ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20220329102606

Original scientific paper
Received: 2022-03-29, Accepted: 2022-03-30

Reducing Short Circuit Current with a Novel Approach Model in Wind Power Plants

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Abstract: Wind energy from renewable energy sources, the share of electric power system is increasing faster than other sources. This requires the analysis of the effect of the wind power plants have on the power system in connection with the network. The wind produces energy-dashed and variable power, which can cause some disruptive effects. In this study, a short circuit analysis was performed using the DIgSILENT PowerFactory program. Minimum short circuit analysis calculations have been performed for 15 wind turbines and 19 bus-bar wind power plants. The error current has been reduced to a minimum by changing the transformer connection and ground resistance for the most commonly encountered phase-to-ground short circuit analysis. This application has been developed against more complex and costly methods. This prevents the generators from switching to island mode after a phase-to-ground short circuit current is affected by the fault.

Keywords: Bus-Bar; DIgSILENT; Island mode; Short circuit; Wind power

1 INTRODUCTION

The history of taking advantage of wind power dates back five thousand years. The use of wind has only been aimed at obtaining mechanical power in a significant part of human history [1]. Initial irrigation practices in Mesopotamia were conducted in Babylon in 2800 B.C. [2]. Windmills were first found in Alexandria. It is known that Turks and Persians use windmills in 7 [3]. In European countries, windmills started to be used in the 12th century [4]. Until the early 20th century, the wind was used to provide the mechanical power needed to pom-palate or grind grandees. Due to the industrial revolution, the start of industrial progress and the high efficiency of fossil fuel (oil, coal, etc.) consumption and electricity production have increased the interest in wind energy.

Wind energy among renewable energy sources has improved greatly in recent years in terms of the share of use in electricity production [5]. This increase in the number of wind plants has made it necessary to increase work on network integration in particular. National and international IEEE standards must be adhered to when integrating wind energy distributed production systems into the network [6]. These standards are important to ensure high power quality and system reliability of the network.

A significant factor in ensuring network quality and reliability is the limitation of short-circuit currents. Failure in power systems is unpredictable. Therefore, faults that may occur in the system must be limited to a certain level [7]. The most common short circuit fault in an electrical system is a phase to ground short circuit [8]. The method of application used in our country to protect the system is to limit the phase-to-ground short circuit current of the 34.5/154 kV power trans-former to 995 A. [9]. For literature scans, the world application has limited this current to 360 A for overhead lines and 800 A for underground cables [10].

A short circuit fault that will occur on the low voltage (LV) side of a power plant connected to the mains causes an increase in the fault current value [11]. This results in complexity and increased cost in relay coordination. Therefore, the fault current is limited to the minimum level before the relay is coordinated. In this way, relay coordination can be more effective.

Italy, Japan, Ireland, Russia, Peru, In Spain [12] the unearthed system, which is widely used, is defined as a system where conductors of energy pass through have no direct connection to the ground [13]. Such systems are actually ground-induced with distributed capacitances, transformers and motor windings. When there is no earth fault, the phase ground voltage is approximately equal to each three phases due to the system's off-sitive effect on the 3-phase system [14].

In the case of the first failure of the unearthed system, there is a possibility that the voltage will increase [15]. This high voltage causes a second fault at the weakest point of the system and a more harmful fault current is generated. Over-current protection devices clear the fault. Therefore, surface resistance between phase grounds causes a large rear cause. The size of the fault current may not be sufficient for protection equipment, so that both compensations can result in costly damage and the system can remain unenergized until the fault is repaired. It is very important to locate the first fault and to rectify the fault.

In northern and South Europe, the Peterson coil, which is widely used in China and Israel [16], is used to limit the arching in a 3-phase ground-plunging system that is not grounded during a soil fault [17]. This coil was originally developed by W Petersen in 1916 [18]. This solution is sometimes used in high voltage networks and industrial distribution systems. The sensitivity of the active components' residual currents and operating protection relays and current transformers are used to provide selectivity [19].

When phase ground failure occurs, the inductance of the Peterson coil changes immediately, the zero-component current of the faulty seedling changes very quickly, the others remain the same [20]. The zero-component current of the faulty seedling is maximum in phase ground failure [21]. The equivalent soil capacitance of the network can be measured instantaneously, compensating the capacity of the Peterson coil and the system [22]. The reactor is used between neutral and ground, compensating for the capacitive currents of the system [23]. This grounding method is mainly used in 110 kV systems. The Peterson coil is a reactor used in the system to clear the fault current.

Our aim in this study is to prevent the general from being affected by this fault and going into island mode in the phase ground short circuit that will occur in the system when the generator is operating in parallel with the network. Therefore, the phase ground fault current that may occur in the system must be limited to a certain value, either by neutral ground resistance or by using the Peterson coil. The short circuit current has an active and a reagent component. Therefore, the active component of the short circuit current can be limited to the resistance and the reagent component can be limited to the Peterson coil to be connected in series to the resistance. It's more effective to use this kind of neutral ground in high-voltage networks where generators are connected. The faulty area must then be isolated from the system, depending on the system specification, by means of the relay and protection circuits to be used in relation to the radial or ring mains condition.

2 SHORT CIRCUIT

Most of the faults that may occur in alternating current power systems are unstable, and few are stable. Normal operation of the system is balanced, but a short circuit fault in the system temporarily impair normal conditions [24]. The frequency of occurrence is usually the same, although faults are practically different to the point of occurrence of the fault and the structure of the system. According to a study, these frequency power systems are:

- 5% for three-phase symmetrical short circuit
- 10% for dual phase to ground short circuit
- 15% for phase short circuit
- The phase-to-ground short circuit is 70% [25].

This data shows that the short circuit fault in three-phase systems is less than the other types of fault. Short circuit failures in three-phase systems are often caused by operational errors. However, faults in power systems may initially have a different type of short circuit fault, but depending on the duration of the short circuit that has occurred, they may eventually become a three-phase short circuit. Although calculations of three-phase symmetric short circuit faults can only be carried out easily by knowing the correct component value, calculation is required by determining all component impedances according to the type of fault to calculate other short circuit fault variations [26].

2.1 Short Circuit between Phase and Ground

The phase-to-ground short circuit occurs when any of the phase conductors touch the ground, the neutral conductor or a metallic body with ground contact, as a result of an isolation puncture or jump during incorrect maneuvers. The most common short circuit fault when examining transmission systems is a phase-to-ground short circuit fault [27].

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & r & r^2 \\ 1 & r^2 & r \end{bmatrix} \begin{bmatrix} I_R \\ 0 \\ 0 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} I_R \\ I_R \\ I_R \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & r & r^2 \\ 1 & r^2 & r \end{bmatrix} \begin{bmatrix} V_R \\ V_S \\ V_T \end{bmatrix} \tag{2}$$

As described in the formulas, all component currents are equal and the sum of these three components current reaches the current. This allows the calculation of a phase-to-ground short circuit fault current to be carried out using Eq. (1) and Eq. (2).

2.2 Short Circuit between Phase and Phase

The phase-to-phase short-circuit condition, which results from two conductors touching each other or incorrect maneuvers, is the second common short-circuit fault after the phase-to-ground short-circuit condition in practice. In the phase-to-phase short circuit, the current of the two phases is equal to each other as absolute magnitude, while the current directions are reversed. In the phase not included in the fault, the current value is zero (Eq. (3) and Eq. (4)).

$$I_S = -I_T , I_R = 0 \tag{3}$$

$$V_{Sg} - V_{Tg} = Z_f I_S \tag{4}$$

Symmetrical components can be calculated with Eq. (5) using phase-to-phase short circuit failure impedance. The current and voltage values in the system can then be checked.

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & r & r^2 \\ 1 & r^2 & r \end{bmatrix} \begin{bmatrix} 0 \\ I_S \\ -I_S \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 0 \\ \frac{1}{3}(r - r^2) I_S \\ \frac{1}{3}(r^2 - r) I_S \end{bmatrix} \tag{5}$$

2.3 Short Circuit between Two Phase and Ground

Two phase-to-ground short-circuit events occur when the two conductors touch the conductors connected to the ground or earth. It's very rare in practice. For example, S and T phases are a short-circuit condition that can result in contact with each other and the ground. In phases S and T, the voltage to earth is equal to each other in the event of a short circuit fault. This allows all component currents of the two phase-to-ground short circuits to be calculated as described in Eq. (6) and Eq. (7).

$$V_{Sg} = V_{Tg} = Z_f (I_S + I_T) \tag{6}$$

$$I_R = I_0 + I_1 + I_2 = 0 \tag{7}$$

2.4 Short Circuit between Three Phases

A three-phase short circuit fault with a symmetrical fault occurs in practice as a short circuit variant that is least encountered. However, some short-circuit statuses are initially starting in a different short-circuit type, resulting in a three-phase short-circuit fault. The highest short circuit current value occurs in three phase short circuit. Phase voltages are equal and zero in three phase short circuit failure. In this way, component currents can be calculated as described in Eq. (8) and Eq. (9).

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & r & r^2 \\ 1 & r^2 & r \end{bmatrix} \begin{bmatrix} V_R \\ V_S \\ V_T \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \tag{8}$$

$$I_R = \frac{V_f}{Z_1} \tag{9}$$

The internal phase in the I_R phase conductor is the value of the short circuit current that can occur and the absolute values of the short circuit current that occurs in all phases are equal ($I_R = I_S = I_T$).

3 MATERIAL AND METOD

The study performed short circuit analysis of the power system on the wind power plant. Phase-to-ground short circuit calculations have been carried out by performing different scenarios in the system. The DIgSILENT PowerFactory program uses the IEC 60909 standard for short-circuit calculation. This standard can allow a short circuit to be calculated in rated frequency 50 Hz and 60 Hz for high voltage networks up to 550 kV.

The necessary protection measures must be taken to prevent the transformer from entering island mode. Island mode is the operating state in conjunction with the loads it supplies independently by leaving the network to prevent the transformer from affecting or affecting as a result of a fault on the network. Protection methods are important for this type of situation and for continuous energy transmission to the network.

In renewable energy sources that are connected to the network, they may be affected by any errors that may occur in the system. The system can switch to island mode for the error to occur. In this case, the earth makes it necessary to carry out fault protection. This means that the phase-to-ground fault current in the system must first be reduced using resistance or the Peterson coil. It is a more effective method to take such a protection measure on the transformer first. This has been identified and explained as the most effective method.

The modeled system is a radial system. The load flow in the radial system is unidirectional [28]. In this case, the current of the fault is not only supplied by the network but also by wind turbines. In this context, the effects of wind turbines on the bar and other bars at the common connection have been analyzed. Phase-to-ground short circuit analysis, when wind turbines are in the circuit and wind turbines are out, phase-to-ground short circuit is created in the system and output results are recorded. The calculation results in pulse current, initial symmetric short circuit current, short circuit thermal current and short circuit power values. The generated short circuit has been performed for the maximum condition according to IEC 60909 standard. The most important factor affecting phase-to-ground short circuit analysis is the connection and ground resistance of the transformer [29]. In this context, different scenarios have been carried out for the transformer link assembly and earth-to-ground resistance.

3.1 Dyn Transformer Connection and 0 Ohm Grounding Resistance

When the output results are analyzed with transformer connection section Dyn, ground resistance 0 ohms, very high short circuit currents are observed on the side where wind turbines are connected. This can cause a disruptive effect on the protection elements and can cause transformers to overheat. Tab. 1 shows the values that occur when turbines are engaged and turbines are not engaged in all bars.

Table 1 Phase-to-ground short circuit values for Dyn transformer connection in the modeled system

Fault Point	WPP On		WPP Off	
Dyn Connection	I_k'' (kA)	S_k'' (MVA)	I_k'' (kA)	S_k'' (MVA)
WPP 34.5 kV	4.38	87.67	4.26	84.12
Bus-Bar-1	3.72	74.89	3.61	71.22
Bus-Bar-2	4.19	83.41	4.17	81.81
Bus-Bar-3	2.61	50.02	2.42	48.47
Bus-Bar-4	2.71	53.61	2.74	52.63
Bus-Bar-5	3.02	59.45	2.97	58.74
Bus-Bar-6	3.16	63.45	3.08	62.60
Bus-Bar-7	3.72	74.15	3.68	73.01
Bus-Bar-8	3.98	78.02	3.86	76.45
Bus-Bar-9	4.06	80.72	3.97	79.05
Bus-Bar-10	30.22	73.15	28.56	71.86
Bus-Bar-11	31.45	74.78	29.74	72.63
Bus-Bar-12	31.89	75.02	29.98	73.33
Bus-Bar-13	32.72	76.15	30.53	74.32
Bus-Bar-14	32.86	76.89	30.74	75.09
Bus-Bar-15	33.32	77.62	31.40	76.02
Bus-Bar-16	34.23	79.75	32.45	77.60
Bus-Bar-17	35.12	81.63	33.42	80.03
Bus-Bar-18	37.85	83.84	35.76	81.09
Bus-Bar-19	38.48	85.47	36.23	83.78

3.2 YNyn Transformer Connection and 0 Ohm Grounding Resistance

The phase-to-ground short circuit current was analyzed, which was used by changing the transformer connection pattern, but was kept constant at 0 ohms. The fault will be supplied by both the mains and wind turbines as the connection is changed to. This is an important role for the protection elements on both sides. Phase-to-ground short circuit analysis of all the barges of the modeled power system has been analyzed as 0 ohm transformer connection and ground resistance of the YNyn.

Table 2 Phase-to-ground short circuit values for YNyn transformer connection and 0 ohm grounding resistance in the modeled system

Fault Point	WPP On		WPP Off	
YNyn Connection	$I_k^{"}$ (kA)	$S_k^{"}$ (MVA)	$I_k^{"}$ (kA)	$S_k^{"}$ (MVA)
WPP 34.5 kV	4.68	87.91	4.56	85.12
Bus-Bar-1	3.79	75.85	3.71	73.23
Bus-Bar-2	4.39	84.42	4.27	82.85
Bus-Bar-3	2.81	52.12	2.72	50.45
Bus-Bar-4	2.91	54.71	2.84	53.29
Bus-Bar-5	3.22	60.45	2.99	58.74
Bus-Bar-6	3.23	64.55	3.18	62.64
Bus-Bar-7	3.98	75.85	3.78	73.06
Bus-Bar-8	4.09	79.92	3.98	76.47
Bus-Bar-9	4.15	81.52	4.06	79.14
Bus-Bar-10	33.22	74.35	30.56	72.87
Bus-Bar-11	34.55	74.68	31.74	72.73
Bus-Bar-12	35.89	75.12	33.38	73.13
Bus-Bar-13	36.72	78.55	34.63	76.22
Bus-Bar-14	36.86	78.69	34.44	76.19
Bus-Bar-15	37.52	79.52	36.50	77.12
Bus-Bar-16	37.83	80.65	36.65	78.69
Bus-Bar-17	39.12	82.53	38.52	80.23
Bus-Bar-18	39.85	84.74	38.86	82.19
Bus-Bar-19	40.48	86.37	40.23	84.98

When the output results were analyzed, similar results were obtained from the Dyn connection, but the short-circuit currents on the network side increased, even though wind plants were not activated. The activation of wind turbines has also seen the increase in short-circuit currents on both the network and the wind turbine side. This shows the values that occur in Tab. 2 when turbines are engaged and turbines are not engaged in all bars.

Table 3 Phase-to-ground short circuit values for YNyn transformer connection and 20 ohm grounding resistance in the modeled system

Fault Point	WPP On		WPP Off	
YNyn Connection	$I_k^{"}$ (kA)	$S_k^{"}$ (MVA)	$I_k^{"}$ (kA)	$S_k^{"}$ (MVA)
WPP 34.5 kV	4.68	87.91	4.56	85.12
Bus-Bar-1	3.79	75.85	3.71	73.23
Bus-Bar-2	4.39	84.42	4.27	82.85
Bus-Bar-3	2.81	52.12	2.72	50.45
Bus-Bar-4	2.91	54.71	2.84	53.29
Bus-Bar-5	3.22	60.45	2.99	58.74
Bus-Bar-6	3.23	64.55	3.18	62.64
Bus-Bar-7	3.98	75.85	3.78	73.06
Bus-Bar-8	4.09	79.92	3.98	76.47
Bus-Bar-9	4.15	81.52	4.06	79.14
Bus-Bar-10	0.03	0.01	0.03	0.01
Bus-Bar-11	0.03	0.01	0.03	0.01
Bus-Bar-12	0.03	0.01	0.03	0.01
Bus-Bar-13	0.03	0.01	0.03	0.01
Bus-Bar-14	0.03	0.01	0.03	0.01
Bus-Bar-15	0.03	0.01	0.03	0.01
Bus-Bar-16	0.03	0.01	0.03	0.01
Bus-Bar-17	0.03	0.01	0.03	0.01
Bus-Bar-18	0.03	0.01	0.03	0.01
Bus-Bar-19	0.03	0.01	0.03	0.01

3.3 YNyn Transformer Connection and 20 Ohm Grounding Resistance

The phase-ground short-circuit current formed in the case when the transformer connection form is YNyn and the grounding resistance is 20 ohms has been studied. The three-phase short circuit analysis performed on all busbars of the modeled power system was performed on the DIgSILENT PowerFactory diagram.

The importance of grounding resistance has been revealed here and the short-circuit fault currents have decreased with the grounding resistance being 20 Ohms. In Tab. 3, this situation shows the values that occur when the turbines are in operation at all busbars and the turbines are not in operation.

4 FINDINGS

By using the grounding resistor in these three different cases made in the phase-ground short circuit, a serious decrease in fault currents was observed in the busbars connected to the wind turbines. It has become clear how necessary the use of grounding resistance in wind turbines included in the system is for protection. A graph showing how the connection method and the grounding resistance change during a phase-ground short-circuit failure, as well as the fault current and short-circuit power change, is shown in Fig. 1.

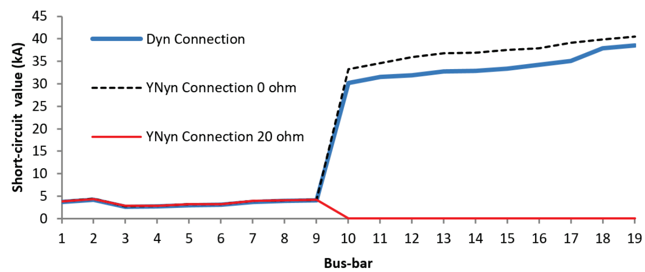

Figure 1 Phase-to-ground short-circuit values according to transformer connection method

In Fig. 1, the vertical axis shows the short circuit values (kA) and the horizontal axis shows the bus-bar numbers. In order to ensure uninterrupted and quality energy, it is likely that phase-to-ground short circuit faults are limited by this method, and the most practical encounter will be avoided.

In the analyzes carried out the DIgSILENT program, the short-circuit current of 4.68 kA in the WPP 34.5kV busbar with the highest short-circuit current was found when the secondary star point of the 250 MVA transformer was directly connected.

5 DISCUSSION AND CONCLUSION

The ohmic value of the resistor to be used for neutral grounding is determined by the voltage of the system and the magnitude of the default ground fault current. The star point is grounded through a 20 Ω resistor in the phase grounding short circuit of the transformer, the value of the current that will flow to the ground through the resistor is 995 A. If 40 Ω or 60 Ω is used, the phase grounding short circuit can be limited to lower current values. However, we are forced to limit it to this value, since the current that occurs in the primer is still not felt by the mechanical relays that continue to be used in our systems.

Since digital relays are used in developed countries, the short-circuit current is limited to 150 A and even up to 10 A with a Peterson coil in some countries. Thus, the opening times can be adjusted to a long time such as 2 hours. In the phase ground short circuit that will occur with advanced relay coordination, the breakers closest to the fault are activated and the defective region is isolated from the system. Thus, there will be no sudden stops in the system due to a malfunction that will be solved in a short time. In fact, the Peterson coil is the most effective of the neutral earths to be made against the phase ground short circuit. Because the Peterson coil compensates for the capacitive currents of the line and clears the fault. That is, the power factor of the system and the power factor of the malfunction are the same, and the malfunction is easily eliminated at the time of switching the current from zero. Especially in systems with a high concentration of small powerful generators, a resistor is connected to the Peterson coil in series. The purpose of this is to help the generators return to their old regimes after the fault has been cleared in the phase ground short circuit that has occurred.

In the phase ground short circuit that will occur in the system when the generator is operating parallel with the network, it must prevent the generator from being affected by this fault and going into island mode so we first limited the phase ground fault current that could occur in the system to a certain value using neutral ground resistance or the Peterson coil. The short circuit current has an active and a reagent component. Therefore, the active component of the short circuit current can be limited to the resistance and the reagent component Peterson coil to be connected in series. We have noticed that using this kind of neutral ground is more effective in the medium voltage networks that the Generators are connected to. The faulty area was then compressed and isolated from the system, thanks to the relay and protection circuits (50 N or 51 N), which will then be used according to the system specification, depending on whether radial or ring is a main.

Notice

The paper was presented at the International Congress of Electrical and Computer Engineering (ICECENG'22), which took place in Bandırma (Turkey), on February 9-12, 2022. The paper will not be published anywhere else.

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