Coordination of Over Current Relay of Wind and Solar Power Plants

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Abstract: Wind generation systems and solar energy systems are used widely due to increase in power demand. So the protection of the plants are also becoming more important. The most commodious and common protection apparatus are overcurrent relays responsible for protecting power systems from impending faults. In order to employ a prosperous and proper protection of wind and solar power plants, these relays must be set precisely and well-coordinated with each other to clear the faults at the system in the shortest possible time. This paper explains the coordination of overcurrent relays to effectively attain the protection of wind and solar power plants to protect them during fault incidence. Matlab/Simulink is applied to model a wind farm and solar module and to achieve precise setting for coordination of overcurrent relays.

Keywords: Wind generation systems, solar energy systems, Coordination of overcurrent relays, DFIG, solar PV and Wind Turbine.

I. INTRODUCTION

The ever increasingly air pollution rate and the limitation of fossil fuel sources have led to comprehensive implementation of renewable energies specifically wind energy. Wind power plants have been vastly employed as the means of power generation in smart grids as a distribution generation (DG) system. Undoubtedly, wind power has come to be mainstay of the energy systems in several countries and is regarded as a reliable and financially reasonable source of electricity. The contribution of wind energy to power generation has reached a considerable share even on the worldwide level. Among many countries that are investing hugely on wind power generation, the top ten leading nations in total power generation capacity are: China, USA, Germany, Spain, India, United Kingdom, Italy, France, Canada and Portugal. One of the most important studies of power quality and power system protection in wind plants is providing adequate and continual power to the loads, therefore in order to ensure having perpetual power from wind farms, wind plants must feed grids continually. One way of meeting this phenomena is applying a proper protection in the system that in case of fault, only the section of faulty feeder is disconnected from the system and the rest of healthy parts are kept connected to the system. By using overcurrent relays (OCRs) as a protection system and applying an accurate coordination in wind plants, not only in case of fault, the power components are protected from damages from excessive currents but also continual power flow is fed to the grid and superb power quality is provided by wind power plants.

This paper demonstrates how OCRs have been successfully used and properly coordinated in a wind power plant. The software which has been used is Matlab/Simulink which is known as one of the best Simulation software for electrical engineers and researchers. All of the OCRs have been modelled and designed and the accurate settings have been selected to protect the wind plant. This paper discusses about OCRs, their function, how they are set and coordinated to provide proper protection. Moreover IEC standards for setting the OCRs have also been represented. The wind plant model studied in this project has been illustrated and load flow during normal operation and during fault occurrence have been simulated as well.
II. METHODOLOGY

2.1. Concept of over current relays coordination

Coordination of OCRs basically means that the closest relay to the fault location, which is referred to as the primary relay, must first trip the circuit breaker, and in the case the relay does not trip or malfunctions, the other relay closest to the primary relay, which is called the backup relay, must trip. This coordination is extremely crucial and is conducted in order to decrease the expanded power loss and avert power quality compromise. The coordination phenomenon is depicted in Fig 1. In this protection must trip to the fault. In case of any malfunction, OCR2 as backup protection should trip. Also if OCR2 does not operate, OCR3 as the second backup protection must trip and disconnect the feeder.

2.2 Installation and operation of OCR in wind power plants

In South Korea, renewable energy generators (REGs) have generally been linked to the 22.9 kV distribution system. The power plant reviewed in this paper is the Sihwa wind power plant, which is currently under construction to be a micro grid. Figure 1 shows the single line diagram of the Sihwa wind power system with two wind power generators connected in parallel. The specifications of wind generator are followed as 1500 kW, 690 V, and 0.9 pf of a squirrel cage induction generator. Two different types of digital composite relays were installed at each unit to protect the generators redundantly. One is the magnetic circuit breaker (MCB) relay provided by the generator manufacturer and the other is the digital integrated protection and monitoring equipment (GIPAM-2200DG) installed by the power plant operating company.

![Figure 2.1: Coordination of over current relay](image1)

![Figure 2.2: Single line diagram of Sihwa wind power system](image2)
During the generation of the wind turbine, the OCR (51) of GIPAM-2200DG operated frequently, whereas the MCB relay operated rarely and this discrepancy motivated our research to study a new re-coordination of the overcurrent relay (OCR). The coordination of the OCR in a renewable energy system may be similar to that in general electric equipment; however, the time-delay OCR of this wind generator is often operated. Such operation occurred 39 times for approximately 26 months at one unit. The minimum and maximum operating currents were 1788.5 A and 2316.7 A, respectively.

2.3 The Wind Turbine and the Doubly-Fed Induction Generator System

The power flow illustrated in the figure is used to describe the operating principle

The mechanical power and the stator electric power output are computed as follows:

\[ P_m = T_m \omega_r \]
\[ P_s = T_{em} \omega_s. \]

For a lossless generator the mechanical equation is:

\[ s \frac{d\omega_r}{dt} = T_m - T_{em}. \]

In steady-state at fixed speed for a lossless generator \( T_m = T_{em} \) and \( P_m = P_s + P_r \)

It follows that:

\[ P_r = P_m - P_s = T_m \omega_r - T_{em} \omega_h = -T_m \frac{\omega_h - \omega_r}{\omega_s} \omega_h = -sT_m \omega_h = -sP_s, \]

Where \( s \) is defined as the slip of the generator: \( s = (\omega_r - \omega_s)/\omega_s \)

2.4 Power Flow in Wind Turbine Doubly-Fed Induction Generator

Generally the absolute value of slip is much lower than 1 and, consequently, \( P_r \) is only a fraction of \( P_s \). Since \( T_m \) is positive for power generation and since \( \omega_h \) is positive and constant for a constant frequency grid voltage, the sign of \( P_r \) is a function of the slip sign. \( P_r \) is positive for negative slip (speed greater than synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). For super-synchronous speed operation, \( P_r \) is transmitted to DC bus capacitor
and tends to rise the DC voltage. For sub-synchronous speed operation, $P_r$ is taken out of DC bus capacitor and tends to decrease the DC voltage.

**Figure 2.4: Power Flow in Wind Turbine Doubly-Fed Induction Generator**

$C_{\text{grid}}$ is used to generate or absorb the power $P_{gc}$ in order to keep the DC voltage constant. In steady-state for a lossless AC/DC/AC converter $P_{gc}$ is equal to $P_r$ and the speed of the wind turbine is determined by the power $P_r$ absorbed or generated by $C_{\text{rotor}}$. The power control will be explained below. The phase-sequence of the AC voltage generated by $C_{\text{rotor}}$ is positive for sub-synchronous speed and negative for super-synchronous speed. The frequency of this voltage is equal to the product of the grid frequency and the absolute value of the slip. $C_{\text{rotor}}$ and $C_{\text{grid}}$ have the capability of generating or absorbing reactive power and could be used to control the reactive power or the voltage at the grid terminals.

### III. RESULTS AND DISCUSSIONS

#### 3.1 Simulation Circuit

The wind turbine and the doubly-fed induction generator (WTDFIG) are shown in the figure called The Wind Turbine and the Doubly-Fed Induction Generator System. The AC/DC/AC converter is divided into two components: the rotor-side converter ($C_{\text{rotor}}$) and the grid-side converter ($C_{\text{grid}}$). $C_{\text{rotor}}$ and $C_{\text{grid}}$ are Voltage-Sourced Converters that use forced-commutated power electronic devices (IGBTs) to synthesize an AC voltage from a DC voltage source. A capacitor connected on the DC side acts as the DC voltage source.

**Figure 3.1: Block diagram of proposed system in MATLAB/SIMULINK**
A coupling inductor $L$ is used to connect $C_{\text{grid}}$ to the grid. The three-phase rotor winding is connected to $C_{\text{rotor}}$ by slip rings and brushes and the three-phase stator winding is directly connected to the grid. The power captured by the wind turbine is converted into electrical power by the induction generator and it is transmitted to the grid by the stator and the rotor windings. The control system generates the pitch angle command and the voltage command signals $V_r$ and $V_{gc}$ for $C_{\text{rotor}}$ and $C_{\text{grid}}$ respectively in order to control the power of the wind turbine, the DC bus voltage and the reactive power or the voltage at the grid terminals.

### 3.2 Simulation results

**Figure 3.2: Currents in Circuit Breaker 1 and Circuit Breaker 2 during fault creation between 0.5 sec and 1.0 sec**

**Figure 3.3: Current from Circuit Breaker 7 and Circuit Breaker 8. Both are closed at the same time.**
The above graphs show photovoltaic real power and reactive power of PV system. The output of PV is not affected by fault due to relay operations. The above waveform shows the dynamics of the solar system which is hybrid with wind system. The solar is operated like initially 1000 w/m2 irradiance. At .75 secs it reduces to 250 w/m2 and again increases at 1.5 secs then and reaches 1000 w/m2 at 2 secs. Now it produces 250 irradiance at 2.5 secs then at 2.75 to 3 secs it is increased to 1000 w/m2 again. This changes to irradiance cause changes to generation of power which is show in the above figure. The solar is not supplying any reactive power as per the standards. The fault is created at the 1 secs. Here solar is not affected by fault due to relay operations.
The above figure shows the current at the circuit breaker (CBs). The fault is given at 0.5 sec in the wind turbine. And the fault is cleared at 1 sec. the faulted point currents is at CB1 and CB2. The other two circuit breakers at grid side is not affected by the faults. So, the relay operation is proper to protect the faults from grid. And the coordination between the relays also good as it is not affecting the grid side relays.

**Figure 3.6:** Current supplied to grid during fault time between $t = 0.5$ sec to $t = 1$ sec

**Figure 3.7:** Figure showing that the relay voltage is not affected much due to the proper switching of circuit breakers
IV. CONCLUSION

In this paper, a comprehensive protection for wind power plants has been successfully implemented by using OCRs. Three phase fault has been imposed at each CB and the settings for each relay has been conducted. Moreover all of the relays have been modelled based on IEC standards in order to provide proper protection for the system, prevent the damage from fault current to the power components, provide perpetual power to the grid and contribute to superb power quality. The results have shown that OCRs can be successfully employed for wind power plants and has proved to be effective, accurate, and be considered as the best method for protection.

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