Dynamic Phasor Based Model of Single Phase Induction Motor

August 10, 2021
Load Modeling Update
WECC MVS Meeting Online

Jamie Weber, Ph.D.
Director of Software Development
weber@powerworld.com

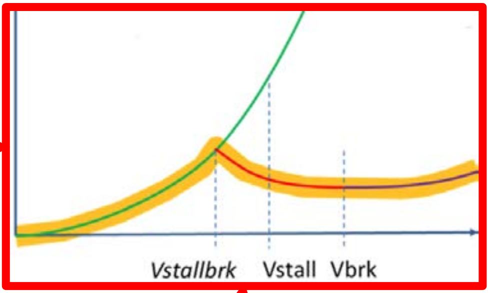
PowerWorld Corporation

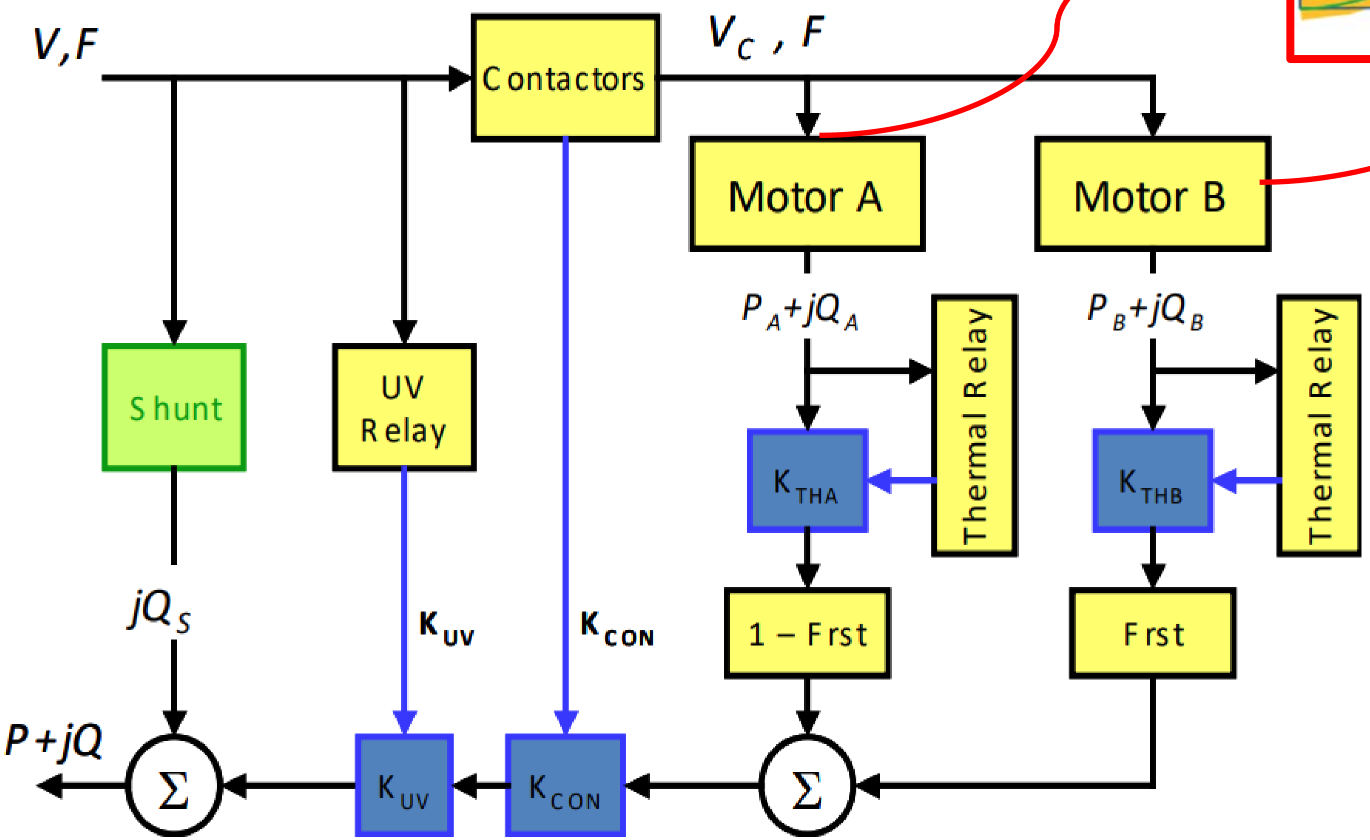
Summary

- Present the existing "Performance Model" LD1PAC for a single-phase induction motor model
- Show how Dynamic Phasor-based model (INDMOT1P) is different

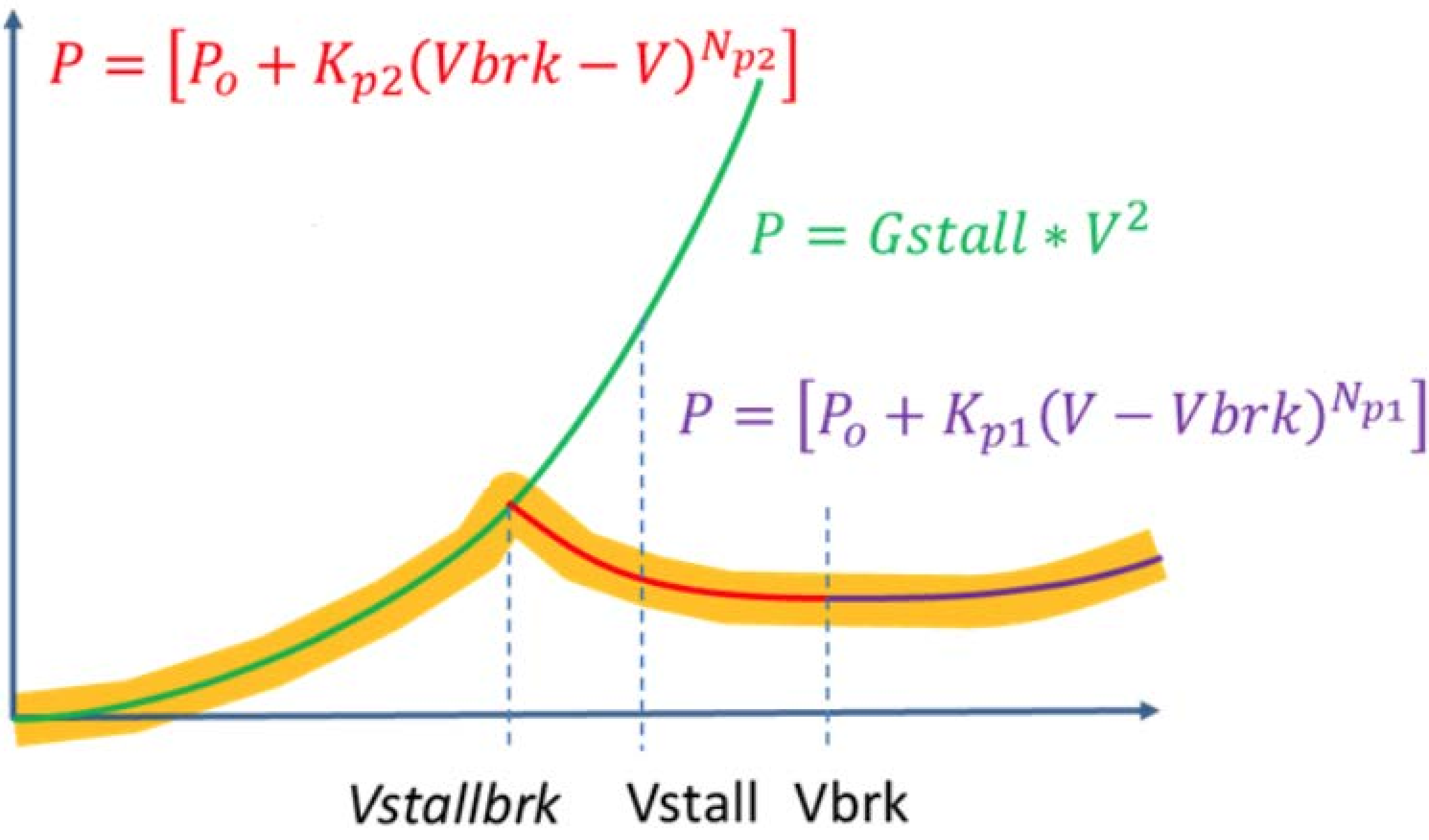
Existing "Performance Model" LD1PAC

- Dynamic Motor Equations are not used. Steady State only



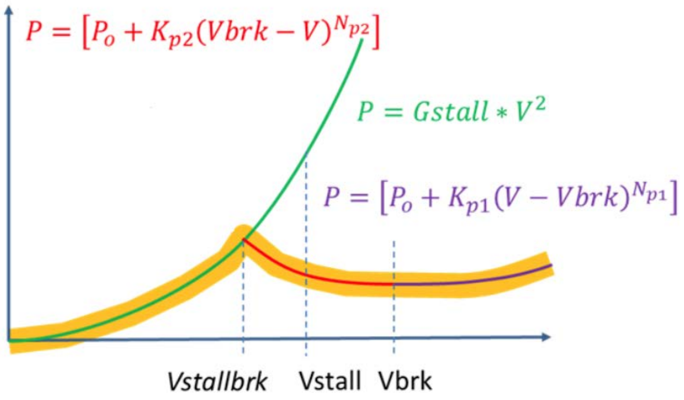


LD1PAC
Motor Equations



LD1PAC
Motor Equations

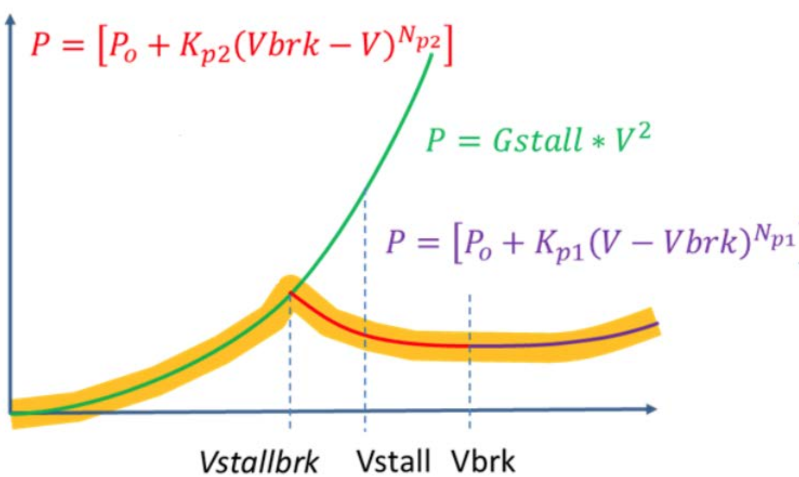
- Motor Speed ***<u>is not simulated</u>***
- These curves reflect steady-state behavior of motor
- All dynamic flux equations are ignored
  - No differential equations at all



- Model has 2 modes: "Stalled" or "Running"
  - Stalled means follow the green curve
  - Running means follow the yellow curve (which has 3 pieces)

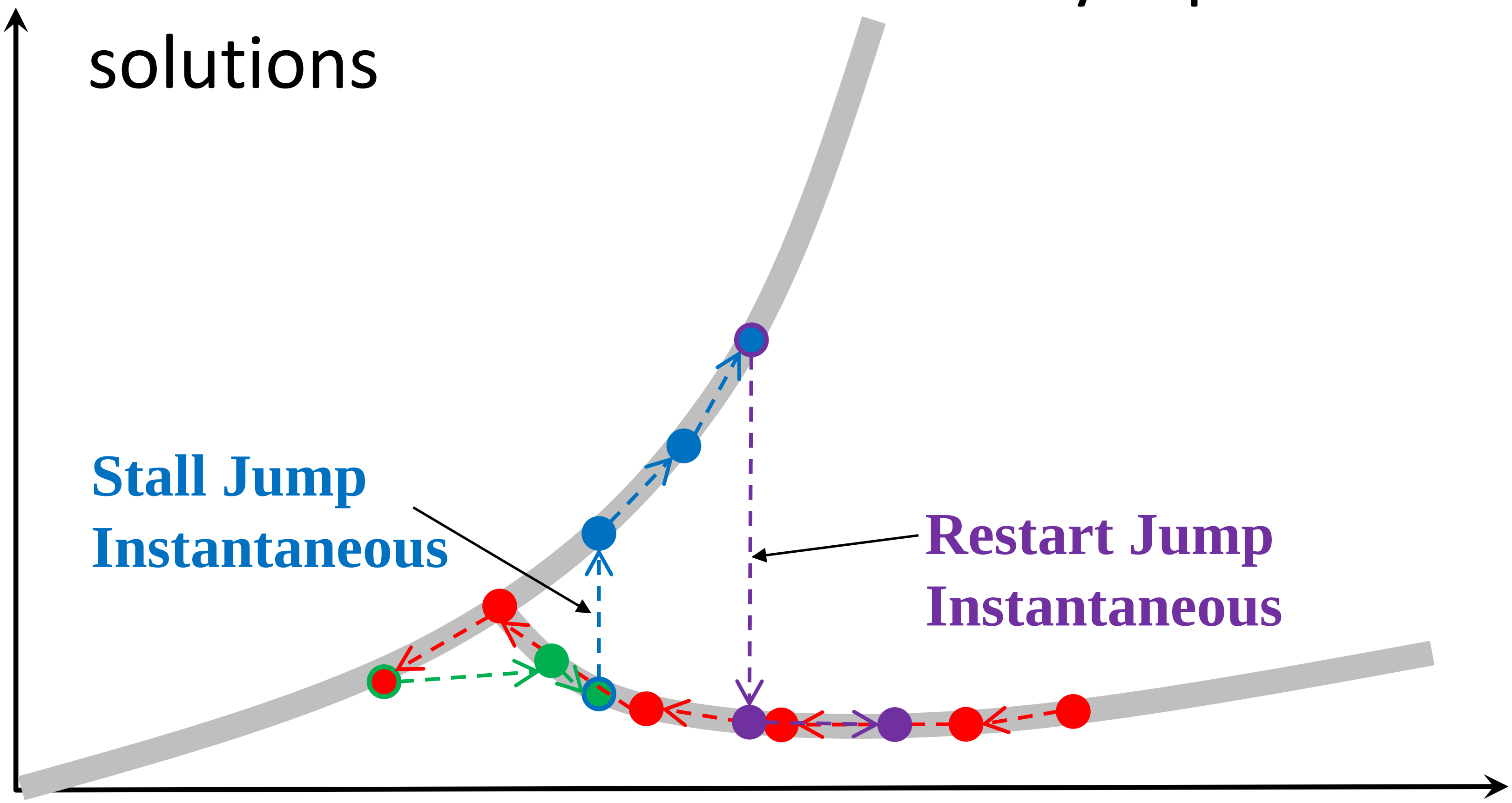
LD1PAC: Stall Transition is *Instantaneous*

- Transition between Stall and Running is done with a "relay-like" model
  - We have a definite time relay (Tstall, Vstall)
  - Also have hard-coded indefinite time relay option (Tstall < 0)
  - Regardless equations are in one mode or the other and it jumps *instantaneously* between the two modes



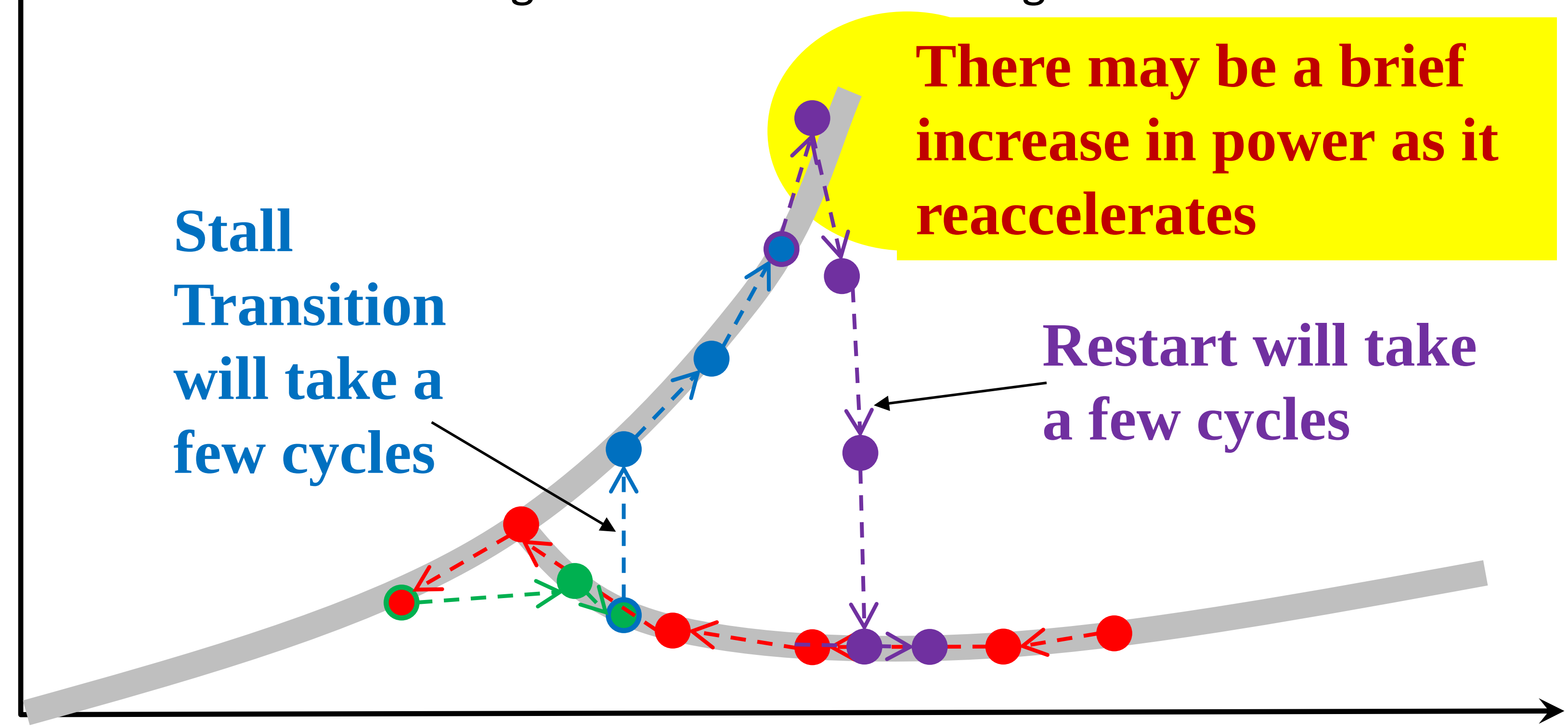
LD1PAC: Stall Transition is Instantaneous

- Instantaneous Jumps can cause numerical trouble with network boundary equation solutions



INDMOT1P Stall Transition: There will be a small time delay

- Not certain how a big an impact this will have on the system
  - Brief increase to reaccelerate motor might be important?
- It will be very beneficial for software though
  - Abrupt, algebraic mode changes in network boundary equations are difficult things for the numerical integration routines



Reference for INDMOT1P

- Phasor Modeling Approach for Single Phase A/C Motors by B. Lesieutre, D. Kosterev, and J. Undrill published in the 2008 IEEE Power and Energy Society General Meeting – Conversion and Delivery of Electrical Energy in the 21st Century
- Premise of the Model
  - There are an equal number of identical single phase motors and all three phases
  - Still a 3-phase balanced model and thus studying only the positive sequence of the model is appropriate
  - Model using a special coordinate transformation from the dq reference frame to a “forward rotating” and “backward rotating” field

Forward/Backward Flux Dynamics

- After lots of clever transformations the differential equations in the "forward/backward" reference frame are

$$T_o' \frac{d\left(\psi_{fR}\right)}{dt} = X_m I_{fR} - \psi_{fR} Sat + T_o' \omega_b (\omega_s - \omega_r) \psi_{fI}$$

$$T_o' \frac{d\left(\psi_{fI}\right)}{dt} = X_m I_{fI} - \psi_{fI} Sat - T_o' \omega_b (\omega_s - \omega_r) \psi_{fR}$$

Small Number

$$T_o' \frac{d\left(\psi_{bR}\right)}{dt} = X_m I_{bR} - \psi_{bR} Sat + T_o' \omega_b (\omega_s + \omega_r) \psi_{bI}$$

Large Number

$$T_o' \frac{d\left(\psi_{bI}\right)}{dt} = X_m I_{bI} - \psi_{bI} Sat - T_o' \omega_b (\omega_s + \omega_r) \psi_{bR}$$

$$2H \frac{d\omega_r}{dt} = 2 \frac{X_m}{X_r} \left(I_{fI} \psi_{fR} - I_{fR} \psi_{fI} - I_{bI} \psi_{bR} + I_{bR} \psi_{bI} \right) - T_{mech}$$

Simplification

- Insight of Lesieutre, Kosterev, Undrill was that the backward dynamics are very fast
  - $\omega_s + \omega_r \approx 2.0$ → backward dynamics fast
  - $\omega_s - \omega_r \approx slip$ → forward dynamics slower
- Approximate those dynamics by treating them as infinitely fast
  - Those equations become algebraic in the same way the stator dynamic equations of a synchronous machine are treated as algebraic

Dynamic Equations for INDMOT1P

- This model has characteristics similar to a 3-phase induction motor
  - Mvar output is solved for at initialization, thus "ExtraVars" modeled as a shunt are required
  - Initialization requires an iterative solution to determine the initial rotor speed
- These equations are documented in great detail on PowerWorld's public help documentation on our website
  - Thanks to Joe Eto at Lawrence Berkeley National Lab for helping me make the time to write this all up
  - https://www.powerworld.com/WebHelp/Default.htm#TransientModels_HTML/Load%20Characteristic%20INDMOT1P.htm
    - 13 pages of mathematical theory
    - 12 pages of pseudo code documenting the numerical implementation in PowerWorld Simulator

Example Simulation of INDMOT1P