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Power System Stability and Control

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***Abstract:* The electric power generation-transmission-distribution grid in developed countries constitutes a large system that exhibits a range of dynamic phenomena. Stability of this system needs to be maintained even when subjected to large low-probability disturbances so that the electricity can be supplied to consumers with high reliability. Various control methods and controllers have been developed over time that has been used for this purpose. However, in the area of communications and power electronics, have raised the possibility of developing much faster and more wide-area stability control that can allow safe operation of the grid closer to its limits.**

Keywords- Transmission Line, Transformer, Stability of Power transmission, FACTS devices, Controllers

I. INTRODUCTION

At present the demand for electricity is rising phenomenally especially in developing country like India. This demand is leading to operation of the power system at its limit. On top of this the need for reliable, stable and quality power is also on the rise due to electric power sensitive industries like information technology, communication, electronics etc. In this scenario, meeting the electric power demand is not the only criteria but also it is the responsibility of the power system engineers to provide a stable and quality power to the consumers. These issues highlight the necessity of understanding the power system stability. In this course we will try to understand how to assess the stability of a power system.

II. Literature Review

2.1 Basic Concepts and Definitions of Power System Stability

Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most of the system variables bounded so that practically the entire system remains intact. The disturbances mentioned in the definition could be faults, load changes, generator outages, line outages, voltage collapse or some combination of these. Power system stability can be broadly classified into rotor angle, voltage and frequency stability. Each of these three stabilities can be further classified into large disturbance or small Disturbance, short term or long term. The classification is depicted in Fig. 1.1

2.1.1 Rotor angle stability

It is the ability of the system to remain in synchronism when subjected to a disturbance. The rotor angle of a generator depends on the balance between the electromagnetic torque due to the generator electrical power output and mechanical torque due to the input mechanical power through a prime mover. Remaining in synchronism means that all the generators electromagnetic torque is exactly balanced by the mechanical torque. If in some generator the balance between electromagnetic and mechanical torque is disturbed, due to disturbances in the system, then this will lead to oscillations in the rotor angle. Rotor angle stability is further classified into small disturbance angle stability and large disturbance angle stability.

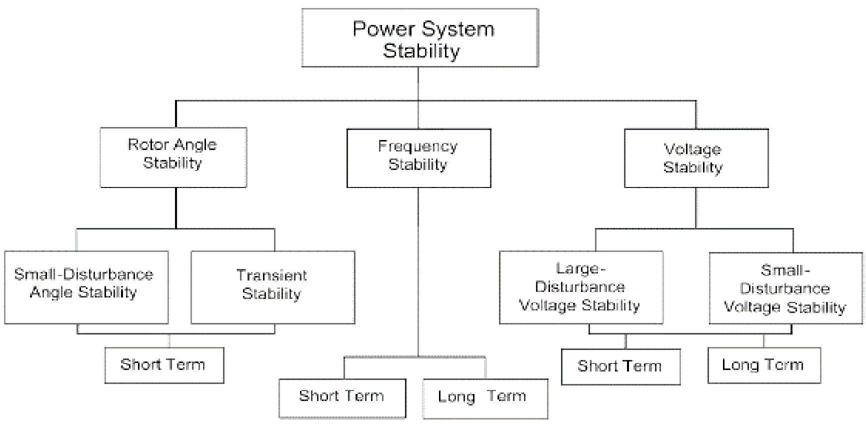

Fig. 1.1: Classification of power system stability

- **Small-disturbance or small-signal angle stability**

It is the ability of the system to remain in synchronism when subjected to small disturbances. If a disturbance is small so that the nonlinear power system can be approximated as a linear system, then the study of rotor angle stability of that particular system is called as small-disturbance angle stability analysis. Small disturbances can be small load changes like switching on or off of small loads, line tripping, small generators tripping etc. Due to small disturbances there can be two types of instability: non-oscillatory instability and oscillatory instability. In non-oscillatory instability the rotor angle of a generator keeps on increasing due to a small disturbance and in case of oscillatory instability the rotor angle oscillates with increasing magnitude.

- **Large-disturbance or transient angle stability**

It is the ability of the system to remain in synchronism when subjected to large disturbances. Large disturbances can be faults, switching on or off of large loads, large generators tripping etc. When a power system is subjected to large disturbances they will lead to large excursions of generator rotor angles. Since there are large rotor angle changes the power system cannot be approximated by a linear representation like in the case of small-disturbance stability. The time domain of interest in case of large-disturbance as well as small-disturbance angle stability is anywhere between 0.1- 10 s. Due to this reason small and large-disturbance angle stability are considered to be short term phenomenon.

2.1.2 Voltage stability

It is the ability of the system to maintain steady state voltages at all the system buses when subjected to a disturbance. If the disturbance is large then it is called as large-disturbance voltage stability and if the disturbance is small it is called as small-disturbance voltage stability. Unlike angle stability, voltage stability can also be a long term phenomenon. In case voltage fluctuations occur due to fast acting devices like induction motors, power electronic drive, HVDC etc. then the time frame for understanding the stability is in the range of 10-20 s and hence can be treated as short term phenomenon. On the other hand if voltage variations are due to slow change in load, over loading of lines, generators hitting reactive power limits, tap changing transformers etc. then time frame for voltage stability can stretch from 1 minute to several minutes.

The main difference between voltage stability and angle stability is that voltage stability depends on the balance of reactive power demand and generation in the system where as the angle stability mainly depends on the balance between real power generation and demand.

2.1.3 Frequency stability

It refers to the ability of a power system to maintain steady frequency following a severe disturbance between generation and load. It depends on the ability to restore equilibrium between system generation and load, with minimum loss of load. Frequency instability may lead to sustained frequency swings leading to tripping of generating units or loads. During frequency excursions, the characteristic times of the processes and devices that are activated will range from fraction of seconds like under frequency control to several minutes, corresponding to the response of devices such as prime mover and hence frequency stability may be a short-term phenomenon or a long-term phenomenon.

Though, stability is classified into rotor angle, voltage and frequency stability they need not be independent isolated events. A voltage collapse at a bus can lead to large excursions in rotor angle and frequency. Similarly, large frequency deviations can lead to large changes in voltage magnitude.

Each component of the power system i.e. prime mover, generator rotor, generator stator, transformers, transmission lines, load, controlling devices and protection systems should be mathematically represented to assess the rotor angle, voltage and frequency stability through appropriate analysis tools. In fact entire power system can be represented by a set of Differential Algebraic Equations (DAE) through which system stability can be analyzed.

III. Solution

3.1 Power System Control

Given the complexity of the power system and its dynamic phenomena, one would expect that various controls have been developed over time to control various phenomena. These developments have followed the availability of enabling hardware technologies (e.g. electronics, communications, and microprocessors) as well as the evolution of control methodologies. In this section, a brief survey is presented of the various controls available today. The survey is neither comprehensive nor complete but is meant to provide a general feel for the technologies being utilized today and the phenomena that are being controlled.

3.1.1 Power System Protection

From the very beginning there was the necessity of protecting electrical equipment from burning up due to a short circuit. From the humble fuse to today's microprocessor based relay, protection gear and methodology have progressed to the point where protection can be looked upon as a fast method of control. The many types of protection technology used in many ways are obviously outside the scope of this section and only a few applications that affect power system stability are mentioned.

When a fault (short circuit) occurs, the faulted equipment has to be isolated. A short circuit is characterized by very low voltages and very high currents, which can be detected and the faulted equipment identified. If the fault is on a shunt element, like a generator or a distribution feeder, the relay will isolate it by opening the connecting circuit breakers. If the fault is on a series element, like a transmission line or transformer, the breakers on both sides have to be opened to isolate it. The main characteristic of the protection system is that it operates quickly, often in tens of milliseconds, so as to protect the equipment from damage. In addition, protective relays can be used to do such switching of circuit breakers under other circumstances. For example, if the frequency deviates much from 60Hz or the voltage from nominal, this may be an indication that the system may be going into an unstable state. Generation or load can be shed (isolated) by the protective relays to correct the situation.

The main characteristics of protective systems are that they are fast and usually triggered by local variables. Circuit breakers that are switched are close to the detection points of the anomalous variables. This obviously makes sense when the purpose is to isolate faulted equipment. However, communication technology today makes it possible to open circuit breakers far from the detected anomalies and this raises the possibility of remote or wide-area control.

3.1.2 Voltage Control

As is mentioned before, one way to control node voltages is by varying the excitation of the rotating generators. This is done by a feedback control loop that changes the excitation current in the generator to maintain a particular node voltage. This control is very fast. Another way to control node voltage is to change the tap setting of a transformer connected to the node. Other ways are to switch shunt capacitors or reactors at the nodes. These changes can be made manually by the operator or automatically by implementing a feedback control that senses the node voltage and activates the control. Unlike the generator excitation control, transformer taps and shunt reactances can only be changed in discrete quantities. Often this type of control schemes has time delays built into them to avoid excessive control actions.

More recently power electronic control devices have been introduced in the shunt reactance voltage control schemes. This makes the control much more continuous and often is done it a much faster time frame than the usual shunt switching. These static var controllers (SVC) are becoming more common. As is obvious, voltage control is always a local control. However, controlling the voltage at one node affects the neighboring nodes.

3.1.3 Transmission power flow control

Most power systems have free flowing transmission lines. This means that although power injections and node voltages are controlled quite closely, the power flow on each transmission line is usually not controlled. However, such control is feasible.

A phase shifting transformer can control the power flow across it by changing the phase using taps. This has been used, especially on the Eastern interconnection in North America. The control is local, discrete and slow. A power electronic version of this is now under experimentation.

The major advantage of the AC transmission grid is its free flowing lines with relatively less control and so the wholesale control of every transmission line is not desirable and is not contemplated. However, controls on some lines have always been necessary and some new advantages may be realized in the more deregulated power system when monitoring transactions between buyers and sellers have to be better controlled.

3.1.4 Frequency Control

Frequency is controlled by balancing the load with generation. The governors on every generator senses any change in the rotational speed and adjusts the mechanical input power. This governor control is the primary control for maintaining frequency. A secondary control to set the governor set points is used to ensure that the steady state always returns to 60Hz. The secondary control is done over the whole system. This secondary control is done by the central controller and is slow. This control is also known as Automatic Generation Control (AGC) or Load Frequency Control (LFC).

3.1.5 Control Center

As mentioned in the above sections most of the controls are local. The only area wide control is the secondary frequency control or AGC. This is implemented as a feedback control loop in which the generator outputs and tie-line flows are measured and brought back to the control center and the governor control set points are calculated and sent out to the generators from the control center. The data rate – both input and output – is between 2 and 4 seconds. The control center performs many other functions although AGC is the only automatic feedback control function.

The main function is real time data acquisition from all over the grid so that the operator can monitor its operation. Another is the manual operation of controls like opening or closing circuit breakers, changing transformer taps, etc. These functions are jointly known as the Supervisory Control and Data Acquisition (SCADA) and the control center is often referred to as SCADA. These SCADA-AGC functions at central control centers evolved in the earlier part of the last century but in the 60s their implementation was accomplished with digital computers. Remote terminal units (RTU) were positioned in every substation and generating station to gather local data and this data was then transmitted from the RTUs to the control center over communication lines, usually microwave channels but sometimes telephone lines.

3.2 Stability Limits

Power systems are designed and operated so that they can survive large disturbances like storms, lightning strikes and equipment failures. This usually means that even though some power system equipment will be separated or isolated as a result of automatic protection and control actions, power supply to customers will not be disrupted or at least, that any such disruptions will be very localized.

Operational limits for the transmission network can then be set using the following logic:

The maximum power each transmission line can transmit is limited by its current carrying capacity, known as its thermal limit the maximum loading of the transmission network is determined by any one of the lines hitting its thermal limit. The SCADA continually checks for such thermal limit violations as the operating condition changes over time.

Thus the operating limit is not when the first line hits its thermal limit but when the loss of any one piece of equipment will make a line hit its thermal limit.

If a disturbance or short-circuit occurs, the first line of protection should isolate the faulted equipment. In such a case the maximum loading of the system will have to be lowered so that instability does not occur. This loading limit is thus set by the stability criterion rather than the thermal loading. Those power systems that are stability limited are of interest in this paper. If better controls can increase this stability limit, then the system can be loaded at a higher level. This provides better utilization of the transmission network.

3.3 New Technologies

Essentially, there are three classes of technologies that are relevant:

- Faster, cheaper computers
- Broadband, cheap communications and
- Better power electronic controls (also known as FACTS – flexible AC transmission systems – which covers this class of technology specifically developed to control the AC power system).

What we are proposing here is the development of new controls utilizing a combination of these technologies. These controls will be significantly different in concept than the existing ones, and will be fast and system-wide to dramatically increase stability limits.

3.3.1 Computers

Computers (or microprocessors) are embedded in everything – meters, protective relays, data concentrators, communication switches. They are programmable, that is, the functions of the gadget in which they are embedded can be changed by software. Thus controls that utilize these components can be adapted, through changed settings (simple) or changed logic (more difficult), providing flexibility in the design of this software.

Workstation computers are also much faster and cheaper. Thus very large amounts of calculations can be done very quickly. Such analysis can then be part of the control bringing even more intelligence into the control loop. For example, if a control is devised to shed load to avoid instability, an optimal power flow could determine which loads are to be switched off.

3.3.2 FACTS

Although they are different in detail by model and manufacturer, but they fall into three classes:

- DC transmission controls
- SVC (static VAR controller) and
- PFC (power flow controller)

In addition, special controllers can be built for specific purposes using the same principles. One major advantage to these controllers is their speed with control actions taking place in milliseconds which is in the same timeframe as protection actions.

IV. Conclusion

From these study, according to load, TRANSIENT AND DISTURBANCES CAN use protection. In today's era maximum approach for power stability and power factor correction FACTS devices are generally used. In that, for medium transmission line Shunt Compensator is used whereas series compensator used in long transmission line. As the demand of power is increased more transmission is done by long transmission line and due to some limitations series compensator is used for it. FACTS devices also give power factor correction.

The roadmap outlined here ranks the conceptual developments by the difficulty of their implementation. The requirement of more complex computation or communication makes implementation more difficult, but several of the steps outlined above can be taken right now using existing technology without significant new development.

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