# Positive-Sequence and EMT Modeling of IBR

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# Modeling in General

- Hardware In the Loop (HIL)
  - Proprietary, shared under NDA
  - Use for design, commissioning tests
- 3-phase vendor specific models (EMT – Black box)
  - Proprietary, shared under NDA
  - Use for detailed analysis of grid interactions
- Positive sequence vendor specific models (DLL – Black Box)
  - Again, often shared under NDA
  - Typically, benchmarked against second level model above
  - Used for gird interconnection studies
- Generic positive sequence models
  - Open and public
  - Can be parameterized to be quite useful for BES stability analysis

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# Positive-Sequence Models

# User-Written Models

- Obviously cannot discuss details of any user-written models (UWM) since they are all proprietary

- What is a UWM?
  - It is a detailed model develop by a specific vendor of their own equipment/controls
  - It is based on actual control design
  - More recently, there has been proposed the concept of using real-code (CIGRE/IEEE TF, lead by G. Irwin)

# User-Written Models

- In tools such as Siemens PTI PSS®E a UWM is typically a “block-box” compiled DLL
- In tools like GE PSLF™ presently it cannot be complied and is often obfuscated code in the tools own language
- In tools like PowerTech TSAT™ it can be a DLL or a UDM defined model in the tools own language

# Pros and Cons of UWM

- **<u>Pros:</u>**
  - Vendor specific and quite detailed
  - Can be essential for local studies in the vicinity of the particular equipment and for facility studies; ***so still needed for detailed local studies***
  - Often many control parameters will have a one to one correspondence between model and actual controls and thus any site specific tuning done during facility studies can be easily translated to actual controls tuning

# Pros and Cons of UWM

- **Cons:**
  - Black-box and so not easy to understand all details
  - Typically, governed by NDAs and not easy to share with reliability entities, other neighboring utilities, etc.
  - Complex (can have 100’s of parameters) and so data management can be an issue if proliferated in a system wide model
  - Hard to debug/trouble shoot – software vendors cannot support
  - Not transportable across software platforms

# Pros of Generic Models [1]

The value of the 2nd generation generic models:

- **Validation:** numerous validation cases shown for the new 2nd generation RES generic models
- **Portability across software platforms:** implemented and tested in major commercial tools, and consistent across the tools
- **Transparency:** standard, generic, public and open with documentation/specifications that are available to all
- **Documentation:** specification and user guides available and public
- **Modeling the Future:** generic models are useful for performing futuristic studies where the actual equipment to be used is not yet known

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# Limitation of Generic Models [1]

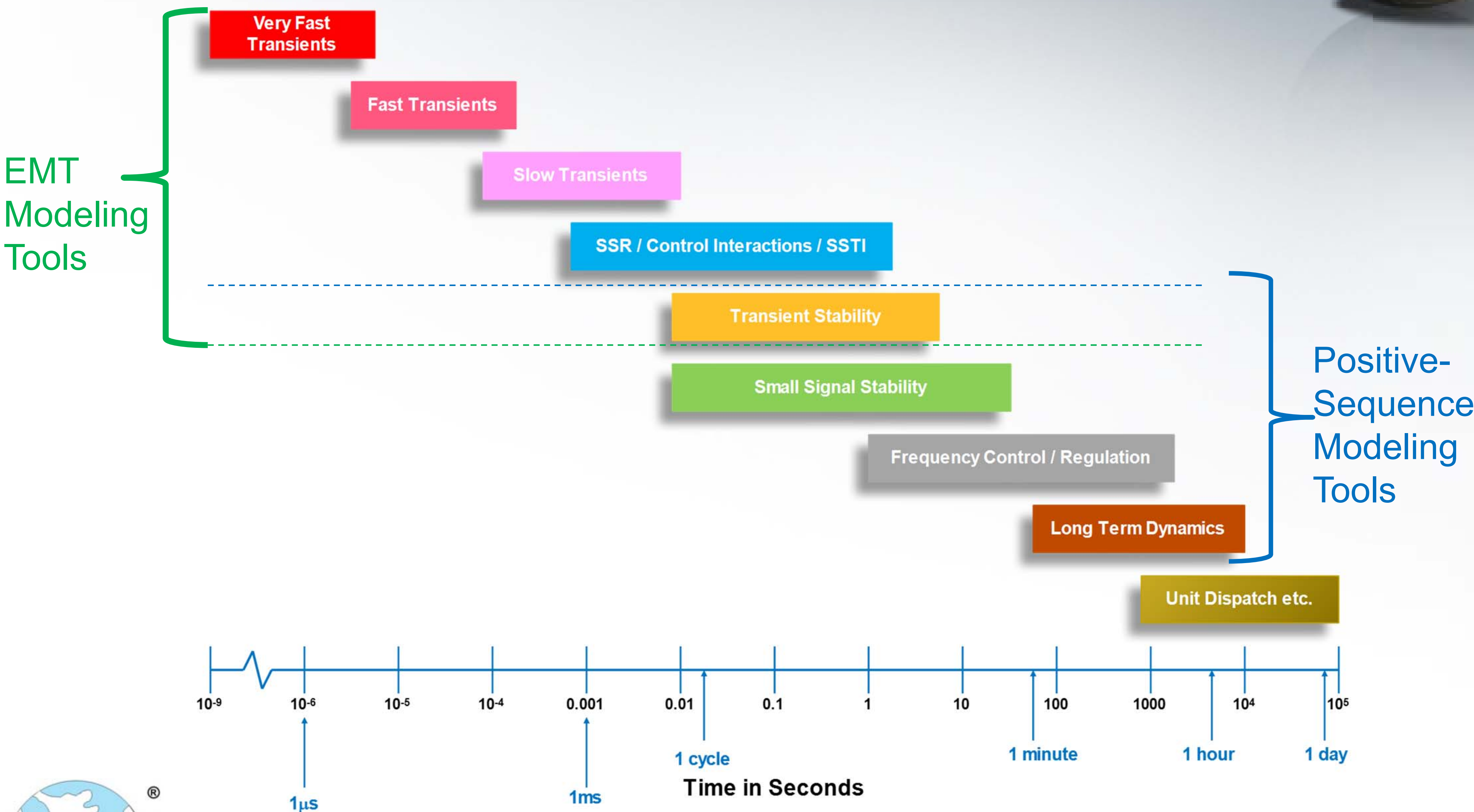
The limitations of the 2nd generation generic models:

- **Positive-sequence:** cannot be used for accurate assessment of unbalanced conditions.
- **Typical range of stability studies:** consider dynamics in the typical range of stability studies (0.1 – 3 Hz) – **note:** network and other models are all only good within this range. The control loops, however, within the models (e.g. closed-loop voltage control) may also consider frequencies ranging up to 10 Hz.
- **Constant wind speed:** the generic models assume that wind speed (and solar irradiation) is constant during a stability simulation.
- **Weak Systems:** not intended for detailed local studies associated with control tuning and design for the interconnection of wind/PV plants to very weak systems (i.e. short-circuit ratios below approximately 2 or 3) ***– there is current consideration being given to extending this capability (REGC_B & REGC_C)***
- **Specialized Studies:** The models cannot be used for detailed studies that relate to phenomena such as potential torsional interactions between the wind turbine generator and the electrical power system (e.g. nearby series capacitor).

# Limitations of Positive-Sequence Models

To some extent, all of the limitations quoted above for "generic" positive-sequence models can also apply to positive-sequence UWMs

# Power System Dynamics



# Where Are EMT Tools Used?

- Insulation Coordination
- TOV, TRV, Switching Surge
- Electrical or Electromechanical Resonances such as Subsynchronous Resonance (SSR)
  - Induction generator self-excitation (wind + series capacitor)
  - Subsynchronous torsional interaction (more common on convention steam and gas turbines)
- High-bandwidth Control interactions
- Weak-grid issues which may require PLL/Inner Current Control Loop tuning (SCR ≈ 2 or less)

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# EMT Model for a IBR Unit

# Actual Inverter Controls

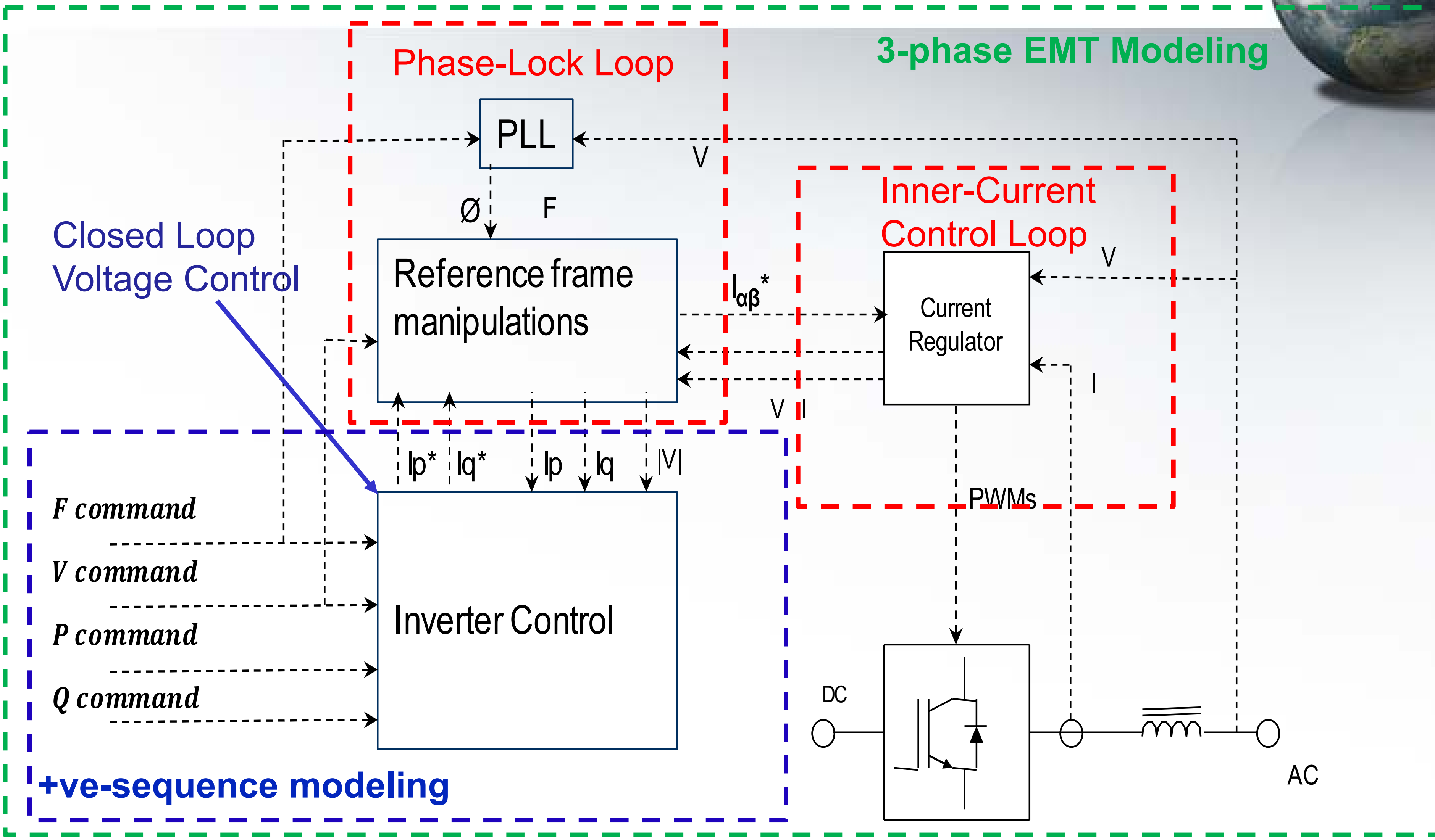


Diagram from reference [2] (© CIGRE 2017) – same basic principles/controls apply for all inverter based generation

# EMT Model

- Let us take a high-level look just to understand the concepts
- What is shown here is at a **generic level model**, based on the NREL public document https://www.nrel.gov/docs/fy15osti/62053.pdf
- ***Actual vendor specific models are typically black-box, and should be based on actual controls or  real-code***

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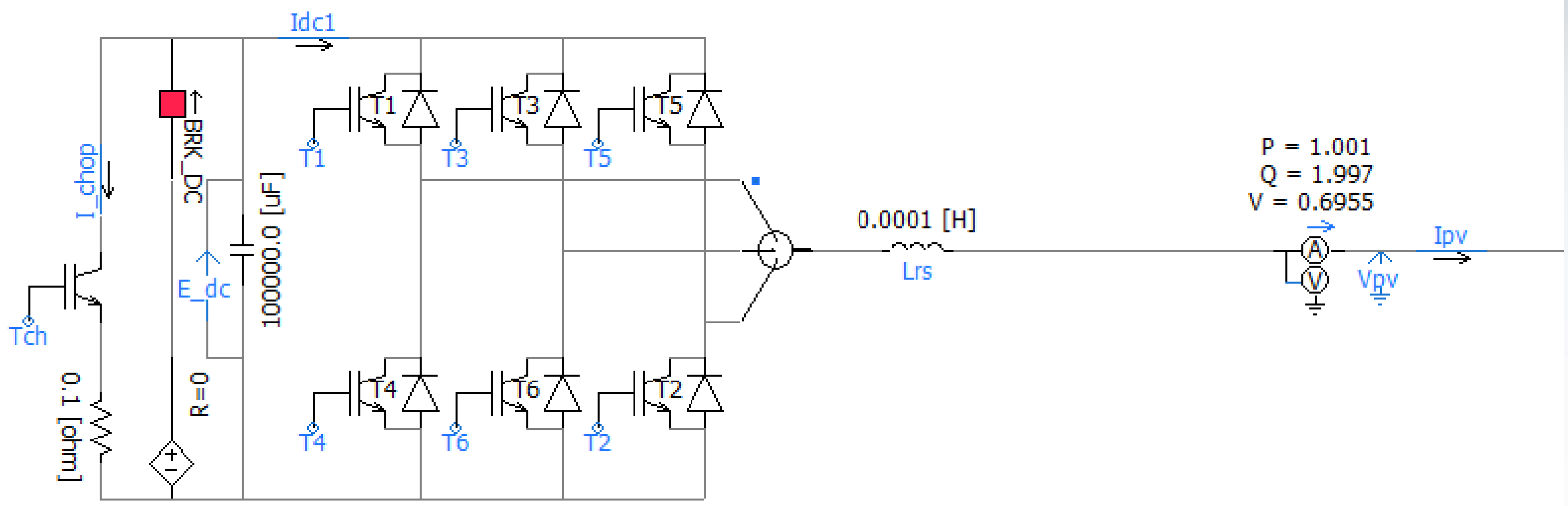
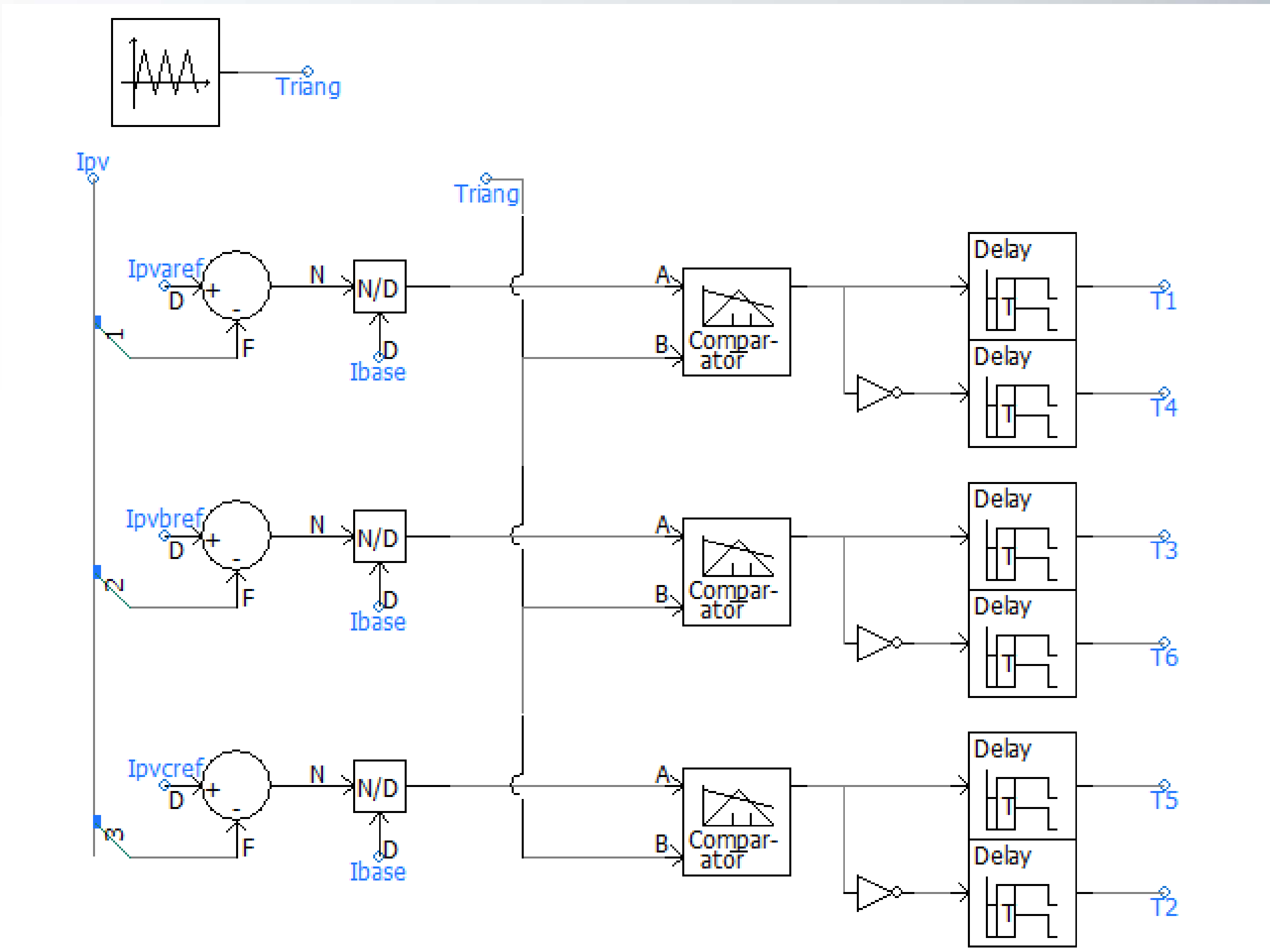
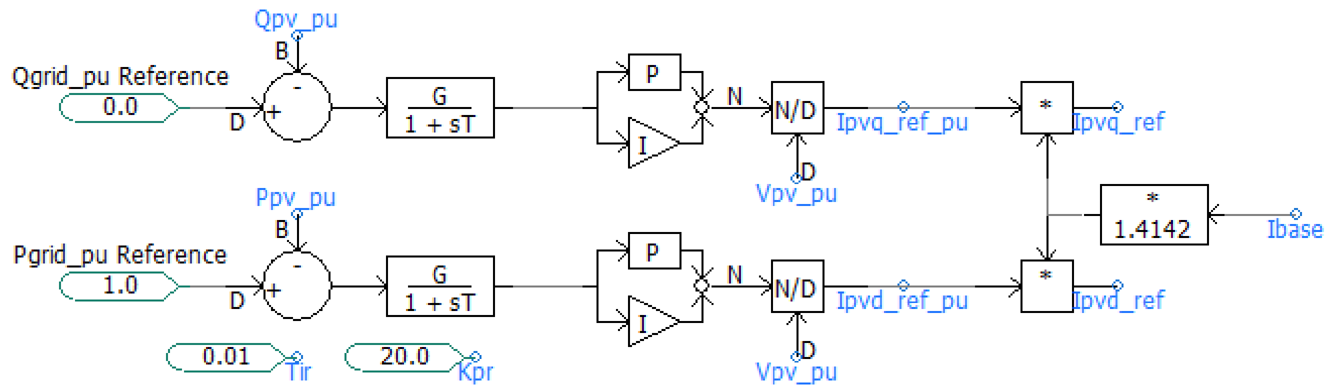
# Main Circuit of Inverter



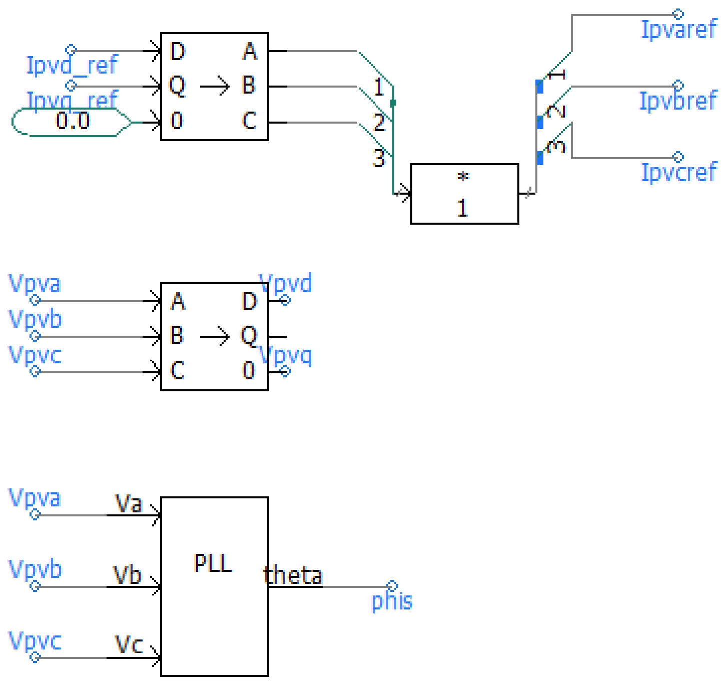
# PWM Controls



# Inner-Current Control Loops



# PLL



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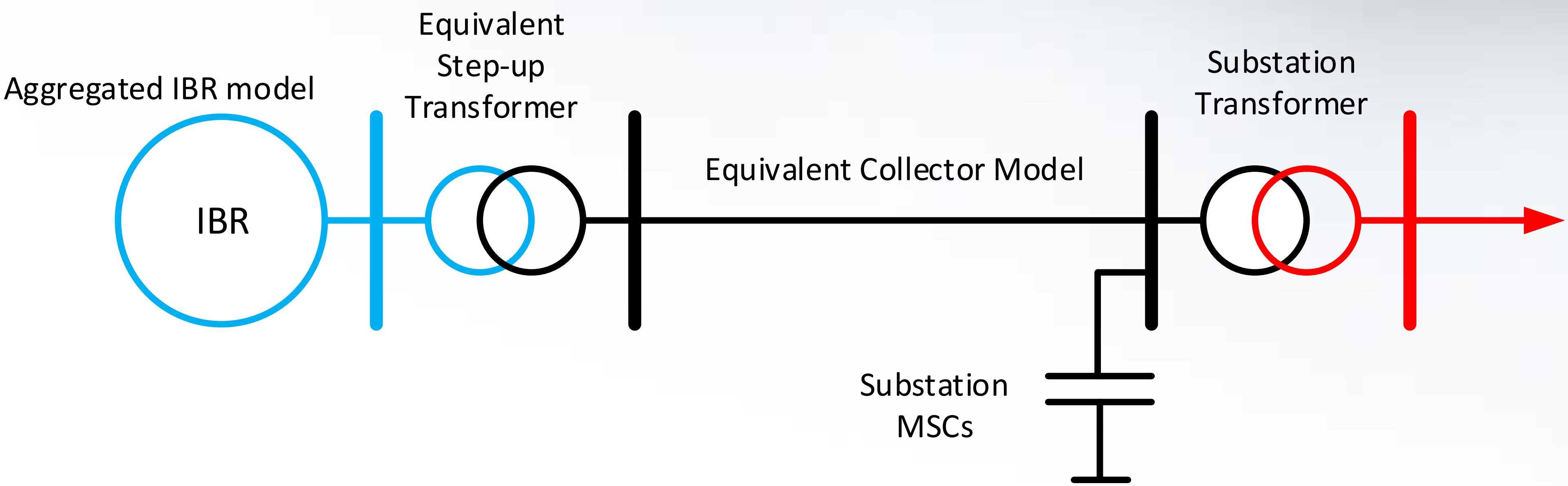
# IBR Plant Model



# Observations

- Collector model is an equivalent – often not practical nor desirable to model every piece of cable and each individual IBR one-by-one

- Thus, this is still a simplification and carries with it all the inherent assumptions

# Data Needed for EMT Modeling

- Detailed collector system data:
  - All cable lengths and geometry and parameters
- Detailed data on all substation equipment:
  - Substation transformer
  - Substation capacitor banks
- Detailed vendor specific EMT model for the IBR units
  - Good example of "ideal" model requirements are those provided by Electranix for PSCAD (see: http://www.electranix.com/wp-content/uploads/2020/05/PSCAD-Requirements-Rev.-9-May-2020.pdf)

# Modeling Considerations

- No model is perfect – all models include assumptions
- Certain details may not be included in the model, depending on the phenomenon under study

# Further Modeling Consideration

- May not need to model mechanical side in EMT (pitch-controls etc.)
- Are we studying switching surges or TRV, and so do we need to model stary capacitance, grading capacitors, bushing capacitance, CCVT, etc.?
- Considerations for modeling grounding transformers
- Inrush rector on MSCs
- How much of the EHV network is to be modeled?
  - Depends on phenomena to be studied
- Type of line/cable models:
  - Need for detailed over-head line tower geometry or distributed parameter line model adequate?
- Modeling transformers with precision:
  - Transformer winding configuration
  - Level of detail of transformer model again depends on phenomena under study – how detailed a model of transformer saturation is needed? Do we need a frequency-dependent model?
- Series capacitors:
  - Detailed model of over-voltage protection (MOV + trigger-gap; TPSC; etc.)
- Etc.

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# Bottom Line

- No model is perfect – the level of detail needed is driven by the phenomena under study

# References

[1] P. Pourbeik, J. Sanchez-Gasca, J. Senthil, J. Weber, P. Zadehkhost, Y. Kazachkov, S. Tacke and J. Wen, "Generic Dynamic Models for Modeling Wind Power Plants and other Renewable Technologies in Large Scale Power System Studies", *IEEE Trans. on Energy Conversion*, September 2017 https://ieeexplore.ieee.org/document/7782402

[2] P. Pourbeik and J. K. Petter, "Modeling and validation of battery energy storage systems using simple generic models for power system stability studies", *CIGRE Science and Engineering*, October 2017, pp. 63-72. (free download at: https://e-cigre.org/read_cse/read_cse.asp#readBook/63)

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