# Impact of Biomass Based Distributed Generation on Electric Grid

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## ABSTRACT

Advances in technology and the push for alternative clean energy systems have created a new paradigm in the last ten to fifteen years. The most commonly used technologies for alternative energy systems include wind turbines, photovoltaics, fuel cells, and biomass powered generators within range of 10 kW to 50 MW. These small generating units connected near the loads on the distribution network are called Distributed Generations (DG). With the increasing use of DGs in the electric power system, it becomes necessary to study the impacts of connecting the DGs to the grid. This research work aims at analyzing the steady state and transient impacts of biomass based DG on the electric grid. Transient analysis has been done to assess the impact of DG with energy storage devices connected near the DG. The work presented here further relates to optimizing siting and sizing of biomass based DG to maximize the steady state voltage stability using a mathematical approach.

***Keywords*:** distributed generation, energy storage, simulink, steady state stability, and transient stability.

## 1. INTRODUCTION

Distributed Generation (DG) is the concept of placing small generating units at or near the load center. This concept is gaining wider interest due to advancements in technology, increased conventional fuel price, environmental concerns, and increased social awareness. This technology could be beneficial especially for the states like Mississippi that are agriculturally dominant and has abundant resources of biomass derived from organic waste and residues. If properly planned and implemented DG can be beneficial to the power industry by providing necessary voltage support, stability, reliability and reducing the cost of future expansion.

In addition to supplying local loads, excess energy produced by the DG can be supplied or connected to the grid. The interconnection of the DG brings many challenges for protection, stability and security of the electric grid. Energy storage devices may also be connected near the DGs in order to help supply the loads during peak periods. These devices are connected to the grid by means of power electronic interface. During periods of low demand, these energy storage devices are charged and when there is a peak demand, the storage devices provide addition power above the normal maximum of the DG. The most commonly used energy storage devices are the batteries, supercapacitors and flywheels. Steady state stability of a system with DG depends on the voltage profile. There could be undesired voltage profiles in the system due to oversize and improper location of DG, which affects the steady state stability of the system. The importance of size and location creates a broad scope of research. Several researchers have attempted to address impact of DG in stability in the past [1-4].

In this study the impact of the biomass based DG on the transient and steady state stability of the grid will be analyzed. Most of the research on optimizing the siting and sizing of the DG was based on minimizing the power losses, cost of network expansion, or energy supplied. This work aims at optimizing size and location based on voltage support and stability. Impact on transient stability includes presence of energy storage with DG.

## 2. TRANSIENT STABILITY ANALYSIS

Transient stability study of a system is done in order to analyze the response of the system to severe disturbances/ faults. Transient stability depends upon various factors such as the type and location of fault, severity of the fault as well as the initial conditions of the system. In our study three different stability indicators have been chosen. They are

a. Rotor angle deviation
b. Terminal voltage
c. Rotor speed deviation

Terminal voltage was analyzed by considering the amount of drop in voltage during a fault as well as the time taken for the voltage to settle after the clearance of the fault. Similarly rotor angle deviation and rotor speed deviation were analyzed considering oscillation duration and maximum magnitude.

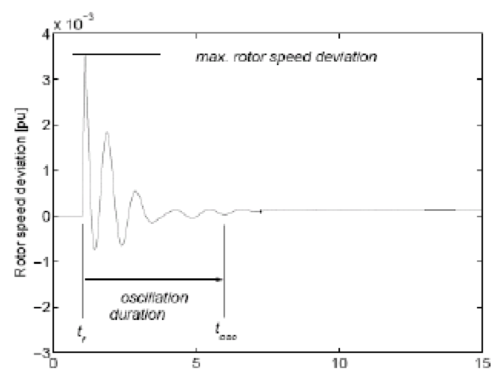


Figure 1: Rotor speed deviation and oscillation duration



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## 2.1 Test System

The one line diagram of the 8-bus test system built in Matlab/ Simulink is given in Figure 2. The system consists of a three phase main source and three DG's. Out of the three DG's, two are represented by synchronous generators and one by an induction generator. There are a total of 15 loads comprising of six induction motors and 9 RL (variable resistance and inductance) loads. The total load of the system is 45 MVA. The ratings of the system components are given in Table 1.

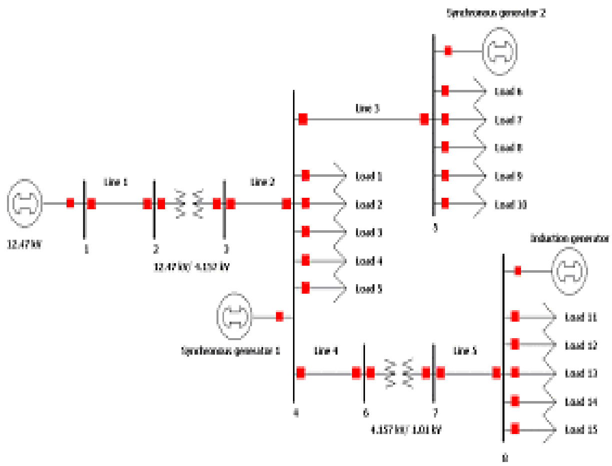


Figure 2: One Line diagram of the 8-bus test system

| | |
|---|---|
| Synchronous generators | 4.157kV |
| Induction generator | 1.01 kV |
| Transformers | 12.47 kV/4.157 kV<br>4.157 kV/1.01 kV |
| Main source | 12.47 kV |
| Loads | 6 induction motors<br>9 R-L |
| Total load demand | 45 MVA |

Table 1: Ratings of the test system components

## 2.2 Test Scenario

Three different types of faults, namely three phase, line to ground and double line to ground, are applied to the system at bus 4. The fault duration is taken to be 100 ms. Transient stability indicators mentioned earlier, are observed and analyzed. A similar process is repeated for different penetration levels of the DG. The penetration level of DG is calculated based on equation (1).

$$\% DG = \frac{\sum P_{DG}}{\sum P_{load}} * 100 \qquad (1)$$

Where $\sum P_{DG}$ represents the total power supplied by the DG and $\sum P_{load}$ represents the total load power. In our case all three DG's are considered to supply equal power to the load. Analysis is done for penetration levels of a total of 5% – 50% and for different types of faults. Depending on the level of penetration, the rated power of the DG is changed. During the fault period, none of the equipment is considered to be disconnected.

## 2.3 Simulation Results

### *a. Rotor Angle*

Figure 3 shows the deviation in the rotor angle during the fault due to different types of faults and different total penetration levels of DG. The deviation in the rotor angle during the fault is found to decrease with more penetration level of DG's. This means that the rotor angle stability is increased with increase in penetration level of the DG.

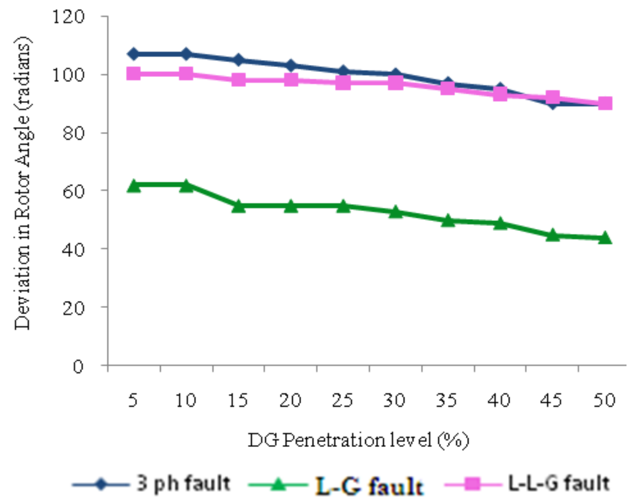


Figure 3: Deviation in rotor angle due to different types of faults and different penetration levels of DG

### *b. Terminal Voltage*

Terminal voltage for different types of faults and DG penetration levels has been shown in Figure 4. Time taken to return to normal voltage after the fault was also observed.

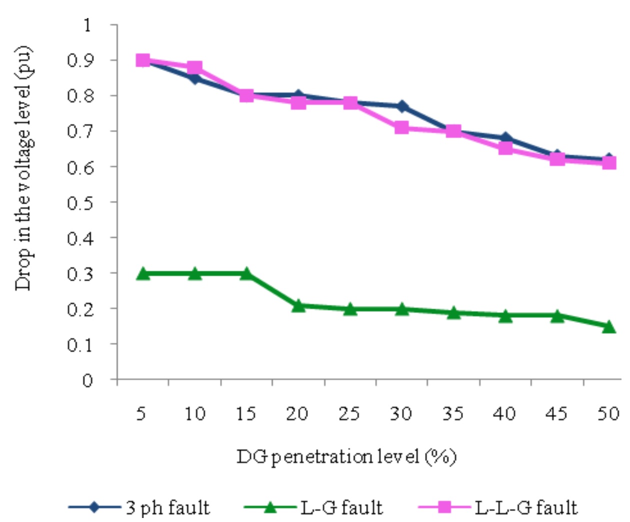


Figure 4: Drop in terminal voltage during fault

The drop in voltage during a fault as well as the time to settle decreases with an increase in the penetration level of the DG. This shows that increased penetration of the DG improves the voltage transient stability of the system.

### c. *Rotor Speed Deviation*

As shown in Figure 5, the rotor speed deviation decreases with increasing total DG penetration levels. The oscillation duration is also found to decrease with the increase in penetration level of the DG's.

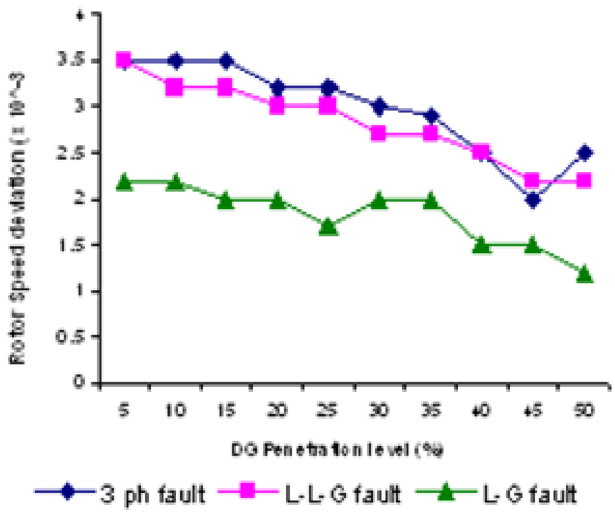


Figure 5: Rotor speed deviation for different faults

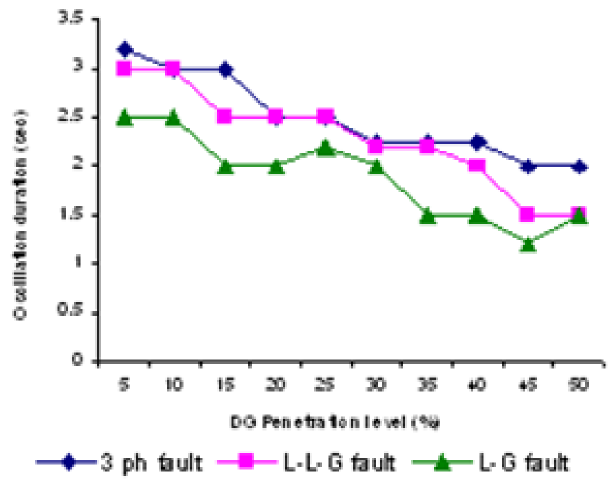


Figure 6: Oscillation duration for different types of faults

From the transient analysis based on chosen indicators, it can be seen that by increasing the penetration level of the DG's, the transient stability of the system can be improved.

## 3. STEADY STATE ANALYSIS

Distributed generators have a significant impact on the voltage profile of the system especially in rural areas where voltage swings and outages are more common. This investigation is working to identify if oversize or improve location of a DG within the grid might cause undesired voltage profiles within the system. Steady state analysis was done using the Unbalanced Three Phase Power Flow (UTPFLOW) software developed at MSU [5]. This developed software tool has the option of choosing DG modeled as either a PQ or PV node and also can handle multiple DG sources.

### 3.1 Test System

IEEE 13 node feeder as shown in Figure 7 is used for this analysis and the component models of the test case are developed in the UTPFLOW. The data for the feeder was obtained from the IEEE test case archive for the distribution feeders [6]. This feeder, being highly loaded and unbalanced, aptly suits for the analysis of unbalanced distribution power flow analysis. The regulator was removed to see the effects of the DG on the voltage profile.

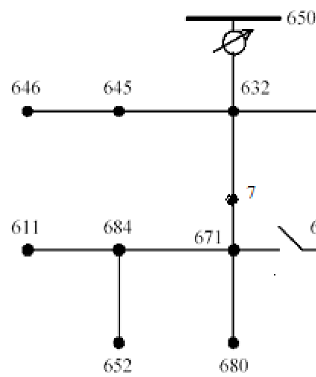


Figure 7: IEEE 13 Node Feeder

IEEE 13 node feeder is short and a highly loaded feeder for a 4.1 kV level and the total load of the feeder is 3.466 MW. It has spot loads, distributed loads, single phase and three phase unbalanced loads, wye and delta connected, constant kW, kVAR, constant Z and constant I type loads. It also has a substation transformer and inline transformer as well as three phase and single phase lines with different spacing between the phases.

### 3.2 Stability Index

A suitable stability index was selected from the literature to find the stability of unbalanced distribution networks. The mathematical formulation for the index is derived from the voltage equation used in distribution power flow problem [7]. For a single line connecting two buses with impedance $R_i + jX_i$ the stability index is given by equation (2).

$$L(i) = 4\left[\left[V_i V_j \cos(\theta_i - \theta_j) - V_j^2 \cos(\theta_i - \theta_j)^2\right]\right/ V_j^2 \quad (2)$$


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Where,

$V_i \angle \theta_i$ is the voltage and voltage angle at bus *i*.

$V_j \angle \theta j$ is the voltage and voltage angle at bus *j*.

$L(i)$ is the value of stability index at node *i*.

If $L(i)$ <1.0, system is stable

$L(i) \geq 1.0$, system is unstable.

This index can be extended to larger systems and for all the phases.

### 3.3 Simulation Results

Two DG's that are modeled as PV nodes are placed at nodes 632 and 671, the total penetration of the DGs is varied from 10% to 60%, power flow is run for each case and the voltage profile obtained for each phase is compared with the base case having no DG in the system.

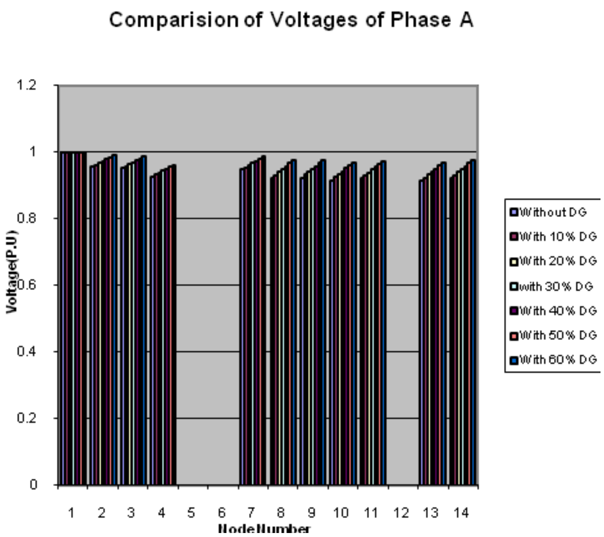


Figure 8: Comparison of voltages of phase A with and without DG.

It can be seen from the Figure 8 that as the penetration level of the DG increases, the voltage profile of the system improves. Similar results are obtained for phase B and C.

Steady state analysis was further extended to calculate the stability index for a particular DG size using equation (2). The IEEE 13 node feeder, a relatively small system, was quite stable except at a few nodes where the index was close to 1.0. If the size of the DGs goes beyond a particular size the system may lose stability. To maximize the stability a formulation is being developed in LINGO [8] to optimize the DG size.

## 4. SUMMARY AND FUTURE WORK

Transient and steady state analysis have been done to assess the DG impact on electric grid. The transient stability of an 8-bus system was analyzed with the help of three transient stability indicators. Different types of faults were applied to the system and different penetration levels of the DG were considered, and the response of the indicators to the faults was analyzed. From the results it was found that the transient stability of the system increases with an increase in the penetration level of the DG up to certain extent. Models of battery and ultracapacitor have been developed and modeling of a power conditioning device is currently being developed in Simulink. These energy storage devices would be connected to the test system by means of suitable power conditioning devices and the transient stability of the system will be analyzed.

The voltage profiles for different sizes of the DG are obtained using the UTPFLOW software and compared with the base case. Results indicate that higher penetration of DG have a positive impact on grid. A mathematical formulation is being developed in LINGO to maximize the steady state stability of the grid by finding the optimal size and location.

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