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Wind Power Plant Short-Circuit Modeling Guide

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Abstract

This report presents a discussion on modeling a wind power plant for short-circuit studies at the transmission level. Due to the longer history of use and experience with synchronous machines in the electric power grid, the short-circuit behavior of power plants using these types of machines is well understood compared to a wind power plant. It is the goal of this guideline to educate utility engineers on short-circuit modeling of wind power plants in order to increase the level of understanding of wind power plant behavior. The methods presented in this paper will assist in determining the maximum short-circuit contribution from a wind power plant for system impact studies (verifying current is within interrupting ability of protection devices), relay coordination, and arc flash hazard studies.

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NOMENCLATURE

DFIG	Double Fed Induction Generator
DOE	Department of Energy
IG	Induction Generator
PM	Permanent Magnet
POI	Point of Interconnection
SCIG	Squirrel Cage Induction Generator
SNL	Sandia National Laboratories
WRIG	Wound Rotor Induction Generator
WTG	Wind Turbine Generator

1. INTRODUCTION

The purpose of this guide is to educate utility engineers on methods for modeling wind power plants when conducting short-circuit studies at the transmission level. As the installed capacity of wind generation in the United States continues to grow it is necessary for utility engineers to be aware of the behavioral characteristics of wind power plants and the impacts they have on the electrical grid. In the first decade of the 21st century the United States has seen wind capacity grow from less than 4GW to over 40GW [1], and that growth poses unique challenges for utilities in properly integrating wind energy into the electric grid. A unique aspect of wind generation that separates it from conventional generation is its short-circuit behavior. Wind turbines typically employ an induction generator directly connected to the grid, or decoupled from the grid through power electronics. These topologies have different short-circuit characteristics compared to a synchronously connected machines. Proper short-circuit studies are necessary for determining that the maximum short-circuit contribution from a given machine is within the limits of circuit breakers, and that protective devices are properly coordinated. This paper will assist relay engineers with modeling the short-circuit behavior of wind power plants, and the different types of wind turbines that those plants may employ, in order that these short-circuits studies achieve accurate results.

1.1. Utility Short-Circuit Studies and Assumptions

Because multi-megawatt wind farms are interconnected to the transmission grid, the concern for short-circuit contribution from the wind generation is at the transmission level, which typically consist of multiple wind turbines connected to systems greater than 69kV. The effects of smaller wind turbine systems that are connected to the distribution system are not investigated in this paper. Also, the design of the internal protection and coordination system within a wind power plant is not discussed in this paper as that is beyond the area of responsibility for utility transmission engineers. This guide will examine the components of a wind power plant in order to determine the worst case fault-current contribution from a wind power plant based on balanced and unbalanced faults.

2. TECHNICAL BACKGROUND

2.1. Wind Power Plant Topology

A significant difference between a wind power plant and a typical power plant is the number of machines employed. A typical conventional 100MW power plant (combustion, hydro, steam) might consist of a single unit or a few large units. The components that would be modeled for short-circuit studies for a conventional power plant are the generator and step-up transformer. A wind power plant of similar size will consist of many machines, their individual step-up transformers, a medium voltage collector system, and a substation transformer as shown in **Error! Reference source not found.**Figure 1 below. It is necessary to include the impedances of all these components in a short-circuit study. Representing each of these machines individually is not a recommended practice as it is overly burdensome and time consuming. At the transmission level it is unnecessary to model the internal busses within the wind power plant. The main concern for transmission studies is the wind power plant's effect at the Point of Interconnection (POI). Section 4 will discuss the methods for representing an entire wind plant into a single machine equivalent.

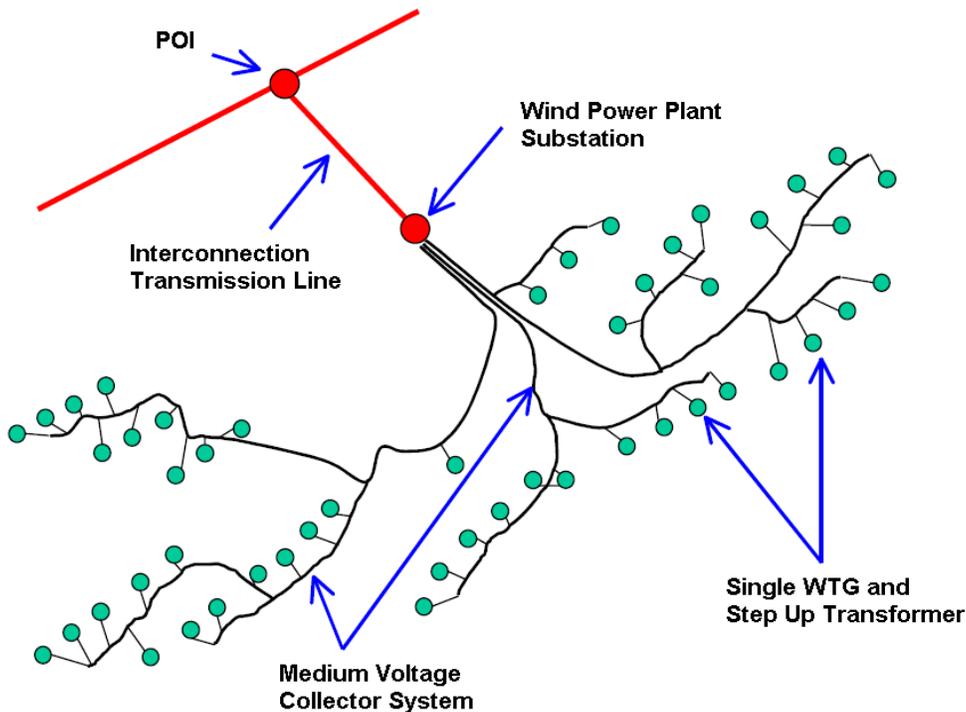


Figure 1. Typical Wind Plant Topology

2.2. Various Wind Turbine Configurations

Industry has divided wind turbines into four different types based on the different configurations available for large megawatt rated machines, labeled as Type I through Type IV. This section will provide a brief background the differences between these configurations.

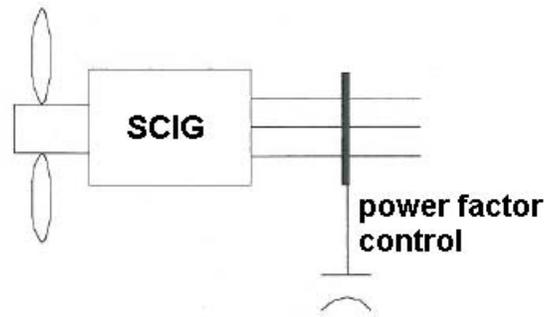


Figure 2. Type I Wind Turbine Generator.

Figure 2 shows the layout of a Type I Wind Turbine Generator (WTG). In this configuration a squirrel cage induction machine is directly coupled to the grid. Due to the poor power factor present during induction machine operation, compensating capacitor banks are used near the terminals of the WTG. This type of configuration was popular in the 1990's when larger utility scale wind farms were starting to come online.

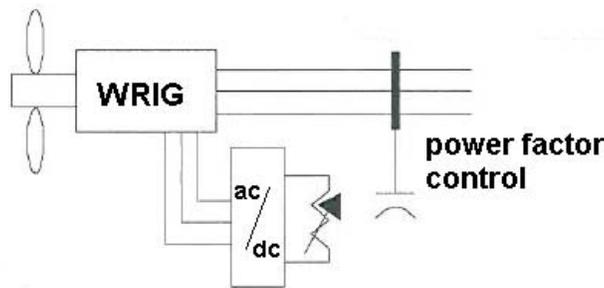


Figure 3. Type II Wind Turbine Generator.

Figure 3 shows the layout of a Type II WTG. A disadvantage of using the Type I WTG is the large torque swings that occur with turbulence in the wind speed. The Type II WTG employs a wound rotor induction machine in which the rotor windings are coupled to a resistive bank. By varying the resistance of the rotor windings, a more dynamic response to wind turbulence can be achieved by allowing a change in speed in the generator rotor which reduces large torque swings, prolonging the life of the mechanical components. The Type II WTG still requires a compensating capacitor banks to achieve operation within typical power factor limits.

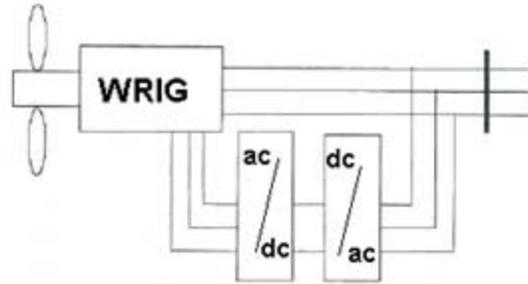


Figure 4. Type III Wind Turbine Generator.

Figure 4 shows the layout of a Type III WTG. The Type III wind turbine generator is known as a doubly-fed induction generator (DFIG). It is a wound rotor similar to the Type II design, however, rather than the rotor windings being connected to dynamically controlled resistors, there is a power converter between the rotor windings and the grid. The addition of the power converter between the rotor windings and the grid allows the same benefits of the Type II design without the resistive losses, the ability to provide reactive support without external capacitor banks, and variable speed operation that allows for more efficient energy capture below rated wind speeds. The power electronic devices in the power converter are sensitive to above rated currents. In order to protect the power converter from high short-circuit currents, protection devices such as a “crowbar” or “chopper” circuit are used. The type of protective device used for the rotor converter will have a significant impact on the short-circuit behavior of the Type III machine and this is discussed further in Section 3.4.

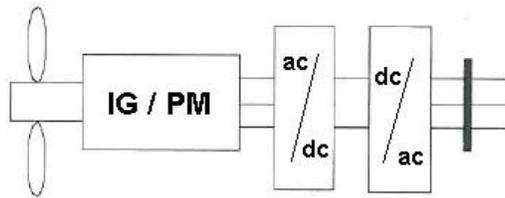


Figure 5. Type IV Wind Turbine Generator.

Figure 5 shows the layout of the Type IV WTG. The Type IV machine is known as a full converter type wind turbine. In this design the wind turbine generator is decoupled from the grid through a power converter that is rated to the full output of the turbine. It has the same advantages of the Type III design with variable speed operation and reactive power support. Since the generator is decoupled from the grid the stator windings can operate at variable frequencies, expanding the type of machine that can be used. Permanent Magnet (PM) synchronous and squirrel cage induction machines are the most common. Since a machine in

this configuration is decoupled from the grid the short circuit contribution is determined by the behavior of the power electronic interface

3. WIND TURBINE SHORT-CIRCUIT BEHAVIOR

As stated in [2], representing a synchronous machine for fault studies can be done with the following circuit.

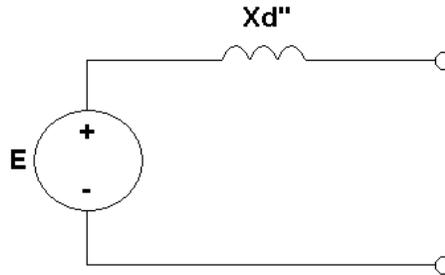


Figure 6. Synchronous Machine Short-Circuit Equivalent.

X_d'' is the subtransient reactance that comes from manufacturers supplied data. It is important to note that this circuit is only valid at $t=0+$, given that a fault occurs at $t=0$. The machine is represented with a Thevenin equivalent where the voltage and impedance represent the worst case condition (highest short-circuit current contribution) immediately following a fault. This assumption will give usable results in order to determine relay settings and has been verified through years of experience in the utility industry.

Wind power plants on the other hand do not employ these types of machines for energy production. Wind power plants either employ an induction machine with a direct connection to the 60Hz electrical grid, or they decouple the wind turbine generator from the 60Hz grid through power electronic devices as previously discussed. The following sections describe the short-circuit behavior of each the wind turbine generator topologies. The short-circuit behavior of the Type III machine will be discussed last because it is more complex and can be modeled different ways depending on the method used for the protection of the rotor converter.

3.1. Type I WTG Short-Circuit Model

The major difference between an induction machine and synchronous machine in regards to their behavior during a fault is their method of excitation. In a synchronous machine the excitation is provided from an independent DC source that is unaffected by a fault on the AC system. Due to this separate excitation, a synchronous machine will continue to supply high transient currents throughout the duration of a fault. In contrast to this, the drop in line voltage caused from a fault will cause the induction machine to lose excitation, and it will only supply transient currents to the fault for one or two cycles. Most induction machines on the electric power grid are small enough that their contribution to the fault current can be neglected. However the induction machines used in a Type I WTG are large enough that they should be taken into account for determining total fault current. The equivalent machine impedance for

fault calculations is the sum of the stator and rotor reactance as shown in Figure 7. The values for stator and rotor reactance are supplied from the induction generator manufacturer.

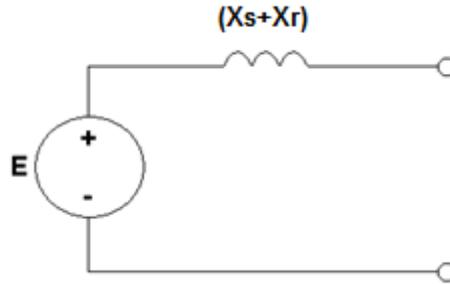


Figure 7. Subtransient Induction Motor Equivalent Circuit.

3.2. Type II WTG Short-Circuit Model

The addition of the external rotor resistance will act as an impedance in the short-circuit equivalent, lowering the maximum available fault current of the induction machine. However, the Type II wind turbine is operated such that the external rotor resistance is applied only when necessary since the losses in the resistor equate to lost energy production from the generator. This will make the short-circuit behavior for a Type II machine similar to that of a Type I machine. The same equivalent circuit for a Type I machine shown in Figure 7 should also be used for a Type II machine.

3.3. Type IV Short-Circuit model

Unlike the previous designs where the short-circuit behavior was dominated by the generator characteristics, it is the design of the power converter that drives the electrical behavior of the Type IV WTG. As mentioned previously, the power converter in the Type III design is sensitive to excessive currents, so too is the converter in a Type IV design. In order to protect the power electronics devices a current limit of 1.1pu is designed into the power converter. Rather than the common voltage source behind an impedance short-circuit equivalent used to model most generators, the Type IV design looks like a simple current source for maximum short-circuit contribution as shown in Figure 8.

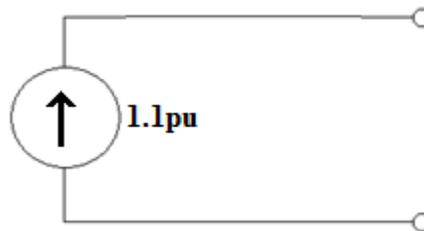


Figure 8. Type IV WTG Short-Circuit Equivalent.

3.4. Type III Short-Circuit Model

As mentioned earlier the short-circuit behavior of the Type III WTG should be modeled differently depending on the method used for the protection of the rotor power converter. Figure 9 below shows the two methods used to protect the power converter on the rotor circuit. It can be modeled as either a typical induction machine similar to Figure 7 or a current limited generator as that in Figure 8. Early designs of the Type III WTG used a crowbar circuit that is activated during the initial phase of a fault. The crowbar circuit diverts the short-circuit current away from power converter, essentially shorting out the rotor windings. The removal of the power converter during a fault makes the Type III WTG behave similar to the Type I and Type II design, where worst case short-circuit current is based on the internal impedance of the induction machine. In this case the equivalent circuit shown in Figure 7 should be used. The newest and now more common method of protecting the rotor converter is done with a chopper circuit. With a chopper circuit better grid support, such as Low Voltage Ride Through, is achieved during a fault by keeping the rotor converter active, but still limiting the currents to protect the sensitive power electronics within the power converters. When this method is used the short-circuit contribution from a Type III WTG is similar to that of a Type IV WTG and the equivalent circuit shown in Figure 8 should be used.

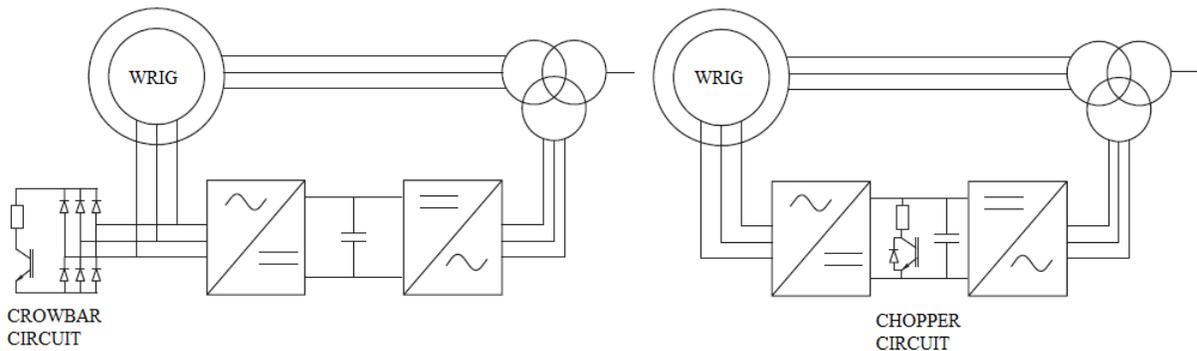


Figure 9. Type III Wind Turbines; Crowbar and Chopper Protection of Power Converter.

4. EQUIVALENCING WIND POWER PLANTS FOR SHORT-CIRCUIT STUDIES

This section will describe the method for reducing a wind power plant to a single machine equivalent. It is typically not recommended to model the entire wind plant within a utility’s system model as this adds an unnecessary number of buses and complexity to the power system model. A detailed description of the method for equivalencing a wind power plant for load flow studies was presented in the “*WECC Wind Power Plant Power Flow Modeling Guide*” [3]. This section will use the same example presented in the WECC Guide and apply those methods to create a short circuit model of the wind plant. In this section an example wind power plant will be studied consisting of 18 wind turbines, each with a step-up transformer tying into the collector system, a single station transformer, and an interconnecting transmission line to the Point of Interconnection (POI). Figure 11 in Section 4.3 shows the layout of the example 18 turbine wind plant

Determining the fault contribution of a wind power plant into the transmission network can be done by reducing the plant to the following circuit.

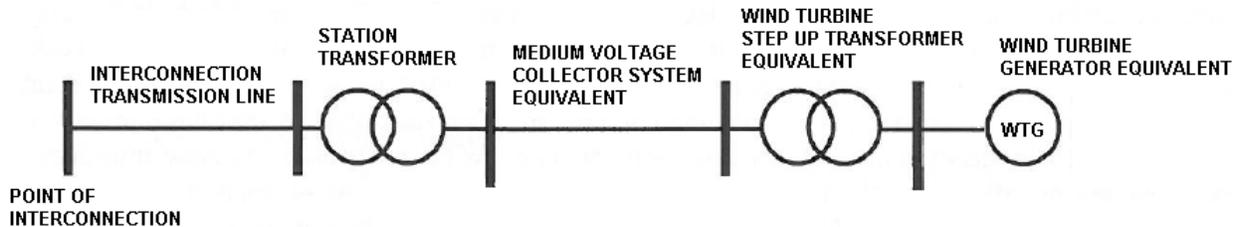


Figure 10. Wind Power Plant Single Machine Equivalent.

The challenge lies in calculating the equivalent impedance based on the components of the wind power plant. An initial conversion of all impedances to be on the same Volt-Amp base (S_{BASE}) must be done before the equivalent impedance can be calculated. The equation for converting a per unit (pu) impedance to a new S_{BASE} is done with the following equation.

$$Z_{pu_new} = Z_{pu_old} \times \left(\frac{S_{BASE_new}}{S_{BASE_old}} \right)$$

The following sections will discuss the calculation of equivalent pu impedances for the components shown in Figure 10.

4.1. Interconnection Transmission Line

Depending on the wind power plant’s distance to the transmission system the construction of a transmission line could be necessary for delivery of power to the grid. The method for calculating line impedance is well understood by transmission engineers. Given a tower geometry and conductor type one can calculate the line parameters for a given distance of line.

For the example wind power plant in Figure 10 above, the interconnection transmission line parameters are as assumed to be:

$$R_{line} = 0.0031 \quad X_{line} = 0.0047$$

4.2. Substation Transformer

The impedance of transformers in power system studies is also well understood. Typically a value of X along with an X/R ratio is supplied from the transformer manufacturer. Per unit values of X on the transformer's base are consistent across industry with 7% to 10% and an X/R ratio of 40 to 50. For the example being studied we will assume a transformer impedance of 8%, an X/R ratio of 40, and a transformer rating of 50MVA. Changing these parameters to a 100MVA S_{BASE} yields:

$$Z_{pu_new_XFMR} = (0.002 + j0.08) \times \left(\frac{100MVA}{50MVA}\right) = 0.004 + j0.16$$

4.3. Medium Voltage Collector System

The most challenging part in deriving the impedance of a wind power plant is reducing the collector system to an equivalent impedance. The method for equivalencing the collector system of a wind power plant is documented in [4] and is calculated with the following equations.

$$Z_{eq} = \frac{\sum_{i=1}^I Z_i n_i^2}{N^2} \quad B_{eq} = \sum_{i=1}^I B_i$$

Where I is the number of branches in the collector system, Z_i and n_i is the impedance of the i^{th} branch, and N is the total number of wind turbines in the plant. Using the same example for a collector system as in [3] this method is demonstrated in Figure 11 below.

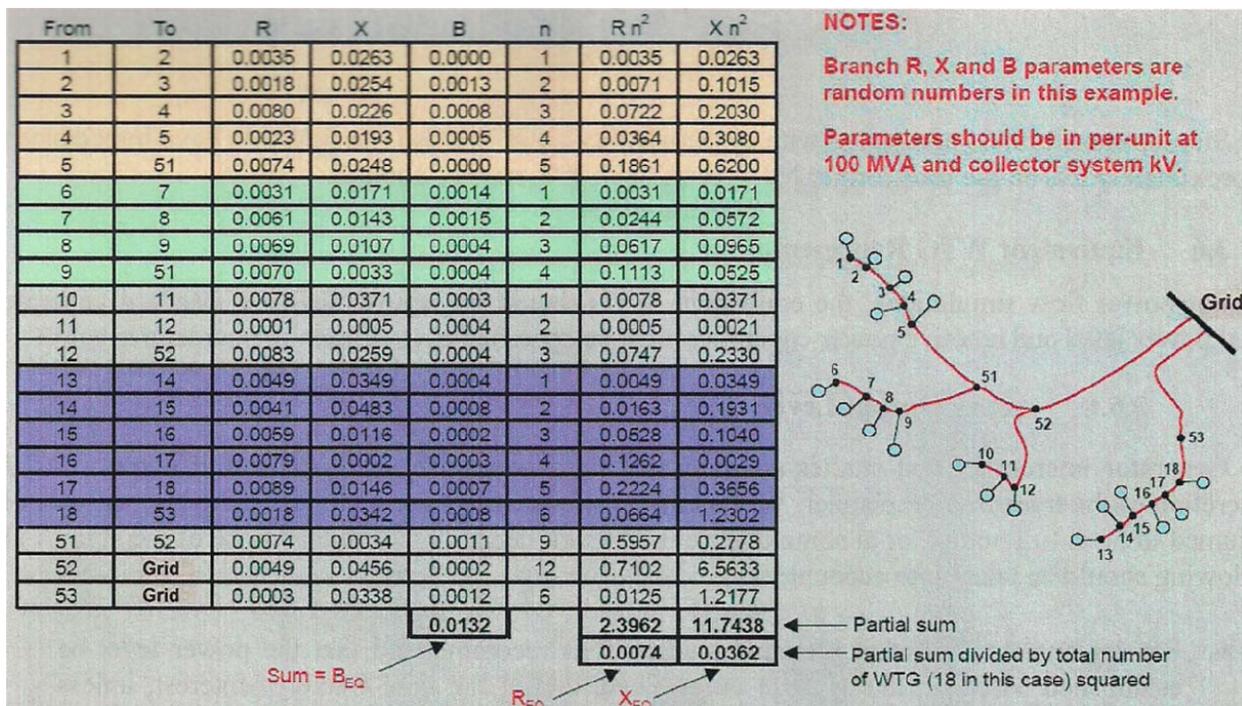


Figure 11. Calculation of Collector System Equivalent Parameters.

4.4. Wind Turbine Step-Up Transformer

Wind turbine generators usually operate at a voltage in the range of 600V, and thus need a step-up transformer for power delivery into the medium voltage collector system. Modeling the impedance of the wind turbine generator step-up transformer is similar to the substation transformer except that the typical values for impedance are a little different, with an X of usually 6% and X/R ratio of 8. For the example in question we'll assume that each of the 18 wind turbines throughout the plant have a 2MVA rated step-up transformer. The equation for converting the step-up transformers to an equivalent impedance on a 100MVA S_{BASE} is illustrated below.

$$Z_{SU_XFMR} = (0.0075 + j0.06) * \left(\frac{100MVA}{2MVA}\right) * \left(\frac{1}{18}\right) = (0.021 + j0.167)$$

4.5. Wind Turbine Generator

The equivalent impedance for induction machine type wind generator was show in Figure 7, this applies to Type I, Type II, and Type III systems with a crowbar circuit. Finding an equivalent impedance for a single machine is similar to the method above for the step-up transformer, with 18 2MVA rated wind turbine generators, and assuming a subtransient reactance of 0.15pu on the wind turbine generator's base.

$$Z_{WTG} = (j0.15) * \left(\frac{100MVA}{2MVA}\right) * \left(\frac{1}{18}\right) = (j0.417)$$

4.6. Equivalent Circuit of Wind Plant

Once the equivalent impedances of the components of a wind power plant have been derived we can reduce the diagram in Figure 10 to a single equivalent impedance value. For the entire wind power plant the equivalent values of R and X can be shown with the summation of impedance of the wind plant components. For our example, below is the equivalent impedance calculation.

$$R_{eq} = R_{LINE} + R_{SUB_XFMR} + R_{COLLECT} + R_{SU_XFMR} = 0.0031 + 0.004 + 0.0074 + 0.021$$

$$R_{eq} = 0.0355$$

$$X_{eq} = X_{LINE} + X_{SUB_XFMR} + X_{COLLECT} + X_{SU_XFMR} + X_{WTG} = 0.0047 + 0.16 + 0.0362 + 0.167 + 0.417$$

$$X_{eq} = 0.785$$

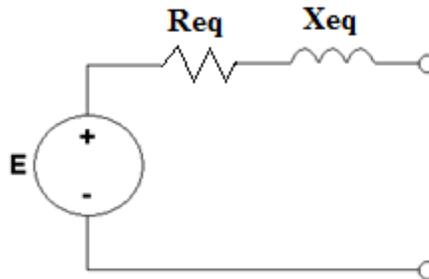


Figure 12. Short-Circuit Equivalent of entire Wind Plant.

4.7. Special Case: Current Limited Generators

As discussed in Section 3.3-3.4 the Type IV and the Type III (with Chopper) wind turbine generator short-circuit equivalent is not modeled as a voltage source behind an impedance, but rather a current source that is limited to 1.1pu. Finding the short-circuit equivalent of a wind power plant consisting of current limiting machines will require a different approach than that outlined above. Using the wind power plant topology in the previous example we will assume 18 Type IV wind turbine generators rated at 2MVA for this example. Finding the equivalent short-circuit diagram of the entire wind power plant consists of the summation of each of the wind turbine generator's current contribution and a change of base. The equivalent short-circuit diagram of a wind power plant with current limited power converters is represented in Figure 13 along with the corresponding current contribution from the 18 Type IV WTGs.

$$I_{SC_plant} = (I_{SC_WTG} \cdot N) \cdot \left(\frac{S_{BASE_OLD}}{S_{BASE_NEW}} \right) = (1.1 \times 18) \cdot \left(\frac{2MVA}{100MVA} \right)$$

$$I_{SC_plant} = 0.396 pu$$

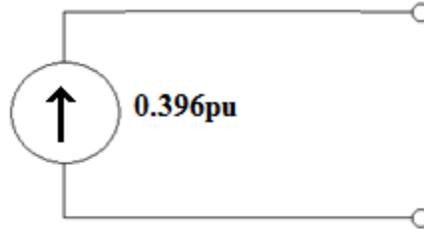


Figure 13. Short-Circuit Equivalent of plant with Current Limited Power Converters.

4.8. Unbalanced Faults: Negative and Zero Sequence Equivalent

In the examples above only the positive sequence equivalents were discussed. The positive sequence impedances will provide the worst case fault current for a balanced three phase fault. When studying unbalanced faults it is necessary to also know the negative and zero sequence impedance of the network. The equivalent negative and zero sequence impedance networks discussed below apply to wind power plants with both conventional machines and current limiting power converters.

The negative sequence impedances will be the same as the positive sequence impedance and the equivalent circuit is shown below in Figure 14. The only difference is the lack of the positive sequence voltage source E .

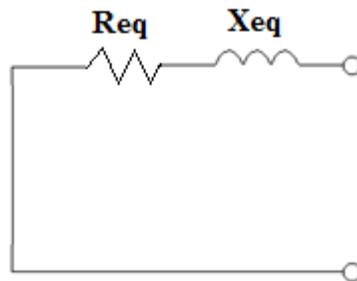


Figure 14. Negative Sequence Equivalent for the Wind Power Plant.

The zero sequence equivalent is not as trivial due to the effect of the transformer windings. A common configuration for station transformers is the delta to grounded-wye transformer with the delta on the high side. The delta configuration of the high side of the station transformer does not allow the flow of zero sequence currents and in the equivalent circuit this is shown with an open circuit. The same open circuit is also achieved for zero sequence current due to the wind turbine generator being ungrounded. This is illustrated in the zero sequence circuit for the wind power plant shown below in Figure 15. Wind turbines generators are ungrounded which will

also cause an open circuit for the zero sequence current. If a delta connection is present in the WTG step up transformer this too will inhibit the flow of zero sequence current.

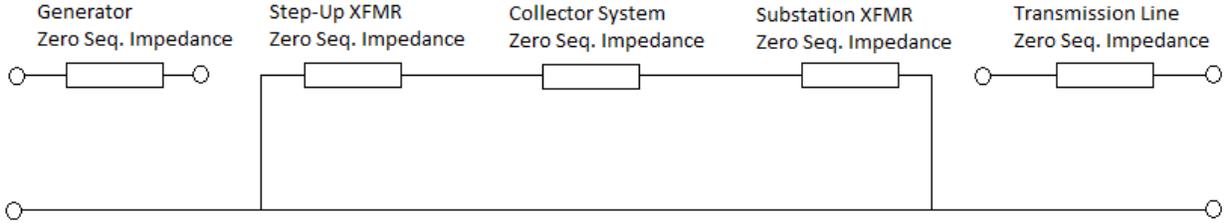


Figure 15. Zero Sequence Network for the Wind Power Plant.

Faults internally within the wind power plant are beyond the scope of this paper because the focus is with faults at the transmission level. For this purpose the zero sequence equivalent at the Point of Interconnection can be reduced to an open circuit, which can be modeled as an infinite impedance and thus, the WTG will not contribute any zero sequence fault current to the grid.

5. APPLICATION IN SHORT-CIRCUIT SOFTWARE

Short-circuit studies at the transmission level are often done using engineering software. This section will discuss the development of a single machine equivalent for an entire wind power plant using the common platform of ASPEN One-Liner. Section 5.1 will describe the method for equivalencing a wind power plant whose wind turbine generators short-circuit contribution is based on the impedances of the machines. Section 5.2 will show how to model the same wind power plant but with current limited wind turbine generators such as the Type III (w/ Chopper) and Type IV WTG.

5.1. Non-Current Limited WTG

This section will apply the methods presented in Section 4 that can be used in typical engineering software. The same example wind power plant described in Section 4 was modeled in ASPEN and shown below in Figure 16 .

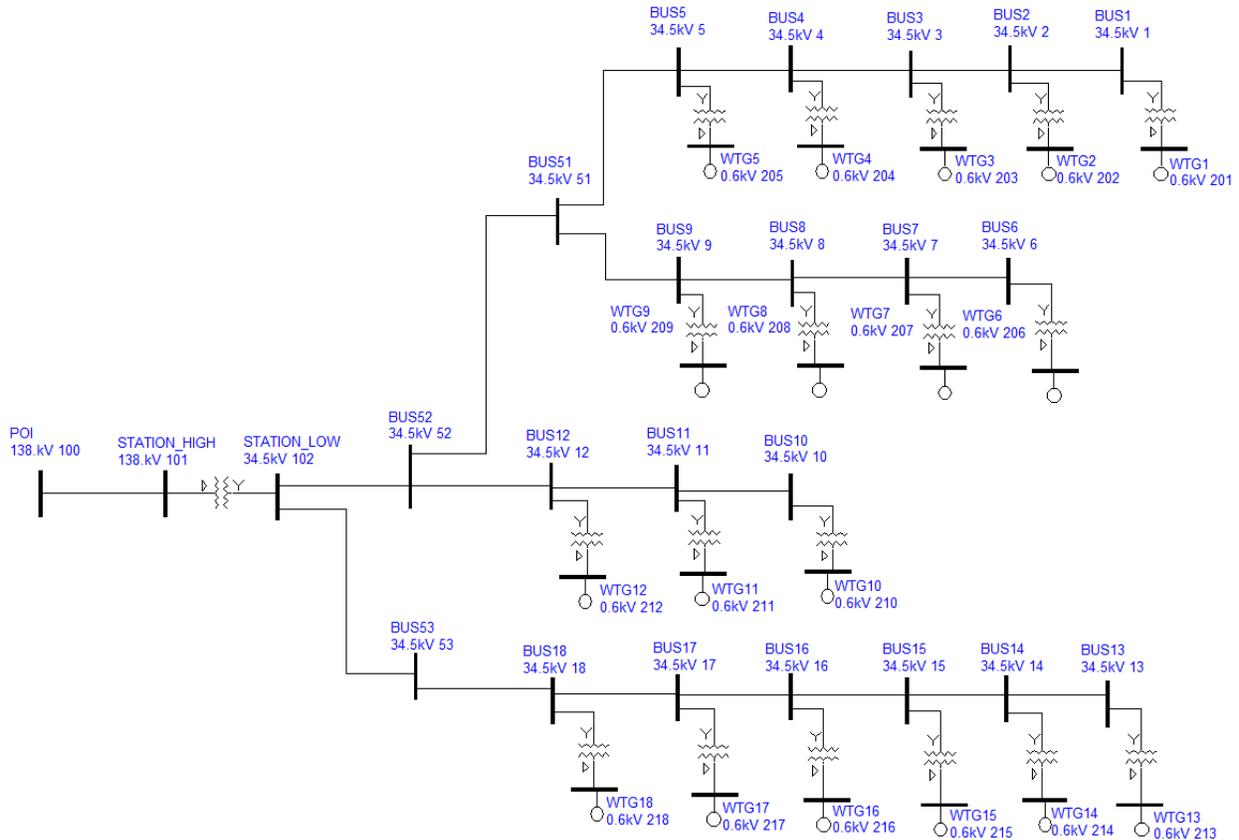


Figure 16. Wind Power Plant Implemented in ASPEN One-Liner.

As stated earlier it is not recommended to add all the detail of the wind power plant to the system model of a utility's transmission network, but rather the single machine equivalent at the Point of

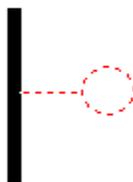
Interconnection. Another way to reduce the wind power plant to a single machine equivalent is to build a separate model for the wind power plant in a short-circuit program, simulate a fault at the POI, and make note of the equivalent sequence impedances in the output of the simulation. Table 1 below is a comparison of the method described in Section 4, to the output in ASPEN One-Liner of a 3-Phase fault simulated at the POI.

Table 1. Comparison of Methods for Single Machine Equivalent

	Section 4 Method	ASPEN One-Liner
Positive Seq. Impedance	0.0355+j0.785	0.03561+j0.78883
3-Phase Fault Current	1.272pu	1.266pu

Both methods will give accurate results when simplifying an entire wind power plant into a single machine equivalent; the choice is up to the preference of the relay engineer. Figure 17 below shows the single machine equivalent implemented in ASPEN One-Liner. Note that 999pu was used to represent the infinite impedance of the zero sequence equivalent as explained in Section 4.8.

POI
138.kV



Generating Unit Info

ID= 1 Unit rating= 100. MVA

Impedances (pu based on unit MVA)

Subtransient	0.03561	+j	0.78883	Fill
Transient	0.03561	+j	0.78883	
Synchronous	0.03561	+j	0.78883	
- sequence	0.03561	+j	0.78883	
o sequence	999.	+j	999.	

Neutral Impedance (in actual Ohms)

	0.	+j	0.
--	----	----	----

Scheduled generation. Enter MVAR for PQ buses only

MW=	0.	MVAR=	0.
-----	----	-------	----

P and Q limits (MW and MVAR)

Pmax=	9999.	Qmax=	9999.
Pmin=	-9999.	Qmin=	-9999.

OK Cancel Help

Figure 17. Single Machine Equivalent in ASPEN One-Liner.

5.2. Current Limited WTG

ASPEN One-Liner has the ability to represent the effects of the power electronics in Type III (w/ chopper) and Type IV WTGs with a current limited generator model. As discussed in Section 4.7 the short-circuit contribution from these types of machines is typically limited to 1.1pu on the generators base. In ASPEN the current limit must be supplied in engineering units so it will be necessary to convert the short-circuit contribution to the proper value. Using the same example described in Section 4, the 1.1pu current limit of a 600V 2MVA WTG is equivalent to 2117Amps. Modeling this in ASPEN One-liner is shown below in Figure 18.

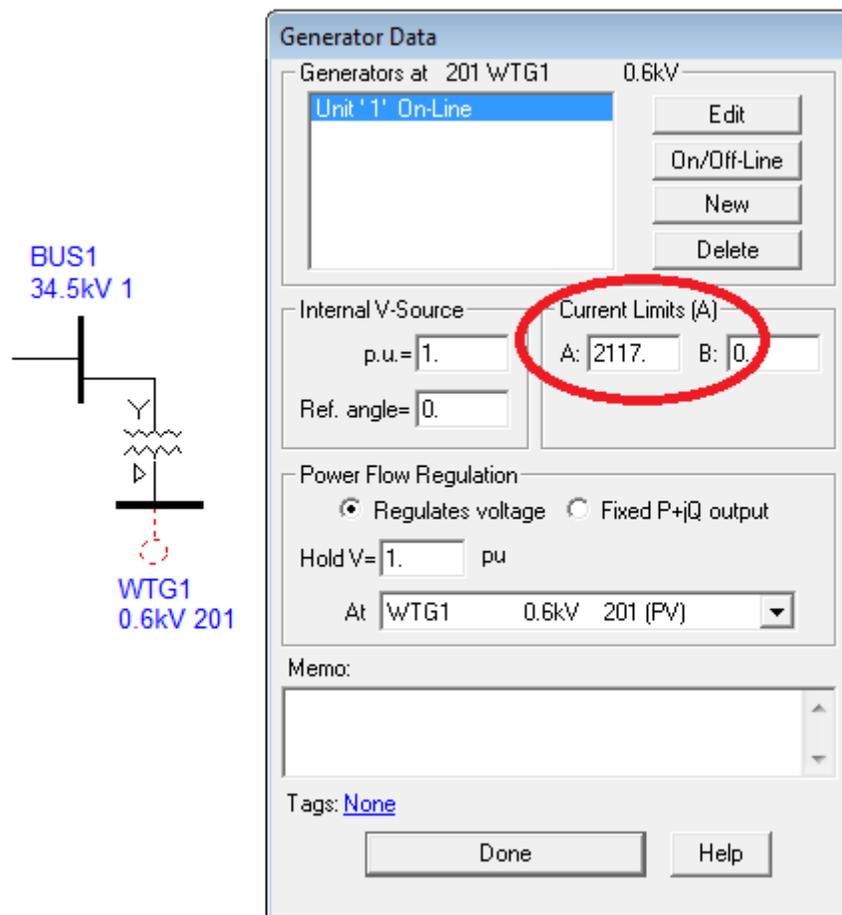


Figure 18. Defining a Current Limited Generator in ASPEN.

The 18 wind turbine generators in Figure 16 were modified in this manner to reflect the 1.1pu maximum short-circuit contribution to a fault. The same method used in section 5.1 can then be done to determine a single machine equivalent by running a 3 phase fault at the POI. It is necessary to make sure the correct settings are in place within ASPEN One-Liner in order to enforce the current limits, otherwise the results will not reflect the correct short circuit

contribution of current limited devices. The changes that will need to be made to the fault option in ASPEN are shown below in Figure 19.

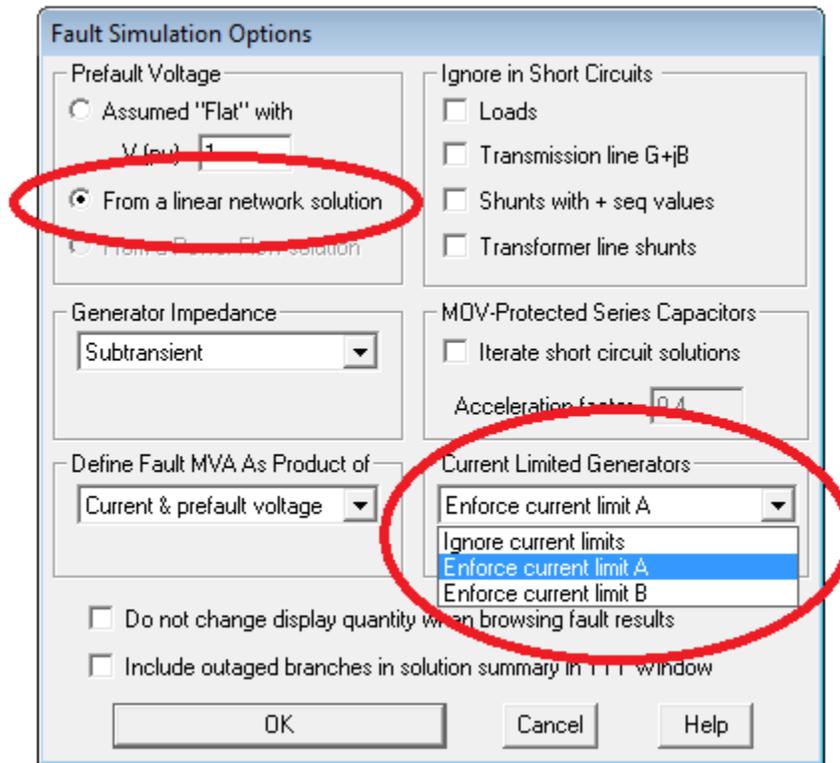


Figure 19. ASPEN One-Liner Settings for Current Limited Generators.

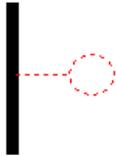
Once the current limits are defined for each wind turbine and the proper settings are in place, the simulation of a fault at the POI will produce the needed quantities for a single machine equivalent. Table 2 below shows a comparison of the results in ASPEN to the method in Section 4.7.

Table 2. Comparison of Methods for Single Machine Equivalents (Current Limited WTG)

	Section 4.7 Method	ASPEN One-Liner
3-Phase Fault Current	0.396pu	0.397pu

A single machine equivalent can now be modeled by limiting the plant to an output current of 0.397pu. This is equivalent to 166A on a 100MVA - 138KV base. The single machine equivalent for the example wind power plant with current limited generators is shown below in Figure 20. Note that the impedances for the negative and zero sequence equivalents should also be defined as these are necessary for simulating unbalanced faults.

POI
138.kV



The image shows two overlapping dialog boxes from the ASPEN One-Liner software. The 'Generator Data' dialog is on the left, and the 'Generating Unit Info' dialog is on the right. In the 'Generator Data' dialog, the 'Current Limits (A)' section is circled in red, showing 'A: 166.' and 'B: 0.'. The 'Generating Unit Info' dialog shows various parameters for a generating unit, including impedances, neutral impedance, and P and Q limits.

Type	Value	Phase	Value
Subtransient	0.03561	+j	0.78883
Transient	0.03561	+j	0.78883
Synchronous	0.03561	+j	0.78883
- sequence	0.03561	+j	0.78883
o sequence	999.	+j	999.

Value	Phase	Value
0.	+j	0.

Parameter	Value	Parameter	Value
Pmax	9999.	Qmax	9999.
Pmin	-9999.	Qmin	-9999.

Figure 20. Single Machine Equivalent in ASPEN One-Liner (Current Limited WTG).

6. CONCLUSIONS

A difficult task in creating a short-circuit model for a wind turbine generator is making sure the correct data is used. Appendix A shows an example data sheet that can be used by the relay engineer to get the electrical characteristics of the WTG from the supplier. The electrical characteristics of the collector system are important for developing the single machine equivalent of a wind power plant and these can be taken from a one-line diagram. The WECC Wind Power Plant Power Flow Modeling Guide contains a sample data sheet for wind power plants that can assist in collecting the necessary data for the collector system and wind power plant transformers [3].

Although the focus of this paper was with wind power plants the same methods can also be supplied to utility scale solar plants. The solar panels in a PV plant are decoupled from the 60Hz system with a power converter in the same manner as the Type IV WTG, and thus will have similar short-circuit behavior that is dominated by the power electronics. When modeling a solar plant the user should use the same method presented in this guide for current limited machines.

This goal of this guide was to assist relay engineers in modeling wind power plants for short-circuit studies. Compared to conventional thermal and hydro generating plants the behavior of large scale wind power plants is not as well understood, and the utility industry is still investigating how to best model these plants in short-circuit studies [5]. As additional requirements for wind power plants, such as fault ride through, continue to evolve so too does the design of wind turbine generators, as shown in the trend of Type III WTGs to use a chopper circuits compared to the older method of the crowbar circuit in the rotor converter. The methods presented in this paper represent a best practice given the state of the industry today.

4. REFERENCES

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APPENDIX A: EXAMPLE WTG SHORT CIRCUIT DATA

Wind Turbine Generator Short Circuit Data*

WTG Manufacturer and Model: _____

MVA Rating: _____

Voltage Rating: _____

WTG Type: _____ (I, II, III, IV)

If Type III does the Power Converter employ a chopper circuit: ____ (Y/N)

For Type I, II, and III Machines**

X_d'' : _____ pu

X_d' : _____ pu***

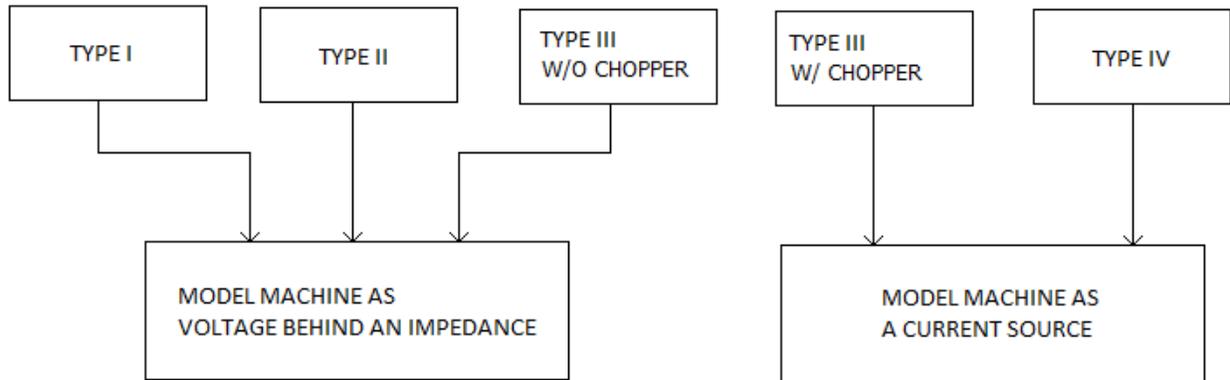
For Type IV and Type III machines with chopper circuit

Current Limit of WTG: _____ pu

**Wind Plant may include different WTG types, parameters should be filled out for each type*

***In a Type IV WTG the generator is decoupled from the 60Hz system. The series reactance of the power converter may be used in lieu of X_d'' if known.*

****It has been proposed that X_d'' will yield conservative results for studies involving relays. The subtransient time constant is less than 1/2 cycle, shorter than most relays' reaction time. It may be more appropriate to use X_d' for relay studies.*



If the machine type is known but the data is unavailable the following parameters may be used to represent typical values:

X_d'' : 0.15 - 0.20pu

Current Limit: 1.1 - 1.5pu

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