U.P.B. Sci. Bull., Series C, Vol. 77, Iss. 1, 2015 ISSN 2286 – 3540

IMPACT OF THE WIND POWER PLANTS TO THE SETTING OF STEP 2 DISTANCE PROTECTION

Ionuț Ciprian BORĂSCU[1]

At the moment the most important concern in the electric power industry is the integration of wind power plants. The main challenges for the TSO's concerning system operation, with a significant contribution from wind generation, are: balancing production and consumption in the presence of wind variability, shortcircuit capacity, the amount of rotating mass and voltage support. As the amount of wind generation increases, the variability and uncertainty of the wind leads to the adoption of several operating schemes in order to maintain the wind power plant connected to the grid, even in case of unavailability of a 110 kV line. In this context the multitude of operating schemes leads to changes in SIR (source impedance ratio), which has a significant impact on the operation of the distance protection.

In this article are presented the main types of wind generators (Type 3 and Type 4) from the power system, their behavior in case of shortcircuit and an example of setting the reactance reach of step 2 distance protection from 110 kV power grid, considering the influence of type 3 generators to the total shortcircuit current.

Keywords: distance protection, wind turbine generators

1. Introduction

Regarding the integration of wind power plants in the electricity system it can be noted that they contribute to improving the functioning of the power system by: reduction of power loss, better voltage support, minimize the loading effect of transmission line, peak shaving, improvement of overall efficiency, stability and reliability [1]. Therefore, to maintain the wind farms connected to the network and to ensure the integrity of the power system, must be adopted adequate protection schemes.

The most common backup protections found in the 110 kV bay afferent to the wind power plant are the distance protections. Absolute selectivity in this case is provided by longitudinal differential protection. Given the high risk of high unavailability of communication for differential protection and low dependence of longitudinal diferential protection towards system conditions, the article

[1] PhD student, Faculty of Automatic Control and Computers, University POLITEHNICA of Bucharest, Romania, e-mail: borascu.ciprian@yahoo.com

highlights the influence of the wind power plants on the operation of the distance protection.

As it is known, distance protection distinguishes load conditions from minimum and maximum shortcircuit conditions by measuring the impedance modulus and the angle between the voltage and current. In case that the source impedance behind the relay is strong (SIR<4) and the fault is without fault resistance, the shortcircuit impedance is proportional with the distance between the protection location and fault location. If the value of the fault resistance is too large, the distance relay may misoperate in case a fault occurred on the next line, or may not operate if a fault appears on the protected line.

Unavailability of some elements (line, transformer, etc.) in power system leads to carry out maneuvers to connect/disconnect lines/transformers that will influence directly the operation of the distance protection.

Studies in the field of wind power plants and osciloperturbograf records from digital distance protection relays near the wind power plants, have shown that the impedance measured by the distance protection from 110 kV bay is influenced by a number of factors, such as [2-6]:

- Significant variations in the value of short-circuit current. The existence of the power convertors it determines the value of the fault current, which in most cases, is close to the nominal current after typically not more than 50 ms. Overall, the influence of wind power plants contribution to total shortcircuit current is relatively small.
- Dynamic changes of the wind farm generating power. In this context, operating at maximum output power in conjuction with the limitation imposed by the Dispatcher, can lead to overlapping the operating and load area characteristics.
- Incorrect fault localization for distance protection, due to the intermediate in-feed effect at the wind farm connection farm.
- Frequency fluctuation. When a fault occurs on an electrical grid, some frequency variations are detected due to generator speed variations.

To ensure the proper functioning of the distance protection, even with a weak source behind the relay, chapter 3 shows an example of setting the distance protection.

2. Doubly-Fed asynchronous generators (Type 3) and Full – Conversion Generator (Type 4)

2.1. DFAG (type 3)

The DFAG is an excited machine, as is a synchronous generator. However, the „excitation" applied to the rotor is ac. The excitation is provided by a power electronic converter of variable frequency and magnitude. The application of an ac excitation causes an apparent rotation of the rotor's magnetic field, relative to the rotor. The rotor's magnetic field, rotates at a speed which is the sum of the rotor's mechanical rotation speed plus the apparent rotation speed caused by the applied ac excitation [7-10].

Fig. 1 illustrates the topology of a DFAG machine, including the induction-type rotating machine with a three-phase wound rotor, and an ac-dc-ac power converter. The power rating of the converter, relative to the total power rating of the power rating of the wind turbine, is approximately in proportion to the amount of speed variation allowed.

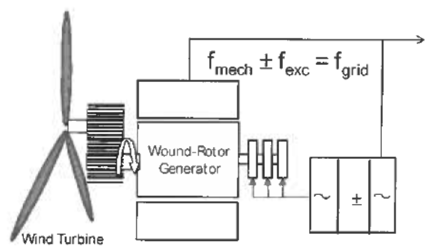


Fig. 1. Topology of a doubly-fed asynchronous generator (Type 3)

All type 3 wind turbine generators use some form of "crowbar" scheme to bypass the excess induction onto the rotor circuit. The effect of the crowbar is transition the generator from a controlled current source into an induction generator, characterized as a voltage source behind the physical reactance. Fig. 2 shows short-circuit current for a three-phase fault that reduces the voltage at the MV terminals of the wind turbine's unit transformer to 20% of nominal. In this case, the crowbar was activated for the first two cycles.

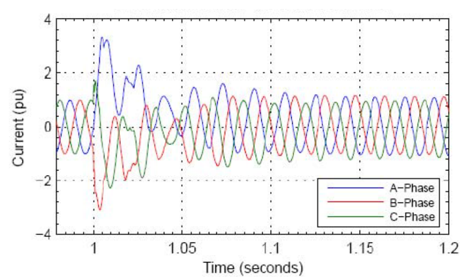


Fig. 2. Short-circuit current from a Type 3 wind turbine generator for a fault reducing the voltage at the unit step-up transformer MV terminals to 20%.

2.2. Full conversion generator (type 4)

A full-conversion wind turbine generator uses back-to-back ac-to-dc and dc-to-ac voltage source converters to allow the physical generator to operate over a wide range of speeds. The topology of a Type 4 wind turbine generator is illustrated in Fig. 3. The generator-side converter rectifies the variable frequency power generated by the machine and the line-side converter inverts the resulting dc power to inject power into the grid at the grid's operating frequency. Although, the line-side converter is a ,,voltage source converter", the converter is controlled at high bandwidth to yield a controlled current source behavior [7-10].

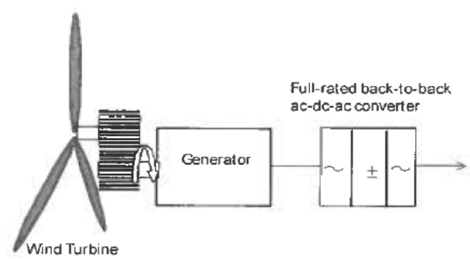


Fig. 3. Topology of a full-conversion generator (Type 4)

The short-circuit current from a Type 4 wind turbine generator for a fault reducing the voltage at the unit step-up transformer MV terminals to 20% is presented in Fig. 4 [7-10].

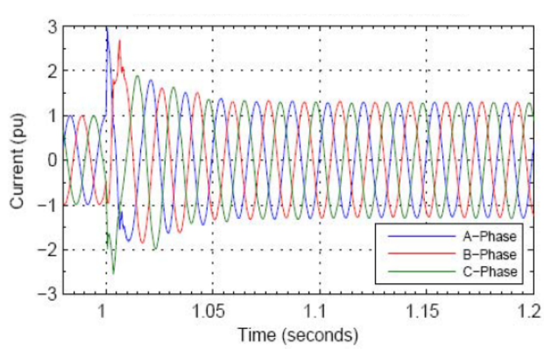


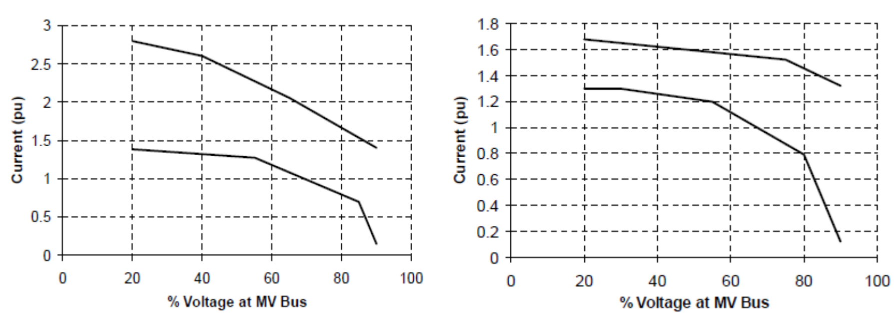
Fig. 4. Short-circuit current from a Type 4 turbine generator for a fault reducing the voltage at the unit step-up transformer MV terminals to 20%

2.3. Maximum and minimum shortcircuit current for type 3 and type 4 wind turbine generators

Type 3 and 4 wind turbine generator fault behaviours, in contrast, are primarily defined by control characteristics rather than fundamental physics. There are significant similarities between the fault behaviours of type 3 and type 4 generators, as both operate as controlled current sources. Because power electronic converters are used in both types of generators, and the power electronic devices (typically insulated-gate bipolar transistors-IGBTs) are quickly limited. For very severe faults, however, the performance of these two wind turbine generator types diverges due to the discontinuous effects of crowbar protection of the Type 3 generator's rotor circuit [7-10].

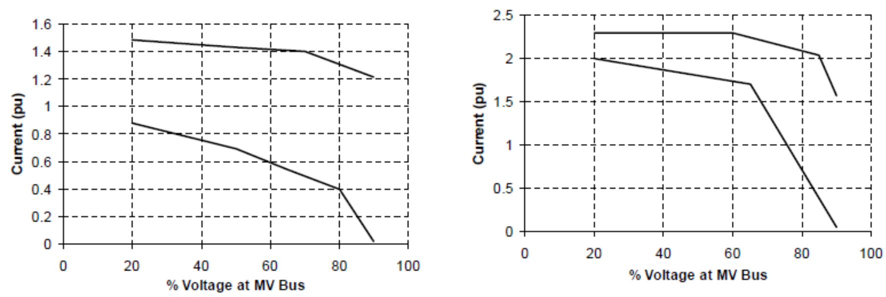
The fault current current contribution from a Type 4 generator consists of an initial transient overcurrent, followed by controlled injection of a current magnitude as defined by the fault response (i.e., Low Voltage Ride-Through) behavior programmed into the controls. For a very severe fault, the initial current may reach a crest value of two to three times rated current. The subsequent controlled current injection is typically less than 1.5 p.u. of the wind turbine rating. The fault current contribution of a Type 3 generator is similar to that of a Type 4 generator, except when the fault severity is sufficient to initiate crowbar action. In most situations, total fault current, or the total current seen by a protection relay, is dominated by sources other than wind turbines. Even within a wind plant's collector system, the external grid contribution to fault current is often dominant.

Figs. 5 and 6 show the shortcircuit current envelopes, defined by the maximum and minimum currents as a function of MV bus voltage, for a typical Type 3 and Type 4 wind turbines generators, respectively.



a. b.

Fig. 5. Maximum and minimum symmetrical short-circuit current magnitudes immediately after fault application (a) and following three cycles (b), as a function of residual MV bus voltage, for a typical Type 3 wind turbine generator



a. b.

Fig. 6. Maximum and minimum symmetrical short-circuit current magnitudes immediately after fault application (a) and following three cycles (b), as a function of residual MV bus voltage, for a typical Type 4 wind turbine generator

3. Calculation of step 2 distance protection

Step 2 of distance protection should be set so as to ensure elimination of any type of shortcircuit appeared on any portion of the protected line in maximum 1 second. Although, the impedance set for stage 2 can cover all or a percentage of the shortest line that goes from the opposite bus bar, the most important desideratum is to cover: internal relay error (around 5%), imprecision of line impedances due to climatic variations such as humidity, wind speed, temperature, errors due to the electromagnetic transient phenomena (transients lead to voltage and current harmonics with important frequencies), measurement errors introduced by the voltage and current transformers, measurement errors introduced by zero sequence mutual impedance (in case of parallel 110 kV lines) and measurement errors introduced by a reasonable value of fault resistance.

In the context of connecting a wind power plant to the power system is necessary to perform a series of shortcircuit scenarios to determine also the step 2 of the distance protection. In Fig. 7 is presented the equivalent model of BETA wind farm with DFAG (type 3), modellated in EDSA Paladin. The power produced by the BETA wind power plant is distributed in the 110 kV network through two 110 kV line, Delta and Gama.

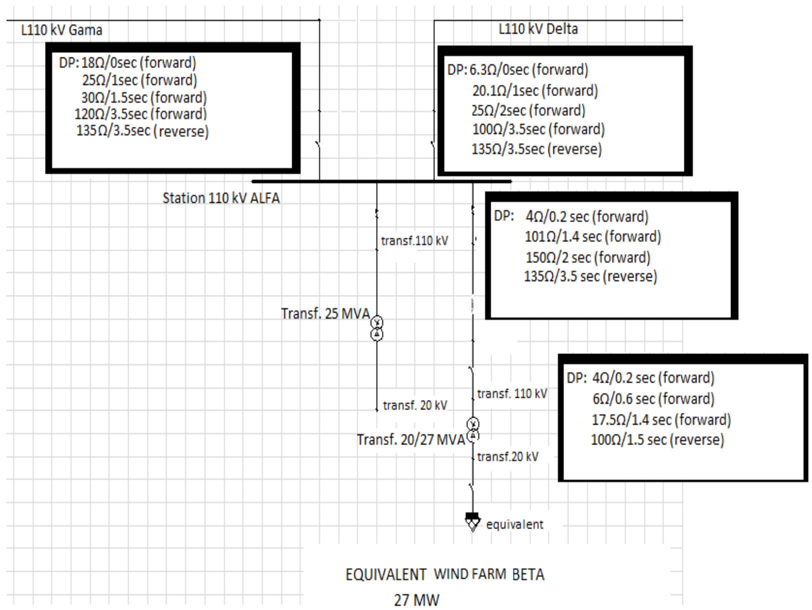


Fig. 7. Equivalent Wind Farm Beta 20 kV.

For establishing the settings of the distance protection were made some shortcircuit scenarios, as shown in tables 1, 2, 3 . To determine the minimum and maximum shortcircuit currents, changes were made to normal operation scheme. Also, considering the impedances of the 110 kV cable Beta-Alfa and of the 110 kV overhead lines Gama-Alfa, Delta-Alfa, it was not useful to simulate shortcircuit currents with fault resistance.

Table 1

Contribution of station 110 kV Beta to shortcircuit, maximum conditions, RF=0 ohm

Shortcircuit	Contribution-Station 110 kV Beta				
	Scc1ph			Scc3ph	
	Ur[kV]	Iphase[kA]	3I0[kA]	Ur[kV]	Ia[kA]
	Mag/deg	Mag/deg	Mag/deg	Mag/deg	Mag/deg
Station 110 kV Alfa	0.35/-62	0.38/97.4	1.13/97.4	0.26/-27	0.38/-88
Station 110 kV Gama	27.15/-2	0.04/96.9	0.11/96.9	30.22/-4	0.20/-85
Station 110 kV Delta	30.98/0	0.06/106.7	0.19/106.7	28.7/-5	0.21/-84

Table 2

Contribution of station 110 kV Alfa to shortcircuit, maximum conditions, RF=0 ohm

Shortcircuit	Contribution-Station 110 kV Alfa				
	Scc1ph			Scc3ph	
	Ur[kV]	Iphase[kA]	3I0[kA]	Ur[kV]	Ia[kA]
	Mag/deg	Mag/deg	Mag/deg	Mag/deg	Mag/deg
Station 110 kV Beta	3.20/-25	4.42/-72	3.70/-70	3.65/-11	5.29/-71
Station 20 kV Beta	63.51/0	-	-	53.47/2.8	0.92/-87

Table 3

Contribution of station 110 kV Alfa to shortcircuit, maximum conditions for station 110 kV Beta and minimum conditions for station 110 kV Alfa by disconnecting L110 kV Gama, RF=0 ohm

Shortcircuit	Contribution-Station 110 kV Alfa				
	Scc1ph			Scc3ph	
	Ur[kV]	Iphase[kA]	3I0[kA]	Ur[kV]	Ia[kA]
	Mag/deg	Mag/deg	Mag/deg	Mag/deg	Mag/deg
Station 110 kV Beta	1.96/-26	2.72/-74	2.12/-72	1.93/-11	2.80/-72
Station 20 kV Beta	63.51/0	-	-	46.4/4.7	0.80/-85

The reactance reach for step 2 of distance protection from station 110 kV Beta is:

$$\begin{aligned} &X_{Line} = 0.663\ \Omega; \\ &X_{1\_alfa-delta} = 6.3\ \Omega; \\ &X_{2\_beta-alfa} = 0.85 \cdot (X_L + X_{1\_alfa-delta}) = 5.919\ \Omega; \\ &X_{2\_beta-alfa} \cong 6\ \Omega; \\ &t_2 = 0.6\,\text{sec}.; \end{aligned} \tag{1}$$

The reactance reach for step 2 of distance protection from station 110 kV Alfa is:

$$X_{Line} = 0.663\ \Omega;$$
$$X_{\max\_transformer} = 83.449\ \Omega;$$
$$X_{2\_alfa-beta} = 1.2 \cdot (X_L + X_{\max\_transformer}) = 100.934\ \Omega; \quad (2)$$
$$X_{2\_alfa-beta} \cong 101\ \Omega;$$
$$t_2 = 1.4\,\text{sec.};$$

4. Conclusions

In this paper it has been studied the influence of the wind farm generators type 3 and type 4 to the shortcircuit and a method of establishing the setting of the reactance reach of step 2 of distance protection in 110 kV power grid. Total fault current is dominated by sources other than wind turbines. Even within a wind plant's collector system the external grid contribution to fault current is often dominant.

As it has been shown from the shortcircuit scenarious, if the wind farm fault current is close to their nominal current value, can occur delayed tripping of distance protection from 110 kV bay afferent wind farm substation 110/20 kV.

Nowadays distance protection, through polygon feature, allows individual settings for resistance and reactante. To avoid inappropriate triggering of the distance protection, the resistance reach should include faults with an arc and of high resistances. However, setting a high value for phase to phase resistance can result in incorrect tripping of distance protection, especially when are used high temperature low sag conductors, which of course extends the impedance area of admitted loads.

Errors that influence the settings of distance protection, with the presence of wind farms, lead to the conclusion that using these protections is insufficient even with pilot lines. Therefore, in this situation, are useful synchrophasors techniques which can evaluate the state estimator of the local network and in consequence activate the adapted settings of impedance algorithms to the changing conditions.

In summary, the method of calculating the reactance reach of step 2 distance protection, also considering the errors generated by the presence of the wind power sources, is made according to the topology of corresponding energetic area and represents an important example for protections engineers.

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