abundantly clear; it brought the problem of stability and the importance of power system reliability beyond the focus of engineers and to the attention of the public and of the regulatory agencies. Much of the industry effort and interest related to system stability since the 1960s has been concentrated on transient stability. Power systems are designed and operated to criteria concerning transient stability. As a consequence, the principal tool for stability analysis in power system design and operation has been the transient stability program. Very powerful programs have been developed, with facilities for representing very large systems and detailed equipment models. This has been greatly facilitated by developments in numerical methods and digital computer technology. There have also been significant developments in equipment modelling and testing, particularly for synchronous machines, excitation systems, and loads. In addition, significant improvements in transient stability performance of power systems have been achieved through use of high-speed fault-clearing, high initial-response exciters, series capacitors, and special stability aids. Accompanying the above trends has been an increased tendency of power systems to exhibit oscillatory instability. Higher-response exciters, while improving transient stability, adversely affect small-signal stability associated with local plant modes of oscillation by introducing negative damping. The effects of fast exciters are compounded by the decreasing strength of transmission systems relative to the size of generating stations. Such problems have been solved through use of power system stabilizers.

Another source of the oscillatory instability problem has been the formation, as a consequences of growth in interconnections among power systems, of large groups of closely coupled machines connected by weak links. With heavy power transfers, such systems exhibit interarea modes of oscillation of low frequency. In many situations, the stability of these modes has become a source of concern. Present trends in the planning and operation of power systems have resulted in new kinds of stability problems. Financial and regulatory conditions have caused electric utilities to build power systems with less redundancy and operate them closer to transient stability limits. Interconnections are continuing to grow with more use of new technologies such as multi terminal HVDC transmission. More extensive use is being made of shunt capacitors. Composition and characteristics of loads are changing. These trends have contributed to significant changes in the dynamic characteristics of modern power systems. Modes of instability are becoming increasingly more complex and require a comprehensive consideration of the various aspects of system stability. In particular, voltage instability and low-frequency interarea oscillations have become greater sources of concern than in the past. Whereas these problems used to occur in isolated situations, they have now become more commonplace. The need for analyzing the long-term dynamic response following major upsets and ensuring proper coordination of protection and control systems is also being recognized. Significant research and development work has been undertaken in the last few years to gain a better insight into physical aspects of these new stability problems and to develop analytical tools for their analysis and better system design. Developments in control system theory and numerical methods have had a significant influence on this work.

LITERATURE REVIEW

Abro, Abdul Ghani, and Junita Mohamad-Saleh (2012) - Electric power grid is a widely distributed system, consisting of dispersed generators interconnected through transmission lines, mounting real and reactive power compensators, etc. Moreover, with deregulation and growth of the power industry, power systems elements are forced to operate very near to their maximum capacity and hence, the system became vulnerable. Therefore, controlled operation of power systems is very critical and of utmost importance in order to achieve stable power system. Naturally, this paves ways for implementing fast, efficient and reliable control algorithms. Robustness and efficiency of power system controllers can be improved by using complimentary paradigms of intelligent systems; neural networks, fuzzy logic and bio-inspired optimization algorithms. Difficulties encountered in designing controls for nonlinear, dynamic and uncertain systems can be easily tackled by using intrinsic observability property of various intelligent systems. The other advantage of intelligent system is lesser modeling error, which leads to efficient control loop. Intelligent controllers have been successfully applied to enhance operation and control of power system. This paper reviews and summarizes implementation of intelligent controllers at the generator end of power systems, during the past decade. Few proposals are also given for further investigation in the realm discussed in this paper

Abido(2009) - In recent years, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system steady state control problems. However, recent studies reveal that FACTS controllers could be employed to enhance power system stability in addition to their main function of power flow control. The literature shows an increasing interest in this subject for the last two decades, where the enhancement of system stability using FACTS controllers has been extensively investigated. This paper presents a comprehensive review on the research and developments in the power system stability enhancement using FACTS damping controllers. Several technical issues related to FACTS installations have been highlighted and performance comparison of different FACTS controllers has been discussed. In addition, some of the utility experience, real-world installations, and semiconductor technology development have been reviewed and summarized. Applications of FACTS to other power system studies have also been discussed. About two hundred twenty seven research publications have been classified and appended for a quick reference

Atputharajah (2009) - Increasing electrical energy demand, modern lifestyles and energy usage patterns have made the world fully dependant on power systems. This instigated mandatory requirements for the operators to maintain high reliability and stability of the power system grid. However, the power system is a highly nonlinear system, which changes its operations continuously. Therefore, it is very challenging and uneconomical to make the system be stable for all disturbances. The system is usually designed to handle a single outage at a time. However, during the last decade several major blackouts were reported and all of them started with single outages. Each major blackout was mandatorily and transparently reported to the public. The properly written blackout reports help to minimize the operational risk, by strengthening the system and its operations based on selected high risk contingencies. In the last decade, several major blackouts were reported separately in many research papers. This paper lists a good collection of properly reported literatures on power system stability and reliability including history of blackouts. Some critical comments on root causes, lessons learnt from the blackouts and solutions are addressed while briefly discussing the blackout events presented in published literatures.

Kundur (1994) - Voltage stability is a major concern in the planning and operation of electric power systems. This is the first book to provide a clear, in-depth explanation of voltage stability, covering both transient and longer-term phenomena and presenting proven solution to instability problems. An essential tool for all electric power and utility engineers, the book describes equipment characteristics for transmission, generation, and distribution/load subsystems of a power system, together with methods for the modeling of equipment. Readers will find static and dynamic computer simulation examples for both small equivalent power systems and for a very large power system, plus an account of voltage stability associated with HVDC links. They will also get helpful planning and operating guidelines, computer methods for power flow and dynamic simulation, and descriptions of actual voltage instability incidents.

Kundur (2004) - Joint task force on stability terms and definitions - The problem of defining and classifying power system stability has been addressed by several previous CIGRE and IEEE Task Force reports. These earlier efforts, however, do not completely reflect current industry needs, experiences and understanding. In particular, the definitions are not precise and the classifications do not encompass all practical instability scenarios. This report developed by a Task Force, set up jointly by the CIGRE Study Committee 38 and the IEEE Power

System Dynamic Performance Committee, addresses the issue of stability definition and classification in power systems from a fundamental viewpoint and closely examines the practical ramifications. The report aims to define power system stability more precisely, provide a systematic basis for its classification, and discuss linkages to related issues such as power system reliability and security.

TRANSIENT STABILITY USING NUMERICAL METHODS

This subject is the part of numerical analysis which studies the methods for finding numerical approximations to the solutions of ordinary differential equations (ODEs). This field is also known under the name numerical integration, but some people reserve this term for the computation of integrals.

Many differential equations cannot be solved analytically; however, in science and engineering, a numeric approximation to the solution is often good enough to solve a problem. The algorithms studied here can be used to compute such an approximation. An alternative method is to use techniques from calculus to obtain a series expansion of the solution.

Ordinary differential equations occur in many scientific disciplines, for instance in physics, chemistry, biology, and economics. In addition, some methods in numerical partial differential equations convert the partial differential equation into an ordinary differential equation, which must then be solved.

NUMERICAL INTEGRATION METHODS

EULER METHOD

Consider the first-order differential equation

$$dx/dt=f(x,t)$$

with $x=x_o$ at $t=t_o$' Figure illustrates the principle of applying the Euler method.

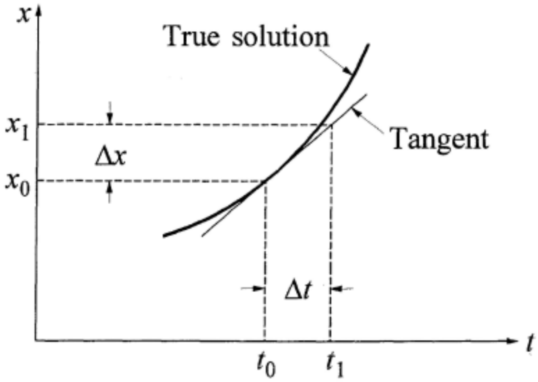

Figure 2 - True Solution and Tangent

The Euler Method is equivalent to using the first two terms of the Taylor Series expansion for x around the point (x0, t0)

$$x1 = x0 + \Delta t\ (x0) + \Delta t^2/2!\ (x_0) + \Delta t^3/3!(x_0) + \ldots$$

After using the Euler technique for determining x=x1 corresponding to $t=t_l$ we can take another short time step and determine x_2 corresponding to $t_2 =t_l + \Delta t$ as follows:

$$x_2 = x_1 + dx/dt\ (x=x_1)\ .\ \Delta t$$

By applying the technique successively, values of x can be determined corresponding to different values of t. The method considers only the first derivative of x and is, therefore, referred to as a first-order method. To give sufficient accuracy for each step, Δt has to be small. This will increase round-off errors, and the computational effort required will be very high. In the application of numerical integration methods, it is very important to consider the propagation of error, which may cause slight errors made early in the process to be magnified at later steps. Numerical stability depends on the propagation of error. If early errors carry through but cause no significant further errors later, the method is said to be numerically stable. If, on the other hand, early errors cause other large errors later, the method is said to be numerically unstable.

Modified Euler Method

The standard Euler method results in inaccuracies because it uses the derivative at the beginning of the interval as though it applied throughout the interval. The modified Euler method tries to overcome this problem by using the average of the derivatives at the two ends.

The modified Euler method consists of the following steps:

(a) Predictor step. By using the derivative at the beginning of the step, the value at the end of the step is predicted

$$x_1{}^p = x_0 + \frac{dx}{dt} \quad x{=}x_0 \,.\, \Delta t$$

(b) Corrector step. By using the predicted value of xf, the derivative at the end of the step is computed and the average of this derivative and the derivative at the beginning of the step is used to find the corrected value

$$x_1{}^p = x_0 + \frac{dy}{dx}\, x{=}x_0 \,.\, \Delta t$$

If desired, a more accurate value of the derivative at the end of the step can be calculated, again by using x =xf. This derivative can be used to calculate a more accurate value of the average derivative which is in turn used to apply the corrector step again. This process can be used repeatedly until successive steps converge with the desired accuracy. The modified Euler method is the simplest of predictor-corrector (P-C) methods. Among the well known higher order P-C methods are the Adams-Bashforth method, Milne method, and Hamming method.

The applicability of these methods to power system stability analysis has been investigated and has been found to suffer from a number of limitations.

Runge-Kutta (R-K) Methods

The R-K methods approximate the Taylor series solution; however, unlike the formal Taylor series solution, the R-K methods do not require explicit evaluation of derivatives higher than the first. The effects of higher derivatives are included by several evaluations of the first derivative. Depending on the number of terms effectively retained in the Taylor series, we have R-K methods of different orders .

Second-order R-K method

This method is equivalent to considering first and second derivative terms in the Taylor Series; error is on the order of Δt^3

TRAPEZOIDAL METHOD

In order to reduce the error, instead of approximating $f(x, t)$ by $f(x0, t0)$, one can approximate $f(x, t)$ by 12 $[f(x0, t0) + f(x1, t1)]$.

This is called the trapezoidal rule, which obtains
$x_1 = x_0 + h/2\ [f(x_0, t_0) + f(x_1, t_1)]$

But then, we need to assume some approximate value of $x1$. A possible way of doing that is to take clue from the Euler method, that is, by assuming $x1 = x0 + hf(x0, t0)$.

This is also called the second order Runge Kutta formula.

It can be shown that the error per step in this method is of the order of h3, which is considerably smaller than that in the Euler's Method.

For further iterates, one has to obtain k1 and k2 for each step, and xn+1 is calculated as

$$x_{n+1} = x_n + \frac{1}{2} (k_1+k_2)$$

CONCLUSION

Power System Stability is one of the key attribute and dimension in the electrical power system. It is mainly concerned with the production of electrical power and its transmission from the sending end to the receiving end as per consumer requirements, incurring minimum amount of losses. The power at the consumer end is often subjected to changes due to the variation of load or due to disturbances induced within the length of transmission line. For this reason the term power system stability is of utmost importance in this field, and is used to define the ability of the of the system to bring back its operation to steady state condition within minimum possible time after having undergone some sort of transience or disturbance in the line

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