Impacts of Placement of Wind Turbine Generators with Different Interfacing Technologies on Radial Distribution Feeder Short Circuit Currents.

Kemei P. Kirui [1], David K. Murage[2], and Peter K Kihato[3]

Abstract**—**Integrating distributed generations (DGs) into a power systems distribution network provides various benefits; however, their connection has associated several technical implications with distribution network protection and coordination being one of the major issues

With the global increase in wind turbine distributed generators penetration levels, the need for a detailed assessment of the impacts of the wind turbine generation on the power systems distribution network operations has become critical. This assessment is normally done to allow for the simulation of the dynamic response of the distribution network to major disturbances like the short circuits once the wind turbine generators (WTGs) have been integrated. The penetration of the wind turbine generators into a distribution network has great impacts on the short circuit current levels of the system with some factors contributing to these impacts being: The size of the WTG penetrating the distribution network, The location at which the WTG is connected on to the network and the Type of the WTG interfacing technology used.

An important aspect of the WTGs impacts studies is to evaluate their short circuit current contribution into the distribution network under different fault conditions. The magnitudes of these short circuit currents, both the three phase and the single-line-to-ground (SLG) faults, are needed for sizing the various Over-Current Protective Devices (OCPDs) which are utilized in protecting the distribution network. Due to the topological and operational differences between the different types of WTGs interfacing technologies, the electrical generators design industry has divided wind turbine generators into four different types labeled as Type I, Type II, Type III and Type IV.

This paper presents a detailed investigation on the effects of integrating each of the four types of WTG configurations on apower systems distribution network's short circuit currents levels/magnitude. The radial distribution feeder studied was the IEEE 13 nodes radial test feeder and it was modeled and simulated for short circuit currents analysis

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Keywords**—**Distributed Generators, Type I to IV WTG, Three Phase Fault Currents, and SLG Fault Currents.

I. Introduction

A. Distributed Generation Interfacing Technologies into a Distribution Power Systems Network

All of the DGs utilizing various types of renewable energy resources fall into two major categories regarding their modes of interfacing with the main grid. Normally inverters are used in DG systems after the generation process, since the generated voltage may be in DC or AC form but it is required to be changed to the nominal voltage and frequency of the distribution network. Therefore, this voltage has to be converted to the nominal requirements of the distribution network by use of inverters [1]. DG interfacing technologies provides the protection that allows a DG unit to operate in parallel with the main utility grid. Protection requirements for connecting DG units into the distribution network are generally established by each utility and should adhere to the required standards. The interfacing requirements established at the point of common coupling between the utility and the DG address the concerns of both the DG owner and the utility and it should satisfy the main utility requirements before the DG is connected to the main grid [2][3]. The two major categories of DG interfacing technologies into the main grid are: [2].

i. Directly Interfaced Distributed Generators (DIDG)
ii. Inverter Interfaced Distributed Generators (IIDG)

The interfacing schemes used in IIDG maintains a constant output voltage, active and reactive power that matches the desired predetermined set points of the main utility grid [4][5]. Fault currents in critical conditions with an IIDG connected into the power grid are limited by the inverters having current limiting ranges, hence the fault current share injected by IIDGs is not as much as DIDGs which shares most of their fault currents with the main utility grid [5][6]. The DIDG type has the ability to easily synchronize with the grid and produce active and reactive power simultaneously [5]. Complexity is added to the network when different types of DGs in terms of their fault current responses are interconnected together in a distribution network since they all play a major role in the distribution network's response during fault condition.

There are three basic interfacing technologies for DGs namely the synchronous generators, the induction generators and the power electronics devices [7]

II. Wind Turbine Generator Technologies

A. *Type I Wind Turbine Generator*

Generic models have been developed for four major WTG topologies the first topology being referred to as a Type I WTG. This machine is pitch-regulated and drives a squirrel cage induction generator which is directly coupled to the grid. Fig 1 shows the layout of a Type I Wind Turbine Generator (WTG)[8]. Due to the poor power factor present during induction machine operation, compensating capacitor banks are used near the terminals of the Type I WTG[9].

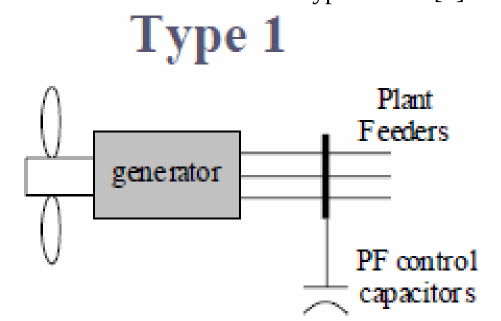

Fig 1: Type I Wind Turbine Generator

B. *Type II Wind Turbine Generator.*

Type II WTG is a variation on the Type I WTG. It is an induction generator operating at variable slip. It utilizes a wound rotor induction generator whose rotor windings are brought out via slip rings and brushes and then coupled to a resistive bank[9]. Fig 2 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. By varying the resistance of the rotor windings of the type II WTG, a more dynamic response to wind turbulence can be achieved by allowing a change in speed in the generator rotor reducing the large torque swings hence prolonging the life of its mechanical components[8]. Type II WTG still requires compensating capacitor banks to achieve its operations within the required typical power factor limits.

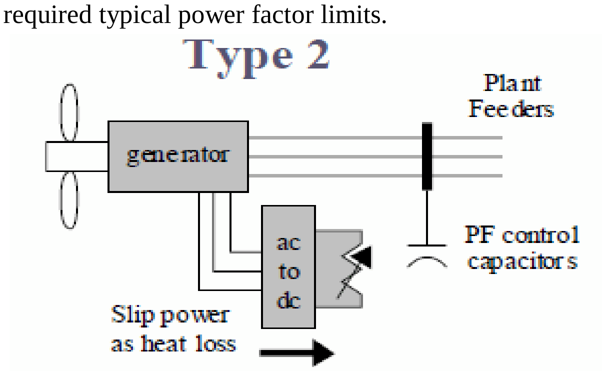

Fig 2: Type II Wind Turbine Generator

C. *Type III Wind Turbine Generator.*

Type III wind turbine generator is pitch-regulated and features a wound rotor induction generator with an AC/DC/AC power converter connected between the rotor terminals and the main grid. The generator stator winding is directly coupled to the grid[8]. Fig 3 shows the layout of a Type III WTG. The Type III wind turbine generator is known as a doubly-fed induction generator (DFIG). Rather than its 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 and the ability to provide reactive power support without external capacitor banks hence a variable speed operation that allows for a more efficient energy capture below rated wind speeds[8]. In order to protect the power converter from high short-circuit currents, protective devices such as a “crowbar” or a “chopper” circuit are used. The type of protective device used to protect the rotor converter has a significant impact on the short-circuit behavior of the Type III machine[9].

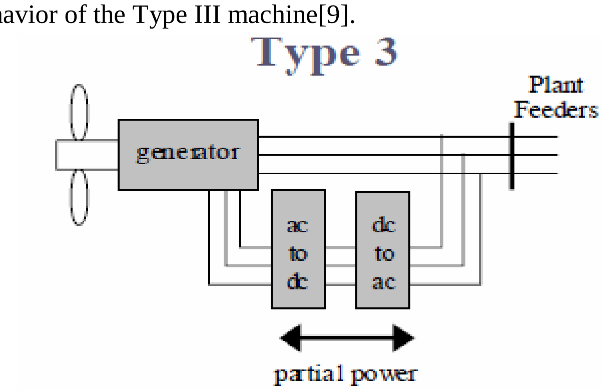

Fig 3: Type III Wind Turbine Generator

D. *Type IV Wind Turbine Generator.*

Type IV WTG is pitch-regulated and features an AC/DC/AC power converter through which the entire power of the generator is processed as shown in Fig 4 [8]. The power converter allows for independent control of the quadrature and the direct axis output currents at the grid interface, providing fast active and reactive power control over a wide range of generator speeds[10]. Type IV WTG is decoupled from the grid through a power converter which 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 hence expanding the types of the machines that can be used with the most common being the synchronous machines and the squirrel cage induction machines[10].

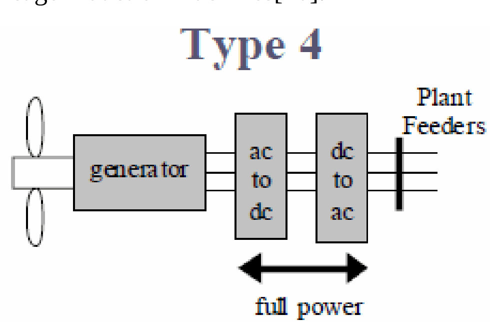

Fig 4: Type IV Wind Turbine Generator

III. Wind Turbine Generator Short-Circuit Behaviors

A synchronous machine for short circuit modeling can be represented with a Thevenin equivalent circuit where the voltage and impedance represent the worst-case condition which is the highest short-circuit current contribution immediately following a fault. Fig 5 shows the Thevenin's equivalent of a synchronous machine having a sub-transient reactance equivalent of X_d'' [8].

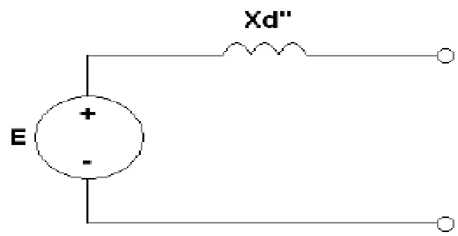

Fig 5: Synchronous Machine Short-Circuit Equivalent.

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 main electrical grid, or they decouple the wind turbine generator from the main grid through power electronic devices[11].

A. 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[9]. In contrast to this, the drop in the line voltage caused by a fault will cause the induction machine to lose excitation hence it only supplies 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 are taken into account for determining the total fault current. The equivalent machine impedance for fault calculations is the sum of the stator and rotor reactance as shown in Fig 6 [9].

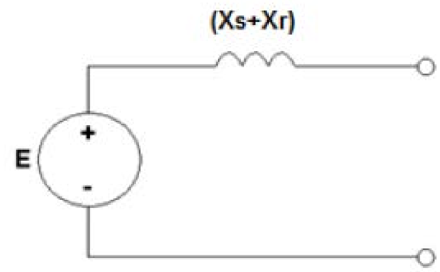

Fig 6: Induction Machine Short Circuit Equivalent.

B. Type II WTG Short-Circuit Model

The addition of the external rotor resistance to a type II WTG acts as an impedance in the short circuit equivalent circuit, thus lowering the maximum available fault current of the induction machine[8]. However, the Type II wind turbine generator 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 makes the short-circuit behavior for a Type II WTG machine similar to that of a Type I WTG machine. The same equivalent circuit for a Type I WTG machine shown in Fig 6 is also used for a Type II WTG machine[10].

C. Type III WTG Short-Circuit Model

The short-circuit behavior of Type III WTG is modeled differently depending on the method used for the protection of the rotor power converter. Fig 7 and Fig 8 shows the two methods used to protect the power converter on the rotor circuit[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 currents away from the 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 WTG and Type II WTG design, where worst case short-circuit current is based on the internal impedance of the induction machine[8]. The other method of protecting the rotor converter is done with a chopper circuit. With a chopper circuit, better grid support is achieved during a fault by keeping the rotor converter active, but still limiting the currents to protect the sensitive power electronic devices 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 Fig 8[9].

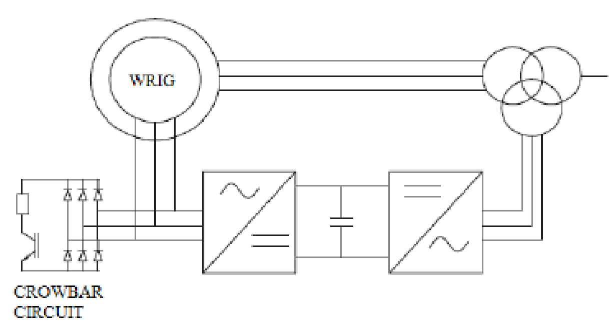

Fig 7: Type III Wind Turbine Generator Crowbar Protection of the Power Converter.

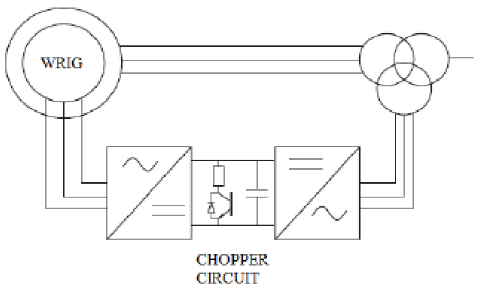

Fig 8: Type III Wind Turbine Generator Chopper Protection of the Power Converter.

D. Type IV WTG Short-Circuit Model

Unlike the type I, type II and type III 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. The power converter in the Type III design is sensitive to excessive currents, so too is the converter in a Type IV WTG design. In order to protect the power electronics devices a current limit of $1.1pu$ is designed into the power converter[8]. Rather than the common voltage source behind impedance short-circuit equivalent used to model most generators, the Type IV WTG is a simple current source designed for maximum short-circuit contribution as shown in Fig 9 [9].

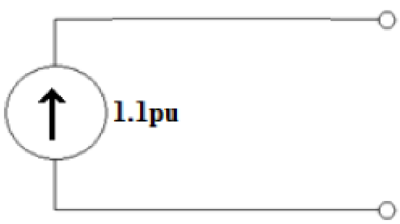

Fig 9: Type IV WTG Short-Circuit Equivalent

IV. IEEE 13 Node Radial Test Feeder Configuration

The IEEE 13 node radial test feeder is a short, unbalanced and relatively highly loaded 4.16kV feeder. The features of the IEEE 13 node radial test feeder is basically the presence of: A 5000kVA 115kV/4.16kV Delta/Star substation transformer connected to the swing/grid node; One substation voltage regulator consisting of three single phase units connected in star; Eight overhead distribution lines and two underground cables with variety of lengths and phasing; Unbalanced delta and star connected distributed and spot loads; Two shunt capacitor banks one having a single phase connection at node 611 and the other a three phase connection at node 675; and a 500kVA 4.16kV/0.48kV star/star solidly grounded in-line transformer connected between node 633 and node 634. Fig 10 shows the schematic layout of the IEEE 13 node radial test feeder used as the model which was simulated without showing the different connected loads or the nature and configuration of the distribution components of the network[12]. The effect of the voltage regulator located at node 650 is not taken into consideration in the simulations, calculations and analysis and the short circuit currents contribution by the motoring loads was considered minimal at 1% of their Locked-Rotor Current (LRC). The short circuit contribution by the WTGs is set at 600% of their Locked-Rotor Current (LRC)

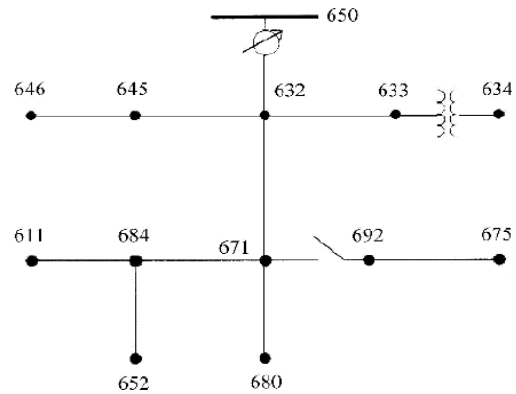

Fig 10: The IEEE 13 Node Radial Test Feeder Schematic Diagram

V. Impacts of WTG Interfacing Technology on IEEE 13 Node Radial Test FEEDER Short Circuit Currents.

Table I: Three Phase Fault Currents with 1MW and 3MW Type I/II/III WTGs and Type IV WTGs Connected at Node 634

NODE ID	Three Phase Symmetrical Fault Currents in (kA)				
	NO WTG	1MW Type I/II/III WTG	1MW Type IV WTG	3MW Type I/II/III WTG	3MW Type IV WTG
GRID	0.025	0.048	0.028	0.065	0.040
NODE650	0.647	1.334	0.733	1.921	1.048
NODE632	0.609	1.346	0.696	2.068	1.016
NODE633	0.597	1.353	0.686	2.133	1.012
NODE634	4.367	12.813	5.221	29.773	8.407
NODE645	0.597	1.290	0.680	1.934	0.983
NODE646	0.589	1.253	0.667	1.846	0.956
NODE671	0.575	1.191	0.653	1.721	0.934
NODE692	0.575	1.191	0.653	1.721	0.934
NODE675	0.572	1.176	0.646	1.685	0.919
NODE684	0.568	1.159	0.641	1.652	0.910
NODE611	0.556	1.108	0.624	1.547	0.876
NODE680	0.560	1.126	0.633	1.588	0.897
NODE652	0.558	1.113	0.621	1.545	0.861

Table II: Three Phase Fault Currents with 1MW and 3MW Type I/II/III WTGs and Type IV WTGs Connected at Node 650

NODE ID	Three Phase Symmetrical Fault currents in (kA)				
	NO WTG	1MW Type I/II/III WTG	1MW Type IV WTG	3MW Type I/II/III WTG	3MW Type IV WTG
GRID	0.025	0.057	0.028	0.104	0.04
NODE650	0.647	1.624	0.719	3.582	1.037
NODE632	0.609	1.406	0.673	2.668	0.958
NODE633	0.597	1.346	0.658	2.459	0.929
NODE634	4.367	8.216	4.691	11.979	6.23
NODE645	0.597	1.346	0.658	2.458	0.929
NODE646	0.589	1.306	0.646	2.327	0.904
NODE671	0.575	1.239	0.633	2.122	0.888
NODE692	0.575	1.239	0.633	2.122	0.888
NODE675	0.572	1.223	0.627	2.075	0.873
NODE684	0.568	1.205	0.622	2.024	0.866
NODE611	0.556	1.151	0.606	1.873	0.835
NODE680	0.56	1.169	0.614	1.924	0.855
NODE652	0.558	1.159	0.603	1.883	0.819

From table I and table II it can be seen that Type I/II/III WTGs contribute the highest amount of three phase fault currents at the feeder nodes as compared to the contribution from Type IV WTGs. The three-phase short circuit fault currents also increases as the WTG capacity increases from 1MW to 3MW.Table III: Asymmetrical SLG Fault Currents with 1MW and 3MW Type I/II/III WTGs and Type IV WTGs Connected at Node 634

NODE ID	Asymmetrical SLG Fault Currents in (kA)				
	NO WTG	1MW Type I/II/III WTG	1MW Type IV WTG	3MW Type I/II/III WTG	3MW Type IV WTG
GRID	0	0	0	0	0
NODE650	1.292	2.494	1.116	3.192	1.504
NODE632	1.085	2.048	0.958	2.6	1.299
NODE633	1.026	1.947	0.919	2.486	1.258
NODE634	6.574	15.133	6.462	22.502	9.753
NODE645	1.022	1.835	0.912	2.274	1.216
NODE646	0.975	1.692	0.88	2.068	1.16
NODE671	0.936	1.576	0.84	1.887	1.089
NODE692	0.936	1.576	0.84	1.887	1.089
NODE675	0.909	1.502	0.823	1.789	1.061
NODE684	0.897	1.469	0.812	1.742	1.043
NODE611	0.86	1.375	0.785	1.615	0.999
NODE680	0.876	1.413	0.791	1.659	1.007
NODE652	0.793	1.228	0.748	1.439	0.941

Table IV: Asymmetrical SLG Fault Currents with1MW and 3MW Type I/II/III WTGs and Type IV WTGs Connected at Node 650

NODE ID	Asymmetrical SLG Fault Currents in (kA)				
	NO WTG	1MW Type I/II/III WTG	1MW Type IV WTG	3MW Type I/II/III WTG	3MW Type IV WTG
GRIDNODE	0	0	0	0	0
NODE650	1.292	3.402	1.084	7.037	1.488
NODE632	1.085	2.261	0.935	3.445	1.228
NODE633	1.026	2.018	0.894	2.915	1.159
NODE634	6.574	10.376	6.026	12.821	7.345
NODE645	1.022	2.001	0.891	2.881	1.154
NODE646	0.975	1.829	0.86	2.546	1.103
NODE671	0.936	1.696	0.822	2.289	1.04
NODE692	0.936	1.696	0.822	2.289	1.04
NODE675	0.909	1.609	0.806	2.138	1.015
NODE684	0.897	1.572	0.795	2.072	0.999
NODE611	0.86	1.463	0.769	1.89	0.958
NODE680	0.876	1.508	0.775	1.961	0.965
NODE652	0.793	1.293	0.733	1.641	0.904

From table III and table IV, it can be seen that Type I/II/III WTGs contribute the highest amount of SLG fault currents at the feeder nodes as compared to the contribution from Type IV WTGs. The SLG short circuit currents also increase as the Type I/II/III WTG capacity increases from 1MW to 3MW.
1MW Type IV WTGs at node 634 and at node 650 causes a slight reduction on the magnitudes of the SLG fault currents as compared to the SLG fault currents when there was no WTG connected. The SLG fault currents would again increase as the capacity of the Type IV WTGs is increased from 1MW to 3MW for both placement at node 634 and node 650.

VI. IMPACTS OF LOCATION OF WTGSON IEEE 13 NODE RADIAL TEST FEEDER SHORT CIRCUIT CURRENTS

Table V: Three Phase Fault Currents with 1MW Type I/II/III WTGs and Type IV WTGs Connected at Node 634 and Node 650

NODE ID	Three Phase Symmetrical Fault Currents in (kA)				
	NO WTG	Type I/II/III WTG		Type IV WTG	
		634	650	634	650
GRID	0.025	0.048	0.057	0.028	0.028
NODE650	0.647	1.334	1.624	0.733	0.719
NODE632	0.609	1.346	1.406	0.696	0.673
NODE633	0.597	1.353	1.346	0.686	0.658
NODE634	4.367	12.813	8.216	5.221	4.691
NODE645	0.597	1.29	1.346	0.68	0.658
NODE646	0.589	1.253	1.306	0.667	0.646
NODE671	0.575	1.191	1.239	0.653	0.633
NODE692	0.575	1.191	1.239	0.653	0.633
NODE675	0.572	1.176	1.223	0.646	0.627
NODE684	0.568	1.159	1.205	0.641	0.622
NODE611	0.556	1.108	1.151	0.624	0.606
NODE680	0.56	1.126	1.169	0.633	0.614
NODE652	0.558	1.113	1.159	0.621	0.603

Table VI: Three Phase Fault Currents with 3MW Type I/II/III WTGs and Type IV WTGs Connected at Node 634 and Node 650

NODE ID	Three Phase Symmetrical Fault Currents in (kA)				
	NO WTG	Type I/II/III WTG		Type IV WTG	
		634	650	634	650
GRID	0.025	0.065	0.104	0.04	0.04
NODE650	0.647	1.921	3.582	1.048	1.037
NODE632	0.609	2.068	2.668	1.016	0.958
NODE633	0.597	2.133	2.459	1.012	0.929
NODE634	4.367	29.773	11.979	8.407	6.23
NODE645	0.597	1.934	2.458	0.983	0.929
NODE646	0.589	1.846	2.327	0.956	0.904
NODE671	0.575	1.721	2.122	0.934	0.888
NODE692	0.575	1.721	2.122	0.934	0.888
NODE675	0.572	1.685	2.075	0.919	0.873
NODE684	0.568	1.652	2.024	0.91	0.866
NODE611	0.556	1.547	1.873	0.876	0.835
NODE680	0.56	1.588	1.924	0.897	0.855
NODE652	0.558	1.545	1.883	0.861	0.819

From table V and table VI, it can be seen that Type I/II/III WTGs connected at node 650 contribute high magnitudes of currents to three phase short circuit faults as compared to the contribution from Type I/II/III WTGs connected at node 634. Type IV WTGs connected at node 634 contribute high magnitudes of currents into a three-phase short circuit fault on the feeder as compared to the contribution from Type IV WTGs connected at node 650.

Table VII: Asymmetrical SLG Fault Currents with 1MW Type I/II/III WTGs and Type IV WTGs Connected at Node 634 and Node 650

NODE ID	Asymmetrical SLG Fault Currents in (kA)				
	NO WTG	Type I/II/III WTG		Type IV WTG	
		634	650	634	650
GRID	0	0	0	0	0
NODE650	1.292	2.494	3.402	1.116	1.084
NODE632	1.085	2.048	2.261	0.958	0.935
NODE633	1.026	1.947	2.018	0.919	0.894
NODE634	6.574	15.133	10.376	6.462	6.026
NODE645	1.022	1.835	2.001	0.912	0.891
NODE646	0.975	1.692	1.829	0.88	0.86
NODE671	0.936	1.576	1.696	0.84	0.822
NODE692	0.936	1.576	1.696	0.84	0.822
NODE675	0.909	1.502	1.609	0.823	0.806
NODE684	0.897	1.469	1.572	0.812	0.795
NODE611	0.86	1.375	1.463	0.785	0.769
NODE680	0.876	1.413	1.508	0.791	0.775
NODE652	0.793	1.228	1.293	0.748	0.733

Table VIII: Asymmetrical SLG Fault Currents with 3MW Type I/II/III WTGs and Type IV WTGs Connected at Node 634 and Node 650

NODE ID	Asymmetrical SLG Fault Currents in (kA)				
	NO WTG	Type I/II/III WTG		Type IV WTG	
		634	650	634	650
GRID	0	0	0	0	0
NODE650	1.292	3.192	7.037	1.504	1.488
NODE632	1.085	2.6	3.445	1.299	1.228
NODE633	1.026	2.486	2.915	1.258	1.159
NODE634	6.574	22.502	12.821	9.753	7.345
NODE645	1.022	2.274	2.881	1.216	1.154
NODE646	0.975	2.068	2.546	1.16	1.103
NODE671	0.936	1.887	2.289	1.089	1.04
NODE692	0.936	1.887	2.289	1.089	1.04
NODE675	0.909	1.789	2.138	1.061	1.015
NODE684	0.897	1.742	2.072	1.043	0.999
NODE611	0.86	1.615	1.89	0.999	0.958
NODE680	0.876	1.659	1.961	1.007	0.965
NODE652	0.793	1.439	1.641	0.941	0.904

From table VII and table VIII, it can be seen that Type I/II/III WTGs connected at node 650 contribute high magnitudes of currents to SLG short circuit faults as compared to the contribution from Type I/II/III WTGs connected at node 634. Type IV WTGs connected at node 634 contribute high magnitudes of currents into the SLG short circuit fault currents of the feeder as compared to the contribution from Type IV WTGs connected at node 650.

VII. CONCLUSION

WTG interfacing technologies have great impacts on both the three phase and the single line to ground short circuit fault currents occurring in a radial distribution power systems network.

The Type I, Type II and Type III WTGs exhibit the same characteristics during a fault event. The magnitudes of the short circuit currents injected by Type I, Type II and Type III WTGs are all equal in magnitudes hence the representation of this class of WTGs for a fault event are similar.

Type I/II/III WTGs contribute the highest amount of currents to a short circuit as compared to the contribution from the Type IV WTGs. The location/point of connection of the WTGs on to a distribution network has great impacts on the magnitudes of the short circuit currents contributed by the WTGs into a fault.

REFERENCES

[1] Martin Geidl "*Protection of Power Systems with Distributed Generation: State of the Art*" Power Systems Laboratory Swiss Federal Institute of Technology (ETH) Zurich 20th July 2005

[2] "*IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*" Standards Coordinating Committee 21, 28 July, 2003.

[3] Juan A. Martinez and Jacinto M Arnedo "*Impact of Distributed Generation on Distribution Protection and Power Quality*" Power & energy society general meeting 26th-30th July 2009.

[4] Pecas J A Lopes, Hatziargyriou N, Mutale J, Djapic P, Jenkins N. "*Integrating Distributed Generation into Electric Power Systems: A review of drivers, challenges and opportunities*" ScienceDirect. Electrical Power Systems Research 77(2007) 1189-1203.ELSEVIER.

[5] Pooria Mohammadi, Hassan El-Kishyky, Mamdouh A Akher and Mazen A Salam "*The Impacts of Distributed Generation on Fault Detection and Voltage Profile in Power Distribution Networks" IEEE Conference on* Power Modulator and High Voltage (IPMHVC) 1st -5th June 2014.

[6] Galina Antonova, Massimo Nardi, Alan Scott and Michael Pesin "*Distributed Generation and its Impact on Power Grids and Micro grids Protection"* Protective Relay Engineers 65th annual conference 2nd -5th may 2012.

[7] Seema Jadhar, Ruchi Harchandani '' *Grid Interfacing Technologies for Distributed Generation and Power Quality Issues-A Review''* International Journal of Innovative and Emerging Research in Engineering Volume 2, Issue 3, 2015.

[8] *"WECC Wind Power Plant Dynamic Modelling Guide*" Western Electricity Coordinating Council Modelling and Validation Work Group. Technical Report. April 2014.

[9] Edward Muljadi and Abraham Ellis. "*WECC Wind Generator Development"*. National Renewable Energy Laboratory. Technical Report. March 2010.

[10] Angel F Sarabia. "*Impact of distributed generation on distribution system"* Aalborg University Denmark. Masters Dissertation June 2011.

[11] Thomas Gallery, Laura Martinez and Danijela Klopotan "*Impact of Distributed Generation on Distribution Network Protection"* ESBI Engineering & Faculty Management, Ireland

[12] Kersting W H,*"Radial Distribution Test Feeders"* IEEE Power engineering society. Distribution systems analysis subcommittee report. 2000.