Testing and Evaluation of Wind Power Plant Protection System

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Abstract. This paper discusses test set up and methodology which may be used for wind power plant (WPP) protection system evaluation. The test set up cosists of a digital simulator, a number of physical relays and recorders, as well as software for modeling, simulation, signal editing, etc. Correct operation of the WPP protection system is crucial during grid disturbances to prevent unwanted power source disconnection. Since there are no standardized requirements or methodology for testing WPP protection system, evaluation of WPP condition impacts on protective relay operation is challenging. This paper discusses test requirements and test methodology to perform the evaluation in a standardized and comprehensive manner.

Key words

Wind Power Plant, Protection System, Testing, Digital Simulator, Relaying.

1. Introduction

The Department of Energy (DOE) estimated that by 2030 20% of total generation in the US will be from wind generation. In such high penetration scenario the WPP will stay connected to the grid during grid disturbances to avoid severe effects to the power system due to lack of generation, which makes bigger technical challenges to protection. Regulators and system operators in many countries have established grid codes for operation and connection of wind power plants (WPP). The objective is to guarantee the WPPs can offer the system support as close to what is the role of the conventional power plants as possible. In the past, it was the common practice to disconnect the WPP during a grid disturbance. However, disconnecting large scale WPPs could cause instability of the power system. For this reason, the WPPs are required to remain connected for a predefined time period during a grid fault. Moreover, fast active and reactive power restoration to the pre-fault values after the grid voltage recovery is included into requirements. The Federal Energy Regulatory Commission (FERC) in the USA proposed requirements for WPP low-voltage ride through the fault for specific time period for particular voltage levels.

The impact of WPP to the grid protection system, such as the short-circuit (SC) current contribution, cannot be ignored. Moreover, the impact of grid disturbances on WPP protection system needs to be well understood. As wind generation penetration level is increasing and regualtors are placing new rules regarding WPP behavior during and after grid disturbance, correct operation of the WPP protection system is becoming the study focus and it requires comprehensive testing. In the literature there have not been significant work reported in this area. The IEEE 1547 standard for interconnecting distribution resources in electric power systems is an attempt to providing technical specifications for testing of the WPP interconnection [1]. The document is mainly focused on general technical requirements for grid system interconnecting with WPP and protection system testing requirements are too general. Beside this, the only work on testing reported in the literature relates to evaluation of some new protection algorithms for WPP applications. So far there has not been standardized procedure or requirement defined for WPP protection system testing.

2. Background

To maintain the WPP connected to the electricity grid during disturbance is a real challenge. Utilities' grid codes require WPP to be connected to the grid and to maintain certain profile of reactive and active power during and after disturbances condition, which means that the power electronic converter has to inject reactive current for grid voltage support during voltage sags, and it has to inject active current immediately after fault clearance. Low Voltage Ride Through (LVRT) feature is provided by installation of power electronic control components into existing WPP. There are many controller designs, such as voltage control or direct power control design that may be utilized in the system and many adverse conditions have to be taken into account in designing control components.

3. Test Requirements

Dependability is a measure of the capability of a protective relay system to operate correctly when required. Security is a measure of the ability of protective relay system to not operate incorrectly. These two factors are used as criteria for evaluating the effectiveness of the relaying system. In the past emphasis was on developing highly dependable protection systems. With new types of generation and line loading condition, relay tripping for no-fault disturbances is unacceptable due to cost reasons and potential deterioration of system stability. Security of relay operation for such reasons is becoming the focus of special interest and should be evaluated at the same extent as the dependability.

The problem recognized in this study may be classified as impact of the grid to the WPP protection system and the impact of the WPP to grid protection system. In the impact of WPP to the grid protection system the dependability of the grid relays may be disturbed by WPP short circuit current contribution. In the case of SC in the nearby grid the WPP contribution to the SC level differs from SC current from conventional generation and depends on penetration level. On the other head, the disturbance in the grid may cause CT saturation during low voltage conditions which may lead to relay misoperation. Moreover, unlike unidirectional power flow from generator to the grid during normal conditions, bidirectional flow is common during fault conditions among collection or interconnection system and it may lead to relay misoperation.

When considering WPP, consequences of relay missoperation can be costly and hazardous as the expensive power electronic components may be damaged and people's life may be endangered. In case of relay misoperation due to no-fault disturbances the consequence is economic loss because significant amount of economically favorable generation will be lost. Thus, the test study should be performed to ensure selectivity of the relay performance in the WPP applications.

Appropriate relay testing should help validate the design of the relay logic, compare the performance of different relays, verify selection of relay settings, identify vulnerable conditions apt to causing unintended operations, and carry out post-event analysis for the understanding of unintended or incorrect relay behavior. The challenge of test and evaluation tasks and related methodology lies in implementation of large number of test and evaluation cases. This requires developing accurate WPP model for tests, easily simulating disturbances, facilitating interfacing relays and power system models, and automatically executing batch tests and collecting relay response events. To retrieve accurate plant model is the biggest concern because those models are proprietary information of wind turbine vendors. Testing study with generalized wind plant models, which do not representing details of control mechanism may lead to misleading results.

4. Test Methodology and Tools

Extensive study and development of new test methodology and test tools has been done by the authors over the years [3]. The solution is allowing interfacing digital protective relay model and power network model in a real time simulation interaction [2].
According to the test objectives two different types of tests are defined: design test and application test. Design tests may be performed using phasors while application test may be performed using transients. The test weaveforms may be generated through modeling and simulation, or in the cases of transients, through replaying recorded waveforms.

A. Design Test

The objective of design test is to evaluate relay design functionality and operating characteristic, and to verify relay settings, which is achieved through implementation of comprehensive series of tests. The concern of this test is the response of the relays to phasor inputs that are approximating dynamic changes of signal waveforms during normal and fault conditions [2]. Short-circuit current contribution from the wind induction generators have different time decays and peaks compared to the conventional generations. Moreover, SC current contribution differs for each wind generator type and applied control mechanism. For this reason, simulations should be carried out with faults in a number of locations, such as terminals of HV transformer, point of interconnection, etc. for different generating conditions and relay settings should be verified.

B. Application Test

The application problems which may cause relay unwanted operation and/or lack of operation may still go undetected, even though the equipped relaying system was properly tested verifying that operating characteristic and settings are correct. These unexpected problems could be detected by applying application test.

The objective of application test is to verify whether a relay can operate correctly under peculiar circumstances in power system particularly during abnormal operating conditions. This type of test is to investigate whether the "real" performance of a protective relay complies with its expected performance [4]. The concern of this test is the trip/no trip response and relay operating time performance under specific scenarios. The first task for developing the application evaluation is to select those possible scenarios which may cause relay unintended operation. Low-voltage ride through the fault, effect of grid disturbances, operation of the crowbar function during low voltage, etc. and their impact of relay operation should be investigated.

The test lab setup is shown in Fig.1. The major components include a PC used to run related software, a digital simulator used to generate "real" voltage and current signals and the physical relay under test. A commercial software program called Relay Assistant residing on the PC, which communicates with digital simulator is capable of sending transient voltage and current data and receiving contact status data . The digital simulator applies the voltage and current waveforms to the relay and records the relay trip contact status. A relay setting software program residing on the PC communicates with the relay to configure relay settings and an automated relay file retrieval software program residing on the PC communicates to the relay to automatically retrieve relay event reports triggered by certain pre-set conditions.

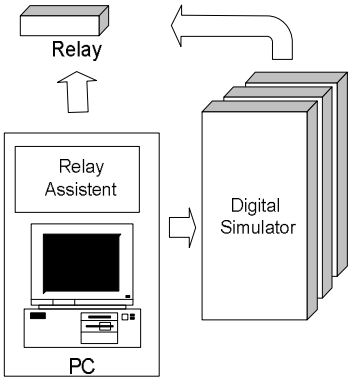

Fig. 1. Lab setup for the relay testing

4. Conclusion

In this paper relay test and evaluation set up and methodology developed for WPP protection system performance assessment are described. Due to the test system flexibility it may be easily used to perform evaluation of WPP protection system. This study outcome is a test plan for evaluating impact of the grid disturbances on the WPP or/and nearby grid protection system and a new protection algorithm.

References

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