New Challenges for Protection System

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Abstract: - With technology progress, the use of new microprocessor and multiprocessor based devices in protection and control of power systems and network, rises. It is essential that new protection devices remain protection devices as their primary function and increase reliability. It is also essential to improve secure and fast communication between these devices. To fulfill all those characteristics, new protection relays (and all of secondary equipment) must be based on new technology platforms that will ensure wanted performances.
The paper describes efforts to find and combine present technologies (available for industrial production) for future functionality, especially for protection of wind generators and to define protection relays to become reliable part in wind generator protection system for direct drive synchronous generators. Direct drive synchronous generators become more popular in last few years and units become larger. Therefore there is need to find out all possible solutions for protection of that kind of wind generators.

Key-Words: - Protection and control, Secondary equipment, Wind generator protection, Direct drive synchronous generator

1 Introduction

Due to now days level of digital equipment and communication possibilities, it is reasonable to expect that automation will be present in Power system deeper and deeper, from extra high voltage to low voltage, from generation, transmission and distribution. Network control through all voltage levels is tendency for some time. Necessary equipment that is capable to fulfill all present and future requirements for control of entire network, has to be advanced in technological and functional sense and with communicational capabilities. Amount of smart secondary equipment will grow with automation of power system. Together with this growth, demands for reliable operation of secondary equipment will rise. This is connected with concept of Smart grids [1]. Smart grids [2] also include distributed generation and we are witnesses of fast growing penetration of wind generation power plants (wind farms) and growth of units that wind farms are consist of [3].

There are different types of wind farms regarding generation. The majority of generators are asynchronous generators, double fed asynchronous generators and synchronous generators, all with gearbox. But there are more and more solutions with synchronous generators without gearbox and this solution has influence on protection system design.

2 Present situation

First and basic function of protection relay is to discover fault conditions on protected area (transformer, generator, overhead line, cable …) and to disconnect parts of network selectively and to localize and eliminate fault in shortest possible time. Through the time, from mechanical relays to microprocessor based relays this function remains the same. Designers of protection relays must never forgot this essential function. All other functions that could be implemented are result of technology improvements and integration of functions (such as control and measuring) into one device.

Once we have possibilities to implement more functions into protection relays, we must ensure that the basic function is working without troubles. More functions implemented into one protection relay lead to more resources necessary to perform those functions. This leads to more hardware requirements (stronger and faster processors, more memory, more inputs and outputs…). More functions results with more data necessary to transfer which lead to stronger requests for communication possibilities.

Grid rules in many countries declare that every generation unit has to have proper protection system regarding size and technology of the unit. Also grid rules in many countries define level of information exchange between generation and transmission systems and fault ride through capabilities [4], [8]. Therefore it is necessary to ensure some kind (appropriate kind) of protection system for wind generation.

2.1 Wind generator protection

Today's situation with wind generator protection system is not totally clear. Basic functions are mostly implemented inside control systems and algorithms are known only to manufacturers. Those basic functions are in most of the cases under voltage protection, under frequency and over frequency protection and over current protection. Rarely there is loss of excitation system protection and reverse power protection.

Because the size of unit groves therefore the importance of reliable protection systems becomes more significant.

2.2 Existing wind generator protection

In this moment there is only one manufacturer that declares dedicated protection device for wind generators [5]. From description and declared characteristics it can be readout that this wind generation protection is designed for generators with gearbox.

3 Possible solution

At the market there are more and more solutions for wind generation with synchronous generators with direct drive. Many manufacturers with increase of unit nominal power also consider change of voltage level of generators. Most of generators have 690V nominal voltage and now we have generators with 3kV or 3,3kV nominal voltage level.

All this have influence on wind generator protection systems. Wind generator protection system for direct drive synchronous generators (possible large units) should be designed.

Electrical parts of wind power plant can malfunction as mechanical can also. Inside one unit of wind power plant there are lots of electrical parts that are subject to fault. Some researches [6] show that electric equipment, control systems and generators have 47% of all faults inside wind generation systems.

If we consider system with wind direct drive synchronous generator, first there is generator, then connection cable, AC/DC/AC converter, transformer and other auxiliary equipment. Generator is placed in nacelle on the top of tower. Connection cable from nacelle (where generator is) to bottom of tower where usually AC/DC/AC converter is placed can be from 60m to 200m regarding rated power and tower height. Transformer is usually outside near tower and raises voltage level from 690V or 3kV to 10, 20 or 35kV according to specific solution.

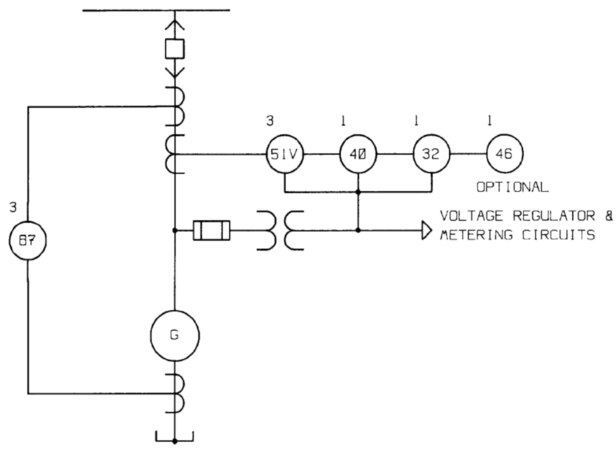

Fig.1 Protection scheme for small HPP generators

If we compare wind generators with other generators as they are used in small hydro power plants, we could see amount and type of protection functions [11] applied in those cases (see Figure 1.). Minimally there are differential protection (87), voltage controlled over current protection (51V), loss of excitation protection (40), reverse power protection (32) and negative sequence protection (46).

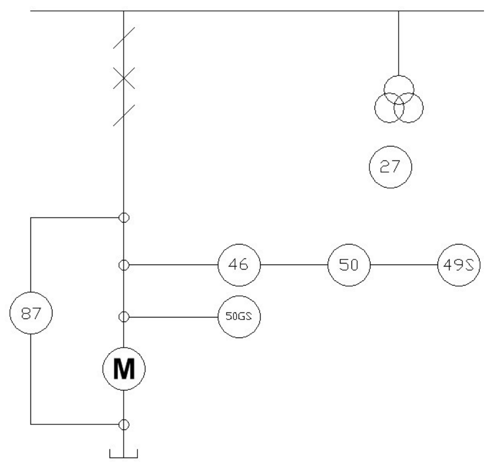

Fig.2 Protection scheme for large motors

Also, we can compare wind generators with large motors. Large motors (as there are motors in industrial applications or motors in thermal power plants) have different level of protection regarding its function and size [12]. Comparable motors (1MW or larger) usually have numerous protection function as shown in Figure 2. There are usually differential protection (87), ground over current protection (50G), over current protection (50), under voltage protection (27), negative sequence protection (46) and thermal protection (49).

3.1 Wind generator protection functions

If we consider those two cases, we can suggest that amount of protection functions for wind direct drive synchronous generators should be as for small HPP generators or as for large motors. So suggested functions would be differential protection, over current protection, loss of excitation protection, frequency protection, under voltage protection, over voltage protection, reverse power protection and thermal protection as basic functions. What could be problem with this conclusion and suggestion?

First problem could be to implement standard numerical relays due to unknown frequency. Standard numerical relays usually have calculations based on FFT (Fast Fourier Transformation) and algorithms based on 50Hz component. In case of wind direct drive synchronous generators it is useless. This kind of generation could have different frequency output at any time.

Figure 3 shows an example of direct drive synchronous generator current during period of 175ms. It can be seen that frequency in that moment was around 6Hz.

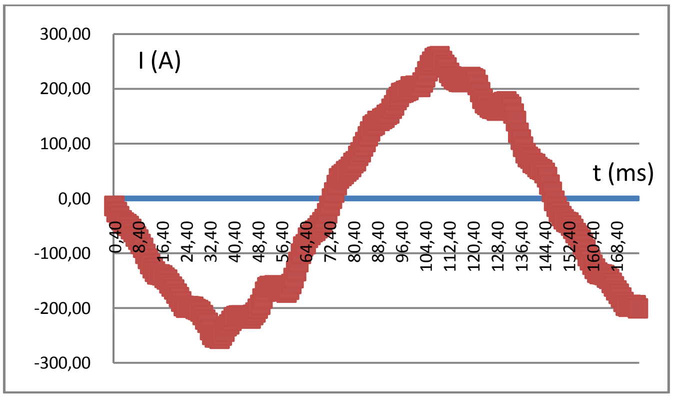

Fig.3 Output current from wind direct drive synchronous generator (example for 1MW, 690V generator)

For the same reason frequency protection for generator is not applicable. It can be considered for use just after AC/DC/AC converter and filter, before connection to the grid. In that case it is protection of converter malfunctioning. Converter is also electrical part that is subject to fault and this protection function could be important part of wind generation protection system.

Loss of excitation protection can be implemented as usually. Excitation system is usually connected to the network side and has normal network conditions (50Hz) as input. Therefore this protection function should be included inside wind generation protection system.

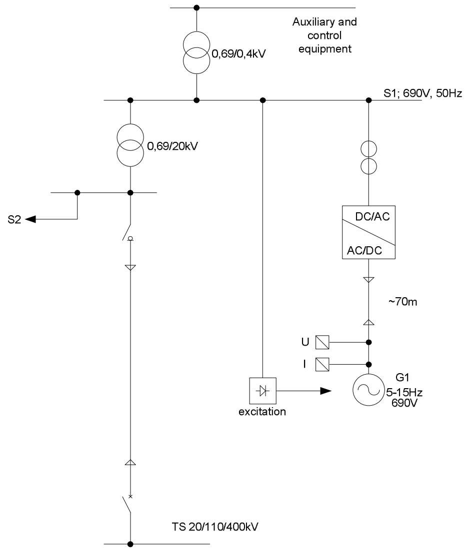

Fig.4 Wind direct drive synchronous generation unit – tested object [7], simplified scheme

Over current and differential protection, as functions based on current measurement and comparation, are basic to conventional generators. In case of wind direct drive synchronous generator these functions should also be implemented.

Regarding differential protection there are two ways to implement it. At first that protected area is generator only and the second that protected area is generator with connection cable. This decision has impact on wind generation project regarding current transformers positions, number of them and possibility of placing them in the first place.

Also, it has to defined how to measure current value and how to calculate it inside numerical protection relays. One of the obvious possibilities is to calculate true RMS (Root Mean Square) value and to use this value for evaluation and decision making inside relays. This means necessary measurement of frequency and measurement of peak value for calculations:

$$I_{RMS} = I_P \sqrt{\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} sin^2\,(2\pi f t) dt} \qquad (1)$$

Frequency (f) is direct functions of wind speed and therefore generator revolution speed (because of direct drive). I_{RMS} is current RMS value and I_P is current peak value. Current waveform can be considered as sinus function.

Over voltage protection function can be implemented as generator protection function. Over voltage condition can occur as defective operation of the automatic voltage regulator when the machine is in isolated operation or as sudden loss of load.

Under voltage protection is rarely fitted to generators. It is sometimes used as an interlock element for another protection function.

Reverse power protection is applied to prevent damage to mechanical power plant parts in the event of failure of the prime mover.

Thermal protection can be implemented using sensors (as Pt100) as it is used within large motors.

Other protection functions, usually used in protection large generators were not in the scope of this review. Some of them just cannot be implemented in way we know them today. For example, stator earth fault protection which is usually implemented by measuring the internally generated third harmonic voltage that appears across the earthing impedance due to the flow of third harmonic currents through the shunt capacitance of the stator windings.

4 Conclusion

Protection systems for direct drive synchronous generators are subject of review and investigation in this paper.

Wind direct drive synchronous generators are taking more place in wind farm installations and become larger (rated power is increasing and nominal voltage is higher). Therefore is important to research protection schemes that could be used for such generators.

These generators are compared to small hydro generators and large motors. Level of implemented protection functions inside compared devices is brought for review for implementation within protection systems for direct drive synchronous generators.

Only basic functions are analyzed and recommended without details about implementation.

Ways of implementation and possibilities of use different protection functions and exact algorithms and settings for different kind of protection functions are subject to further research. For the moment our research is based on WPP Pometeno brdo. This WEE (wind power plant) is still under construction and it is consisting of 1MW, 690V wind generators. We expect that future research will be based on 2.5 MW, 3kV wind generators.

References:

[1] David Scott, *The Smart Grid and Your Utility*, TDWORLD, Penton Media Inc. Vol. 60 No. 5. New York, 2008 May.

[2] ABB, *When grids get smart*, 1KHA-SDE-4.08 Mannheim, 2008.

[3] Angelika Pullen, Steve Sawyer, *Global wind 2007 report*. GWEC, Brussels, 2008.

[4] Florin Iov, Anca Daniela Hansen, Poul Sorensen, Nicolaos Antonio Cutululis, *Mapping of grid faults and grid codes,* ISBN 978-87-550-3622-2. Riso National Laboratory DTU, Roskilde 2007.

[5] GE Power Management S.A. (GE Multilin), *W650 Wind Generator Protection System, Instruction manual*, GEK-113032A, 2006.

[6] S. Faulstich, B. Hahn, K. Rafik, H. Jung, A. Ringhandt, *Appropriate failure statistics and reliability characteristics*, Institut für Solare Energieversogungstechnik, 2008.

[7] KONCAR, *Wind generator project KO-VA 57/1 – Technical description*, Vol. E01, SA01002. 2006.

[8] HEP TSO, *Dodatni tehnički uvjeti za priključak i pogon VE na prijenosnoj mreži*, Zagreb 2008.

[9] Larry L. Henriksen, John J. Kumm, Sivasis Panighrai, *Protective Relaying Considerations with Wind Generation Substations and Collection Systems*, 35th Western protective relay conference, Washington 2008.

[10] Detlef Schulz, Rolf Hanitsch, Karim Moutawakkil, Christoph Saniter, *Power quality behaviour of large wind parks with variable speed wind energy converter*, CIRED S 04, No. 28, Barcelona 2003.

[11] Walter A. Elmore, *Protective Relaying: Theory and Applications,* ISBN-10: 0-8247-0972-1, Marcel Dekker, New York, 2003.

[12] J. Lewis Blackburn, Thomas J. Domin, *Protective Relaying: Principles and Applications*, ISBN-10: 1-57444-716-5, CRC Press, New York 2007.

[13] Siegfried Heier, *Grid Integration of Wind Energy Conversion System,* ISBN-13: 978-0-470-86899-6, Wiley, Chichester, 2006.

[14] Brendan Fox, Damian Flynn, Leslie Bryans, Nick Jenkins, David Milborrow, Mark O'Malley, Richard Watson, Olimpo Anaya-Lara, *Wind Power Integration - Connection and system operational aspects*, ISBN: 978-0-86341-449-7, IET, Stevenage 2007.