Research Article

The Effect of Wind Power Generation on Distance Relay Performance

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ABSTRACT

Wind Power Plants utilize induction generators to generate electrical power. This type of generator produces less short circuit current than synchronous generators; hence it may affect the operation of transmission line protection relays. This research aims to analyze the effect of a large-scale wind power plant connected to the transmission line on the performance of the distance relays. The study utilizes a simulation method using Digsilent Powerfactory on IEEE 5 bus test system. The performance of the distance relays is compared between the original system, and the system in one of its generators is replaced with a wind turbine generator. The simulations are carried out for 3-phase faults that consist of bolted short circuits, 1-ohm fault resistance and 10-ohm fault resistances. The results show that the relays performances in zone 1 are the same for all types of generations. For zones 2 and 3, depending on the relay's position, the reaches may increase or decrease when the generator is replaced by wind power. The increasing reach of the relays is due to the dropping of infeed effect felt by the relay after installation of wind power. While the decreasing reaches of some relays because they see less fault current from the wind generation. The other relays do not experience any changes. Fault resistances cause all relays to experience reduced reach.

INTRODUCTION

In order to combat climate change, United Nations Climate Summit 2021 has reached an agreement that coal power plants will gradually remove from power system operation [1]. Countries need to increase the share of renewable generation in their energy mix to reach a maximum of 1.5°C temperature increase in 2100. Therefore, renewable generation has become a major source of electrical generation. One of well-developed renewable energy generation technology is wind power [2].

In 2018, wind power served 4,8% of annual world electrical consumption, and its share will continue to increase by approximately 20% between successive years [3]. With these significant increases, sufficient understanding of wind generation characteristics will become essential to avoid unknown disturbances.
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Wind power plants have various types of generators. The common generators for wind power are fixed-speed induction generators, small speed range wound rotor induction generators, variable speed doubly-fed induction generators and variable speed series converter-connected generators [4].

Wind power generation systems supply short circuit fault currents, which are relatively small compared to synchronous

generators [4]. The less fault current can affect the operation of the protective equipment. In this study, the effect of wind generation on the ability of distance relay to detect short circuit faults on the transmission line will be analyzed. The aim is to compare the performance of distance relays in term of reach, for system with all synchronous generator versus system that having a wind power plant as one of its generation.

The research was conducted using a simulation technique using Digsilent PowerFactory. The simulation was carried out on IEEE 5 bus test system [5]. The IEEE 5 bus system has two synchronous generators, one of which will be replaced by a wind power plant. The distance relay performance in the original IEEE 5 bus system will be analyzed for bolted (no-resistance) faults and resistive faults. The distance relay settings are kept the same for all system and fault conditions.

Wind Power Generation

Wind power plants have generators of various types, including [4]:

Fixed speed induction generators

These generators use a squirrel-cage induction generator with speed slightly above synchronous speed. They have very small

speed variation from no load to full load and are connected to wind turbines via a gearbox.

Models for fixed-speed induction generators are similar to induction motors. The ac components of fault current consist of subtransient and transient components, which decay as time increases. Since there is no steady-state ac component, the short circuit currents decay to zero in a few cycles. The dc component also decays in a few cycles. Stator windings are isolated neutral; hence their zero-sequence impedance becomes infinite.

Small speed range wound rotor induction generators

This induction generator uses three-phase wound rotor winding connected to an external resistor circuit via a converter. The converter alters the resistance of the rotor circuit by inserting variable external resistance in order to control rotor current magnitude. This control can keep the electro magnitude torque, which allows the generator speed to alter over a small range, typically up to 10%.

During the occurrence of faults at the terminal of the generators, the generator will supply a large stator circuit current. The rotor also experiences a large overcurrent, that can damage the electronic switch components of the converter. Therefore, this large fault current has to be blocked, which has the effect of inserting the entire external resistance in series with the rotor circuit. This will reduce the fault current supplied by the generator.

Variable speed doubly-fed induction generators

This generator has two bidirectional back to back voltage converters. This static rotor converter injects controlled three-phase voltages to the rotor circuit at slip frequency. The function of this converter is to vary generator electromagnetic torque and rotor speed. Also, the converter maintains stator reactive power output, stator power factor and stator terminal voltage.

The rotor winding is connected to the crowbar circuit to protect the electronic converter from large fault currents. The thyristor of the crowbar will prevent large overvoltage on dc links when a fault occurs, and the converter switches are immediately blocked. The rotor current will flow into the crowbar circuit. After crowbar operation, this generator will be similar to a conventional wound rotor induction generator with external rotor resistance.

Variable speed series converter-connected generators

This ac generator is connected to an ac network through an ac/dc/ac series back to back converter. During a short circuit event, this generator can control its short circuit current, becoming the same for the entire fault duration

In Digsilent Powerfactory, there are two models of wind turbine generators according to their short circuit currents [6]. The first is no fault current contribution wind generator and the second, static converter wind generation. The first can model small speed range wound rotor induction generator and doubly fed induction generators if their fault current external rotor resistance relatively

large. The second can model these four kind wind turbine generators. Therefore, both models are applied in this research.

RESEARCH METHODOLOGY

The Digsilent Powerfactory simulation for distance relays is conducted in a test system, i.e. IEEE 5 bus system , as shown in figure 1. The system has two generators (G1 and G2), both synchronous generators. This system is the original system. Another system is a modification of the original system that is conducted by changing G2 into a wind turbine generator. Two types of wind turbine generators are applied in this research, i.e. static converter wind generation and no-fault current contribution wind generation. These two types of wind generation become representative of the four types of wind generation technologies that have been explained above.

The transmission line is protected by Mho distance relays on each end of the line. Names of the distance relays are shown in Figure 2.
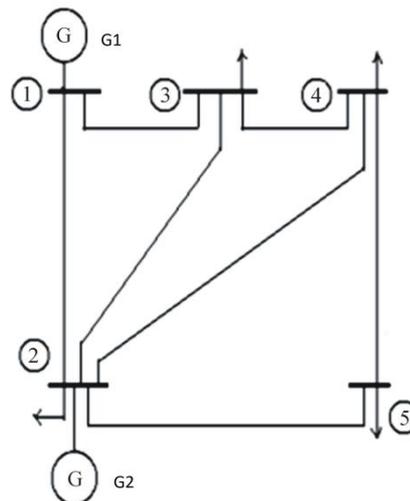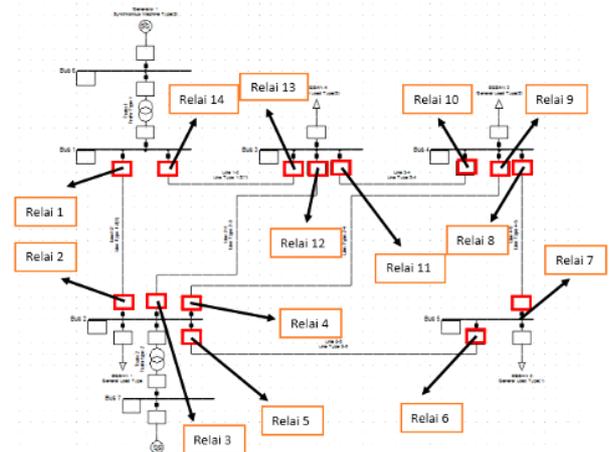

Figure 1. Single line of IEEE 5 bus system

Figure 2. location of the distance relays

The settings of the relays are calculated for zone 1, 2 and 3 according to (1) to (3) [7], [8].

$$\text{Zone}_1 = 0.8 \times Z_{l1} \tag{1}$$

$$\text{Zone}_2 = Z_{l1} + 0.5 \; Z_{l2} \tag{2}$$

$$\text{Zona}_3 = Z_{l1} + 1.2 \; Z_{l2} \tag{3}$$

Where:

Z_{l1} : first-line impedance (line of the relay location)

Z_{l2} : second line impedance (following line of relay location)

For zone 3 settings, there is an additional requirement that the settings should not be more or equal to 50% of the third line impedance. This is intended that no trips coincide with zone 3 other distance relays on the second line. If the zone 3 coverage reach 50% or more of the length of the third line, hence that the zone 3 settings will be reduced according to (4).

$$\text{Zone}_3 = Z_{l3} \times 40\% + Z_{l2} + Z_{l1} \tag{4}$$

Where Z_{l3} : third line impedance (next line of relay location)

The research methodology is shown in a flowchart in Figure 3. The settings of the distance relays are conducted only once for each relay and remain the same for both system conditions (original and with wind generation).

RESULTS AND DISCUSSION

Settings of each distance relays are calculated according (1) to (4). The results are shown in Table 1. Numerous three phase fault simulations are conducted for each transmission line to measure each relay reach according to its zones. Reach of a distance relay is the length (or impedance) of the line that covered by the relay. Reach comparison of distance relays is carried on the original system and modified system. The reaches are also compared for bolted and resistive faults.

Tabel 1. Mho distance relay settings (primary values)

| Relay	Zone 1	Zone 2	Zone 3
1	24.49∠71.57°	61.22 ∠ 71.57°	104.08∠71.57°
2	24.49∠71.57°	91.83∠71.57°	159.123 ∠ 71,61°
3	99.55∠76.50°	132.02∠76.29°	142.63 ∠ 76.04°
4	73.47∠71.57°	99.43 ∠ 71.66°	110.06 ∠ 71.78°
5	48.98∠71.57°	122.44∠71.57°	189.73∠71.61°
6	48.98∠71.57°	76.53 ∠ 71.57°	97.96 ∠ 71.57°
7	97.96∠71.57°	130.04∠ 71.64°	140.67 ∠ 71.73°
8	97.95∠71.57°	153.05∠71.57°	195.91∠71.57°
9	73.45 ∠ 71.57°	107.14∠ 71.57°	128.57 ∠ 71.57°
10	12.16∠72.85°	77.39∠75.79°	149.88∠ 71,69°
11	12.16 ∠ 72.86°	61.11 ∠ 71.89°	119.27∠ 71,73°
12	99.55∠76.50°	139.69∠ 75.96°	161.06 ∠ 75.38°
13	97.95∠71.57°	137.75∠71.57°	159.18∠71.57°
14	97.95∠71.57°	130.04∠ 71.64°	140.67 ∠ 71.74°
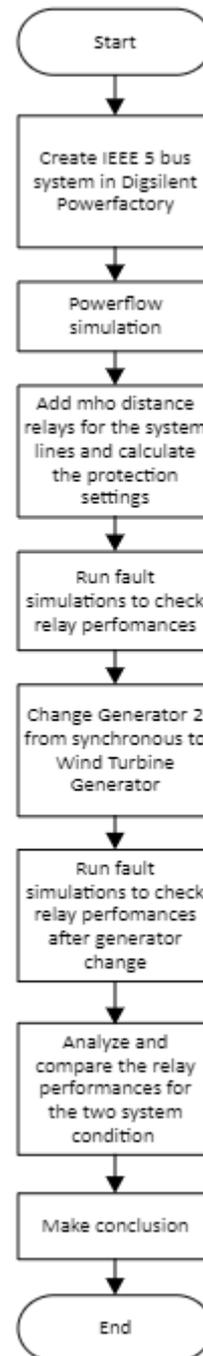
Figure 3. Flowchart of the research methodology

Performance During Non- resistive Faults

The reaches of distance relays for zone 1 caused by no resistance faults are the same for three-generation technology (synchronous generation, static converter wind generation or no-fault current contribution wind generation) in G2. Relay 2 (R2) can still detect faults on line 2-1, even when no fault current contribution wind generation is applied, because the relay receives fault current that is sent by G1 to bus 2 via line 32.

For zone 2 reach, some relays can maintain their reaches in the three generation technologies. Although some relays (R1, R6, R9, R12) experience a reach increase, as shown in Figures 4a to 4d. These increases are caused by the reduction of generation infeed from G2 when G2 is changed from the synchronous generator to wind generation. The most significant reach increase occurs when G2 is a no-fault current contribution wind generation because this generator does not provide any infeed to the relays.
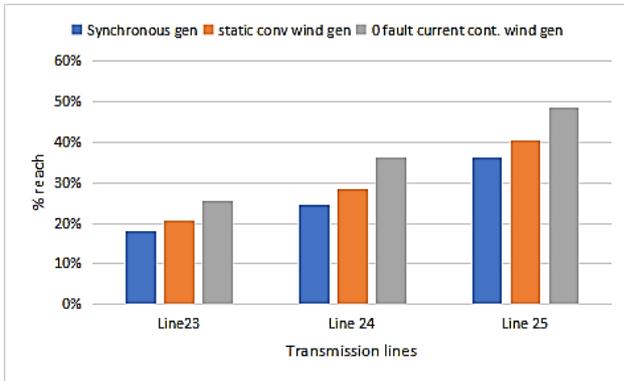

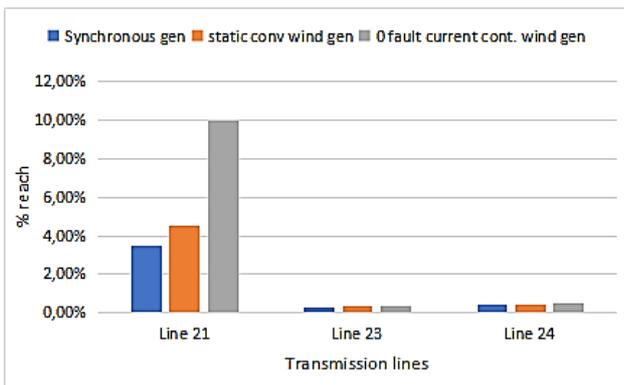Figure 4.a Increasing zone 2 reach of R1 for wind generation

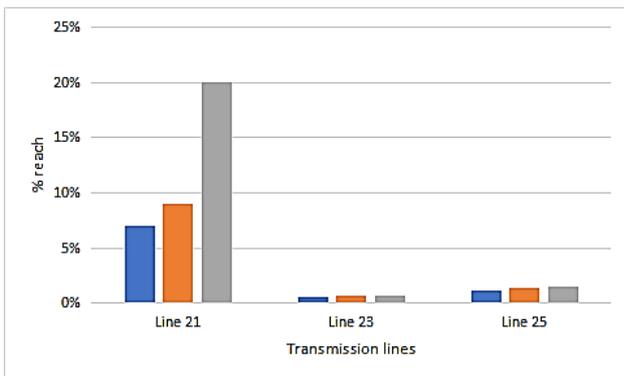Figure 4b. Increasing zone 2 reach of R6 for wind generation

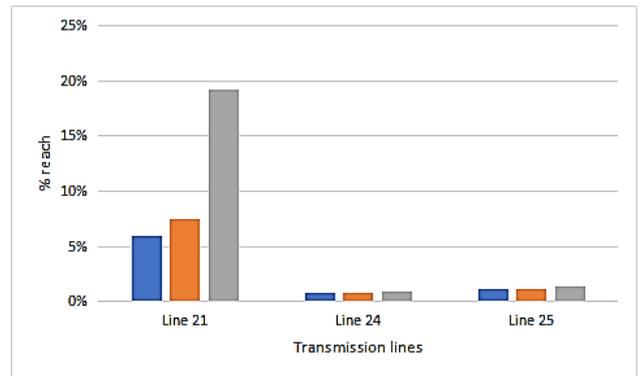Figure 4c. Increasing zone 2 reach of R9 for wind generation

Figure 4d. Increasing zone reach of R12 for wind generation

Although some relays experience increasing reaches, R2, R10 and R13 undergo small reduce reaches. An example of this condition is shown in Figure 5 for R2. The largest reduced reach is for no fault current contribution wind generation where the zone 2 reach of R2 only covers the first line (i.e. the line where the relay is located). The reduced reaches are caused by the smaller fault current from wind generation, which results in larger impedance seen by the relays.
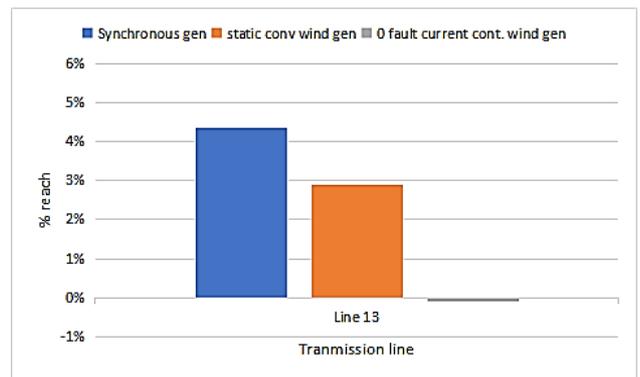

Figure 5. The decreasing reach of R2 for wind generation

For zone 3 reaches, the same relays continue to increase or decrease their reaches. Some other relays have also started to increase their reach. Relays that increase their reaches are R1, R6, R8, R9, R11 dan R12. While, decreased reaches are experienced by the same relay, i.e. R2, R10 dan R13.

The effects of the increasing reaches of the relays may cause mal-operation for faults that they should not trip or trip at a lower zone. This could result in more circuit breakers disconnecting the lines. While, the decreased reaches may make relays trip at the higher zone that they should, hence longer time for fault clearings.

Performance during Resistive Faults

Resistive faults will reduce the reach of distance relays [9], [10]. This research applied 1 ohm and 10 ohm resistance to simulate resistive three-phase faults.

From the simulations of 1 ohm and 10 ohm resistive faults, it is found that the zone 1 reaches of all relays remain the same when G2 is changed from synchronous generation to both types of wind generation. This is because there is no infeed problem for a fault on zone 1 operation of the relays. However, there are decreased

reaches of R2 when no-fault current contribution wind generation is applied, as shown in Table 2.

Table 2. Zone 1 Reach of R2 for different fault resistances and generation technologies

Fault Resistance	Zone 1 Reach		
	Synchronous Gen	Static converter wind gen	no-fault current wind gen
0 Ohm	80%	80%	80%
1 Ohm	68%	68%	45%
10 Ohm	<0%	<0%	<0%

Fram Table 2 can be seen large fault resistances substantially reduces the reach of the distance relay. For 1 Ohm fault resistance, with no-fault current wind generation as G2, the R2 has a lower zone 1 reach than other generation technologies. For 10 Ohms fault resistance, the distance relay fails to detect the fault in zone 1. The notion '<0%' means that the relays only detect the fault in zone 2. This is because the resistance of the faults add-up to line impedance that is seen by the relay, which then results in a lot higher impedance seen by the relay. The R-X diagrams of R2 during 10 Ohm fault resistances are shown in Figure 6. Clearly R2 will fail to protect its zone 1 area if 10 or more Ohm fault resistance occurs on the line, even for original system (all synchronous generation).
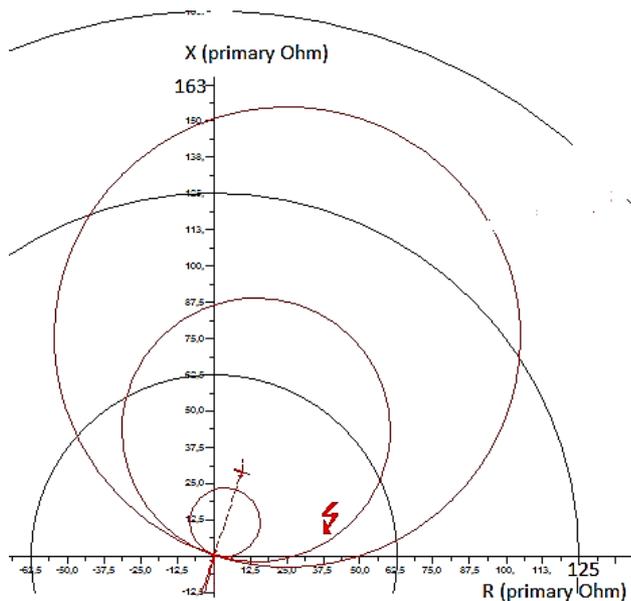

Figure 6. R-X Diagram of R2 for fault on 10% of line length with 10 Ohm fault resistances.

A list of relays that experience changes in their reaches due to generation technology switch from synchronous generation into wind generation can be seen in Table 3. For zone 1, most of the relays do not experience any change, except for R2 for fault with resistance and R1 for 10 ohm fault resistance. R1 and R2 locate very close to both G1 and G2; hence the generation technology change affects them more than other relays. At higher zone, relays are more prone to increase/decrease in their reaches, while fault resistance increase tends to reduce the number of relays that experience reaches increase.

Table 3. Relays that experience reach changes

Fault Resistance	Reach increase	Reach decrease
Zone 1		
0 Ohm	-	-
1 Ohm	-	R2
10 Ohm	R1	R2
Zone 2		
0 Ohm	R1, R6, R9, R12	R2, R10, R13
1 Ohm	R1, R6, R9, R12	R2, R10, R13
10 Ohm	R1, R9, R12	R2, R10, R13
Zone 3		
0 Ohm	R1,R6,R8,R 9, R11, R12	R2, R10, R13
1 Ohm	R1,R6,R8,R 9, R11, R12.	R2, R10, R13
10 Ohm	R1,R8,R9, R11, R12.	R2, R10, R13

CONCLUSIONS

Wind generation technologies affect the performance of Mho distance relays in terms of their reaches since wind generation produces less fault current than a synchronous generation. Depending on their location, the relays may increase or decrease their reaches after switching from synchronous generation to wind generation. The reach changes are greater for no fault current contribution wind generation than static converter wind generation due to fewer fault currents.

Since the fault current generated by the wind generation is smaller than the synchronous generator, the infeed effect received by the distance relays is reduced. As a result, the relay reaches become greater. Meanwhile, the less fault current from the wind generator seen by the other relays results in larger measured impedance, which then reduces the relays' reaches.

ACKNOWLEDGMENT

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