ASSESSMENT OF THE PROTECTION REQUIREMENTS FOR A CLUSTER OF WIND POWERED EMBEDDED INDUCTION GENERATORS

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ABSTRACT

Concern is focused on the introduction of embedded generation (specially wind power) to the low and medium voltage networks. Embedded generation by renewable energy sources has become an urgent need due to environmental problems caused by large central generation.

This paper addresses the protection requirements for a 20 MW wind farm, equipped with induction generators. Protection of each section such as generator, transformer, bus bar and tie line is considered separately. In addition theory behind wind power extraction, types of wind turbines, regulation of wind turbines and their advantages and disadvantages have been addressed.

1. INTRODUCTION

Embedded generation offers considerable environmental benefits and so its continued development can be beneficial for society as a whole. The use of renewable energy sources is clearly desirable as a way of reducing gaseous emissions from conventional generating plant. There is a greater concern for wind power due to its low cost, environmentally friendliness and availability. For generation of wind power, induction generators are preferred due to its low cost, robustness, lack of synchronizing requirement & high damping of the drive train.

Most of the wind turbines are equipped with fixed speed stall regulated turbines, however the new trend is variable speed pitch regulated turbines with Doubly fed induction generators (DFIG). There are some underdeveloped areas of this technology, the standardization of protection and control of DFIG are at research level.

Offshore sites for wind power generation at an increased cost are preferred since these have higher mean wind speed and low wind shear and turbulence.

In the Sri Lankan context, it will be very important and useful to study the protection requirements of a wind plant, which is using asynchronous generators, since the system is dominated by centrally planed and dispatched synchronous generators.

2. EMBEDDED GENERATION

Recently there has been a significant and considerable revival in interest in connecting generation to the distribution network due to the emergence of new technology, renewed interest in environmental factors and a change in economic, commercial environment. This is known as embedded (dispersed) generation.

With significant penetration of embedded generation to the utility network the power flows may become reversed and the distribution network will become an active system with power flows and voltage determined by the generation as well as the loads. The change in real and reactive power flows caused by embedded generation has important technical and economic implications for the power system.

However there is a limit of embedded generation connected to the distribution network, since its not centrally planned or dispatched and they contribute to increase the fault level.

2.1 Wind theory

A wind turbine operates by extracting kinetic energy from the wind passing through its rotor blades. The power developed by a wind turbine is given by,

$$\mathbf{P = C_p \rho V^3 A / 2}$$

Where, C_p = power coefficient

P = power (W)

V = wind velocity (m/s)

A = swept area of rotor disc (m^2)

ρ = density of air (1.225 kgm^{-3})

- Power is proportional to the turbine swept area
- Power is proportional to V^3
- The power coefficient (C_p) is a measure of how much of energy in the wind is extracted by the turbine rotor. It varies with rotor design and the relative speed of the rotor and the wind (known as the tip speed ratio).
- The output of a wind turbine at various wind speeds is shown in the following figure 1

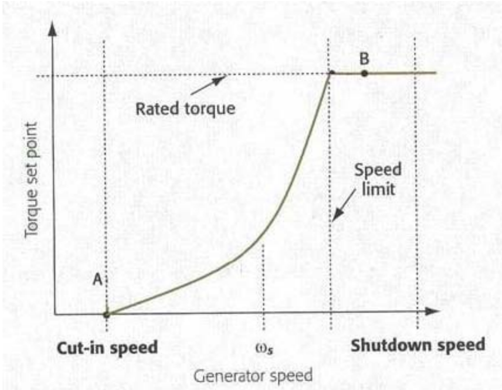

Figure 1 - output of a wind turbine

2.2 Design criteria of wind turbines

Major differences in design philosophy of wind turbines are, Fixed or variable speed of operation and Stall or pitch rotor regulation.

Fixed speed Vs. Variable speed wind turbines

Fixed speed wind turbines are simpler and robust. The aerodynamic rotor is coupled to the squirrel cage induction generator via a speed-increasing gearbox. The induction generator is typically designed for 690V, 1000 or 1500rpm operation. Synchronous generators are not normally used, as it's not practicable to include adequate damping in a synchronous generator rotor to control the periodic torque fluctuations of the aerodynamic rotor. Fixed speed turbines can act only as an active energy supplier to the system without any voltage or frequency support to the system.

In variable speed wind turbines, it is possible to increase the energy captured by the aerodynamic rotor by maintaining the optimum power coefficient over a wide range of wind speeds. However it is then necessary to decouple the speed of the rotor from the frequency of the network through two voltage source power electronic converters.

Rotor regulation

At the rated wind speed, it is necessary to limit the power into the wind turbine rotor and some form of rotor regulation is required.
Stall regulation-This is a passive system with no moving parts, which operates by the rotor blades entering aerodynamic stall once the wind speed exceeds the rated value. It relies on the rotational speed of the rotor being controlled and so is usually found on fixed speed wind turbines.

Pitch regulation-Pitch regulated rotor has an actuator and control system to rotate the blades about their axis and so limit the power by reducing the angle of attack seen by the aerofoil.

Pitch regulation requires a more complex control system, but can capture higher energy.

2.3 Doubly fed induction generator (DFIG) wind turbine

An induction generator with a wound rotor using slip rings to take current into or out of the rotating secondary winding is used in doubly fed induction generator based wind turbines, while squirrel cage induction generator is used in the case of fixed speed turbines. In both cases, the generator is connected to the power system through a local transformer. The rotor winding is fed through a back-to-back variable frequency power converter. The system is typically two AC/DC, IGBT based voltage source inverters linked by a DC bus. The machine and converters are protected by voltage limits and an over current crowbar.

This type could provide voltage and frequency support to the system in addition to providing active power.

3. PROPOSED WIND POWER PLANT

The wind farm consists of 24 horizontal axis wind turbines each coupled (through a gear box) to an induction generator rated at 850 kW and 690V. It is mains exited with partial VAr compensation by local capacitors (connected in delta). The stator is star connected with neutral floating. Each generator is directly connected to its generator transformer by a three single core XLPE/PVC Cables.

The generator transformer is dry type Wye-Delta connected, 1MVA, 690V/33kV.The star winding is solidly earthed. The 33kV delta winding is connected to a 33kV strung bus bar through a 33kV, 3 pole circuit breaker and a 3 pole, 33kV bus bar isolator.

The 33kV-strung bus is tied to the 33kV bus bar at the CEB Puttlam grid substation by a dedicated 33kV overhead tie line. At the wind farm and CEB ends, 33kV line is connected to the bus bars through a line isolator and a 33kV circuit breaker.

4. PROPOSED PROTECTION SCHEME

The proposed protection scheme for the wind power plant is divided in to five sections, viz

- Generator protection
- Generator transformer protection
- Strung bus bar protection
- Two-33kV tie line protection
- Loss of mains protection

4.1 Generator protection

Stator earth fault protection

- Main protection – Overall high impedance differential
- Backup protection- Adjustable fixed time delayed earth fault relay supplied from a current transformer in the transformer neutral to earth connection.

Stator phase fault protection

- Main protection- Overall high impedance differential
- Backup protection- Overcurrent protection on transformer 33kV side.

Over load protection

Temperature detectors embedded in the stator windings.

4.2 Transformer protection

Earth fault protection

- Main protection - Overall high impedance differential
- Backup protection-
  1. 690 winding- this fault will be detected and cleared by the protection under generator backup earth fault protection.
  2. 33kV winding- Residually connected earth fault relay on the 33kV side.

Phase fault protection

- Main protection- Overall high impedance differential protection
- Backup protection- Overcurrent protection on the 33kV side of the transformer.

Overload protection

Temperature detectors embedded in the winding.

4.3 The differential protection should have features to prevent maloperation due to magnetizing inrush current.

This scheme will require the phase conductors to be brought at the neutral end of the generator.

Current transformers for differential protection should be of class X and for Overcurrent and earth fault protection should be protective class P. Fixed time delayed relays are preferred as the earth currents will be restricted to the 690V section.

4.4 Protection for strung bus

Earth fault protection

Residually connected earth fault relay in the tie line and loss of mains protection in the transformer incoming to the 33kV-strung bus.

Phase fault protection

Overcurrent protection in the tie line and loss of mains protection in the transformer incoming.

Overhead strung bus is preferred on economy, however on aesthetic grounds an under ground cable may be used.

4.5 33kV tie-line protection

***Earth fault** protection*

Earth fault protection at the CEB primary end and loss of mains protection at each transformer incoming to the 33kV strung bus.

Phase fault protection

Overcurrent protection at the CEB primary and loss of mains protection at each transformer incoming to the 33kV strung bus.

In this proposal only one tie line is used to connect the wind farm to the utility system. If more than one tie line is used for better reliability, expensive unit protection schemes such as differential, distance together with associated signaling will be required.

4.6 Loss of mains protection

At each transformer incoming to the 33kV strung bus.

- Over and Under frequency protection
- Over and Under Voltage protection
- Vector phase shift protection

Incase of a load change, the rotor displacement angle shift to a new value, causing a change in the period of the respective cycle. The vector shift relay continuously monitors the duration of each cycle and initiate instantaneous tripping if the duration of a cycle changes as compared to the previous cycle by an angle greater than the relay setting.

In the above three relays are fed from a single three phase voltage transformer.

4.7 As the infeed to a fault from an induction generator is weak and unreliable faults are firstly detected by the infeed from the utility and the respective circuit breaker is switched off. The loss of mains protection will thereafter detect the fault and used to switch off the generator circuit breaker and stop the generator.

The overcurrent relays may not operate due to quick drop in fault current infeed caused by lack of excitation from mains.

Single point earthing is adopted for each voltage level to prevent circulation of harmonic currents.

Separate islanding protection such as neutral voltage displacement is not included as the tie line is dedicated and there are no captive loads. Islanding will be detected by loss of mains protection.

Auxiliary ac supply will be provided by a 33kV/400V transformer tapped from the bus bar and protected by DDLO fuses. This will have the advantage of supply availability even when the generator transformer is lost. Also it may be possible to supply the auxiliary power requirements of more than one generator transformer unit by a single auxiliary transformer.

5. CONCLUSION

Protection requirements for a wind power plant with asynchronous generators were considered. Study was carried out by dividing the protection requirements into sections such as generator, transformer, bus bar and the tie line.

Generator and transformer were considered, as a unit and Overall Biased Differential protection is preferred to detect internal faults on economy. For the generator, transformer, strung bus and tie line, protection against earth fault, phase faults and overloads were discussed. Over and under voltage and over and under frequency and vector phase shift protection were proposed against loss of mains.

Analyzing the protection aspects of the grid connected induction generators will be a valued exercise since there is very limited studies and investigations carried out to appraise the operation, effects, protection and stability of the induction generators on a network dominated by synchronous generators.

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7. REFERENCES

1) CEB Guide for Grid Interconnection of embedded Generators, Sri Lanka.
   Part 2: Protection and Operation of Grid Interconnection.
2) Nick Jenkins, Ron Allan, Peter Crossley, David Kirschen and Goran Strbac: "Embedded Generation" (IEE,2000).