# Short Circuit Analysis of Power Systems with Inverter Interfaced Resources

[1]Erandika Kalubowilage, A. D. Rajapakse

University of Manitoba

Canada

Presented by Erandika Kalubowilage

# Contents



# Introduction

**Short Circuit Analysis**

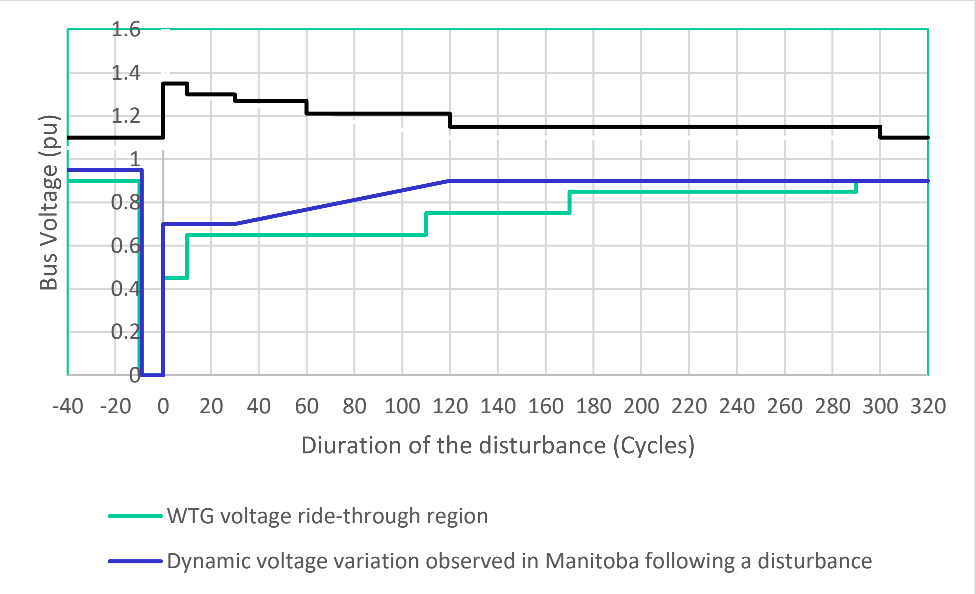
- Sizing new electrical equipment
- Verifying equipment ratings during grid modifications
- Setting protection relays

- Short circuit analysis is well established for power systems with conventional synchronous generators (SGs).
- The fault response of inverter interfaced resources (IIRs), including solar and Type III and Type IV wind turbine generators (WTGs) are inherently different from conventional SGs.

# Introduction

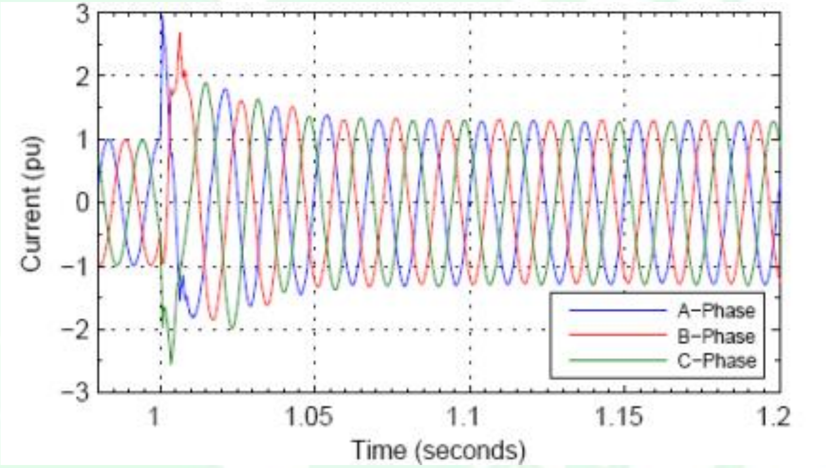
- During a grid fault, IIRs inject controlled currents to the grid.
- The current magnitudes are typically limited around the converter rated current.
- Early stages ⟶ IIRs were allowed to disconnect during a grid fault

Modern grid code requirements [1]
Remain in operation
Support the grid voltage

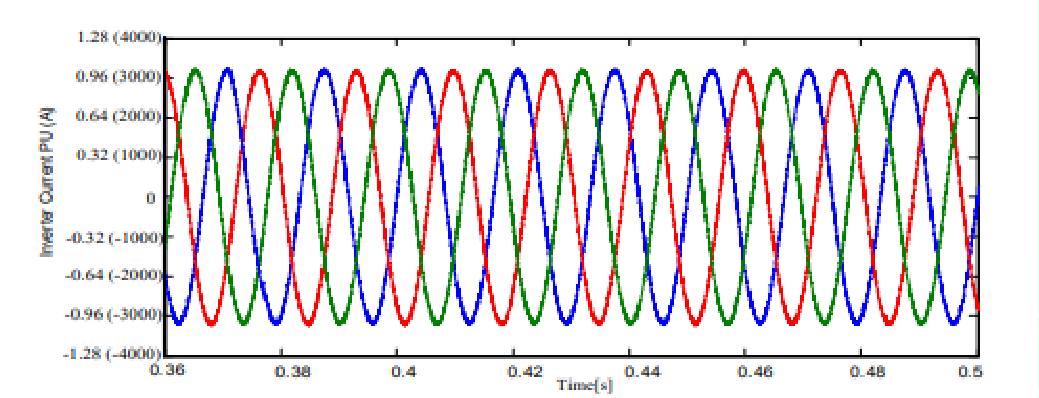



Manitoba Hydro transient voltage performance characteristics following a disturbance with WTG voltage ride-through characteristics [2]

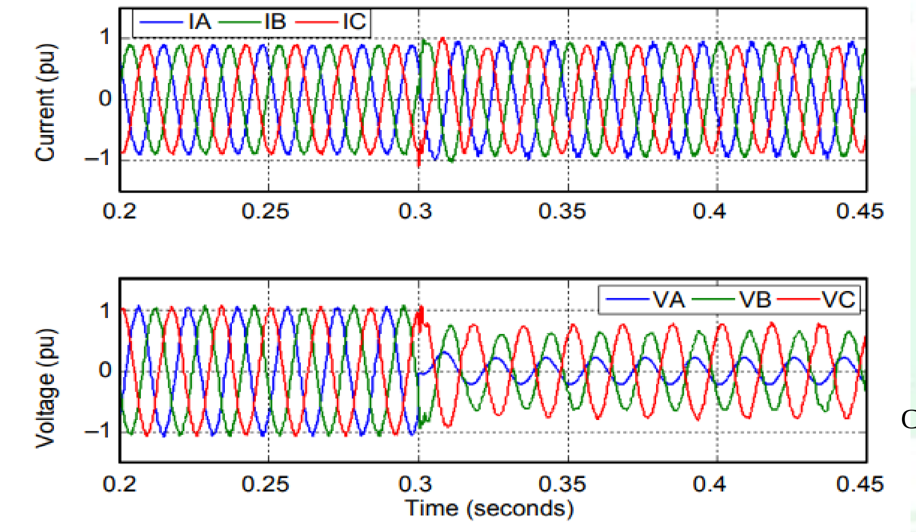
# Nature of Fault Currents from a Type IV WTG




Fault current waveform from Type IV WTG for a balanced three-phase fault on the collector system [3]




The Type IV WTG contribution to a single-phase to ground fault at the WTG terminal [3]




Current and voltage for a single-phase to-ground fault at Type IV WTG terminal bus [3]

# Short Circuit Analysis of IIRs

- Electromagnetic Transient (EMT) simulators such as PSCAD/EMTDC are widely used for studying the operation of IIR connected to a power system during faults and other disturbances.
- The converter models are manufacturer specific and usually black boxed models.

  - Incorporate realistic controls and internal protection mechanisms
- Conventional short circuit programs that use linear phasor domain models cannot properly represent the nonlinear behavior of IIR during the faults.
- Attempts have made to represent IIR using a voltage dependent network equivalent (VDNE) in short circuit analysis to improve the accuracy.

  - **Need iterative solution**

# Contents



# Motivation and Objectives

Derivation of a mathematical framework to obtain a voltage dependent network equivalent (VDNE) to represent a portion of a power system with IIR

Automation of PSCAD/EMTDC to derive VDNE parameters from a detailed model of the concerned part of the power system.

Development of an iterative fault analysis algorithm that incorporates nonlinear VDNE representing the portion of the power system with IIR, and its validation.

# Contents



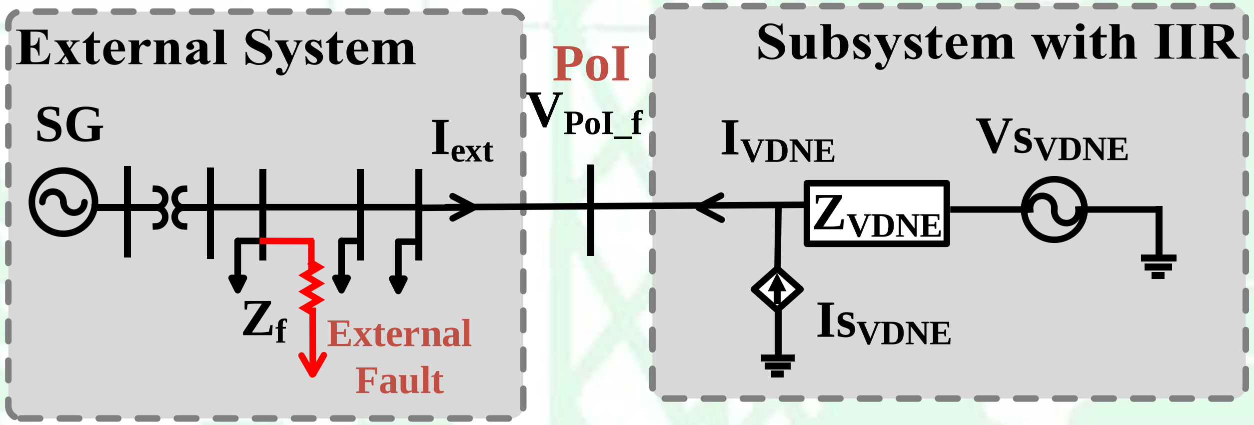
# Iterative Short Circuit Analysis for IIRs

Iterative short circuit analysis

- Develops and implements a phasor domain iterative short circuit analysis technique
- Type IV WTG consisting full scale converters is considered
- Inverter interfaced system : PSCAD/EMTDC
  Automation and short circuit calculation : Python
- Scope is limited to balanced three phase faults
- Incorporates VDNE

# Voltage Dependent Network Equivalent (VDNE)

- External system
  - Represented as a linear phasor domain model
- Subsystem with IIR
  - Nonlinear model referred to as VDNE
  - Thevenin's equivalent represents the linear part of the circuit
  - Voltage dependent current source captures the nonlinear behavior of the IIRs.




VDNE for matrix based iterative short circuit analysis

Challenge is to find the injected current at the POI ($I_{VDNE}$) at different PoI voltages.

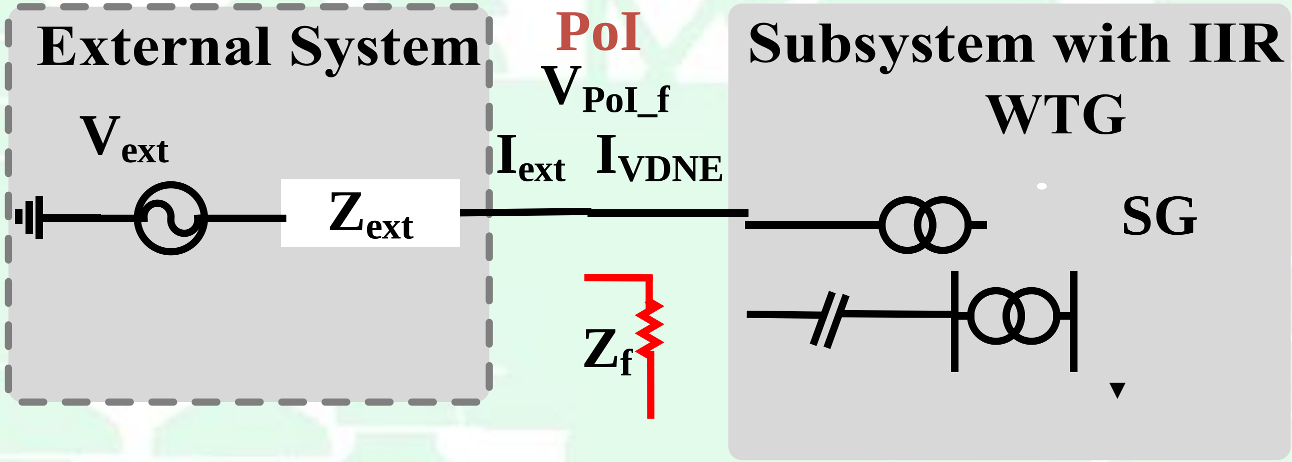
# Voltage Dependent Current Source Data Generation

- Computes $\mathbf{I}_{\boldsymbol{S}_{\mathbf{VDNE}}}$ , current contribution from WTG.
- Determined through a measurement-based approach involving PSCAD simulations.
- Objective is to formulate a set of $I_{S_{VDNE}}$ versus $\boldsymbol{V}_{\boldsymbol{POI\_f}}$ data

$$I_{S_{VDNE}} = I_f - I_{ext} - \frac{(V_{S_{VDNE}} - V_{PoI\_f})}{Z_{VDNE}}$$

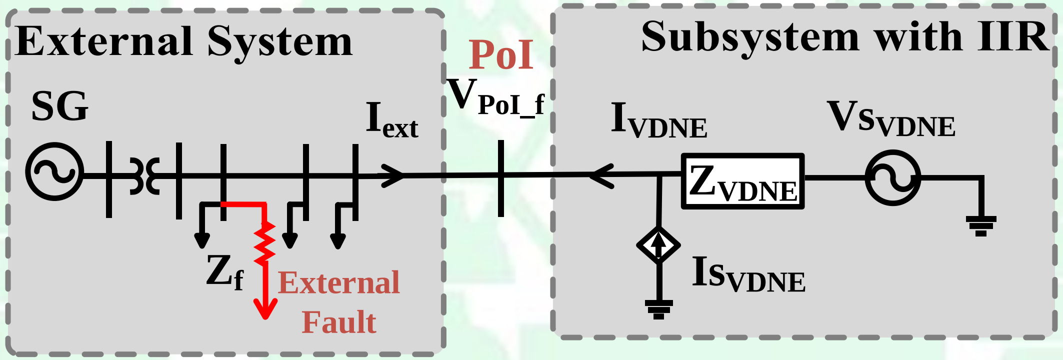
$$I_{S_{VDNE_d}} = I_{S_{VDNE}} \cos(\theta)$$

$$I_{S_{VDNE_q}} = I_{S_{VDNE}} \sin(\theta)$$

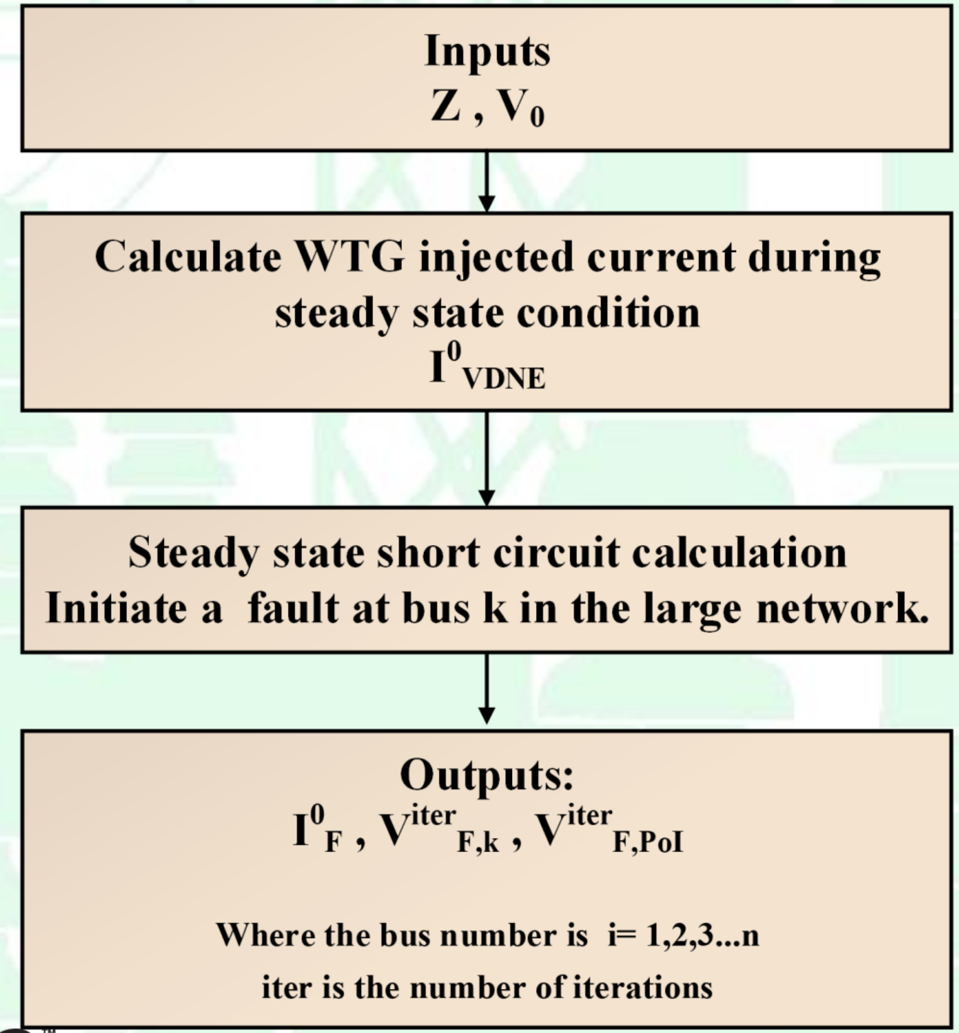



EMT simulation model used for obtaining VDNE parameters

# Iterative Short Circuit Analysis Methodology

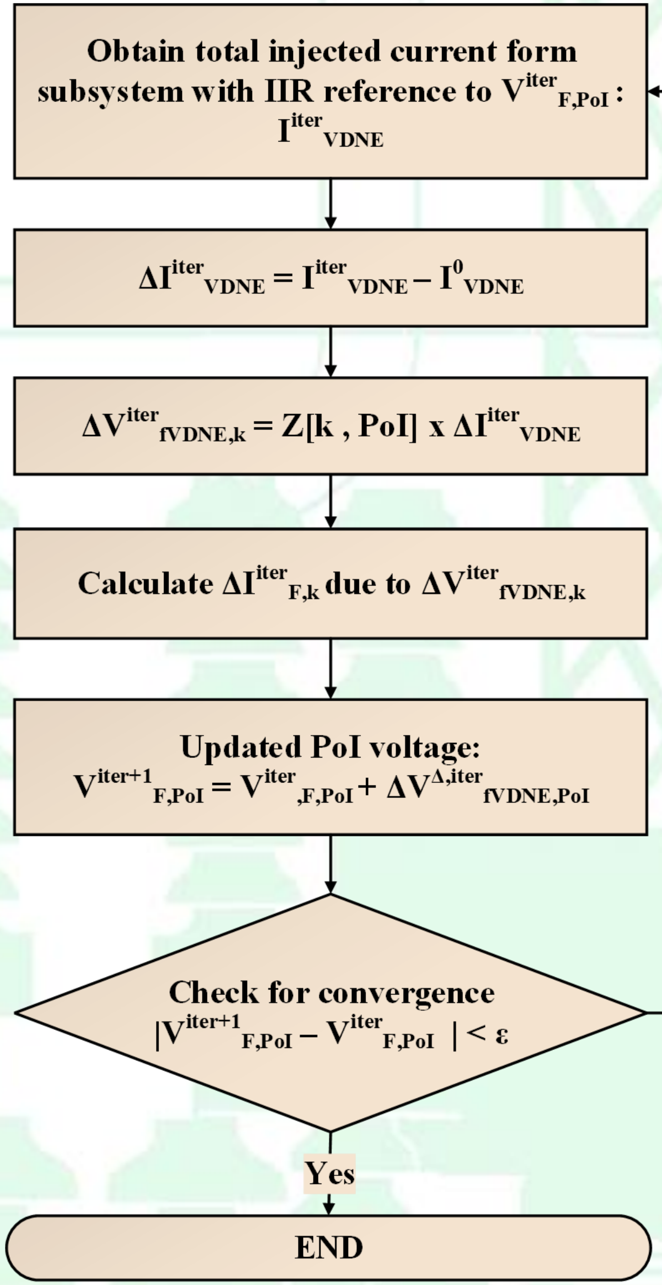



VDNE for matrix based iterative short circuit analysis




Iterative short circuit analysis

# Iterative Short Circuit Analysis Methodology

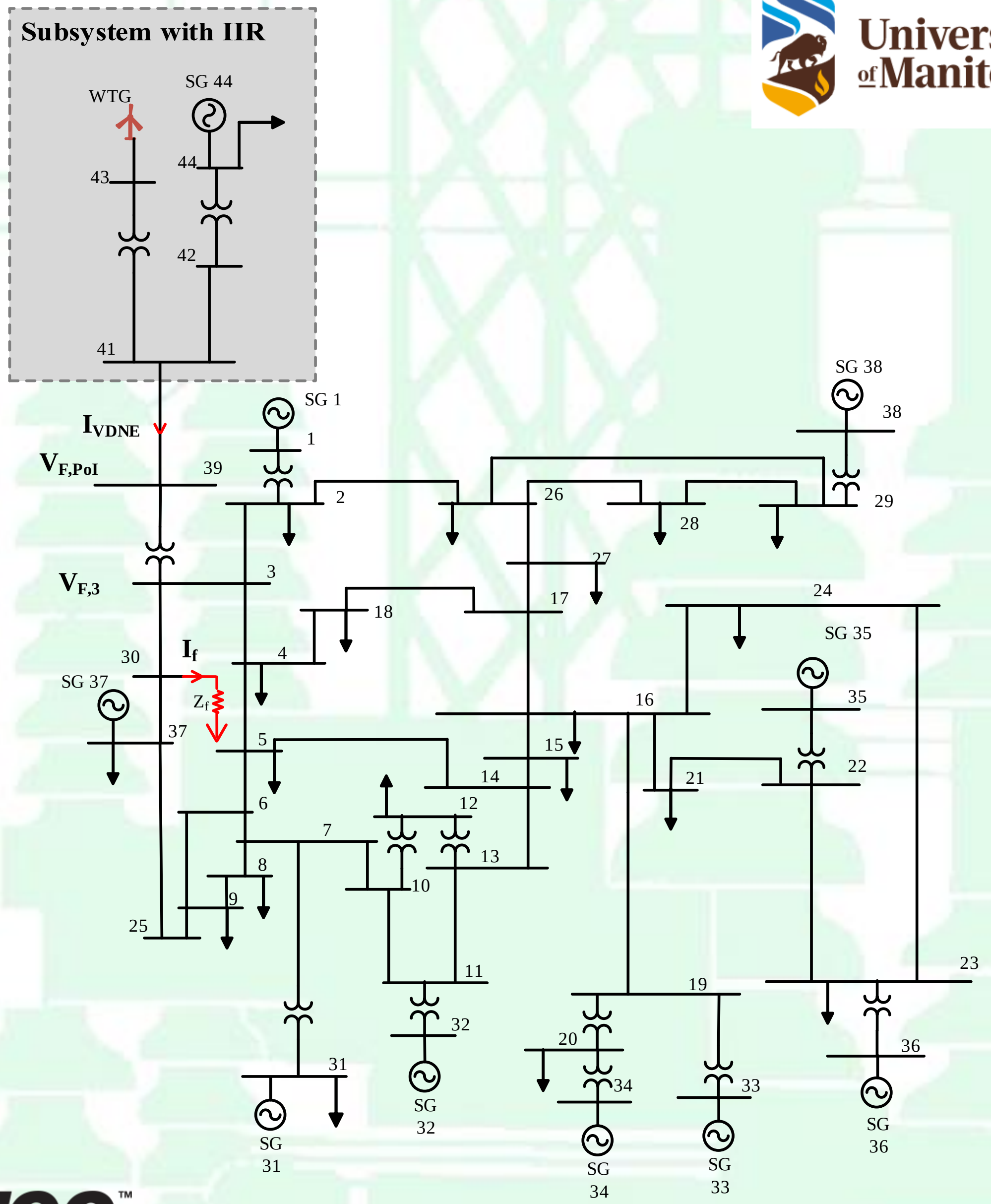


# Contents



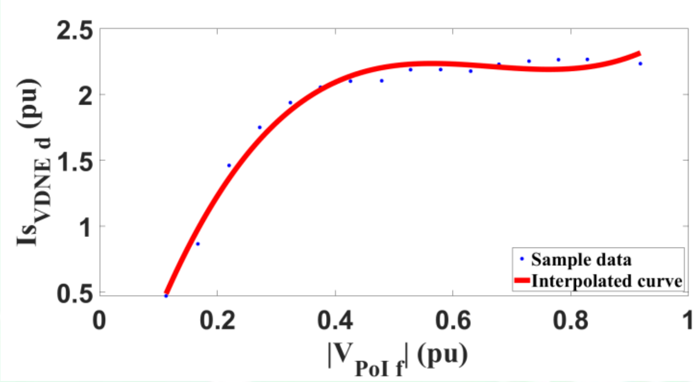
# Test Case: IEEE 39 bus test system

| | |
|---|---|
| PoI | 39 |
| Pre-fault bus voltage at PoI (pu) | 1.0 ∠ 0.0 º |
| Fault MVA at the PoI (MVA) | 2661.090 |
| X/R ratio | 4.749 |

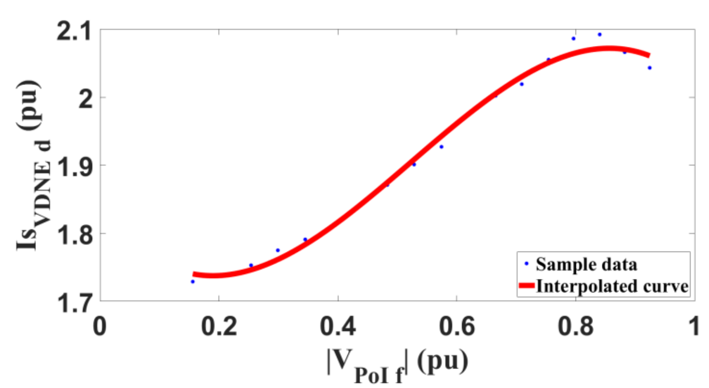


# $I_{s_{VDNE}}$



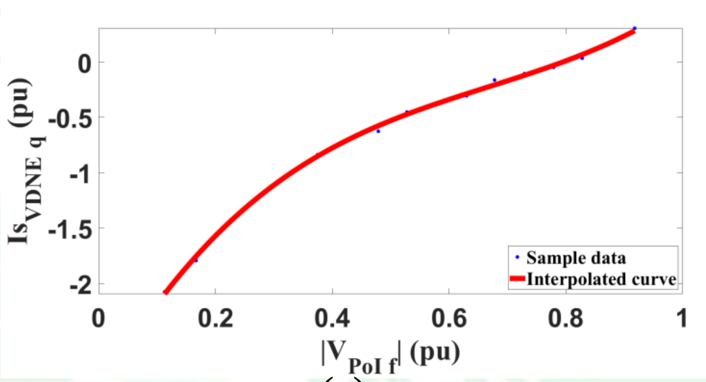



(a)

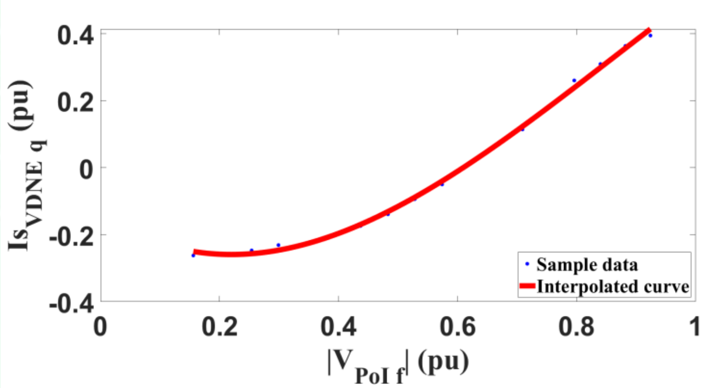



(b)

Variations of (a) $I_{s_{VDNE}}{}_d$ and (b) $I_{s_{VDNE}}{}_q$ (in pu) with the voltage magnitude at the PoI during three-phase faults. Measurements are taken 3-cycles after the fault inception.



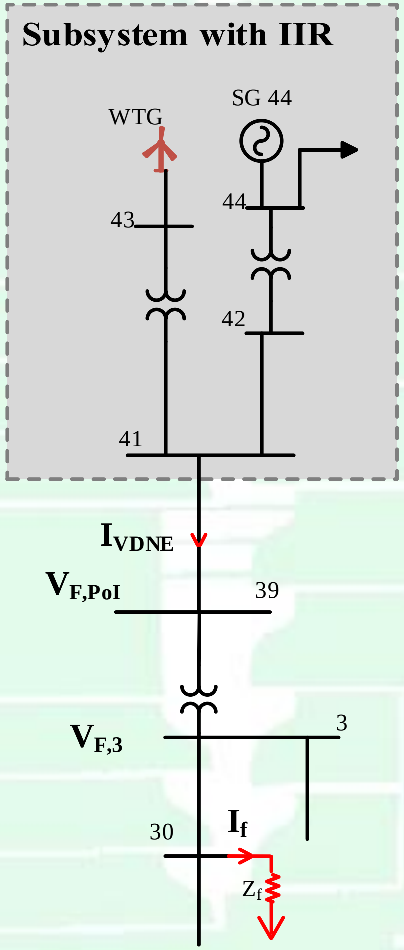

(a)




(b)

Variations of (a) $I_{s_{VDNE}}{}_d$ and (b) $I_{s_{VDNE}}{}_q$ (in pu) with the voltage magnitude at the PoI during three-phase faults. Measurements are taken 6-cycles after the fault inception.

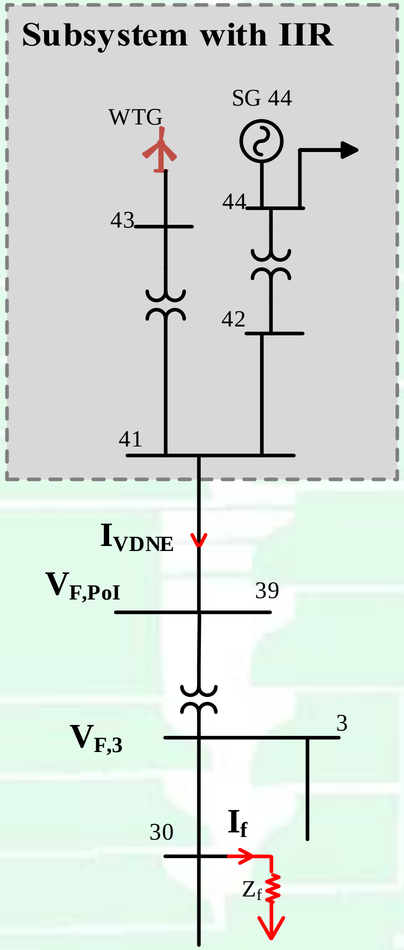
# Results




Comparison between phasor domain and EMT solution for LLLG fault at Bus 30, currents and voltages 3-cycles after fault inception

| Fault Resistance | Parameter | Phasor Domain Solution | EMT solution | Magnitude error % |
|---|---|---|---|---|
| **3 cycles after the inception of the fault** | | | | |
| $R_f$= 0 | $V_{F,PoI}$ | 0.918 ∠ -33.97 º | 0.917 ∠ -33.60 º | 0.1 |
| | $V_{F,3}$ | 0 | 0 | 0.0 |
| | $I_F$ | 6.150 ∠ -97.37 º | 6.074 ∠ -97.21 º | 1.3 |
| | $I_{VDNE}$ | 2.26 ∠ -46.68 º | 2.29 ∠ -32.95 º | 1.4 |
| $R_f$=10 | $V_{F,PoI}$ | 0.920 ∠ -34.62 º | 0.921 ∠ -34.22 º | 0.1 |
| | $V_{F,3}$ | 0.112 ∠ -91.81 º | 0.11 ∠ -91.53 º | 1.8 |
| | $I_F$ | 5.950 ∠ -92.18 º | 5.838 ∠ -91.53 º | 1.9 |
| | $I_{VDNE}$ | 2.260 ∠ -47.47 º | 2.273 ∠ -34.1 º | 0.6 |
| $R_f$=20 | $V_{F,PoI}$ | 0.929 ∠ -35.15 º | 0.927 ∠ -34.72 º | 0.2 |
| | $V_{F,3}$ | 0.215 ∠ -86.93 º | 0.211 ∠ -86.33 º | 1.9 |
| | $I_F$ | 5.69 ∠ -87.05 º | 5.569 ∠ -86.33 º | 2.2 |
| | $I_{VDNE}$ | 2.260 ∠ -47.75 º | 2.261 ∠ -34.91 º | 0.01 |

# Results




Comparison between phasor domain and EMT solution for LLLG fault at Bus 30, currents and voltages 6-cycles after fault inception

| Fault Resistance | Parameter | Phasor Domain Solution | EMT solution | Magnitude error % |
|---|---|---|---|---|
| 6 cycles after the inception of the fault | | | | |
| $R_f = 0$ | $V_{F,PoI}$ | 0.920 ∠ -34.29 º | 0.909 ∠ -33.75 º | 1.2 |
| | $V_{F,3}$ | 0 | 0 | 0.0 |
| | $I_F$ | 6.03 ∠ -98.54 º | 6.011 ∠ -97.21 º | 0.3 |
| | $I_{VDNE}$ | 2.117 ∠ -52.22 º | 2.116 ∠ -25.68 º | 0.05 |
| $R_f = 10$ | $V_{F,PoI}$ | 0.927 ∠ -34.92 º | 0.914 ∠ -34.35 º | 1.4 |
| | $V_{F,3}$ | 0.110 ∠ -92.78 º | 0.109 ∠ -91.51 º | 0.9 |
| | $I_F$ | 5.890 ∠ -92.78 º | 5.778 ∠ -91.51 º | 1.9 |
| | $I_{VDNE}$ | 2.105 ∠ -51.42 º | 2.108 ∠ -26.75 º | 0.2 |
| $R_f = 20$ | $V_{F,PoI}$ | 0.930 ∠ -35.39 º | 0.920 ∠ -34.84 º | 1.1 |
| | $V_{F,3}$ | 0.251 ∠ -87.39 º | 0.208 ∠ -86.28 º | 0.9 |
| | $I_F$ | 5.61 ∠ -87.39 º | 5.513 ∠ -86.28 º | 1.7 |
| | $I_{VDNE}$ | 2.110 ∠ -51.09 º | 2.106 ∠ -27.49 º | 0.2 |

# Contents



# Conclusion

- A method for accurate calculation of three-phase short circuit currents in a power system with inverter interfaced sources using phasor domain techniques is proposed.
- In this approach, a VDNE is utilized to capture the nonlinear behavior of the IIRs, and PSCAD/EMTDC can be automated to obtained VDNE parameters.
- The case study results for three-phase to ground faults in IEEE 39 bus test system show that the proposed VDNE based iterative short circuit analysis methodology works for three-phase faults.

# References


[1] “IEEE Recommended Practice for Conducting Short-Circuit Studies and Analysis of Industrial and Commercial Power Systems, IEEE Std 3002.3-2018,” 2018.

[2] Manitoba Hydro, “Manitoba Hydro Transmission System Interconnection Requirements,” no. July, 2009

[3] B. Chen, A. Shrestha, F. A. Ituzaro, and N. Fischer, “Addressing protection challenges associated with Type 3 and Type 4 wind turbine generators,” *2015 68th Annu. Conf. Prot. Relay Eng. CPRE 2015*, no. Type 3, pp. 335–344, 2015.

# Contents



# Thank You