MANITOBA HVDC RESEARCH CENTRE,
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Renewable Device Modeling and Harmonic Model Derivation using PSCAD™/EMTDC™

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Introduction

Renewable Device Modeling

- Electromagnetic transient (EMT) vs. RMS simulations
- Generic and detailed vendor models
    - Focus on: Type 3 & Type 4 wind turbines, PV inverters
    - Switching and average models
- Collector network aggregation

Harmonic Model Derivation

- Methodology of harmonic injection
- Interpretation and implication of results

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EMT vs. RMS Simulations

EMT vs. RMS Simulations

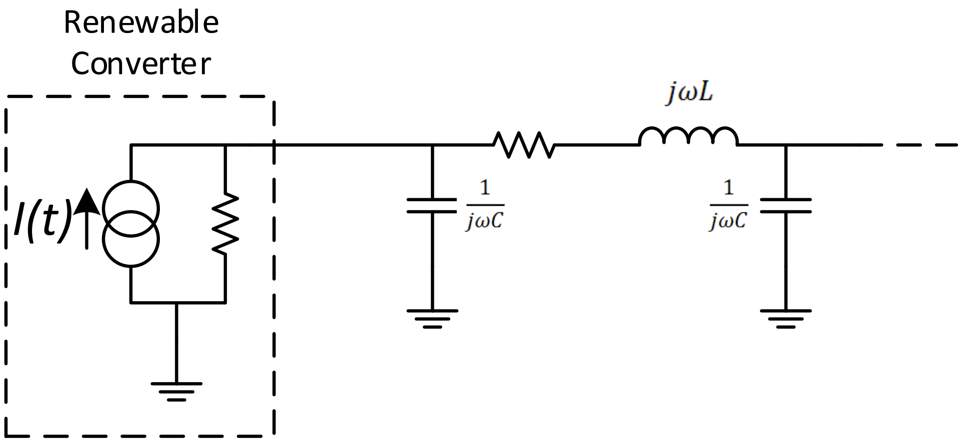
Why EMT models are important in studies involving renewables?

- RMS modeling does not represent the network dynamics.
  - Any phenomena caused by converter interaction with the network is not captured accurately.
- EMT modeling is able to capture these network dynamics accurately.
  - SSR, SSCI, fault ride through in weak grid, harmonic resonances in the collector network, etc.

EMT vs. RMS Simulations

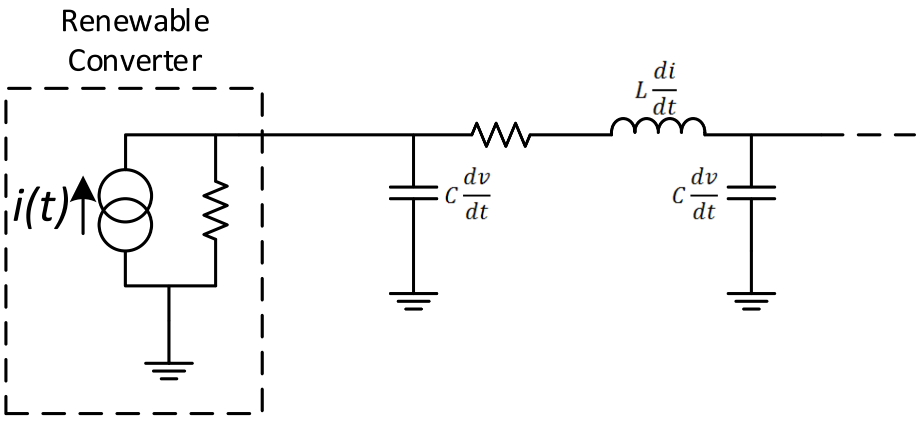
RMS

- Assume quasi-steady state
- Network transients neglected
- Fundamental phasor solution
- Positive sequence
- Large network possible



EMT

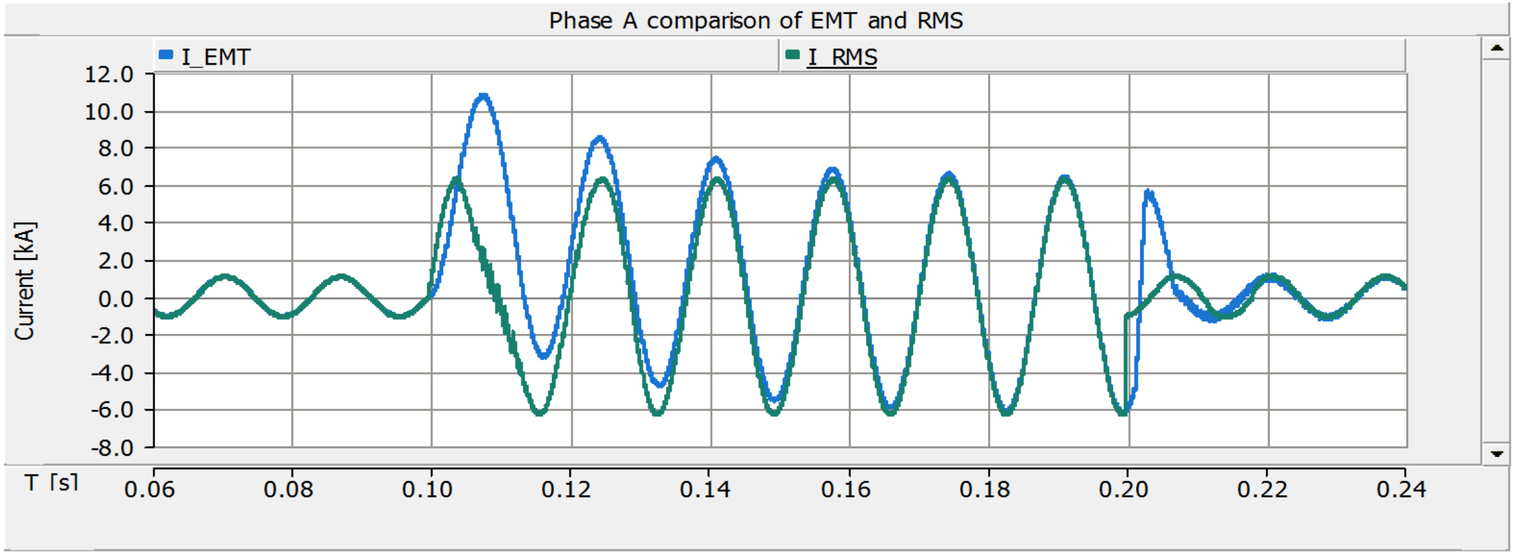
- Consider differential equations
- Numerical integration substitution
- Upper freq. depends on simulation time step (0~MHz)

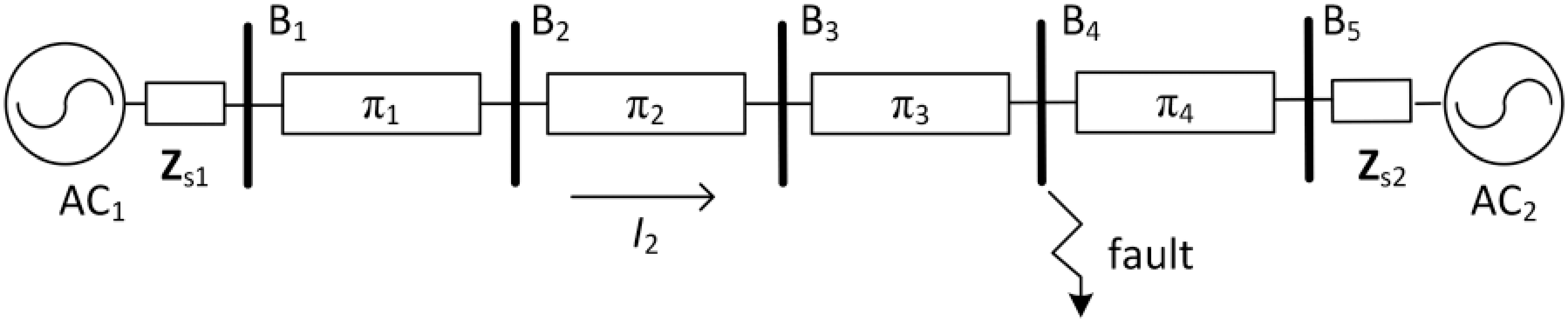


EMT vs. RMS Simulations

Example:

- EMT solutions may have DC offset other high frequency transients
- RMS has the steady state solution of each instant ➔Quasi-steady state

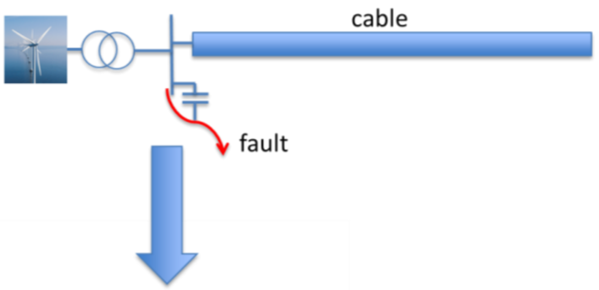


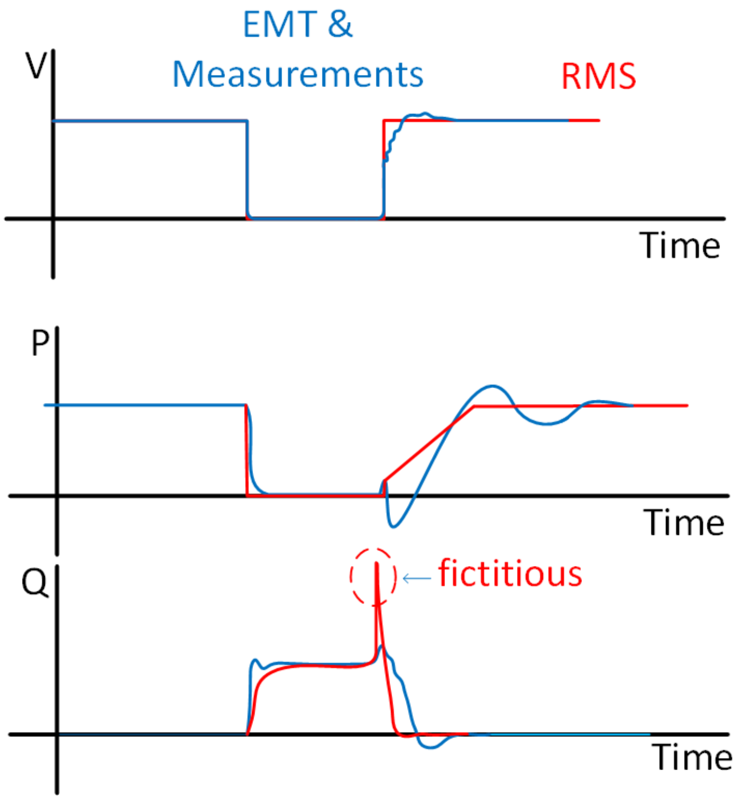


EMT vs. RMS Simulations

Example:

- EMT is able to capture the dynamics during a fault accurately.
- RMS results follow the fundamental.





Generic vs. Detailed Vendor Models

Generic vs. Detailed Vendor Models

Generic model

- Does not represent any particular vendor model/equipment.
- Will provide typical or generic type of response.
- Used in system planning studies (for which individual model details are not crucial), or when modeling nearby wind/PV farms that don't require particular detail.

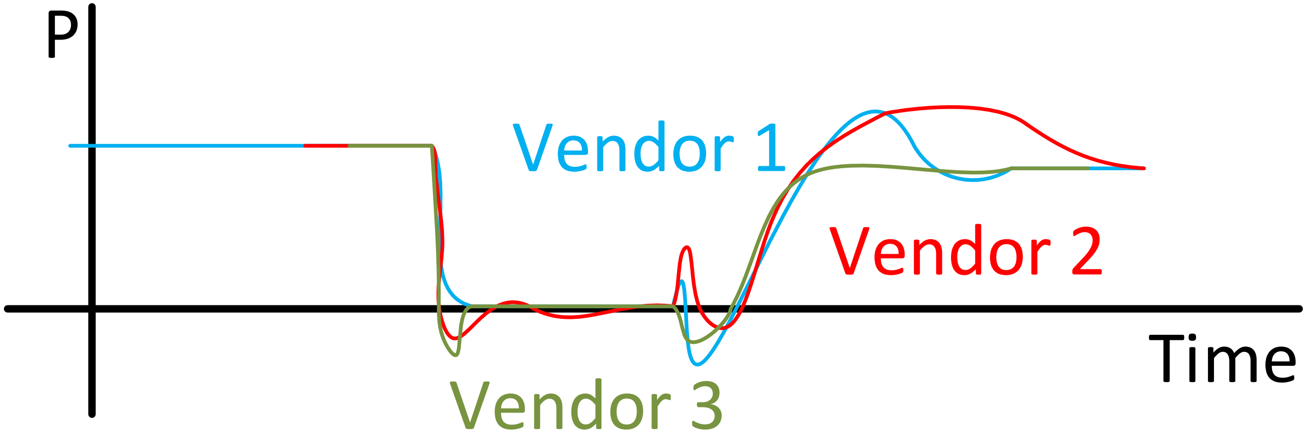
Vendor model

- Represents particular details of equipment.
- Often these details are intellectual property.
    - Thus, models are 'black-boxed' to hide sensitive algorithms.
- Used in interconnection studies and studies involving grid code compliance, SSR/SSCI, tuning controllers etc.

Generic vs. Detailed Vendor Models

Vendor model

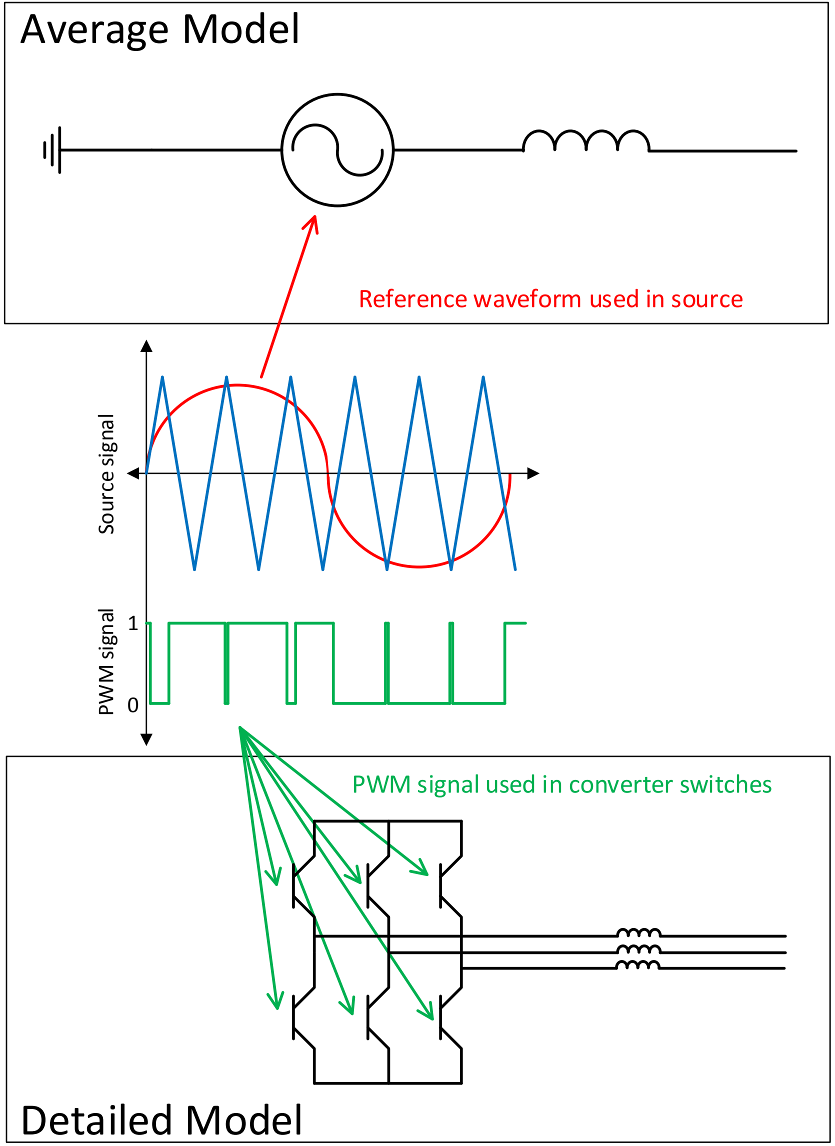
- Different vendor models have significantly different dynamics responses.
- Pre- and post-fault steady state responses may be similar.
- Therefore, the appropriate vendor models are always recommended to be used in detailed EMT studies.



Average Model vs. Detailed Model

Average model vs. Detailed model

- Average model uses reference waveform in source. Fine details of switching events are lost
- Detailed model uses full PWM signal in in source. Fine details of switching events are accurately modelled.
- Note: time step in detailed model must be small enough.

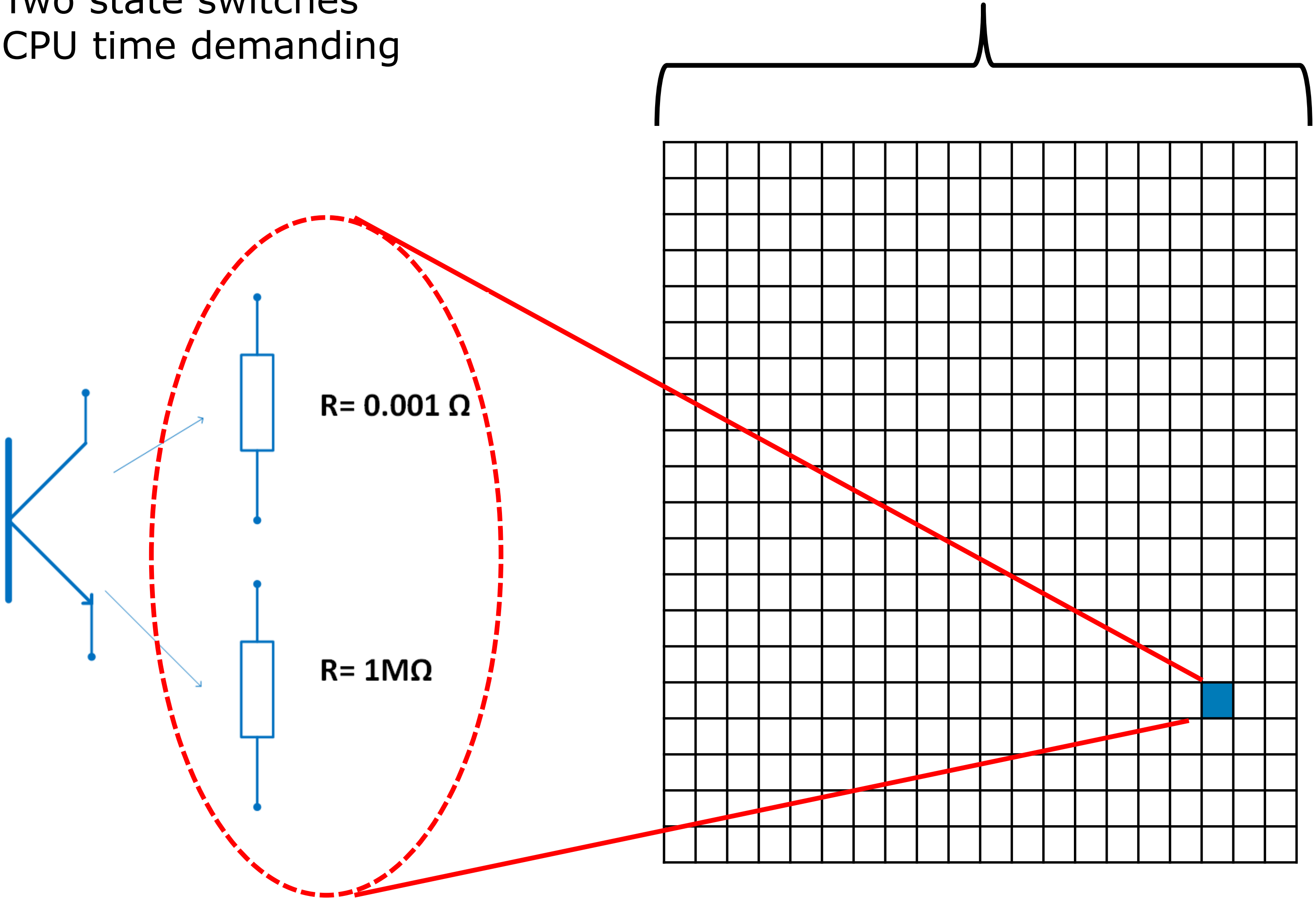


Generic vs. Detailed Vendor Models

Detailed model

- Two state switches
- CPU time demanding

$$[G][V]=[I]$$



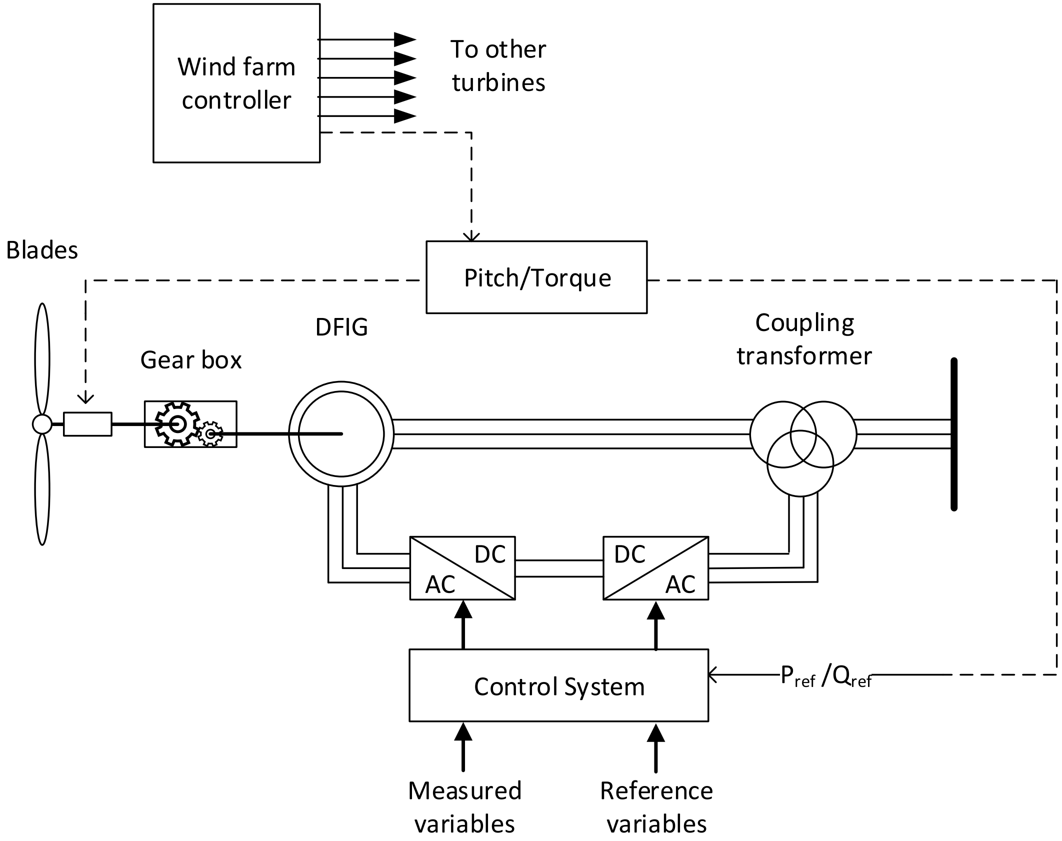
Generic Renewable Models

- Discuss the following generic models:
  - Type 3 wind turbine.
  - Type 4 wind turbine.
  - PV inverter.

Type 3 Turbine

EMT Type 3 Turbine

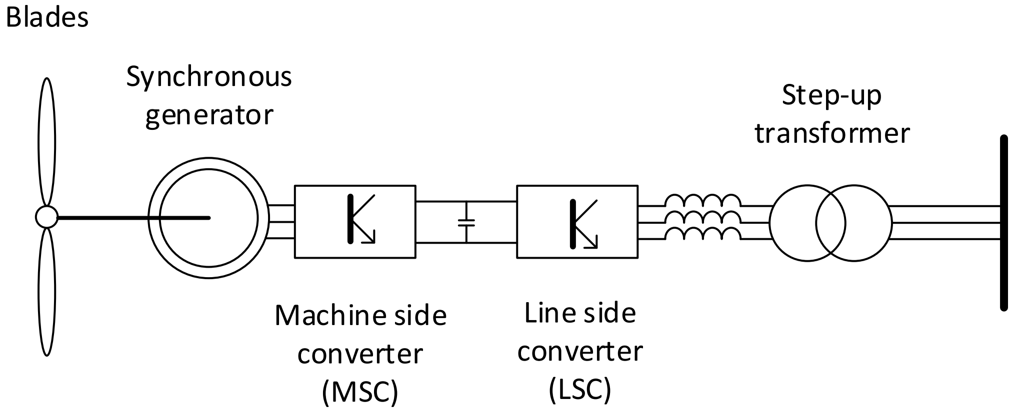
- Induction generator
- Back-to-back converter
  - Average or detailed
- Control system
  - V_{DC}
  - Active and reactive power
- Aerodynamic and drive train
  - 2-mass system
- Pitch and torque/power control
- Wind farm controller (slow)
  - P_{ref} and Q_{ref}.



Type 4 Turbine

Type 4 wind farm

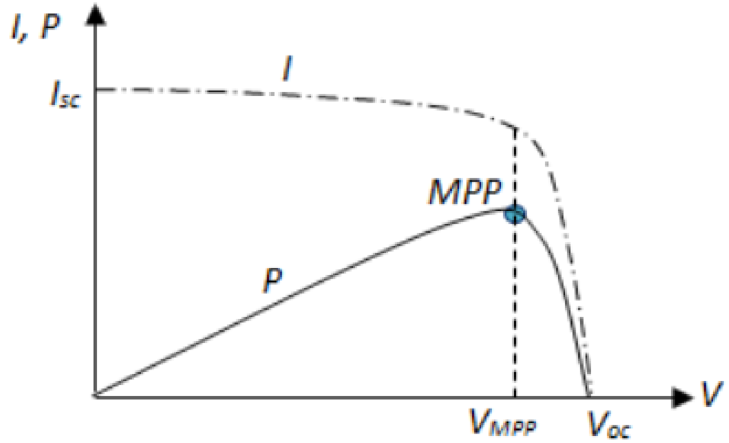
- PM synchronous generator
- Direct back-to-back converter
  - Average or detailed
  - MSC can be replaced by current source (if electro-mechanical behavior is not required. E.g. wind variation tests)
- Not shown: pitch/torque controller, wind farm controller

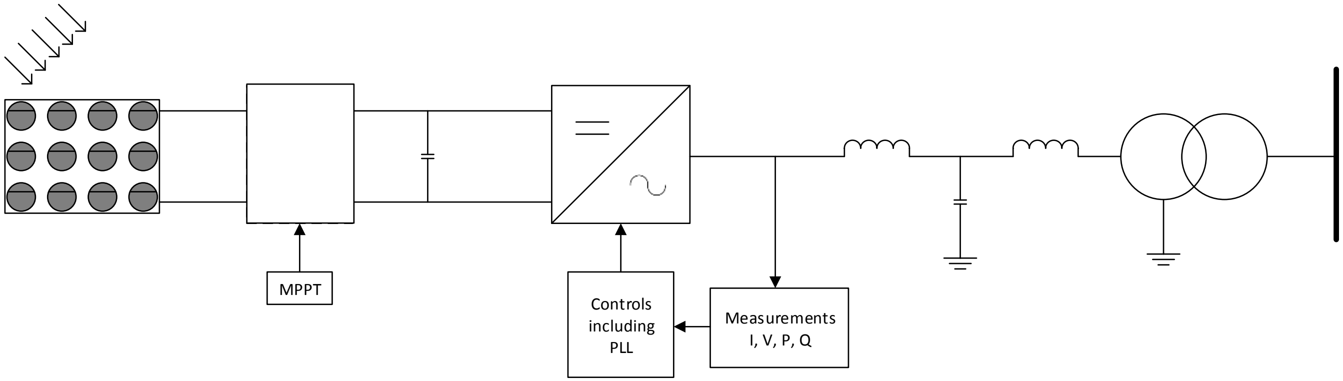


PV Inverter

PV inverter

- Similar to type 4 converter (from AC onwards)
- MPPT

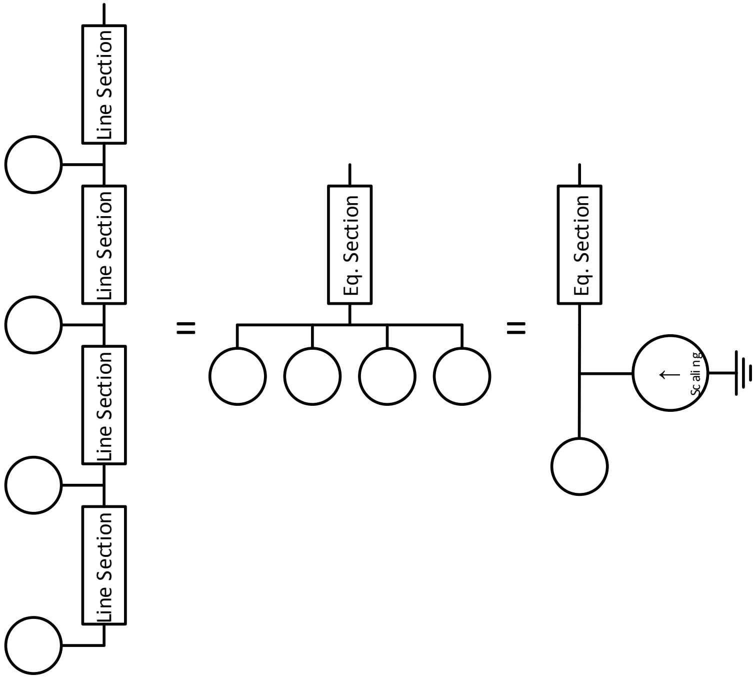




Farm Aggregation

Wind farm/PV Solar farm aggregation

- Computationally demanding simulate full collector network with many detailed models. Answer: aggregate.
- Steps to aggregate:
  1. Make equivalent line section
  2. Scale current *N* times



- Several methods make equivalent line section

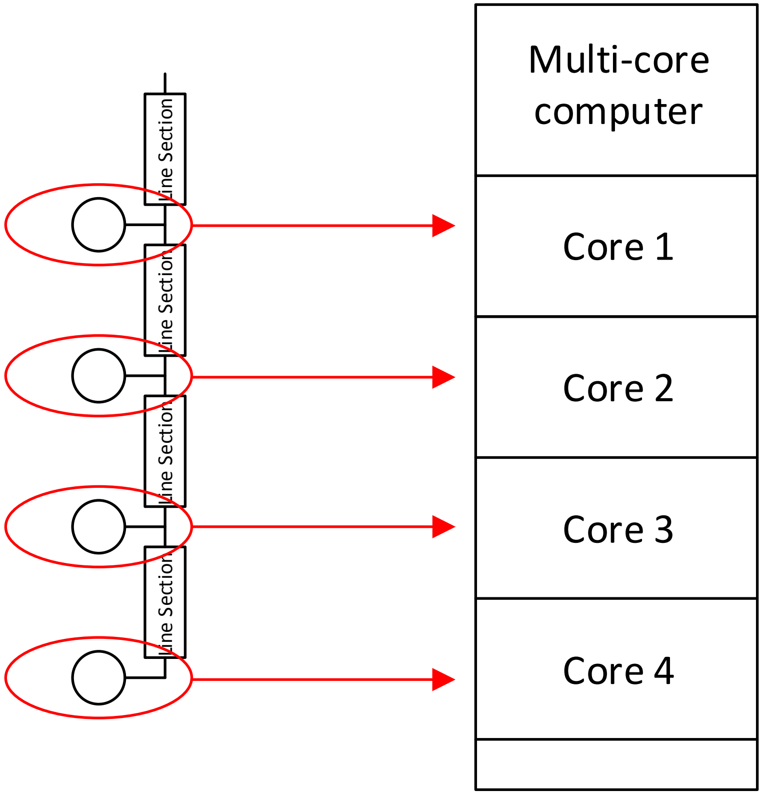
  Ref. 1: *Equivalencing the collector system of a large wind power plant*, Muljadi et. al

  Ref. 2: *Efficient EMT modeling approach to studying resonance phenomenon in PV and wind energy systems*, Pielahn, Mudunkotuwa, Ranaweera, Muthumuni

Parallel Processing - ENI

- If full details of feeder branches are needed -> can't aggregate
  - May have to run all or a large part of the collector network
- Allocate each converter model of the collector network onto a separate core on machine (Electric Network Interface)
- Also possible to split the simulation onto several computers separated by distance

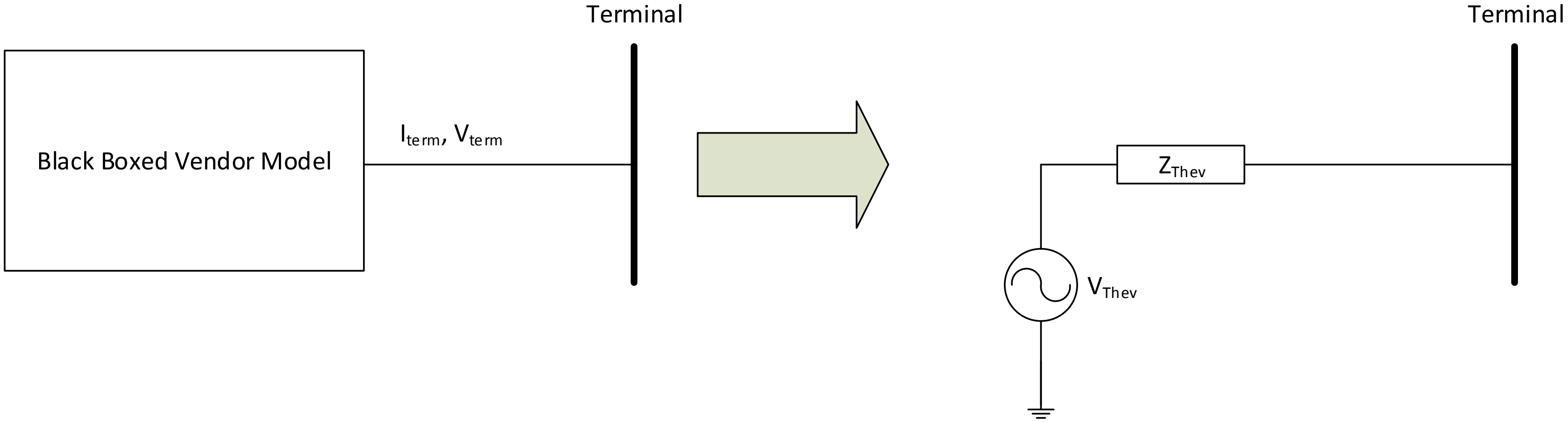
Note: ENI does not cause inaccuracies or time step delays.



Harmonic Model Derivation

Harmonic Model Derivation

- What is a harmonic model?
  - Harmonic model represent the converter as a Thévenin equivalent source.
  - Thévenin equivalence is calculated for different harmonics.



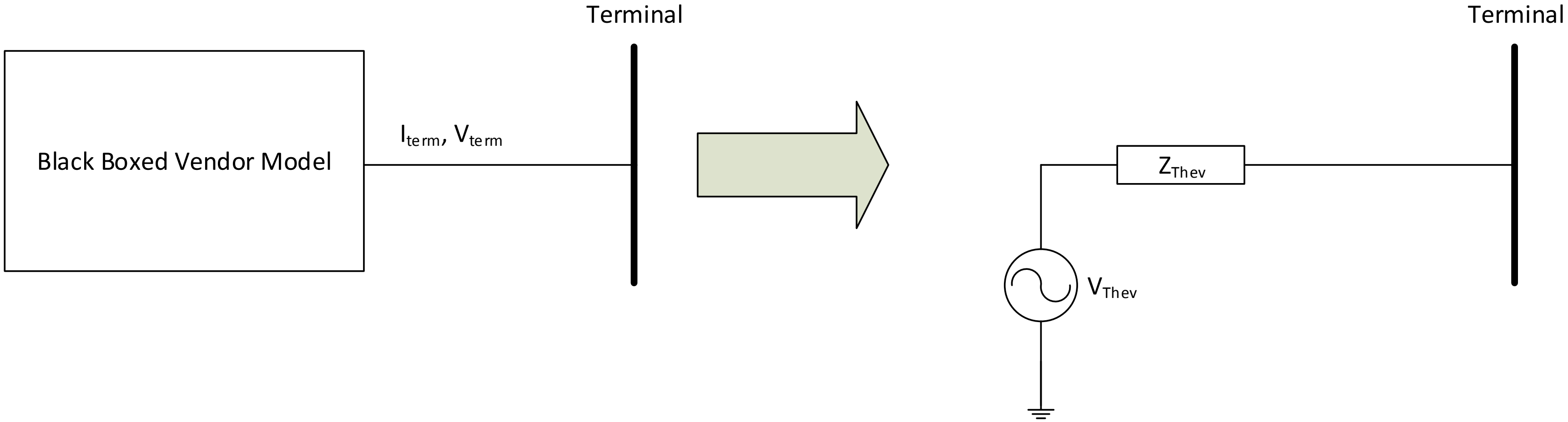
Harmonic Model Derivation

- Why we need harmonic model?
    - To calculate the total harmonic distortion of a renewable farm at the point of interconnection (POI)
    - Utility interest to know the impact upon interconnection of renewable farm.
    - Harmonic model used in harmonic analysis tools.

Harmonic Model Derivation

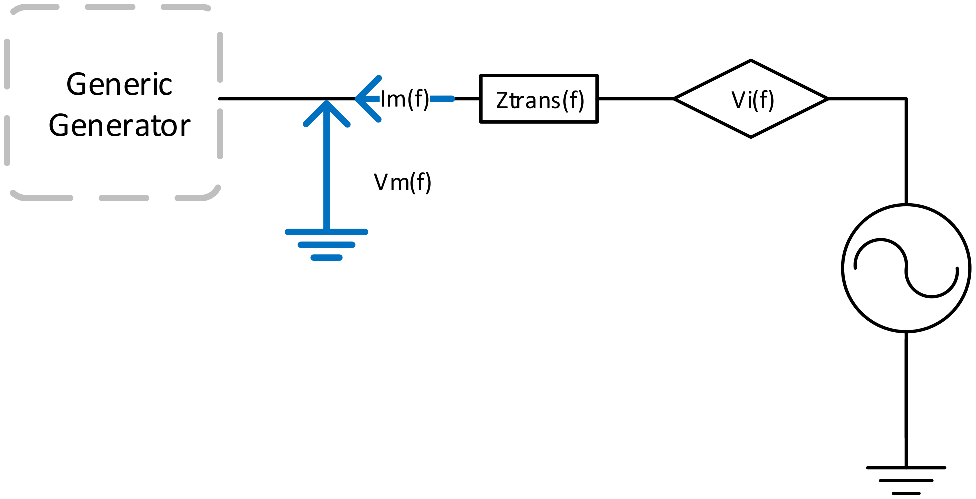
- Generally the harmonic model is a table. E.g.

Harmonic order	**$\lvert V_{thev}\rvert$**	**$Ph(V_{thev})$**	**$\lvert Z_{thev}\rvert$**	**$Ph(Z_{thev})$**
1	x	x	x	x
2	x	x	x	x
…	…	…	..	..
19	x	x	x	x
20	x	x	x	x



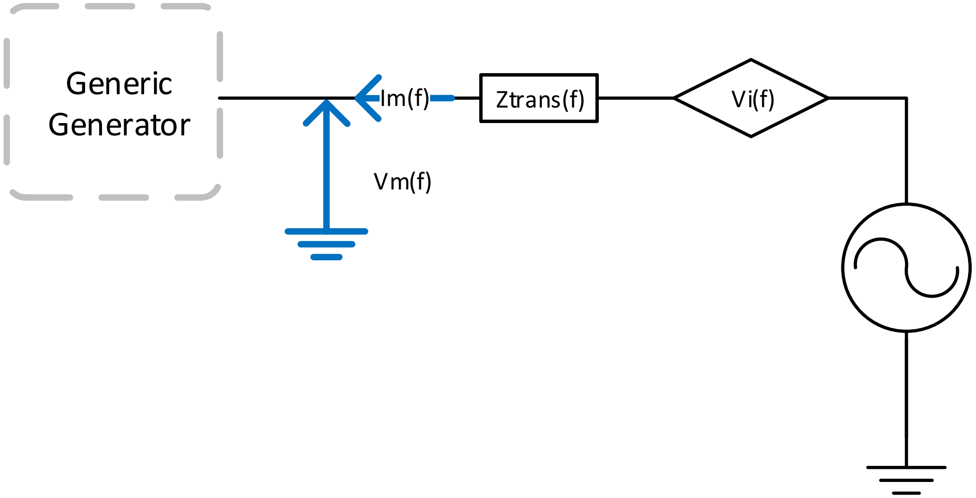
Harmonic Model Derivation

- Converter model is black boxed, provided by vendor
- Only known quantities are the terminal harmonic measurements: Im(f), Vm(f)
- Question: how to determine Thévenin equivalence using only these terminal values?
- Question: Im(f) and Vm(f) are very small -> How to measure them?



Harmonic Model Derivation

- Answer: External excitations are needed
    - Harmonic voltage source is connected in series *Vi(f)*
- The magnitude of *Vi(f)* are determined experimentally. Typically they should be a few % of the fundamental grid voltage.



Harmonic Model Derivation

- To calculate the impedance *Z(f)* at the terminal, inject excitation voltages at the same frequency.
- Measure terminal voltage and current. Repeat with a slightly modified voltage injection
  - $V_1(f), I_1(f), V_2(f), I_2(f)$ -> phasors

$$Z_{th}(f) = \frac{V_2(f) - V_1(f)}{I_2(f) - I_1(f)}$$

$$V_{th}(f) = -I_1(f) \cdot Z_{th}(f) + V_1(f)$$

Harmonic Model Derivation

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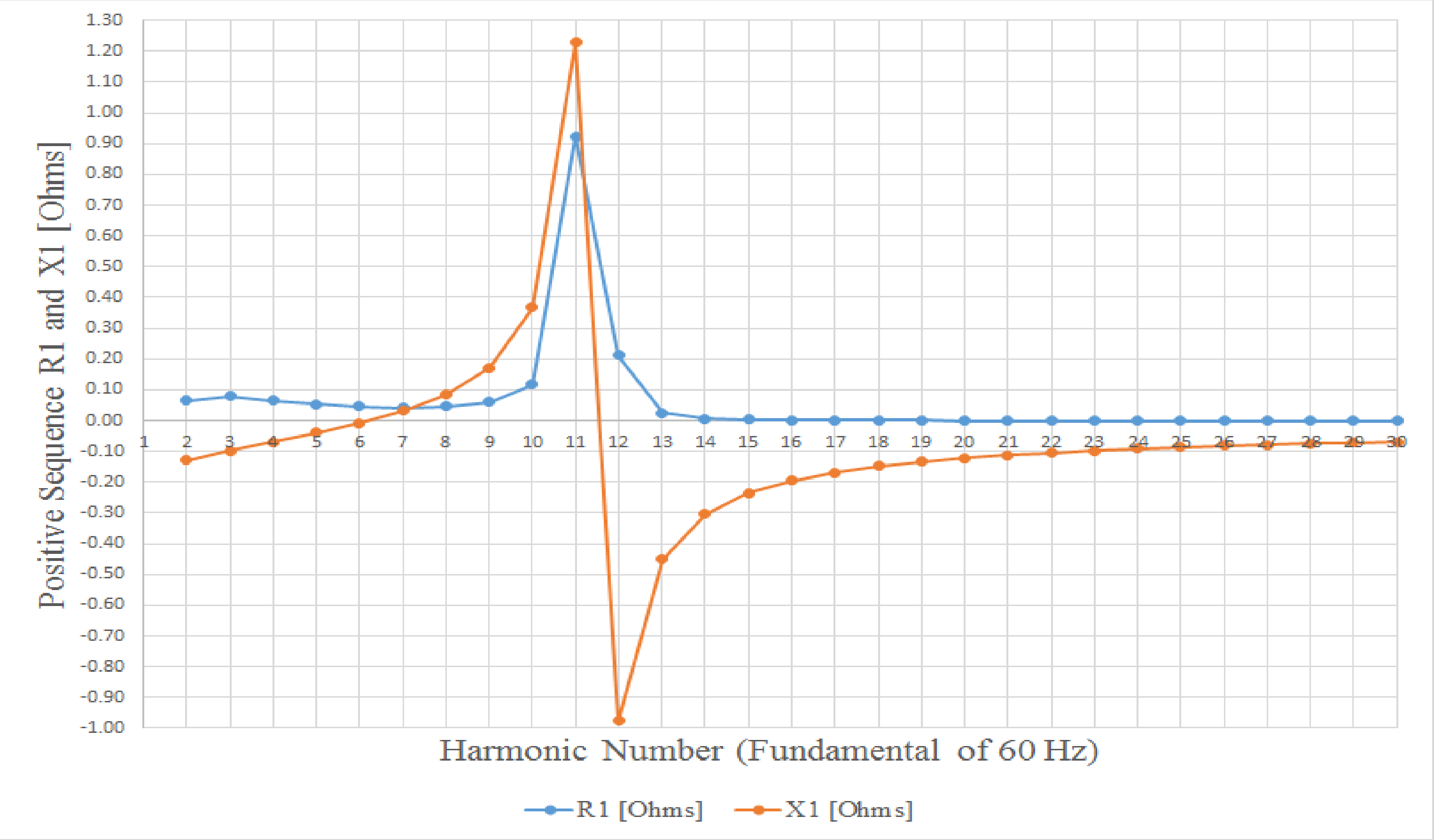
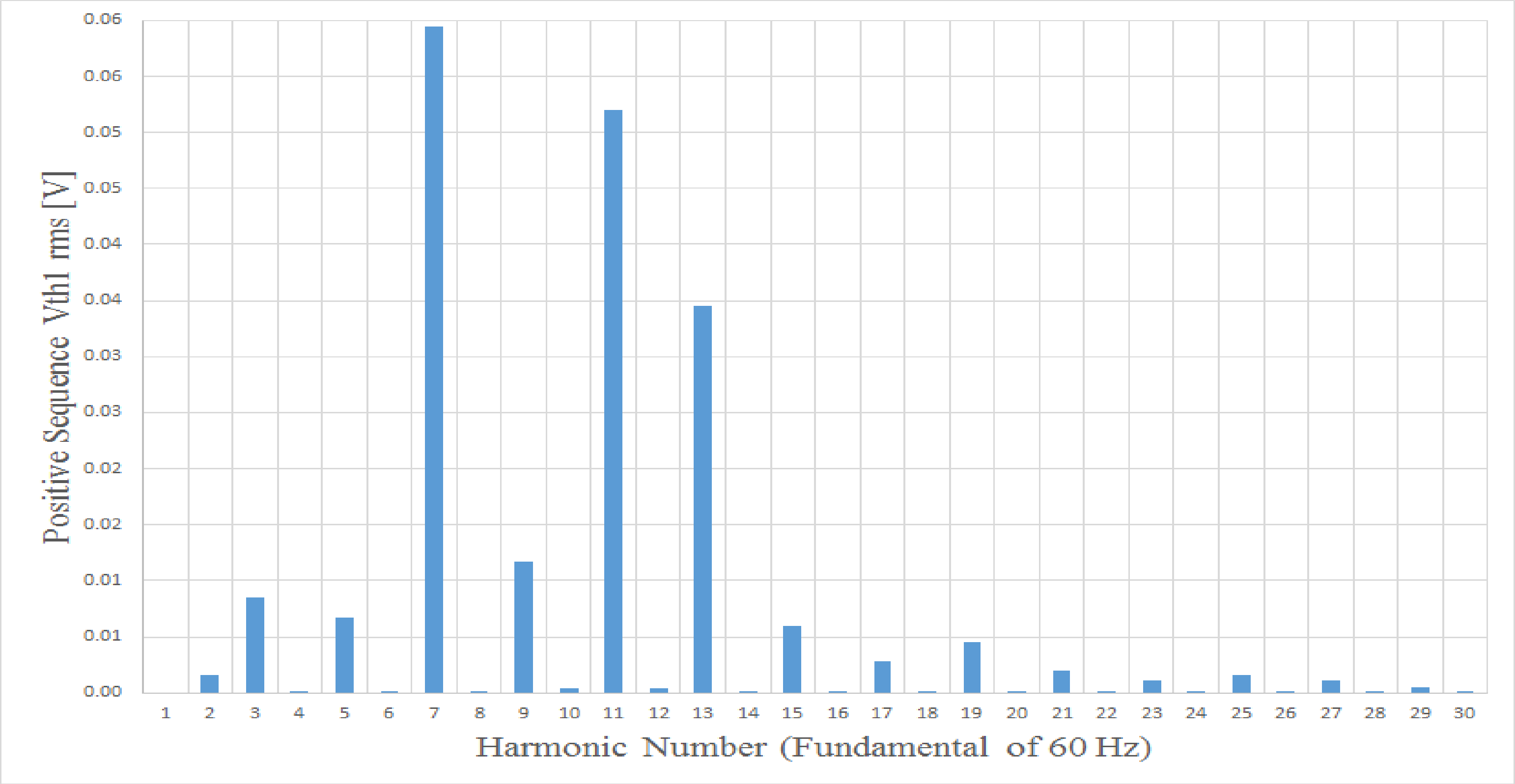
- Typical results…



Harmonic Model Derivation

- Typical results…



Harmonic Model Derivation

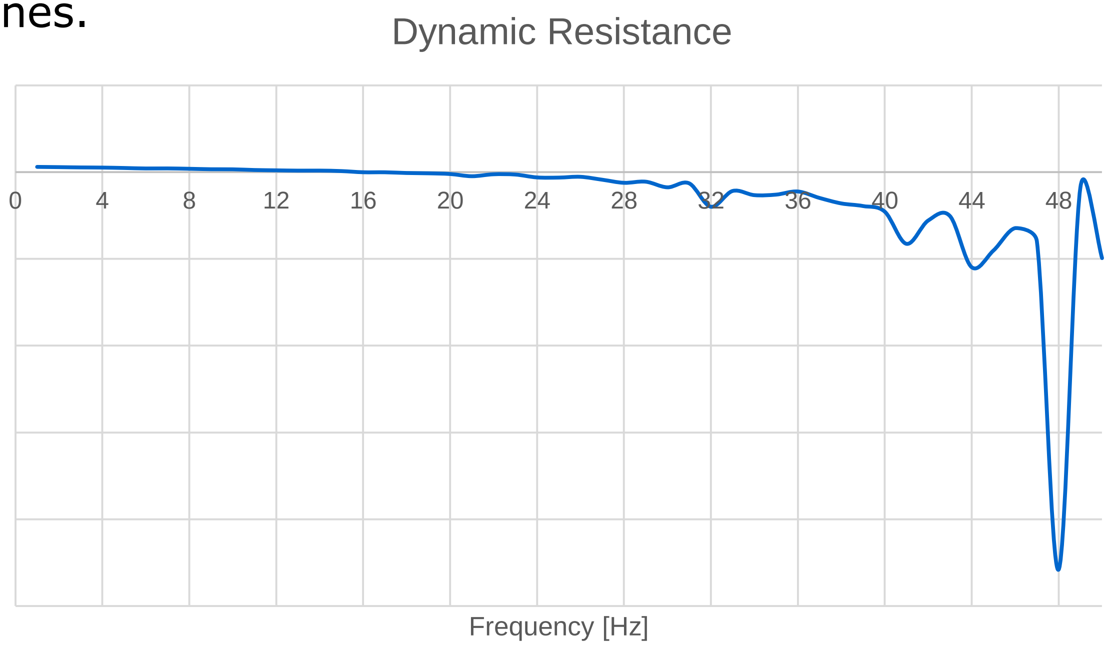
- Practical application has more than one equivalent harmonic model (collector network).
- The fundamental Thévenin angle of the harmonic model is in reference to the phase angle of converter terminal voltage. If voltage angle changes by Δφ, then fundamental Thévenin angle must change by the same amount. (maintain power flow)
- E.g. if the fundamental voltage angle is changed by an amount Δφ, then the angles of the harmonic model must be shifted by

$$\angle V_{th\_shifted}(f) = \angle V_{th}(f) + n \cdot \Delta\varphi$$

where n is the harmonic number.

Harmonic Model Derivation

- What about dynamic resistance?
- $Z(f) = \frac{v(f)}{i(f)}$
- The real part of the Thévenin impedance is called *Dynamic Resistance*.
- Used to screen for negative frequency region in which converter amplifies harmonics.
- Predominant in type 3 turbines.



Thank you