IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 16, Issue 2 Ser. I (Mar. – Apr. 2021), PP 26-38
www.iosrjournals.org

Power System Dynamics and Stability

Kawther Adam Eshag Mhmoud 1[1*], Ahmed abdalla M. Imam 2[2], Ahmed Zakieldeen M. E. Elhassan 3[2*]
[1]*(Electrical Engineering, Nyala Technical College, Sudan)*
[2]*(College of Engineering, karary University Sudan)*

Abstract:
Power System Stability is investigated by simulating a set of critical contingencies to determine whether the disturbances information to classify system states. Low frequency power oscillations that occur between remote generating pools or power stations, due to different types and settings of the automatic voltage regulators at different power stations.

This review paper presented a basic concept of power system stability, classification stability of power system, dynamic Stability, how to assessment the transient stability by using several methods to achieve dynamic and transient stability enhancement and modulate the power system.

***Key Word**: Power System Stability, synchronous machine, Dynamic stability, Low frequency oscillation.*

Date of Submission: 04-03-2021 Date of Acceptance: 17-03-2021

I. Introduction

Power system stability has been recognized as a vital important issue for a reliable and secure interconnected power system operation as far back as the 1920s. The importance of stability problem associated with power system operation arises from increasing power exchange between the constituent parts of a large interconnected power system. In a free deregulated market, utilities are allowed to participate in the market without mandatory upper or lower limits. Thus, a number of highly publicized blackouts happened in the early years. The blackouts illustrate the necessity of assessing the stability of large power systems and maintaining an adequate level of system security to minimize the risk of major blackouts resulting from cascading outages emanating from a single disturbance. The main requirement of system stability is to keep the synchronous operation of power system with adequate capacity and fast reaction to meet the fluctuations in electric demand and changes in system topology. Successful operation of a power system depends largely on the engineer's ability to provide reliable and uninterrupted service to all loads and supply the required amount of loads by the available facilities .Distance between the current state and a hypothetical state wherein units may lose synchronization evaluated after each state of estimation and after each new power flow. In the evaluation, the concern is the behavior of the power system when it is subjected to transient disturbances. If the oscillatory response of a power system during the transient period following a disturbance is damped within acceptable time, and the system can settle in a finite time to a new steady state, it is considered stable [1-3]

Stability of power systems is one of the most important aspects in electric system operation. This arises from the fact that the power system must maintain frequency and voltage levels, under any disturbance, like a sudden increase in the load, loss of one generator or switching out of a transmission line, during a fault [4]. Since the development of interconnection of large electric power systems, there have been spontaneous system oscillations at very low frequencies in order of (0.2 - 3.0) Hz. Once started, they would continue for a long period of time. In some cases, they continue to grow, causing system separation if no adequate damping is available. Moreover, low-frequency oscillations present limitations on the power-transfer capability. To enhance system damping, the generators are equipped with PSSs that provide supplementary feedback stabilizing signals in the excitation systems [5].

II. Material And Methods

2.1 Power system stability

Power system stability is defined as the capability of a system to maintain an operating equilibrium point after being subjected to a disturbance for given initial operating conditions.

From this general definition, two categories of stability are derived: small-signal and transient stability. Small signal stability is the ability of the system to return to a normal operating state following a small disturbance. Investigation involving this stability concept usually involves the analysis of the linearized state space equations that define the power system dynamics. Transient stability is the ability of the system to return to a normal operating state following a severe disturbance, such as a single or multi-phase short circuit or a generator loss. Under these conditions, the linearized power system model dose not usually applies and the nonlinear equations must be used directly for the analysis. A third term, dynamic stability, has been used to describe a separate class of stability. However , this term has represent different concepts for different authors, for these reason several international engineering organizations have recommended that this term not be considered when discussing the stability problem. [6-8].

2.1.1 Power system stability is categorized based on the following considerations:

- ✓ The nature of the resulting instability mode indicated by the observed instability on certain system variables**.**
- ✓ The size of the disturbance which consequently influences the tool used to assess the system stability.
- ✓ The time margin needed to assess system stability [9, 10].

2.1.2 Classifications of power system stability:

Stability phenomenon is a single problem associated with various forms of instabilities affected on power system due to the high dimensionality and complexity of power system constructions and behaviors. For properly understood of stability, the classification is essential for significant power system stability analysis. Stability classified based on the nature of resulting system instability (voltage, frequency and rotor angle instability), the size of the disturbance (small disturbance, large disturbance) and timeframe of stability (short term, changes long term). In the other hand, stability broadly classified as steady state stability and dynamic stability. Steady state stability is the ability of the system to transit from one operating point to another under the condition of small load. Fig. 1. shows the classification of power system stability in IEEE/CIGRE joint task force on stability terms and definitions [1, 11].

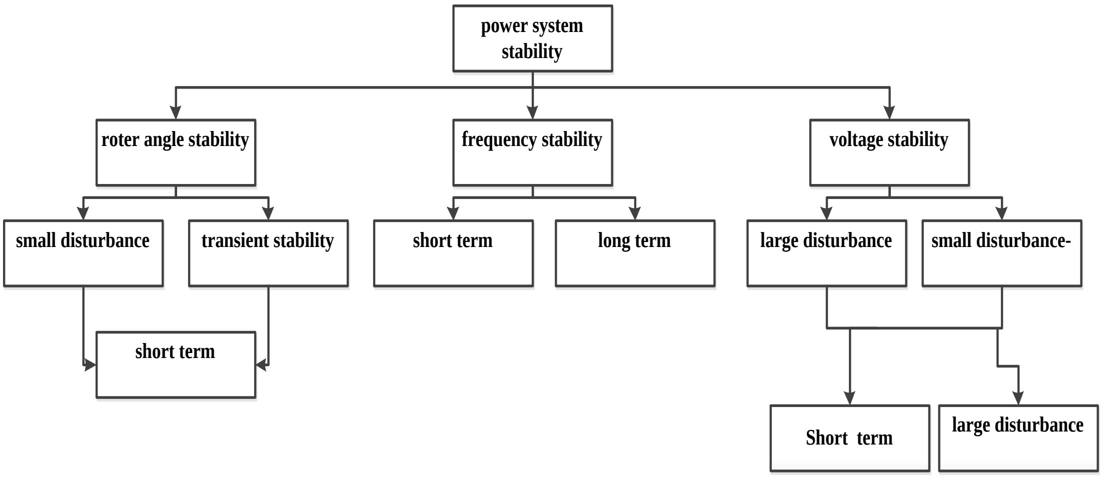


Fig. 1. Classification of stability based on IEEE/CIGRE joint task force on Stability.

2.2 Rotor Angle Stability:

Rotor angle stability is the ability of Synchronous machines to remain in synchronism under normal operating conditions and after being subjected to a disturbance. According to the type of incident, the rotor angle stability can be further classified into small signal (for small disturbance) and transient stability (for large disturbance) [1, 11] , [2, 10, 12]. The stability of synchronous machines depends on the ability of restoring the equilibrium between their electromagnetic outputs torques and the mechanical input torques and keeping at synchronize with other machines following a major disturbance such as short circuit. Under steady state conditions, there is equilibrium between the input mechanical torque and the output electromagnetic torque of each generator, and the speed remains constant. When the system is perturbed, this equilibrium is upset and instability may occur increasing or decreasing angular swings of some generators leading to their loss of synchronism with other generators. The change in electrical torque ΔTe of a synchronous machine following a perturbation can be resolved into two components as follows [10]:

$$Ts\,\Delta\delta + TD\,\Delta\omega = Te \quad \text{……………………………………………..(1)}$$

Where $Ts\Delta\delta$ is the component of torque change in phase with the rotor Angle perturbation referred to synchronizing torque component. Ts is the synchronizing torque coefficient. TD $\Delta\omega$ is the component of torque change in phase with the speed deviation $\Delta\omega$ and it is referred to damping torque component. TD is the damping torque coefficient. Stability of each machine in the system depends on the existence of both components. Lack of sufficient synchronizing torque produces instability through aperiodic or non-oscillatory drift in the rotor angle, whereas lack of damping torque results in oscillatory instability causes rotor oscillating with increasing amplitude. Rotor angle stability depends on the initial operating state and the severity of the disturbance on synchronous machines. Commonly, rotor angle stability classified into small disturbance-rotor angle stability and large disturbance-rotor angle stability.

2.2.1 Small Disturbance Rotor Angle Stability

Small-disturbance rotor angle stability (oscillatory stability) is concerned with the ability of the power system to maintain a steady state operating point when subjected to small disturbances Oscillations have been recognized as a consequence of parallel operation of alternative current generators which are connected to provide more power capacity and more reliability. Thus electromechanical oscillations are understandable because of the change in kinetic energy of rotating parts (rotor) in electrical machines due to their moment of inertia and the synchronizing torque, which acts to keep the generators in synchronism during disturbances. Oscillations can also arise in the power system due to any sudden change in a power system such as high power flows over weak tie lines, which can become heavily loaded if many generators oscillate towards another group at the same time. Fast and powerful voltage regulators or other types of controls may produce oscillations in the network. If the disturbance is small, the synchronizing torque keeps the generators in synchronism with generators relative angles oscillation. These oscillations should decay for small signal stable system operation otherwise; the system is a small signal unstable. Critical oscillatory modes can be triggered by a small disturbance because of the weak[13-15].

Oscillatory stability problems are usually due to insufficient damping for power system oscillations. The system mode parameters can be investigated using two basic approaches; namely modal analysis of complete state spaces or time response analysis of collected synchronized measurements. Rotor angle instability can be oscillatory or non-oscillatory due to the lack of damping or synchronizing torques, The oscillatory instability can be one of the following modes [1, 11], [10]:

- ✓ Local mode or intra-area mode.
- ✓ Inter-area mode.
- ✓ Control mode.
- ✓ Torsional mode.

Local modes are associated with the swinging of units at generating station with respect to the rest of power system at 1.0 to 2.0 Hz. Local modes affected by the strength of the transmission system at the plant, generation level and excitation control system. The oscillation may be removed with a single or dual input power system stabilizer that provides modulation of the voltage reference of the automatic voltage regulator and compensation circuit. Inter-area modes are associated with the swinging of many machines in one area of an interconnected power system against machines in other areas and have major impact on the global stability of the complete power system. It involves two coherent groups of generators swinging against each other at (0.05-1.0) Hz. Poorly damped inter-area oscillation affecting every part of interconnected power system and coordinated analysis are required to check the small signal stability of the whole power system. Inter-area modes depend on various reasons such as weak ties between interconnected areas, voltage levels, and the nature of the load. Additionally, other types of oscillations have been recorded such as interplant modes, torsional modes and control modes. Interplant modes is associated with machines on the same power generation site oscillate and depending on the unit ratings and the reactance connecting them. Usually the rest of the system is unaffected because the oscillations manifest themselves within the generation plant. Torsional modes associated with the turbine, generator shaft and the Components of system. Due to the interaction between generator exciter control and prime mover control, usually these modes are excited when a multi-stage turbine generator connected to the grid through a series compensated line. A mechanical torsional mode of the shaft system interacts with the series capacitor at the natural frequency of the electrical network. The shaft resonance appears when network natural frequency equals synchronous frequency minus torsional frequency [16].

Control modes are associated with generating units and other equipment control such as poorly tuned controls of excitation systems, speed governors, Flexible Alternative Current Transmission Systems (FACTs) devices controls, High Voltage Direct Current (HVDC) converters. Loads and excitation system can interact through control modes. Transformer tap-changing controls can also interact in a complex manner with nonlinear loads giving rise to voltage oscillations.[17, 18]. The minimum damping ratio of oscillation, which is associated with the local and inter-area oscillations, is considered as an indicator for oscillatory stability in this paper. The disturbances should be considered sufficiently small where the linearization of the system equations is permissible for the purpose of modal analysis. In case of inaccurate linearization process, an identification technique is required to identify the system modes based on the time response of electrical signals.

2.2.2 Large Disturbance of Rotor Angle Stability:

Large-disturbance rotor angle stability (transient stability) is the ability of power system to maintain synchronization among synchronous machines when subjected to a server transient disturbance (three-phase short circuit)[19]. Transient stability depends on the current operating conditions of the system and the severity of the contingency on connected generators. The angles between each pair of generator rotor angles will change continuously by small amounts as power distribution change. Transient instability phenomenon is usually in the form of uncontrollable significant increase and separation of the relative angles between two or more rotors due to insufficient synchronizing torque[20]. The resulting system response involves large excursions of generator rotor angles and influences by the nonlinear power angle relationship. Small-disturbance rotor angle stability as well as transient stability is categorized as short-term phenomena.

2.2.3 Voltage Stability:

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition [1, 11], [19]. The voltage deviations need to maintain within predetermined ranges. A voltage stability problem occurs in heavily stressed systems, which associated with long transmission lines. Voltage stability plays a major role in power system security depends on the active and reactive power balance between load and generation in the entire power system and the ability to maintain/restore this balance during normal and abnormal operation. The main contributor in voltage instability is the increase of reactive power requirements beyond the sustainable capacity of the available reactive power resources when some of the generators hit their field or armature current time-overload capability limits. The other contributor is the extreme voltage drop that occurs when active and reactive power flow through inductive reactance of the transmission network for power transfer and voltage support [1, 10, 12]. A typical scenario of voltage instability is unbalance reactive power in the system resulting in extended reactive power transmission over long distances. As long as the load increases, the power transmitted to supply load also increases while bus voltages on transmission line will drop in inductive network. Close to the maximum transmission capability, a small increase of the load implies a great decrease in the voltage level of the network that may lead to cascaded outages (under-voltages protective devices) while instability occurs in the form of a progressive fall of some bus voltages (voltages collapse). Generally, the voltage collapse mainly affected by the large distances between generation and load, under load tap changing transformers performance during low voltage conditions, unfavorable load characteristics, and poor coordination between various control and protective systems. In addition, the system may experience uncontrolled over-voltage instability problem at some buses due to the capacitive behavior of the network and under excitation limiters that preventing generators and synchronous compensators from absorbing excess reactive power. This can arise if the capacitive load of a synchronous machine is too large. Examples of excessive capacitive loads that can initiate self-excitation are open-ended high voltage lines, shunt capacitors, and filter banks from HVDC stations.

The phenomena of voltage stability can be classified into small disturbance and large disturbance voltage stability. Small-disturbance voltage stability refers to the system's ability to maintain steady voltages when subjected to small perturbations such as incremental changes in system load. A criterion for small disturbance voltage stability in that, at a given operating condition for every bus at the system, the bus voltage magnitude increases as the reactive power injection at the same bus increased. A system is voltage-unstable if, for at least one bus in the system, the bus voltage magnitude decreases as the reactive power injection at the same bus increased [20]. Large-disturbance voltage stability refers to the power system ability to maintain steady voltages following large system disturbance such as loss of generation, loss of critical lines, system faults, or protection system failures.

The voltage stability can be classified into short-term stability and long-term voltage stability. Short-term voltage stability involves the dynamics of fast acting load component such as induction motors and electronically connected devices with study period of interest in the order of several seconds. Long-term voltage stability involves the slower acting equipment such as tap-changing transformers and generator current limiters with study period extend several minutes. There are many methods can be used to mitigate voltage instability problem including operation of uneconomic generators to change power flows or provide voltage support during emergencies, using reactive power control and compensation devices, under voltage load shedding to avoid voltage collapse or control of network voltage and generator reactive output.

2.2.4 Frequency Stability

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. A typical cause for frequency instability is the loss of generation, which results in sudden unbalance between the generation and load. The control schemes of frequency deviation used to recover the system frequency without the need for customer load shedding by instantaneously activating the spinning reserve of the remaining units to supply the load demand in order to raise the frequency. In case of an incident with a large frequency deviation, the primary control (in the first 30 minutes) is activated where the partly loaded or carry spinning reserve units selected to initiate an automatic rapid increase of their outputs within a few seconds. The controllers of all activated generators alter the power delivered by the generators until a balance between power output and consumption is re-established. Spinning reserve to be utilized by the primary control should be uniformly distributed around the system. Then the reserve will come from a variety of locations and the risk of overloading some transmission corridors will be minimized. The frequency stabilization obtained and maintained at steady state value, but differs from the frequency set point. The Secondary control, in the portion of the system contains power unbalance, will take over the remaining frequency and power deviation after 15 to 30 seconds to return to the initial frequency and restore the power balance in each control area [1] [2, 21]. Tertiary control is additional to, and slower than, primary and secondary frequency control. Automatic load shedding initiated using under-frequency relays expected to be able to shed the required amount of load during low frequency events. These relays detect the onset of decay in the system frequency and shed appropriate amount of system load until the generations and loads are in balance [21].

Generally, the lack of frequency instability is associated with several problems, such as poor coordination of operation control, protection devices, weakness of equipment response and deficiency in generation reverse [22] [23]. Many countries experienced major frequency disturbances under different circumstances in the past. From 1970s to 2000s, many main systems had experienced serious system frequency disturbances (e.g. islanding grids situation and blackouts) which led to examining the reasons of the system frequency instability problems .[24].

2.3 Factors Affected on Power System Stability

Stability of a nonlinear system depends on the (type, magnitude) of inputs and the initial state of the system. Power system stability is affected by many factors including the (behavior , characteristics) of system, equipment and protection schemes. The most important factors can be summarized by:

- ✓ Pre-and-post-disturbance system state such as the generators loading before the fault and the generator outputs during the fault. The higher the loading before the fault is the more likely to be less stable during faults. The duration, location and type of the fault determine the amount of kinetic energy will be gained. Longer fault duration allows generator rotors to gain more kinetic energy during the fault. At certain limit, the gained energy may not be dissipated after the fault clearance. This gained energy may lead to instability.
- ✓ Synchronous machine parameters such as the inertia constant H (stored kinetic energy at rated speed per rated power), and the generator terminal voltage. The increase of generators inertia constant tends to reduce the swings of rotor angle and hence improve system stability. The generator bus voltages specify the profile of the power angle curve and hence effects on the delivered power into the entire system.
- ✓ Excitation system and governor characteristics of synchronous machines have important role in damping of power oscillations. The automatic voltage regulator (AVR) senses the terminal voltage and helps to control it by acting within the excitation system. Fast valuing for rapidly opening and closing steam valves of the turbine used to control the generators accelerating power during faults. Transmission reliability margin greatly effect on stability where a transmission outage may take place due to overloading during system abnormal conditions, which may lead to uncontrolled loss of a sequence of additional network elements.
- ✓ System relaying and protection have a great importance in system stability. The power system has a finite capacity to absorb such energy and as majority of fault are transient in nature, rapid switching and isolation of unhealthy lines followed by rapid reclosing improves the stability margins. Special protection schemes can be used to split the grid at predetermined points in the network to quickly avoid cascading actions.

2.4 Power System Security Analysis:

Power system security describes the ability of a power system to withstand and survive plausible contingencies without interruption of the customers. Security requires detection of dangerous operating conditions and contingencies as well as the associated actions to steer the system away from any such situations. Security analysis can be divided into static and dynamic security. Static security analysis is the ability of the system to supply load without violating operating conditions and load curtailment, which mainly includes the pre- and post-contingency states.[25] Pre-contingency states determine the available transfer capability of transmission links and identify network congestion. Post-contingency states verify the bus voltages and limits of lines power flow. Dynamic security analysis measures the ability of power system to withstand a defined set of contingencies and survive by the transition to an acceptable steady state condition, which includes methods to evaluate stability and quality of the transition from the pre- to post-contingency state. Dynamic security analysis should be constantly in operation to detect when the security level falls below an adequate safety level to make proper preventive measures for a secure operation. Dynamic stability assessment deals with the analysis of the system in the transition from the initial to the final operation condition following a disturbance or a changing power demand. A power system is dynamically stable for a particular steady state operating condition and for a particular disturbance if, following that disturbance; it reaches an acceptable steady state operating conditions. An important requirement was the ability to determine the risk of blackout, which can be computed by quantifying the distance between the current state and the steady-state stability limit rather than just characterizing it as stable or unstable. This required a fast and accurate online security assessment tools and special actions to prevent system instability, which commonly defined as remedial actions. The remedial actions include curative and preventive actions that should be prepared in the operational planning stage. Urative remedial actions should be prepared in advance and immediately activated after any credible contingency or abnormal conditions to relieve system constraints. Preventive remedial actions should be designed in advance at steady state to anticipate the events and restore the security level in case curative remedial actions which are not sufficient to face the expected contingencies. Dynamic stability studies contain a wider range of phenomena by different authors; dynamic stability concerns the system stability during small disturbance (oscillatory stability) and large disturbance (transient stability). The dynamic stability studies consist of considering the fluctuations in load and generation, the network reactions following critical disturbances and recommending operating measures to avoid undesirable operating modes

2.5 Preventive Measures to Avoid System Instability

In design and preparation stage of power system wide number of disturbances be assessed by system operators. If the system is to be unstable (or marginally stable) following contingency, variety of actions can be taken to improve the system stability. These preventive actions can be classified mainly into Offline and online preventive actions. Offline preventive measures: Improvement of system stability can be achieved by many actions including:

- Organizing the system configuration and maintenances in such that being suitable for the particular operating conditions without overloading during abnormal conditions.
- Reduction of transmission system which can be achieved by adding additional parallel transmission circuits, providing series compensation by using transformers with lower leakage reactance.
- Activating new generation facilities for reactive power support and voltage control service such as power system stabilizers, FACTs, rapid thermal units with fast valuing capability and fast acting automatic excitation systems. Connecting dynamic breaking resistors at the generator and substation terminals in order to break the acceleration of the rotor of generators during faults. Shunt resistors can be switched in to create an artificial load following a fault, in order to improve the damping of accelerated generators.
- Installing efficient protective devices and coordinating between the interconnected system operators for faster fault clearing and initiating proper corrective actions during abnormal conditions.
- Online remedial and preventive measures: The operation of interconnected power system is economically oriented based competitive manner in the most cases. This complicates the ability of Offline preventive measures to keep the power system away from the stability limits. This produces the importance of system operators to use online dynamic stability assessment (DSA) and operating the power system within these limits. There are many online preventive measures can be used to safeguard and enhance system stability such as:

- ✓ Changing the system topology such as tripping of critical generator to ensure that the other generators maintain in synchronism. In addition, generation rescheduling/re-dispatching can be used to reallocate power generation in order to avoid system overloads and relieve constraints.
- ✓ Using of high-speed protective schemes such as transmission line protection with single-pole tripping and adaptive reclosing capabilities to minimizes system disturbance. High-speed automatic reclosing system is effective methodology to restore power continuity.
- ✓ Effectively use of online transformer tap-changers and phase shifting transformers to control the power flow across transmission system by continuous control of voltage regulator set points and changing the phase using taps.
- ✓ Automatic load shedding of interruptible consumers is an effective corrective counter-measure to maintain the frequency at nominal value during abnormal conditions. In the simple implementation, under frequency relays installed at fixed points and with fixed settings can be made adaptive by adjusting the location and level of shedding in accordance with power flow and voltage conditions on the transmission network [26]
- ✓ Assuring reactive-power generation or absorption control and using special control of HVDC links to control the DC power and maintain generation/load balance in AC networks during disturbances.
- ✓ Implementation of high-speed excitation systems to rapidly boosts field voltage in response to disturbances. Increasing of the internal voltage of a generator has the effect of proving transient stability.

In real time application, the system configuration and power distribution are possibly not fully similar to the planned situation studied. Therefore, abnormal operating conditions may require immediate actions for control the generation/consumption facilities to restore the standard security level. In deregulated electricity market, makes a change in scheduled generation, as a recommended action in response to an abnormal condition, may make a request to the independent system operator / transient stability assessment (ISO/TSO) for compensation.

2.6 Dynamic Stability

Dynamic phenomena in power systems are usually classified as:
a. Electro-magnetic transients (100 Hz – M Hz).
b. Electro-mechanical swings (rotor swings in synchronous machines) (0.2 – 0.3 Hz).
c. Non-electric dynamics, e.g. mechanical phenomena and thermodynamics (up to tens of Hz).

A system is said to be dynamically stable if the oscillations do not acquire more than certain amplitude and die out quickly. Dynamic stability is a concept used in the study of transient conditions in power systems. Any electrical disturbances in a power system will cause electromechanically transient processes. Besides the electrical transient phenomena produced, the power balance of the generating units is always disturbed, and thereby mechanical oscillations of machine rotors follow the disturbance [17].

2.6.1 Dynamic Stability Assessment:

Transient stability is the capability of a power system to maintain synchronization when subjected to large disturbances .[1] Sudden changes or disturbances in power systems are associated with a number of phenomena with different timeframe involved. In general, the power system stability can be assessed for the most severe fault possible such as three phase faults. Faults at critical locations may cause circuit tripping due to overloading or loss of synchronism of some generating units. Therefore, DSA is important issue in the modern interconnected power system where the disturbances produce power swings and rotor oscillations. During network disturbances, the power generators have to provide immediate support by changing the currently generated power supplied to the grid. The immediate change is restricted by the power system inertia during the initial few hundred milliseconds. Most turbines are unable to yield the fast torque response required to act in such small level in transient stability. Thus dynamic behavior investment and preparing the proper actions that improve system response during contingencies are important aspects during power system operation and control. The ISO coordinates the available control actions to enhance the system behavior during abnormal conditions.

The operation of a power system requires the fulfillment of all forms of security constraints under different operating conditions. This implies the assessment of limits associated with static constraints as well as dynamic constraints such as rotor angle stability, voltage stability, and frequency stability. Violation of these limits may result in system failures and severe consequences including system blackouts .[27, 28]

Voltage and frequency stability have been the main dynamic constraints to consider for system security assessment.[29] Nevertheless, with the growth of interconnected power systems, the increase in long-distance power flows, and the deregulation of the power sector in many countries across the world, modern power grids are operated near security limits and problems related to small disturbance rotor angle stability (small signal stability) have been reported. The small signal stability (SSS) problem of a power system is usually due to insufficient damping for power system oscillations. [30-32].

2.6.2. Transient Stability Assessment:

Transient stability analysis concerns with the system’s ability to reach an acceptable steady state operating conditions following a large disturbance. Transient stability associated with a large disturbance such as loss of generators, sudden change in loads, network significant changes or three phase short circuit faults. A large disturbance is a disturbance for which the equations describing the system dynamics cannot be linearized for the purpose of analysis. This disturbance causes as imbalance between the mechanical input power to each generator and its electrical output power.

TSA can be represented in a mathematical form by a set of high-dimensional differential algebraic equations which are called time domain simulations (TDS). The accuracy of TDS can be improved with an increase in model complexity, but the computing time also rises. The transient energy function (TEF) [25] [33] is a model-based method that assesses the stability by analyzing the increased energy in the power system after clearing a fault, and the assessment result is conservative with TSA for the implication of the model.[34] Due to these properties, TDS and TEF cannot simultaneously meet the need of accuracy and speed for on-line TSA.

Then, the generator rotors start to swing with respected to each other. There are three approaches for transient stability assessment [10, 19, 35, 36]

2.6.3 Direct / Lyapunov Methods

Such as transient energy function that is based on Lyapunov theory to compute the critical kinetic energy. The system considered in a stable state if the kinetic energy cumulated at the instant of fault clearance and absorbed by the electrical components of the system.

Time-domain (simulation techniques)

- ✓ It can be used to investigate the dynamic stability for the selected set of contingencies and to convert the resulting behavior into index for transient stability assessment. TDS can deal with a very detailed model of the power system, which improves the accuracy of TSA.

Automatic learning techniques

- ✓ It used to assess transient stability in the real time applications in order to reduce the computation time. The well-known families of these approaches include decision tree, and ANN [20]. Good adequate database is certainly the crucial point for automatic learning methods. The main advantage of these methods is they are computationally fast.

2.7 Transient Stability Assessment by Direct Method:

he direct methods determine the stability without explicit solving the system differential equations using transient energy for assessment of transient stability [20]. Transient energy function (TEF) methods are formulated based on Lyapunov theorems for establishing asymptotic stability and regions of attraction for equilibrium[37] .TEF describes the total system transient energy that is gained by the system during the fault-on period, which describes the system state during post-disturbance operation. When the gained kinetic energy is converted into potential energy, the system may be considered in transiently stable state. The transient energy function V, which describes the total system transient energy for the post-disturbances is defined as[38]

$$V = \sum_{i=1}^{N_g} \frac{M_i W_i^2}{2} - \sum_{i=1}^{N_g} p_{mi} \left(\theta_i - \theta_i^2\right) - \sum_{i=1}^{N_g-1} \sum_{j=i+1}^{N_g} \Big(C_{ij} \left(\cos\theta_{ij} - \cos\theta_{ij}^2\right) - \int_{\theta_i^s+\theta_j^s}^{\theta_i+\theta_j} D_{ij} \cos\theta_{ij} d\big(\theta_i + \theta j \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where $M_i$and pmi are the per unit moment of inertia and the mechanical input power of generator i respectively. wi and θ_i^s are the angular velocity of generator i and the angle of bus voltage at post-disturbance. Cij and Dij are depending on the real and imaginary components of the admittance matrix and the generator voltages. In equation1, the first term is called the kinetic energy, which is a function of generator speeds. The sum of terms 2, 3, and 4 is called the potential energy, which is a function of generator angles. The quantity V measures the amount of transient energy which is injected into the system by the fault. The critical energy Vcr measures the energy-absorbing capability of the post-fault of the system, the system is stable if V is less than Vcr [20]. The transient energy margin is defined as (Vcr - V) and is used as a measure of system relative stability. The availability of a qualitative measure of the degree of stability or instability in terms of the energy margin makes the direct methods an attractive tool for a wide range of problems [35]. There are some difficulties associated with the application of TEF in recent power system. These difficulties include the impossibility of an efficient TEF for detailed multi-machine system and the uncertainty of determination the correct energy margin to classify system to be sufficiently stable. There are several works for modifying the TEF to improve these limitations such as Pseudo-Lyapunov approaches, which combine TDS and TEF for online transient stability assessment. These approaches take advantage of the superior ability of TDS in detailed system modeling and the qualitative measure provided by TEF to derive preventive and corrective control actions [20].

The main disadvantage is the proper energy margin suggestion for stable system operation. TDS runs up to the instant of fault clearing to obtain the angles and speeds of all generators, which are used to calculate the total system energy at the fault clearing time. By comparing the calculated value with the critical system energy, the system state of stability can be determined [38]

The transient stability assessment procedure simply involves the following steps:

a. Calculation of the critical energy Vcr.
b. Calculation of the total system energy at the instant of fault clearing V.
c. Calculation of stability index (Vcr - V), the system is stable if the stability is positive.

The calculation of the boundary of the region of stability for a large power system is the most difficult step in applying TEF method. If the boundary can be determined, TEF gives a margin of stability rather than just the stable/unstable result.

2.8 Time Domain Simulation (TDS):

It is deals simultaneously with the system differential equations and algebraic equations to simulate the dynamic behavior of the power system under fault. These equations describe the performance of system equipment and the associated control systems. The simulation period split into pre-fault, during fault and post-fault with different network configuration to investigate the ability of the system to withstand the disturbance under consideration. TDS starts with solving the load flow problem to initialize the pre-disturbance state. The solved load flow gives the data corresponding to the pre-disturbance state.

The post-disturbance dynamic behavior of electrical signals is determined by systematic numerical integration of differential equations, which are modeled the power system. At each time step of simulation, the time derivative of each state variable is calculated. From the present state variables and their corresponding rates of changes, the state variables at the next time step can be calculated by using the integration techniques[20].

Consequently, the algebraic variables are updated by using the algebraic equations. At the instant of disturbance, the appropriate data must be modified. Then, the process repeated until the time of interest reached. The swing curves represent the evolution of rotor angle of each machine known at the end of each time step.

These curves further compared with each other in order to determine whether the rotor angular difference of any two machines exceeds the predefined accepted limit. The iterative process will stop if the system is unstable based on a specified limit otherwise the calculations are pursued for the maximum simulation time.

The stable cases are much more time consuming than the unstable ones.

The angular difference rather than absolute angles is often a better choice to distinguish between stable and unstable system state since it is easily to observe the relative motion of rotor between the machines [20]. If any angular difference becomes larger than a predefined limit, the system is considered under transient instability encountering. The corresponding synchronous generator may loss synchronizing with other machines in the system and may be isolated by the protection system. The critical fault clearing time is considered as CCT, which associated with the contingency. The isolation of faulted element is accomplished by protective rely to activate circuit breaker interruption.

The CCT depends on the system configuration and the loading level at the instant of fault occurrence. The most accurate way to assess the transient stability power system is the systematic TDS. TDS is used to accommodate for the complexity of system modeling and stability conditions by observing its electromechanical angular and voltage swings during the simulation time. To reach this aim, Power System Dynamic (PSD) simulation software based upon TDS method is presented and applied at all system operating points during contingencies in order to calculate the CCT in this dissertation [20, 39].

2.9 Critical Fault Clearing Time (CCT):

The critical fault clearing time is defined as the longest duration of a fault that does not lead any generator loss the synchronism in the system able. During large disturbances such as a three-phase short circuit, the protection system senses the presence of fault and the corresponding relays initiate the tripping of the nearest circuit breakers to isolate the fault. The time duration from the instant the disturbance occurs until the circuit breakers isolate the fault is termed by FCT. Therefore, any generator shall have a CCT higher than FCT of the protection devices installed in the transmission system to avoid a loss of the connected generators. The loss of the connected generators may induce unacceptable consequences for the whole system following contingencies. The total fault clearing time consists of the combination of operating time of the main protection system; signaling time, rely time and breaker interrupting time. Normally, the three phase short circuit faults close to the generator transformer terminals is the worst fault position. Therefore, the corresponding CCT has been used as index to monitor the power system transient stability level during faults in many literatures. As the value of CCT increases, the system has an increased opportunity to isolate and clear the disturbance using the protective relays and circuit breakers.

Thus if the CCT value is less than the operating time of the circuit breaker for the corresponding electric component experiencing the fault, then the system is not considered transiently stable. The accepted limit of CCT is different from system to other but the common value is around 150 milliseconds, The CCT is much more beneficial than the power limits which can be investigated using TEF. TSA using CCT is characterized by the ability to screen and rank a set of contingencies to select the most sever ones beside specifying stability scenarios as stable or unstable state.

2.10Power system modeling:

The power system comprises a large number of electrical components. The modern systems have become more complex as they are enhanced with new devices such as FACTs and Distributed Generation technologies.

The analysis of power system dynamics have been characterized by complex dynamic behavior due to the modeling complexity and interactions/interrelations among individual components as well as the computational structure for describing modern power systems. Modeling of power system dynamics have been associated with describing each individual component by algebraic and/or differential set of equations. Combining the individual dynamic models together with the associated algebraic constraints and power flow equations leads to the dynamic model of the whole power system. A nonlinear dynamic system with its control can be described by equation (3) and equation (4), which should be solved simultaneously in order to investigate the dynamic behavior following a disturbance.[12, 20, 40]

$$X^{\cdot} = f(X,U) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\mathcal{Y} = g(X,U) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, x is the state vector with n state variables. The state vector represents the dynamic states of generators, loads and other system controllers. u is the vector of inputs to the system set which includes the automatic voltage regulator set point and uncontrollable input parameters such as generator power levels variations, and load active and reactive power levels, y is the vector of outputs such as pharos angle and magnitude of bus voltages and bus generated reactive power, f is the vector of nonlinear functions defining state variables in terms of state and input variables, g is the vector of nonlinear functions relating state and input variables to output variables such as power flow equations and system constraints.

Each synchronous generator is represented by three mathematical equations: two electromechanical, and one electromagnetic. A mathematical model of each generator may be written as follows [41, 42]

$$\omega = 1/M(T_{\mathbf{m}} - T_{\mathbf{e}} - T_{\mathrm{D}}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$\delta = \omega\mathrm{b}(\omega - 1) \; , \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\mathrm{e`q} = 1/\mathrm{T'do}(\mathrm{EFD} - \mathrm{e'q}(\mathrm{xd} - \mathrm{x'd})\mathrm{id}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The electric output power is given by the following equation:

$$T_e \approx P_e = \left(\frac{\grave{e}_q . V_t}{\grave{x}_d - x_d}\right) \sin\delta + \frac{{V_t}^2(\grave{x}_d - x_{q)} \sin 2\delta}{2\grave{x}_d x_q} + jx_q(\,ji_q)\,\grave{e}_q = V_t + j\grave{x}_d i_d \;\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where: ω is the mechanical angular speed, M is the inertia constant, and T_m, T_e and T_D are the mechanical, electrical, and damping torques, respectively. Symbol δ defines the power angle, and ω_b is the base angular speed. eq′ is the voltage behind the transient quadrature axis. Tdo′ is the field winding open circuit time constant (sec). EFD defines the excitation internal voltage of the machine, while x_d and $xd`$ are the synchronous and transient direct-axis reactance's, respectively, of the synchronous machine. V_t is the terminal voltage of the machine. The dot denotes the first time derivative of this variable.

2.11Synchronous Machines

The synchronous machine fundamentally consists of two elements, namely the armature or stator and the rotor. Much like the dc generator, the operation of the synchronous machine is based on Faraday's law of electromagnetic induction and can operate as both motor and generator.

The theory of synchronous machines is primarily based on the relative motion of the two cylindrical parts and the distribution of the flux in the air-gap of the machine. These parts are linked in a magnetic circuit, which is set up by currents in conductors near the surfaces of the elements.

The phenomenon of stability of synchronous machine operation has received a great deal of attention in the past and will receive increasing attention in the future. As economies in system design are achieved with larger unit sizes and higher per unit reactance generating and transmission equipment designs, more emphasis and reliance is being placed on controls to provide the required compensating effects with which to offset the reductions in stability margins inherent from these trends in equipment design[43]. Concurrent with these trends are improvements in calculating methods and computing capability which permit predicting complex dynamic effects [44, 45] providing the means for designing control equipment with the proper characteristics.

2.11.1 Stator (Armature)

In power station generators the armature is contained on the stationary member or the stator. The stator is made up of the iron core and the armature windings. The iron core carries the magnetic flux and is laminated to reduce eddy currents and hysteresis losses. On large machines the armature windings are usually copper bars (solid or hollow to allow for cooling) that are placed on the inner periphery of the stator core as illustrated in Fig. 2. below.

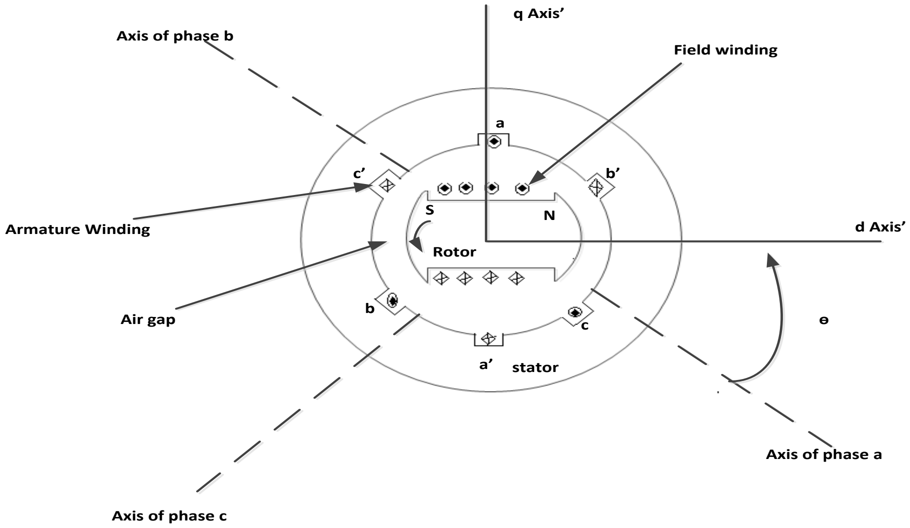
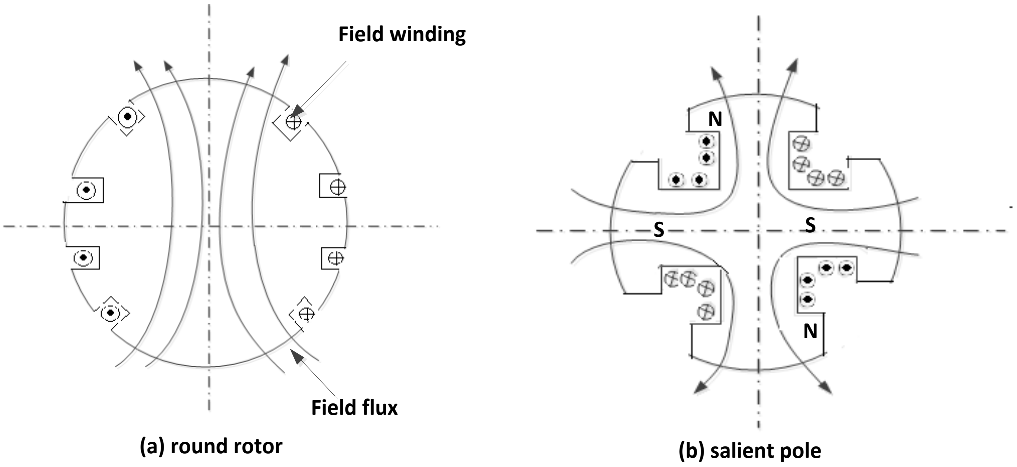


Fig. 2 Placement of stator phase coils with axes at 120^0 displacement within the stator periphery of two-pole synchronous machine [46].

2.11.2 Rotor magnetic circuit

In order to generate an electric current at synchronous frequency, the stator requires a synchronously moving magnetic field. The dc current carrying rotor provides this magnetic field and is driven at synchronous speed by the turbine. There are two types of rotors used, namely a round rotor and a salient pole rotor, shown schematically in Fig 3. The round rotor is found in high-speed applications such as gas and steam turbines. This rotor is characterized by its axially long shaft with diameters not normally exceeding 1.2 m. The rotor is typically made of forged steel with slots cut into the length of the metal. Copper bars or strips are usually contained in the slots along the periphery length of the rotor forming the windings of the rotor. The salient pole rotor has a shorter axial length with a much larger diameter than the round rotor. This rotor is used in lower speed applications such as hydroelectric generating stations. Salient pole rotors have projected pole faces with concentrated windings around the pole face. The rotor winding carries a de current provided by an exciter. The rotor also contains damper bars, which reduce eddy currents during dynamic conditions of operation. The next section develops the theory to mathematically model the physical interaction between the armature and rotor of the synchronous .[47, 48]



(a) round rotor

(b) salient pole

Fig. 3. Field windings and magnetic field paths shown within the (a) round rotor and (b) the salient pole rotor.

Fig. 4 shows the idealized machine with the three-phase windings replaced by windings (dq) on the direct (d) and quadrature (q) axes. The fictitious dq windings carry the currents id and iq which are located on the dq axes and have the same number of turns each as a phase winding that would set up the same magneto-motive force (MMF) wave as the actual currents ia, ib, ic. Since three windings are replaced by two axis windings, the base value of current in the dq axis windings is changed to one and a half times the base value of current in the abc phase windings.

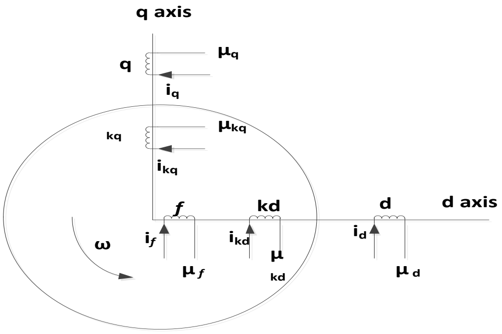


Fig. 4. Two-axis representation of a synchronous machine with one damper winding on each axis.

III. Conclusions

The small perturbation stability characteristics of a single machine supplying an infinite bus through external impedance have been explored by means of frequency response analyses giving insights into effects of machine and system parameters, voltage regulator gain, and stabilizing functions derived from speed and working through the voltage reference of the voltage regulator. The assessment of transient stability requires examining the behavior of a critical group of machines in the post-disturbance period. This is in contrast to the prevailing practice, in the past two decades, of assessing transient stability via a system-wide energy function. In this paper, a review on concepts of power system Stability has been presented. The paper covered the main types of stability assessment and learned it by dateless. A simple and effective for improve the steady-state stability increase system damping oscillations of power system and improve power system dynamic stability extended power transfer limits of system and maintained the reliable operation of the grid.

References:

[1] KUNDUR P, PASERBA J, AJJARAPU V, et al. Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions [J]. IEEE transactions on Power Systems, 2004, 19(3): 1387-401.

[2] VITTAL V, MCCALLEY J D, ANDERSON P M, et al. Power system control and stability [M]. John Wiley & Sons, 2019.

[3] EREMIA M, SHAHIDEHPOUR M. Handbook of electrical power system dynamics: modeling, stability, and control [M]. John Wiley & Sons, 2013.

[4] FRAILE-ARDANUY J, ZUFIRIA P J. Design and comparison of adaptive power system stabilizers based on neural fuzzy networks and genetic algorithms [J]. Neurocomputing, 2007, 70(16-18): 2902-12.

[5] ABIDO M, ABDEL-MAGID Y. Optimal design of power system stabilizers using evolutionary programming [J]. IEEE Transactions on Energy Conversion, 2002, 17(4): 429-36.

[6] ZHANG J, XIA P. An improved PSO algorithm for parameter identification of nonlinear dynamic hysteretic models [J]. Journal of Sound and Vibration, 2017, 389(153-67.

[7] YANG W, NORRLUND P, CHUNG C Y, et al. Eigen-analysis of hydraulic-mechanical-electrical coupling mechanism for small signal stability of hydropower plant [J]. Renewable energy, 2018, 115(1014-25.

[8] ISLAM N N, HANNAN M, SHAREEF H, et al. An application of backtracking search algorithm in designing power system stabilizers for large multi-machine system [J]. Neurocomputing, 2017, 237(175-84.

[9] HAMMONS T, KUCHEROV Y, KAPOLYI L, et al. European plicy on electricity infrastructure, interconnections, and electricity exchanges [J]. IEEE Power Engineering Review, 1998, 18(1): 8-21.

[10] DIGSILENT, GMBH. Power System Stability On Island Networks; proceedings of the IRENA workshop, F, 2013, April [C].

[11] ANDERSON P M. Power System Control and Stability: Vol. I [M]. Science Press, 1977.

[12] NALLAGALVA S K, KIRAR M K, AGNIHOTRI G. Transient stability analysis of the IEEE 9-bus electric power system [J]. International Journal of Scientific Engineering and Technology, 2012, 1(3): 161-6.

[13] KUNDUR P S, BALU N J, LAUBY M G. Power system dynamics and stability [J]. Power System Stability and Control, 2017, 3(

[14] MESSINA A R. Inter-area oscillations in power systems: a nonlinear and nonstationary perspective [M]. Springer Science & Business Media, 2009.

[15] REPORT I C. Excitation system models for power system stability studies [J]. IEEE Transactions on power apparatus and systems, 1981, 2): 494-509.

[16] PADIYAR K. Analysis of subsynchronous resonance in power systems [M]. Springer Science & Business Media, 2012.

[17] VAN CUTSEM T, VOURNAS C. Voltage stability of electric power systems [M]. Springer Science & Business Media, 1998.

[18] ALBATSH F M, MEKHILEF S, AHMAD S, et al. Enhancing power transfer capability through flexible AC transmission system devices: a review [J]. Frontiers of Information Technology & Electronic Engineering, 2015, 16(8): 658-78.

[19] KUNDUR P. Power system stability and control [J]. Edited by Neal J Balu, and Mark G Lauby, 1994, 4(2):

[20] PAVELLA M, ERNST D, RUIZ-VEGA D. Transient stability of power systems: a unified approach to assessment and control [M]. Springer Science & Business Media, 2012.

[21] KABASHI G, KABASHI S. Review of under frequency load shedding program of Kosovo power system based on ENTSO-E requirements [J]. International Journal of Electrical and Computer Engineering, 2018, 8(2): 741.

[22] SILVA F F D. Sintonia de controladores robustos para amortecimento de oscilações utilizando enxame de partículas [J]. 2018,

[23] MOHAMED O, KHALIL A, WANG J. Modeling and control of supercritical and ultra-supercritical power plants: A review [J]. Energies, 2020, 13(11): 2935.

[24] ALTIN M, HANSEN A D, BARLAS T K, et al. Optimization of short-term overproduction response of variable speed wind turbines [J]. IEEE Transactions on Sustainable Energy, 2018, 9(4): 1732-9.

[25] MOARREF N, JAFARZADEH S, YASLAN Y, et al. A Transient Stability Prediction Method based on Multi-Channel Convolutional Neural Networks Using Time Series of PMU Measurements; proceedings of the 2019 11th International Conference on Electrical and Electronics Engineering (ELECO), F, 2019 [C]. IEEE.

[26] MACHOWSKI J, LUBOSNY Z, BIALEK J W, et al. Power system dynamics: stability and control [M]. John Wiley & Sons, 2020.

[27] RUEDA J L, COLOME D G, ERLICH I. Assessment and enhancement of small signal stability considering uncertainties [J]. IEEE Transactions on power systems, 2009, 24(1): 198-207.

[28] TEEPARTHI K, KUMAR D V. Power System Security Assessment and Enhancement: A Bibliographical Survey [J]. Journal of The Institution of Engineers (India): Series B, 2020, 101(2): 163-76.

[29] JHA R, KHANNA K, SENROY N, et al. Normalized Kinetic Energy based Generation Reshuffling to Improve Dynamic Security Constrained Optimal Power Flow; proceedings of the 2019 20th International Conference on Intelligent System Application to Power Systems (ISAP), F, 2019 [C]. IEEE.

[30] YANG L-X, JIANG J, LIU X-J, et al. Adjusting synchronizability of coupled oscillatory power networks via feedback control schemes [J]. Chaos: An Interdisciplinary Journal of Nonlinear Science, 2019, 29(7): 073112.

[31] FLORES J, RODRÍGUEZ D, HOPPE O, et al. Damping of unstable low frequency oscillations through power system stabilizer tuning in the Mexican power system; proceedings of the Proc 2007 CIGRE XII Iberian-American Regional Meeting, F, 2007 [C].

[32] ABOYTES F, SANCHEZ F, CABRA A M, et al. Dynamic stability analysis of the interconnected Colombia-Venezuela power system [J]. IEEE Transactions on Power Systems, 2000, 15(1): 376-81.

[33] KUSCHKE M, STRUNZ K. Energy-efficient dynamic drive control for wind power conversion with PMSG: modeling and application of transfer function analysis [J]. IEEE Journal of Emerging and Selected Topics in Power Electronics, 2013, 2(1): 35-46.

[34] ZHANG R, XU Y, DONG Z Y, et al. Post-disturbance transient stability assessment of power systems by a self-adaptive intelligent system [J]. IET Generation, Transmission & Distribution, 2015, 9(3): 296-305.

[35] FOUAD A-A, VITTAL V. Power system transient stability analysis using the transient energy function method [M]. Pearson Education, 1991.

[36] XUE Y, VAN CUTSEM T, RIBBENS-PAVELLA M. A simple direct method for fast transient stability assessment of large power systems [J]. IEEE Transactions on Power Systems, 1988, 3(2): 400-12.

[37] MONTEIRO I A, MENESES L A E, GIESBRECHT M. A Novel Approach for Determining Salient-Pole Synchronous Machine Magnetizing Reactances from On-line Measurements; proceedings of the 2020 IEEE 29th International Symposium on Industrial Electronics (ISIE), F, 2020 [C]. IEEE.

[38] MOMOH J A, EL-HAWARY M E. Electric systems, dynamics, and stability with artificial intelligence applications [M]. CRC Press, 2018.

[39] ERLICH I. Analysis and simulation of the dynamic behavior of electrical power systems [J]. Postdoctoral lecture qualification, Department of Electrical Engineering, Dresden University, Germany, 1995,

[40] MIAO X, ILIĆ M D. Distributed model predictive control of synchronous machines for stabilizing microgrids; proceedings of the 2017 North American Power Symposium (NAPS), F, 2017 [C]. IEEE.

[41] PARK R H. Two-reaction theory of synchronous machines generalized method of analysis-part I [J]. Transactions of the American Institute of Electrical Engineers, 1929, 48(3): 716-27.

[42] YU Y-N. Electric power system dynamics [J]. ACADEMIC PRESS, INC, 111 FIFTH AVE, NEW YORK, NY 10003, USA, 1983, 256, 1983,

[43] SURJAN B S, GARG R. Power system stabilizer controller design for SMIB stability study [J]. International Journal of Engineering and Advanced Technology (IJEAT), 2012, 2(1): 209-14.

[44] ZHONG Q-C. Virtual Synchronous Machines: A unified interface for grid integration [J]. IEEE Power Electronics Magazine, 2016, 3(4): 18-27.

[45] AFIANIAN A, NIKSEFAT S, SADEGHIYAN B, et al. Malware dynamic analysis evasion techniques: A survey [J]. ACM Computing Surveys (CSUR), 2019, 52(6): 1-28.

[46] PARK R. Two-reaction theory of synchronous machines-II [J]. Transactions of the American Institute of Electrical Engineers, 1933, 52(2): 352-4.

[47] ANTIPIN A, UDINTSEV V, NAZAROV S. Exciter synchronous machine low power on the basis of high-speed regulator current; proceedings of the 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), F, 2017 [C]. IEEE.

[48] SCHMUELLING C, KULIG S. Investigation of the magnetizing inductances of the expanded park equations; proceedings of the 2015 IEEE International Electric Machines & Drives Conference (IEMDC), F, 2015 [C]. IEEE.

Kawther Adam Eshag Mhmoud, et. al. “Power System Dynamics and Stability.” *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 16(2), (2021): pp. 26-38.