Voltage Stability Analysis of Smart Grid and Application of FACTS Controller: A Review

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Abstract: ***Interconnected power systems always operate close to stability limits. Increased penetrations of renewable resources have made the situation worst. A small disturbance to these stretched stability limits may lead to voltage collapse. Thus it is indeed important to develop understanding of the phenomenon through reviewing various case studies in literature. This paper explore the initial review on understanding the voltage collapse phenomena, identification of weak nodes, Synchrophasor technology based voltage collapse detection and control.***

Keywords: voltage stability, voltage collapse, voltage stability index, smart grid, synchrophasor thechnology, FACTS controller

1. Introduction

The rapid growth of power systems have been witnessed worldwide by engineers, utilities, stakeholders and customers. With increasing energy demands, power system is expanding to accommodate the rapid load growths by introducing micro and small renewable resource based generation plants, constructing new power plants, transmission lines, substations, and control devices. The introduction of the deregulation and restructuring has changed the shape of electric power industry [1].

When a system is undergoing to the situation of voltage instability, the voltage decline within minutes dramatic, generally monotonic, following a disturbance. When this decrease is too pronounced, the system integrity is endangered mainly due to protecting devices that trip generation, transmission, or load equipment. This degradation process may eventually lead to a blackout in the form of a voltage collapse [1], [2].

As a result, several blackouts directly related to voltage collapse have been occurred dealing with which is a very costlier affair, and still a threat to power system stability and security. Some well-known incidents of blackout recorded are;

1. December 4 2014 Detroit US
2. July 31 2012 Northern grid in India
3. July 30 2012 Northern grid in India
4. Nov. 10, 2009 in Itapúa Paraguay-Brazil
5. January-February 2008: in the central Chinese city of Changzhou
6. Aug. 18, 2005: in Indonesia

Northern grid collapse in India on 30 and 31 July 2014 affected about 620 million people [3]. Series of events was responsible for grid failure and the major reason is voltage collapse due to contingency.

Voltage stability is one of the concern area to power engineers in power systems. By connecting adjustable series and shunt compensation maximum transfer capabilities of power network can be enhanced [1]. Such compensation injects reactive VAR to the nodes consequently maintain the voltage magnitude in the nodes close to the nominal values, besides, to reduce line currents and therefore the total system losses [2]. With advent of advancement in power electronic devices named Flexible AC Transmission Systems (FACTS), control of magnitude of voltage in power system with proper control become much easier. Fast advances in computer analysis of power systems have enabled appearance of extensive knowledge related to general power system control and stability. Voltage stability has always been a topic of attraction to power engineers, scientist and researchers. A lot of work has been done and still going on, resulting in number of IEEE standards [3], [4] and books [5]-[8] cover modelling issues in depth. Some of them directly concern the voltage stability problem [9], [10]. Useful definitions of terms related to stability are provided within several taxonomies in [11]-[13].

The increased application of communication and information technology in the field of power system has transformed the world of power engineers in the name of smart grid. The development of Phasor Measurement Unit (PMU) technology [11], [12], in late 1980's, together with advances in computational facilities, networking infrastructure and communications, is a fast growing field of research and lot of work is going on in modernization of power system. Voltage stability has been identified as one area where PMU-enhanced functions could prove useful to prevent system blackouts and the associated social and economic losses [10], [13].

2. Voltage Stability Phenomenon in Power System

2.1 Definition

"Voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance"[1]. Simply stated, voltage instability is linked to the inability of the combined generation-transmission system to provide the power requested by loads, as a result of equipment outages and limitations of reactive power generation [14].

2.2 Major reasons for voltage stability problems in power system

In recent years major black outs around the world has been reported due to voltage instability. Reasons for the problems of voltage stability in power system are as follows;

- Large load or large disturbance in a heavily stressed power system.
- Large disturbance between generation and load
- Unfavorable load characteristics
- Large distance between Voltage sources and load centers.
- Low voltage profile.
- In sufficient load reactive compensation.
- Action of ULTC during low voltage conditions and.
- Poor coordination between various control and protective systems.
- High reactive power consumption at heavy loads
- Unsuitable locations of FACTS controllers [3][4].

A. Classifications of Voltage Stability

The classification of voltage stability can be done in o two broad categories; [1]

1. Large-disturbance voltage stability

It is define as the ability of the power system to maintain stable voltages for large disturbances such as such as system faults, loss of load, or loss of generation. Large disturbance voltage stability may be further subdivided into two types

a) Transient stability

b) Long term stability

2. Small-disturbance (Small signal) voltage stability

Small disturbance voltage stability is concerned with a system's ability to control voltages following small perturbations, such as gradual change in load, this types of stability can be studied with steady-state approaches that use linearization of the system dynamic equations at a given operating point

B. Factors Affecting Voltage Instability and Collapse

The main factor causing instability is the inability of the power system to meet the demand for reactive power.

1. Transient voltage instability

Under low voltage condition the electrical torque of an induction motor is not adequate to meet the required mechanical torque due to this effect the induction motor may not regain the original speed and continue to decelerate leading to stalling of motors which intern aggravates the low voltage problem. This phenomenon is called transient voltage instability. Transient voltage instability is also associated with HVDC links, particularly inverter terminals connected to AC systems with low short circuit capacity [2] [5] [6].

2. Long term voltage instability

On-load tap-changing transformers and distribution voltage regulations act within a time frame of tens of seconds to tens of minutes to regulate the load a voltage is termed as long term voltage instability. An important factor in long term voltage stability is the current limiting generator [2] [7].

3. Smart Grid

Smart grid is a step ahead in terms of technology from existing power system. The infrastructure is same but it aims to modernize the operation and components of existing systems. It incorporates the principle of communication and information technology resulting in more sensible and reliable electric grid. The Synchrophasor technology is the basic building block of a smart-grid which include assets, sensors used to monitor those assets, the control logic that realizes the desired operational status and finally communication among those blocks. Synchrophasor technology can help deliver better real-time tools that enhance system operator's situational awareness [15]. A Synchrophasor system - with wide deployment of phasor measurement units and dedicated high-speed communications which collects and deliver time synchronized high-speed grid condition data, along with analytics and other advanced on-line dynamic security assessment and control applications -- will improve real-time situational awareness and decision support tools to enhance system reliability. Distribution management systems (DMS) are considered the control logic for operation and control of the smart-grid. DMS is at the middle of the smart gird. It actually transforms the traditional grid into smart grid [16]. A lot of research work is going on for synchrophasor assisted voltage stability analysis.[17]-[30].

[17] Presents the fundamental concept of smart grid and its various applications to power system stability study. Various case studies has also been discussed applying smart grid concept.[18] discussed concept of wide area monitoring in voltage stability analysis. A scheme based on wide area monitoring protection and control (WAMPC) also presented. Voltage stability studies are now assisted by wide area monitoring system based on synchrophasor technology are now more accurate efficient and robust. [19]-25]

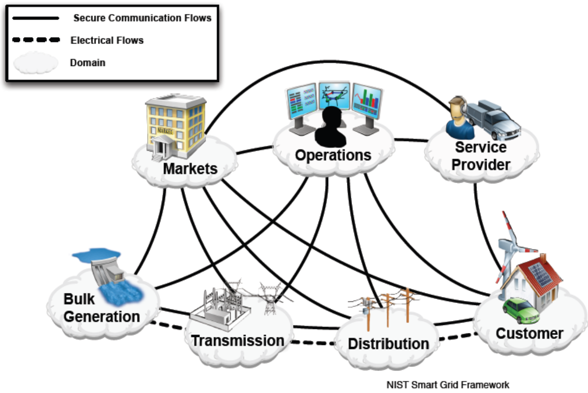

Figure 1: conceptual model of smart grid

[26] presents a comparative analysis of Synchrophasor Based Voltage Stability Index. and PQVSI. Voltage collapse proximity index can be calculated by using voltage phasors from PMUs. Voltage phasors have accurate data to detect voltage stability margin [18-27].

4. Overview of Facts Controllers

Reactive power unbalance creates the problems like voltage deviation during load changes and power transfer limitation. These problems may have a great impact on reliability and security of power supply. Fast and high performance power electronic devices may be a solution to such problems. FACTS controller are power electronics based reactive power controller. They are high power level converter used at high voltages.;[32]

The first FACTS installation was at the C. J. Slatt Substation near Arlington, Oregon. This is a 500 kV, 3-phase 60 Hz substation, and was developed by EPRI, the Bonneville Power Administration and General Electric Company. [33]

A. Types of Var Sources

System components which generate need for compensation
- Inductances in electrical machines, transmission lines, transformers, reactors.
- Capacitances in transmission lines, cables

B. Components which provide required compensation

- Mechanically switched reactors and capacitors
- Synchronous condensers
- Thyristor controlled shunt and series compensation
- Converter controlled shunt and series compensation.

C. Basic types of FACTS controller

Basic Types of FACTS controllers
- Shunt controllers
- Series controllers
- Combined shunt-series controllers
- Combined series-series

The shunt controllers are applied to control voltage at and around the operating point by injecting reactive current. Series controllers are applied to improving voltage profile in a cost effective way ware voltage fluctuations are large. However the series controllers are several times more powerful than the shunt controllers.

The combined controllers provide the best of both i.e. an effective power/current flow and line voltage. A lot of research work has been reported till date, analyzing the effect of FACTS controller on power system stability. [33] Presents the effect of series and shunt compensation in increasing the maximum transfer capabilities of power network. [34] Dealing with voltage stability, FACTS controllers injects reactive power to maintain the voltage magnitude in the nodes close to the normal operating limits, besides, reducing line currents and therefore the total system losses. In general form, system wise aspects are related either to the improvements of security and economics [35]-[50] or to the enhancements of transmission network capability [51]-[56].

Different FACTS devices have various applications in power system operation.

Table 1: Different roles of various FACTs devices

Operating Problems	Corrective action	FACTS controller
Low voltage at heavy load	Supply reactive power	STATCOM SVC
High voltage at low load	Absorb Reactive power	STATCOM SVC TCR
High voltage following an outage	Absorb Reactive power	STATCOM SVC TCR
Low voltage following an outage	Supply reactive power	STATCOM, SVC
Transmission circuit over load	Reduce over load	TCSC UPFC SSSC IPC PS
Tripping of parallel load	Limit circuit loading	TCSC UPFC SSSC IPC PS
Parallel line load sharing	Adjust series reactance	TCSC UPFC SSSC IPC PS
Post fault load sharing	Use thermal limit action	TCSC UPFC SSSC IPC PS
Power flow direction reversal	Adjust phase angle	UPFC SSSC IPC PS

5. Conclusion

This paper presents the review on concept of voltage stability. various taxonomy and definition of voltage stability and voltage collapse. Classification of voltage stability, major reasons for voltage stability problems in power system, Factors Affecting voltage instability and collapse. Also review on transformation of existing grid into smart grid and also concept of Synchrophasor technology has been presented. Basic concepts of FACTS controller and their application under various operating condition of power system has also been surveyed in this paper.

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