Wind Farm Transient Simulation on ATP

Carlos M. Torres Ortolaza
carlos.torres@ece.uprm.edu

Camille Guzmán Torres
camille.guzman@ece.uprm.edu

Abstract – In this paper the analysis of the transient stage of a wind turbine when it is initially connected to power distribution system IEEE 13 Node Test Feeders. The type of induction generator used to run the simulation is a self-excited induction generator.

I. INTRODUCTION

Wind energy has become an increasing source of electrical energy production in recent years. In this project we examine the effect caused by a wind farm in a transmission system when it is initially connected to the grid. For propose of this paper only one wind turbine of 2 MW was used in the analysis. The simulation has been made using only one wing turbine connected to a power distribution system IEEE 13 Node Test Feeders. The type of induction generator (IG) used to run the simulation is a self-excited induction generator.

II. THEORY

Because of growing interest of using wind energy as a source of electrical energy production, it is necessary to study the possible impact a wind turbine will produce on the power network where it is connected. In order to investigate the effects, suitable wind energy models must be used.

The technology used in most of the land based wind farms is stall regulated wind turbines with conventional fixed induction generators which are connected directly to the to the power system. Low and medium self-excited induction generators are ideally suited for non-conventional energy systems such as wing-electric generators, micro hydel power stations, etc. In rural areas where large wind resources are available, stand alone wind turbine driven induction generator can meet the local requirements. Low cost, simple and reliable operation, minimal maintenance, and inherent short circuit protection capability, are only some of the advantages of this system.

The effects of wind turbines on power systems can be classified in two groups: steady-state security and power quality. The goal of steady-state security is to seek network power stability conditions when the wind power is initially injected into a system. Power quality analysis studies the effects of wind power fluctuations in the form and level of electrical waves (harmonics, fluctuations, etc.).

Besides the induction generator a wind energy conversion system also consists of a blade, hub, and a coupler. So the wind energy conversion system follows four aspects [2]:

1. Stochastic wind energy

Because the speed of the wind is affected by the temperature, pressure, humidity, and died degree, actives of the sun and the moon, topography of the wind farm, etc., the speed of the wind is stochastic and uncontrolled, hence the wind energy.

2. Large inertial wind turbine

The wind turbine blade diameter is very large, so the turbine inertia is very large, and the wind energy density is very low.

3. Flexible coupling between the wind turbine and the induction generator

Owing to the low rotational speed of the wind, the turbine can to be connected directly to the generator, so the torque of the turbine must be transferred by a gear box and a coupler. As a result the rigidity between the turbine and the induction generator is very low.

4. Induction generator

The induction generator is used because of its low cost, reduced maintenance, rugged, and brushless rotor. The use of some capacitors provides reactive power to the excitation.

The connection of the wind farm to the nearest primary substation may not be cost effective. So, it is more attractive to use existing rural
distribution systems for the connection of individual or small wind farms.

III. DISTRIBUTION SYSTEM

The distribution system used in the analysis is the IEEE 13 Node Test Feeder (Fig. 1). It is a small one, yet displays interesting characteristics. It is a 4.16 kV short and highly loaded feeder. This system serves a total load of 5 MVA.

This feeder is characterized by:
1. Short and relatively highly loaded for a 4.16 kV feeder
2. One substation voltage regulator consisting of three single-phase units connected in wye
3. Overhead and underground lines with variety of phasing
4. Shunt capacitor banks
5. In-line transformer
6. Unbalanced spot and distributed loads

IV. INDUCTION GENERATOR MODEL

The structure of squirrel cage induction generator is same as induction motor have aluminum bar winding laid into the slots of the rotor core and short-circuited at both ends. Single-phase equivalent circuit of three-phase cage generator is similar to three—phase transformer equivalent circuit with one winding is short-circuited, and the same circuit models apply as shown in Fig. [2]. The circuit shown in Fig. [2] can be used in steady state operation. In this circuit, the machine core losses have been ignored. The successfully build up in self-excited induction generator occurs when $X_m$ have the right value in saturation. The simulation of the induction generator is based upon the following assumptions:

a. Saturation effects and core losses are neglected
b. Space harmonics on air-gap flux are ignored
c. The stator transients are neglected

A 2 MW induction generator (IG) model for wind farms was used in our simulations. The parameters shown below are based on a 60 MVA base. It uses a capacitor for power factor correction ($X_{PFC}$), but it was removed in the simulations in order to simplify it.

![Figure 2](image2.png)

V. SIMULATION AND RESULTS

ATP/ETMP program was used to analyze the transient in a power system when a wind farm is connected to help supply the increasing load. Figure 3 is the schematic of our IG model (without $X_{PFC}$) in ATP. The parameters were changed from p.u. (60 MVA and 0.69 kV bases) to its equivalent in Ohms using a $Z_{base} = 0.007935$ Ω. A three-phase source is connected in series to the $R_s$ to model the voltage created in the stator. It has a 690 V rating, but a 4.16 kV source was used in the model to eliminate the need for a transformer. The elimination of the $X_{mer}$ reduces the reality of the simulation, however this action minimizes simulation problems (multiple frequency, inaccurate waveforms, etc.) that we faced before. The slip used in the simulation is 2% because at this value the torque-slip curve presented in Ref [2]...
is close to its peak. The output in a real wind farm varies time-to-time because of the stochastic nature of wind, so a fixed slip is not ideal. However, simulating this behavior is quite complex using ATP, so behind of our scope. The use of power electronics are becoming widely used to stabilize the output for a certain range of wind energy, so our assumption of a fixed output can be acceptable.

The Wind farm was connected in the node 680, far away from the other sources, including a DG (Distributed Generation) at node 634, to balance the power injection in the distribution system. The simulation consisted in two parts; in the first part the wind farm is disconnected from the main distribution system, but it feed a load connected at the same node, and the second part has this load feed originally from the main distribution system and later the wind farm is connected to inject power in the main system. We want to see the transient produced in the loads when the wind farm is connected to the distribution grid. The controlled voltage switches used for the wind farm are closed sequentially when each voltage phase of the induction generator reach 0V, about 0.1 seconds after the simulation starts. Fig. 3 and 4 show the IG model built in ATP and the complete IEEE 13 node system respectively.

**A- Part I**

The transient were monitored in the loads at nodes 634, 675 and 740 (load close to the wind farm, at the node 680). Loads at node 634 and 675 are feed by the utility at node 650 and the DG in node 634. The load at node 740 originally (disconnected form the main system via breaker) has no power source until it is connected to the wind farm at 0.1 seconds later. The next figure (Fig. 5) shows a perfect the voltage at load node 675, and a similar result is found in the load at node 634. A harmonic analysis of this waveform shows us a THD of 6.1025% (Fig. 6). The harmonics included in the analysis are those from the fundamental (1st) thru the 30th, using the last cycle of the simulation (0.1833-0.2 sec).

![Figure 5. Transient voltage at nodes 675](image)

Figure 5. Transient voltage at nodes 675

![Figure 5. TDH analysis for nodes 675](image)

Figure 5. TDH analysis for nodes 675

When the wind farm is connected to the load at node 740 (Fig. 7) a heavy transient is produced in the load due the sequential closing of the switches, and in the switches themselves (Fig.8), but the transient vanish in about 0.005secs. The %THD in the load during the transient (0.0975-0.114167, a full cycle) is 408.82% (Fig. 9). However, the %THD at this load in steady state is quite lower than those of load 675 and 634, about 4.0650%, probably due to the proximity of the power source.
B- Part II

Before the injection of the wind farm, we compared the voltage output at the utility and the wind farm. Both had equal magnitude and phase just before the wind farm in connected to the grid (Fig. 10). At 0.1 seconds the wind farm is connected to the main distribution system to help supply the 5 MVA load.

Looking at node 675, a transient is evident (Fig. 11), especially in phase A (red) when the wind farm injects power to the grid. The addition of the wind farm in the system raises the voltage in all loads. Apparently the injection of power helps stabilize the voltage because the THD found is less, about 3.9516% (Fig. 12). The same effect is seen in the other loads. Table 1 summarizes the values of THD at load before and after the power injection from the wind farm.
voltage across the voltage controlled switches (Fig 14). The THD during the transient (Fig. 15) was reduced from 408.82% to 34.489%.

![Figure 12. Transient at node 740 when the wind farm is connected to the utility](image)

![Figure 13. Voltage controlled switches transient](image)

![Figure 14. THD analysis at node 740 when the wind farm is connected to the utility](image)

### Table 1. TDH Summary

<table>
<thead>
<tr>
<th>Event</th>
<th>Load THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IG Disconnected</td>
<td>6.0844</td>
</tr>
<tr>
<td></td>
<td>6.1025</td>
</tr>
<tr>
<td></td>
<td>4.0650</td>
</tr>
<tr>
<td>IG Connected</td>
<td>4.0368</td>
</tr>
<tr>
<td></td>
<td>4.0633</td>
</tr>
<tr>
<td></td>
<td>4.0607</td>
</tr>
<tr>
<td>IG Disconnected (transient Interval)</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>---</td>
</tr>
<tr>
<td></td>
<td>408.82</td>
</tr>
<tr>
<td>IG Connected (transient Interval)</td>
<td>22.077</td>
</tr>
<tr>
<td></td>
<td>35.996</td>
</tr>
<tr>
<td></td>
<td>34.489</td>
</tr>
</tbody>
</table>

VI. Conclusion

The interest in renewable energy has encouraged the use of wind farms. Because the use of power electronics to stabilize the output, the assumption of a fixed output is acceptable. Nodes close to the wind farm reported low THD percents. A heavy transient was produced at node 740, but it banished rapidly. Before the connection of the wind farm the utility and wind farm voltage output are at face, but when the farm is connected to the utility a small transient is appreciated. The connection of the wind farm produced a raised in voltage magnitudes and stabilized them.

VII. References

7. IEEE Recommended Practice: Definitions of Basic Per-Unit Quantities for AC Rotating Machines, IEEE Std 86-1987, Feb. 1987