Power System Stability in the Deregulated Environment

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ABSTRACT

The deregulation of power systems has brought several new entities in the electricity market place. There is need to assess the impact of Independent Power Producers (IPP), Non-Utility Generators (NUG) and Distributed Generators (DG) on system operation and stability. This paper is concerned with the problems related to system security and stability resulting from the increased proliferation of DG. The paper presents an up-to-date survey on the impact of DG on system stability. This paper focuses particularly on the DG-grid connection strength. This is done in relation to wind turbine and generators because of the wide application of wind energy into the system

Keywords: Distributed Generators, system stability, DG , wind generators, fuel cells.

1. INTRODUCTION

The electric power industry has been dominated by large utilities that had an overall authority over all activities in generation, transmission and distribution of power within its domain of operation. Such utilities have often been referred to as vertically integrated utilities. Such utilities served as the only electricity provider in the region. It is responsible about the planning and operation of the power system according to certain criteria and policies. The basic objective of the operator in such vertically integrated utilities would be to maintain reliable and uninterrupted services to the load. The reliability of the system is composed of two aspects; adequacy and security. System adequacy is defined as ability to supply the energy requirements of the system taking into account planned and unplanned outages of the electrical components. System security is defined as the ability to withstand sudden disturbances without causing major blackouts and interruptions. System security is made of steady state and dynamic security analysis. Transient stability and small signal stability studies are important tools for the assessment of system security.

Since the 1990, many electric utilities and power network companies' world-wide have changed their ways of doing business, from vertically integrated mechanisms to open market systems. The reasons have been many and have differed over regions and countries from political to purely economical reasons. Reforms have been undertaken by introducing commercial incentives in generation, transmission, distribution and retailing of electricity, with, in many cases, large resultant efficiency gains [1]. The introduction of deregulation has brought several new entities in the electricity market place, while on the other hand redefining the scope of activities of many of the existing players. Variations exist across market structures over how each entity is particularly defined and over what role it plays in the system [1-2].

The deregulated environment has presented the new entities by a variety of problems in the planning and operation. There is need to asses the impact of Independent Power Producers (IPP), Non-Utility Generators (NUG) and Distributed Generators (DG) on system operation and stability. These entities seek transmission access and in many cases cause congestion and overloading of equipment. These in turn are primary causes of problems in system reliability and security.

The recent electricity blackouts, that happened in many countries during 2003-2004, are partly attributed to the restructuring of the power industry [3-6]. Many of the utilities involved were trading large quantities of power with other entities over congested and overloaded transmission lines. Local outages and events caused wide-spread blackouts across national and transnational boundaries. It is impractical to achieve complete immunity to blackouts and there is a need to strike a balance between economy and security. Good design and operating practices could significantly minimize the occurrence and impact of widespread outages.

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Therefore there is a necessity to address the following issues in light of the deregulation of the power system:

1. Reliability criteria
2. On-line security assessment
3. Robust stability controls
4. Coordinated emergency controls
5. Real-time system monitoring and control
6. Wide-spread use of distributed generation

These events showed that there is an urgent need to provide rigorous analysis and tools of system security to determine operating limits under the new operating environment. In the new power system, conditions are extremely unpredictable and the volume of the transactions that have to be examined may be huge. Also the intra-area and inter-area transactions have increased resulting in frequently changing operating points and load flow patterns that my cause stability problems. The traditional approach to deploying preventive controls based on off-line analysis studies may not be satisfactory. Tools are thus necessary such as on-line stability and voltage stability assessment. Therefore, stability analysis of modern power systems becomes more critical, demanding and difficult. This paper provides an overview of issues related to system stability in a deregulated environment. Section 2 is devoted to an extensive review of the subject matter. Section 3 deals with the definition of DG and the technology issues. The system stability and DG are addressed in section 4 while concluding remarks are given in section 5.

2. GENERAL REVIEW

The restructuring of electricity industry from a highly centralized entity to a new model characterized by competition has impacted many aspects of power system stability. The dynamic performance of the system is a function of the joint characteristics of generation, transmission, control and protection, and loads. In a vertically integrated utility the decision process on generation, transmission, distribution and control additions was well structured and defined. The restructuring requires establishing new facilities and control and also requires administering the required ancillary services. The additions of new facilities will be based on most favorable economic conditions. However, there will be some aspects of dynamic characteristics requiring cooperation dictated by the effects on the overall system performance.

The security of a power system is affected by the characteristics of the physical system such as integrated generation, transmission and distribution system and protection and control systems. It is also influenced by the business structures of owning and operating entities and the regulatory framework. In today’s power system environment, systems are large complex covering vast areas of national/continental grids and they are highly nonlinear systems. There are many processes whose operations need to be coordinated and large of devices requiring coordinated and harmonious interplay. The challenges facing the deregulated system include complex modes of instability due to global problems and the different forms of instability: *rotor angle, voltage, frequency*. Moreover, there are many entities with diverse business interests. Also system expansion and operation are driven largely by economic drivers.

The subject of the impact of restructuring on system has attracted the attention of a number of researchers. A workshop organized by the Cornell university and EPRI of the US in 1997 addressed the underlying technical issues in electricity deregulation [7]. The workshop noted that the tools for security assessment in the new environment must continue to be developed. The increased size of the system implies larger lists of contingencies. The selection of contingencies, corrective action strategies for loss of lines, generation and load rejection must be extended. Also the limits on operating states as determined by the transient events must be considered. The system operators need to have tools that determine actions before a contingency occurs. Any required resource to alleviate the contingency has to be purchased as a service from a selling utility. In 2002, the IEEE commissioned a report on the consequence of the electricity deregulation on transient stability [8]. The paper presented a detailed coverage of transient stability and summarized the impact of deregulation by noting that the analysis will involve large size complex systems because of the economy transfer. There is a need to incorporate risk and probability to define extreme events. Moreover, fast techniques to analyze the stability problem are needed especially with the increased complexity in determining the transfer limits. The paper also noted that greater emphasis should be placed on monitoring and measurements to verify and validate simulation models.

Another feature of the new power system is the increased proliferation of non-utility generation such as IPP, NUG and DG. The location, loading, and operating modes of these entities are dictated by purely economical reasons. Some of these plants may be located near load centers and in many cases are connected at distribution levels. Also the power supplied and loading change according to economic justifications. The overall system operation and security are influenced by these entities. Thus the impacts of the non-utility plants on system security need to be carefully addressed and investigated. Several articles dealt with the impact of DG on the power system transient stability. Donnelly et al noted that DG will have significant impact on transmission system stability at heavy penetration levels [9]. In the case presented, the transient stability limit is improved as the DG penetration size is increased. The added inertia of the DG changed the frequency of the dominant mode of oscillation. However, the authors noted that DG with fast excitation and no stabilizers degrade the small signal stability of the test system. Slootweg et al noted that the impact of DG on system stability will be negligible when connected in small amount 10]. However, if the penetration level becomes higher, DG may influence the dynamic behavior of the system. The author also observed that the impact depends on the technology of the DG. In 2003 paper, Reza et al reported on impacts of the DG by investigating different types of DG and various penetration levels [11]. The paper concluded that the maximum rotor speed for most of the synchronous generators decreases as the penetration level increases. The paper did not address the different types of controller, location and type of system fault. In a follow-up paper, Reza et al concluded that large power flows, following network contingencies, have detrimental effects on oscillations [12]. The connection of the DG is a natural way of limiting the power flow on the lines resulting in fewer oscillations. The impact of DG on system stability was addressed recently by I. Genc et al [13]. The author carried out a number of study cases on a hypothetical power system that includes a DG. The authors concluded that the penetration of the DG can cause local or inter-area oscillatory instabilities depending on the system topology, operating point and control parameters.

This limited literature search has shown that there is a need to address several issues regarding system stability in the deregulated environment. Chief among them is the inclusion of the IPP, NUG and DG into the power system security models. Issues regarding the location and loading of these entities are yet to be addressed. The contributions of these plants in system damping and stability improvements have to be addressed.

3. DEFINITIONS & BENEFITS OF DISTRIBUTED GENERATION

Distributed generators, or DG as commonly known, are fairly new entities in the electricity networks. These are defined as small scale generators covering wide technologies from diesel generators to renewable sources such as wind. They are scattered around the network both geographically and electrically. Historically, the generation of electricity started with DG as the normal practice. The renewed interest is attributed to several factors such technological innovations, changing economic regulatory and environmental conditions. The development in the DG technology, constraints on construction of new transmission lines, customer requirements for high quality supply, deregulated electricity markets, and concerns and awareness about the environment and industrial pollution.

3.1 Technology of DG

Table 1 shows a brief description of the DG and associated information [14]. The types of DG technology vary from reciprocating engines to wind turbines and fuel cells. The ratings span few kilowatts to tens of megawatt as in case of Gas Turbines. Some of the DG units use traditional fossil fuel while others use renewable primary energy. The general efficiency of DG varies from twenty percent to over sixty percent in some applications.

Table 1 DG Technology & Characteristics

DG Type	Rating	Efficiency (%)	Fuel
Reciprocating Engines	20 kW-5 MW	25-42	Diesel, heavy fuel oil, Gas
Gas Turbines	1-60 MW	20-40	Gas
Wind	20 kW-6 MW	NA	Wind
PV	1-100 kW	NA	Sun
Fuel Cells	50 kW-5 MW	30-60	Methanol, Hydrogen, etc

3.2 Reasons for the Introduction of DG into Power Systems

The major driving forces for the introduction of the DG into power system are the restructuring of the electricity sector and awareness of environmental consequences.

3.2.1 Restructuring of Electricity Sectors

The restructuring of the electricity sectors has opened new avenues for the introduction and application of the DG . The introduction of the DG provides economic flexibility because of their size and the short construction time of these units. DG are introduced for a variety of reasons and can provide many opportunities.

(i) Peak Use capacity

The introduction of DG at the time of the peak serves to restrict price fluctuations. Many of DG owners enter the market at the time of peak to benefit from the high capacity prices offered by the market operators.

(ii) Reliability and Power Quality

Customers are now more aware of the supply quality and its consequences. The introduction of DG into the power system may provide protection against electricity interruptions and to a low quality service. Fuel cells, uninterruptible power supply and small diesel engines can provide voltage support and improve the quality of supply**.** On the other hand, the introduction of the DG can have detrimental effects on system operation leading to power quality problems. Problems related to voltage instabilities, complicated reactive power requirements and fluctuations of available power , especially in case of wind and solar DG**.**

(iii) Alternative Expansion or Use of local Network

DG may be a viable substitute or alternative for capital investments in transmission & distribution networks. In many instances, the introduction of the DG can relieve transmission and distribution congestion. Several studies have shown that the introduction of DG has resulted in cost savings. In addition, the proximity of DG to load centers lead to reduction in system losses.

(iv) Grid Support

The operation of the power system in the restructured environment requires the availability of sources of reactive power and spinning reserves upon the request of system operators. These are called ancillary services and DG are one of many sources for such services.

3.2.2 Environmental Concerns

Environmental regulations encourage the use of clean energy with least cost. These contributed substantially to the introduction and development of DG. The DG provide in many cases combined generation of heat and electricity. They also exploit opportunities for cheap fuel within the proximity of load centers. However, it should be mentioned that environmental regulations can have a limiting factor on the introduction of DG. The site and size of the DG have to meet certain regulations and rules.

4. System Stability and Distributed Generation

The presence of DG in the power system has changed the structure of the network and has a great impact on real time operation and planning of the grid. When a DG is connected into a weak distribution system, it will increase the fault level, degrade system stability and may lead to power reversal [15]. Several authors attempted to address the impact of the DG on system stability [16]. Although the introduction of the DG at distribution level may influence system stability limits. The influence depends on many factors such point of connection, level of penetration of the DG, technology of the DG, modeling and control of the DG and others. Of course, the characteristics of the distribution and transmission system influence the outcome.

4.1 Modeling of Different Types of DG

DG are classified into three classes for the purpose of dynamic modeling. These are internal combustion engines, renewable energy turbines and storage devices such as fuel cells.

(i) Internal Combustion Engines

This class includes all reciprocating engines and cogeneration turbines. They range from few kilowatts to multi-megawatt of power. These generators are similar to the traditional generators. They are modeled with the well known swing equation. The only constraints are related to minimum power output and the ramp rate. The minimum power output is related to the co-generation requirements and the ramp rate reflects the rate at which the output power is increased.

(ii) Renewable Energy Turbines

This class is dominated by wind turbines even though photovoltaic cells are also used. Several countries and utilities employ large number of wind turbines constituting a substantial portion of their generation capacity. The output power is function of the wind speed which is fluctuating and special control has to be adopted. For the wind turbine, there is no governor control and the dynamic model shall contain two dynamic components. One component represents the ac generator while the wind turbine is represented by the other component. The ac generators can be any one of the following:

1. squirrel cage induction generator,
2. uncontrolled synchronous generator,
3. synchronous generator with voltage and frequency control.

(iii) Storage Elements

Fuel cells are devices that convert chemical energy into electrical energy. The fuel cell has a certain energy, E, to be released. The only constraint will be on the rate at which the energy is related into the power system. In general, this is a static device and does not substantially impact the system stability.

4.2 DG Grid Connection & its Impact on Stability : A Wind Energy Experience

Wind power installation around the world exceeds over 40,000 MW. These installation ranges from isolated wind turbines to large wind farms connected directly into the grid. The Integration of wind power plants into the electric power system presents challenges to power-system planners and operators. These challenges stem primarily from natural characteristics of wind plants. Wind power plants operate when wind is available and power level depends on wind strengths-hence not dispatchable in traditional sense. Wind power generation uncertainty leads to uncertainty in real-time process of maintaining the system's balance between generation and load . The issues related to the connectivity of the wind turbines will have an impact on system stability and security. The impact of this type of DG on system stability depends on the several factors:

- The penetration level or the size of the DG units. In other words, how much of the total power generated by Central Generation Units is contributed by DG(s) in the network. Or how much is the increase in the load that is covered by DG(s).
- The type of wind generators and whether Synchronous/Asynchronous Machines are used.
- The location of the fault in the network.
- The electrical location of the DG unit within the system..

For the purpose of assessing the impact of wind turbines on system security, wind generators are classified as follows:

(i) TYPE A: Fixed wind speed Wind Turbine – asynchronous squirrel cage induction generator connected to the grid via a transformer

(ii) TYPE B: Limited variable speed Wind Turbine – Wound rotor induction generator with variable generator rotor resistance and pitch control

(iii) TYPE C: Variable speed wind Turbine – Doubly fed induction generator (DFIG) and pitch control

(iv) TYPE D: Variable speed pitch control Wind Turbine – Generator is connected to the grid through a full-scale frequency converter

The high wind power penetration requires rethinking of the power system operation methods as wind power cannot be scheduled with the same certainty as conventional power. Also large turbines with variable speed operations tend to absorb gusts, i.e. they briefly store the kinetic energy of the wind by increasing the rotational speed – Hence power output can be kept rather constant. Also large wind farms (> 50 MW) are not very common; – Hence the wind generation capacity is spread geographically over a reasonably large control area so that the short-term fluctuations are smoothed out. But large power variations become a problem if not predicted accurately.

The American Wind Energy Association (AWEA) developed a grid code for wind turbine .

(i) Low voltage ride-through (LVRT) capability for wind plants and wind turbines

Wind turbines are expected to have a ride through capability as shown in figure 1.In order to improve system dynamics, all wind turbine shall be able to ride-through a voltage profile similar to that shown in fig 1.

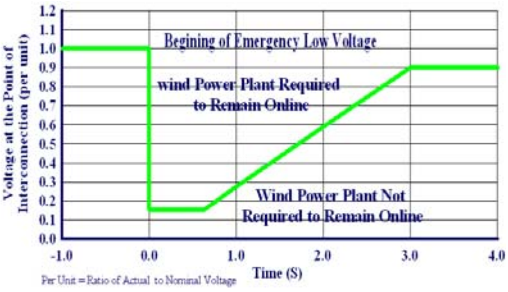

Figure 1 Low Voltage Ride Through Requirements for Wind Turbines

(ii) **Supervisory control and data acquisition (SCADA) equipment for remote control**. Equipment for remote command and control for the limitation of maximum plant output during emergency and system contingency

(iii) Reactive power capability
Wind plants connected to the transmission system be capable of operating over a power factor of ±0.95

(iv) Current wind turbine simulation models
Transmission providers and turbine manufacturers should participate in a formal process for developing, updating, and improving engineering models and turbine specifications used for modeling the wind plant interconnections

5. CONCLUSIONS

The liberalization of electricity markets and the environmental awareness of consumers contributed to the wide application of DG into systems. But the presence of DG presents system operators with new problems regarding DG availability and its impact on system security and stability. This is especially true for wind turbines which represent the majority of DG. The modeling of wind turbines for system stability depends on the technology of the wind generator. Also large turbines with variable speed operations tend to absorb gusts, i.e. they briefly store the kinetic energy of the wind by increasing the rotational speed and power output can be kept rather constant. But large power variations become a problem if not predicted accurately. The paper concludes that much work is needed on the development of mathematical models to account for inclusion of DG into system stability.

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