Caribbean Renewable Energy Development Programme (CREDP)
CARICOM Secretariat

Wind-Grid Integration Brief

MAJOR INTEGRATION ISSUES

- Utilities are seeking to understand possible impacts on system operations when a large amount of wind power is introduced into the electric power system. Their concerns, if not adequately addressed, could significantly limit the development of wind power in the region.
- Because wind is a variable resource, it raises concerns about how it can be integrated into routine grid connections, particularly with regard to the effects of wind on regulation, load following, scheduling, line voltage, and reserves.
- Under various wind and system conditions, what are the power quality, voltage stability, and reactive power support issues?
- How should the cost of wind generated electricity be compared to coal, diesel and natural gas if wind is intermittent and the other resources are firm?

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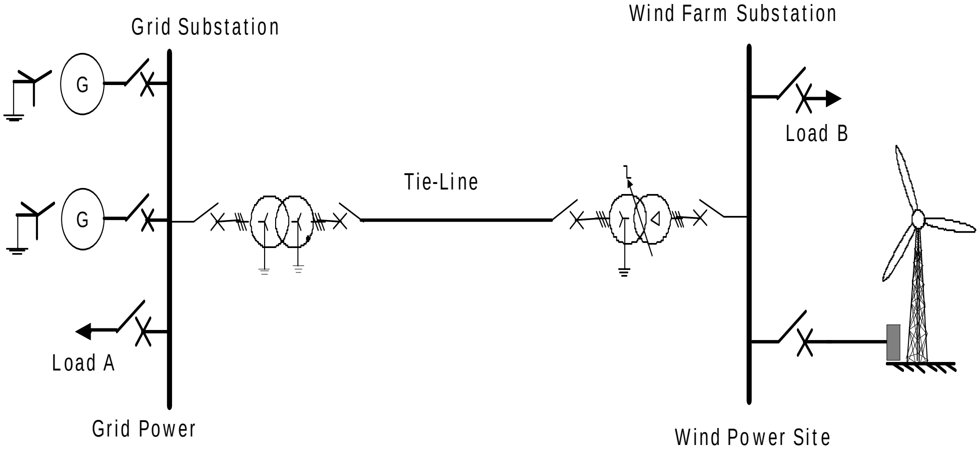

Figure 1: One-Line Diagram of Grid-Connected Wind Farm

GRID INTEGRATION:

No matter what the arguments are, it has been proven that wind power can be successfully integrated with the power grid. The degree of this success and the level of wind penetration varies largely on:

- The design limits of the tie-line—the key design parameters being:
  - ⇒ Voltage levels
  - ⇒ Capacity
  - ⇒ Voltage Regulation
  - ⇒ Tie-line Stability
- Interface standards—mainly related to power quality, which in turn determines the renewable capacity limit. Power Quality issues are:
  - ⇒ Harmonic Distortion
  - ⇒ Voltage Transients and Sags
  - ⇒ Voltage Flicker
  - ⇒ Step Load Voltage
- The firm capacity of the windfarm and the associated wind power dispatch issues.
  - ⇒ Load following
  - ⇒ Scheduling
  - ⇒ Reserve
- Response to abnormal conditions:
  - ⇒ Voltage disturbances
  - ⇒ Faults

Wind-Grid Integration Brief

DISPATCH & CAPACITY CREDIT APPROACHES:

- To alleviate wind power dispatch difficulties, a reliable and accurate forecasting system is needed to forecast next day wind speed and power.
- The annual energy generated from the wind can be estimated with some certainty, on a long-term basis. In addition, some locations (islands with trade winds) can have a degree of predictability on a daily or hourly basis. Thus, it is possible for windfarms to get some capacity credit in these locations.
- As an alternative, hybrid wind/gas or wind/storage systems could earn full capacity credit.
- According to the American Wind Energy Association (AWEA), the technical limits of integration are reached when wind is providing about 40% or more of the total electricity on an annual basis.

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SYNCHRONIZING WITH THE GRID:

Four conditions which must be met for synchronization are:

- The wind power frequency must be as close as possible to the grid frequency—preferably about one third of a hertz higher.
- The terminal voltage magnitude must match with that of the grid—preferably a few percentage points higher.
- The phase sequence of the two three-phase voltages must be the same.
- The phase angle between the two voltages must be within 5 percent.

Following the closure of the circuit breaker any voltage mismatch will result in an inrush current to flow between the site and the grid. The magnitude of this current at the instant the circuit breaker is closed produces the synchronizing power which acts to bring the two systems into synchronous lock. The inrush current is associated with a mechanical torque step and must be minimized, else thermal or mechanical damages may result.

IMPORTANT WIND POWER GENERATOR DRIVES:

Direct Induction Generator Drives:

- Because the squirrel-cage induction generator derives its magnetic excitation from the grid, the response of the turbine during a grid disturbance will be influenced by the extent to which the excitation is disrupted.
- For sudden changes in wind speed, the mechanical inertia of the drive train will limit the rate of change in output of the induction generator.

Variable-Speed Induction Generator Drives:

- Because all of the power from the turbine is processed by the static power converter, the dynamics of the induction generator are effectively isolated from the power grid.
- The power converter provides several advantages for distributed generation interface applications or for interconnection to the medium-voltage lines such as would be typical for many Caribbean countries:
  - ⇒ Low waveform distortion with little passive filtering
  - ⇒ High-performance regulating capability
  - ⇒ High conversion efficiency
  - ⇒ Fast response to abnormal conditions, including disturbances, such as short-circuits on the power system
  - ⇒ Capability for reactive power control

VOLTAGE FLICKER:

Turbine speed fluctuations under varying winds, causes voltage flickers and current variations

- Voltage Flicker severity increases as the square root of the number of machines.
- Flicker may be of concern in low voltage transmission and/or distribution lines connected to the grid.
- The flicker caused by one machine varies inversely with the fault level at the point of grid connection, hence can be a significant issue for weak grids.

HARMONICS:

Harmonics are generated by the power electronics and the speed control systems.

- Normally, to keep the Total Harmonic Distortion within acceptable limits, operating harmonics need to be filtered out.
- Total harmonic content is fount (empirically) to vary with the square root of the number of machines.

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VOLTAGE REGULATION:

Maintaining voltages within tolerances at individual turbines within a wind plant while at the same time meeting power factor or voltage regulation requirements at the point of interconnection with the transmission system requires careful management of reactive power.

- Typical locations for reactive power compensation within a wind plant are: at individual turbines; at the interconnect substation in; at locations along the medium voltage collector lines
- Some plants have the ability to dynamically control reactive power from each turbine, which offers the possibility of reactive power management for transmission system considerations to be accomplished by the turbines themselves. Terminal voltages at individual turbines, however, may be a constraint on the amount of reactive power that can be delivered to the interconnect substation during periods of high wind generation.
- Reactive power support for maintaining target voltages at the transmission interconnection will vary with the real power injected, which is in turn dependent on the temporal variation of wind resource.

STABILITY LIMIT:

- The direction of the power flow across the Tie-Line depends on the sending and receiving end voltages.
- The magnitude of the real power transferred by the Tie-line depends on the power angle δ (the phase angel between V_s and V_r). If $\delta > 0$, the power flows from the windfarm to the grid. When $\delta < 0$, the windfarm draws power from the grid.
- The power flow is maximum when $\delta = 90^{o}$
- Beyond this maximum power (P_{max}), the Tie-Line becomes unstable and will lose synchronism. This is referred to as the steady state stability limit of the system.
- In practice, the line loading must be kept well below Pmax, to allow for transients such as sudden load steps and system faults. The maximum power the line can transfer without losing the stability during transients is referred to as the dynamic stability limit.
- In typical systems, the power angel must be kept below 20^{o} to assure dynamic stability.

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Wind Technology Brief

STARTING INRUSH CURRENTS:

- In starting the windfarm, the induction machine causes voltage transients.
- Transient voltage dip limits should be 2 to 5%.
- In windfarms with many machines, the machines should be started in sequence to minimize this effect.
- For very weak systems (typical of Caribbean countries) this issue can limit the number of machines that can be connected to the grid

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WINDFARM CAPACITY LIMIT:

Most utilities are faced with the issue of compatibility of windfarms for interfacing with the grid from the power quality point of view. The basic consideration in such decision is the source impedance before and after making the connection. This is often and otherwise referred to as the available short-circuit MVA at the point of interconnection—also known as the system stiffness or the fault level.

- The higher the fault level, the stiffer the network
- A minimum grid stiffness in relation to the wind power capacity is required to maintain the power quality of the resulting network
- Not only is the magnitude of the equivalent source impedance of the two systems important, the resistance (R), and the reactance (X) components of this impedance have their individual importance.
- The system fault current decays exponentially as $e^{-t/(X/R)}$. High X/R ratios causes fault currents to decay slowly, making protective relaying more difficult.
- The X/R ratio influences voltage regulation, which may place a limit on the continuous maximum load the windfarm can deliver. The acceptable voltage regulation is typically 5 to 7%.

Interfacing Standards:

- Utilities have found it convenient to meet the power quality requirements by limiting the windfarm capacity to a small percentage of the short-circuit MVA of the grid at the point of interconnection.
- This limit is usually 2 to 5%
- Yet another rule of thumb to address the power quality issues for stiff grids has been to keep the wind farm capacity in MW to less than the grid line voltage in kV.
- In the case of weak grids, only 10 to 20% of the above capacity may be allowed.
- It is complex to determine the maximum wind plant capacity at a given site, which will meet all electrical, operating and power quality requirements. The percentage of the short-circuit MVA at the point of interconnection, in the absence of more rigorous standards and simulation tools, is recommended.