
Open Phase Detection

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EMTP User's Group Meeting

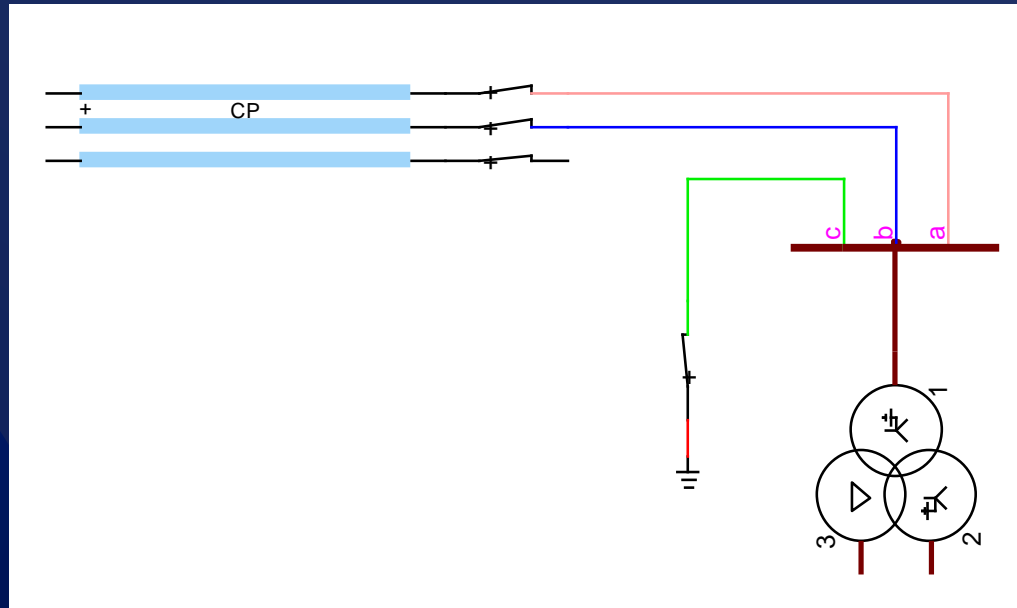
6/6/2014



Overview

- Open Phase Events
- Modeling Approach
 - Transformers
 - Transmission System
 - Plant Auxiliary System
 - Scripting

Byron Event (January 30th, 2012)



- Failed insulator on Unit 2 reserve transformer caused busbar to disconnect and fall to the ground
- Transmission source remained open, so there wasn't a high fault current

Byron Unit 2 Event

- Motors tripped due to overcurrent, causing a trip of the main generator
- Bus voltage on low side of XFMR remained relatively healthy, so buses were not automatically transferred to diesels
- After 8 minutes, operators manually tripped the feed

Regulatory Response

- NRC Bulletin 2012-1
- Considers failure to detect as a design vulnerability
- Common to nearly all nuclear plants in the US

Other Events

- Byron Unit 1 (Feb 2012)
- Bruce Unit 1 (Dec 2012)
- Forsmark (May 2013)
- Fitzpatrick Unit 1 (Dec 2005)
- Beaver Valley Unit 1 (Nov 2007)



Modeling Approach

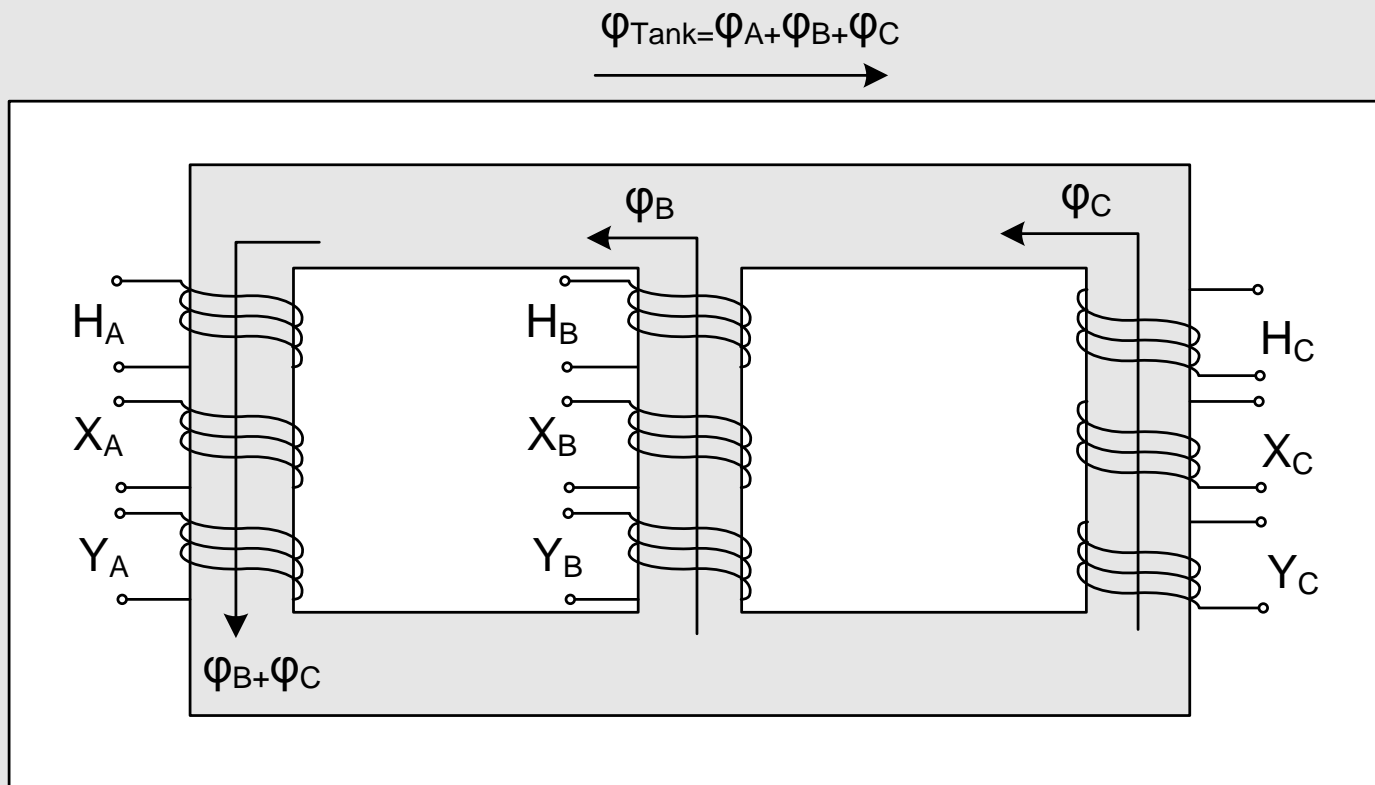
- Transformers
- Transmission System
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Transformers

- Most critical system component for open phase analysis
- Results are sensitive to core type and winding configuration



Core Type Transformer



BCTRAN Model

- Uses coupled R-L matrix
- Parameters are determined based on positive and zero sequence excitation and short circuit test data
- Zero sequence excitation data is most critical (and most difficult to get)

BCTRAN Model

RL coupled multiphase branch

Number of phases: 6
 Test grid data:

R Ω

R	1	2	3	4	5
1	59.4015	0	0	0	0
2	0	0.0237606	0	0	0
3	0	0	59.4015	0	0
4	0	0	0	0.0237606	0
5	0	0	0	0	59.4015

Make symmetric using upper matrix

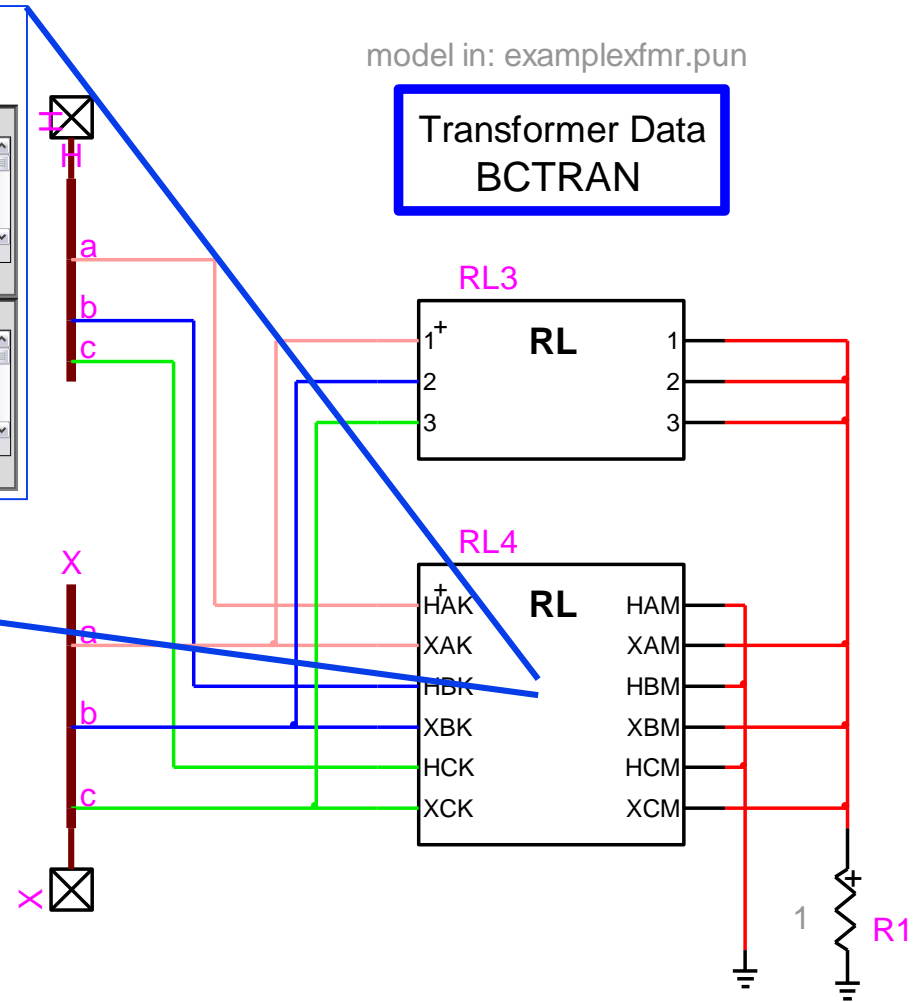
L

L	1	2	3	4	5
1	801125.0554	15999.25772	-394060.158	-7880.805049	-394060.158
2	15999.25772	319.9851544	-7880.805049	-157.816101	-7880.805049
3	-394060.158	-7880.805049	801125.0554	15999.25772	-394060.158
4	-7880.805049	-157.816101	15999.25772	319.9851544	-7880.805049
5	-394060.158	-7880.805049	-394060.158	-7880.805049	801125.0554

Make symmetric using upper matrix

model in: examplexfmr.pun

Transformer Data
BCTRAN



BCTRAN Difficulties

- Lack of data
- Linear model
- Sometimes numerically unstable (high condition number)

Transmission System

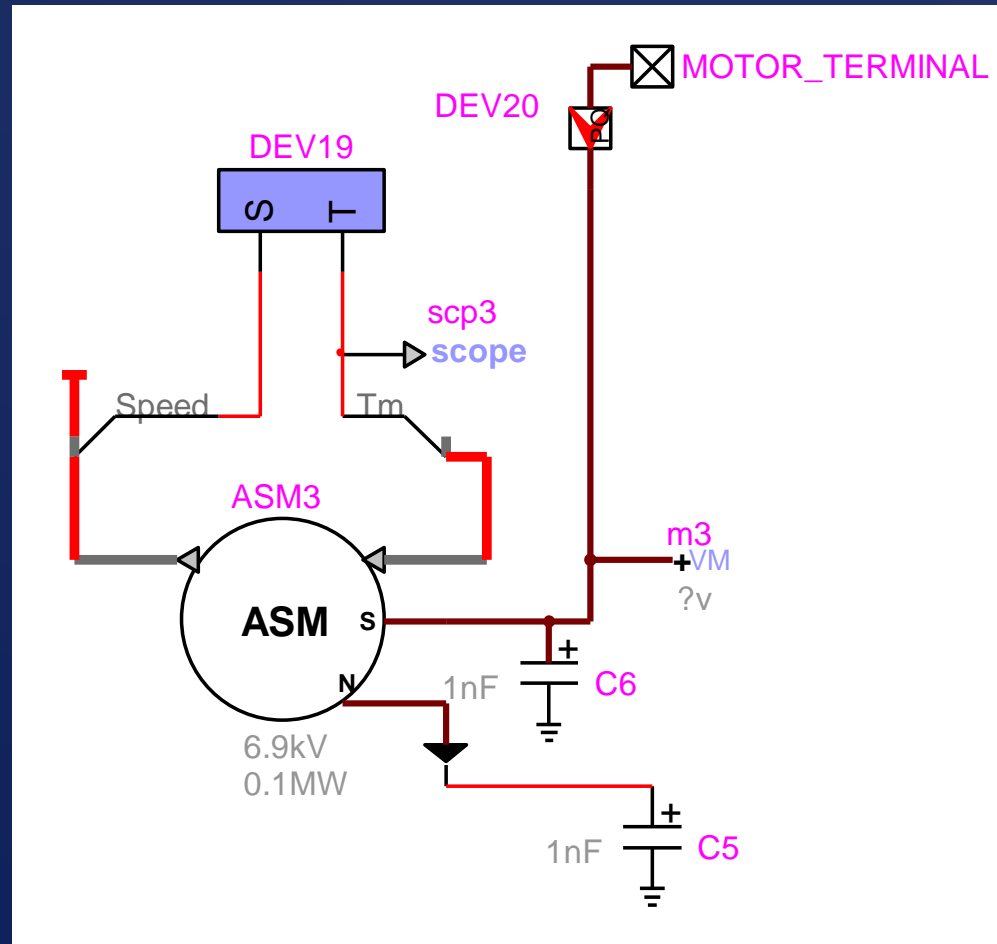
- Unbalances in transmission system can mimic open phase conditions when the transformer is under light loading
- Little or no historical data exists for transmission system unbalance
- Typical system operability criteria is $\pm 3\%$ voltage magnitude unbalance
- Phase angle variation is also important

Transmission System Modeling

- Many different approaches
 - Lumped Thevenin Equivalent with varied voltage magnitude and phase
 - Modeling nearby lines in detail

Auxiliary System Modeling

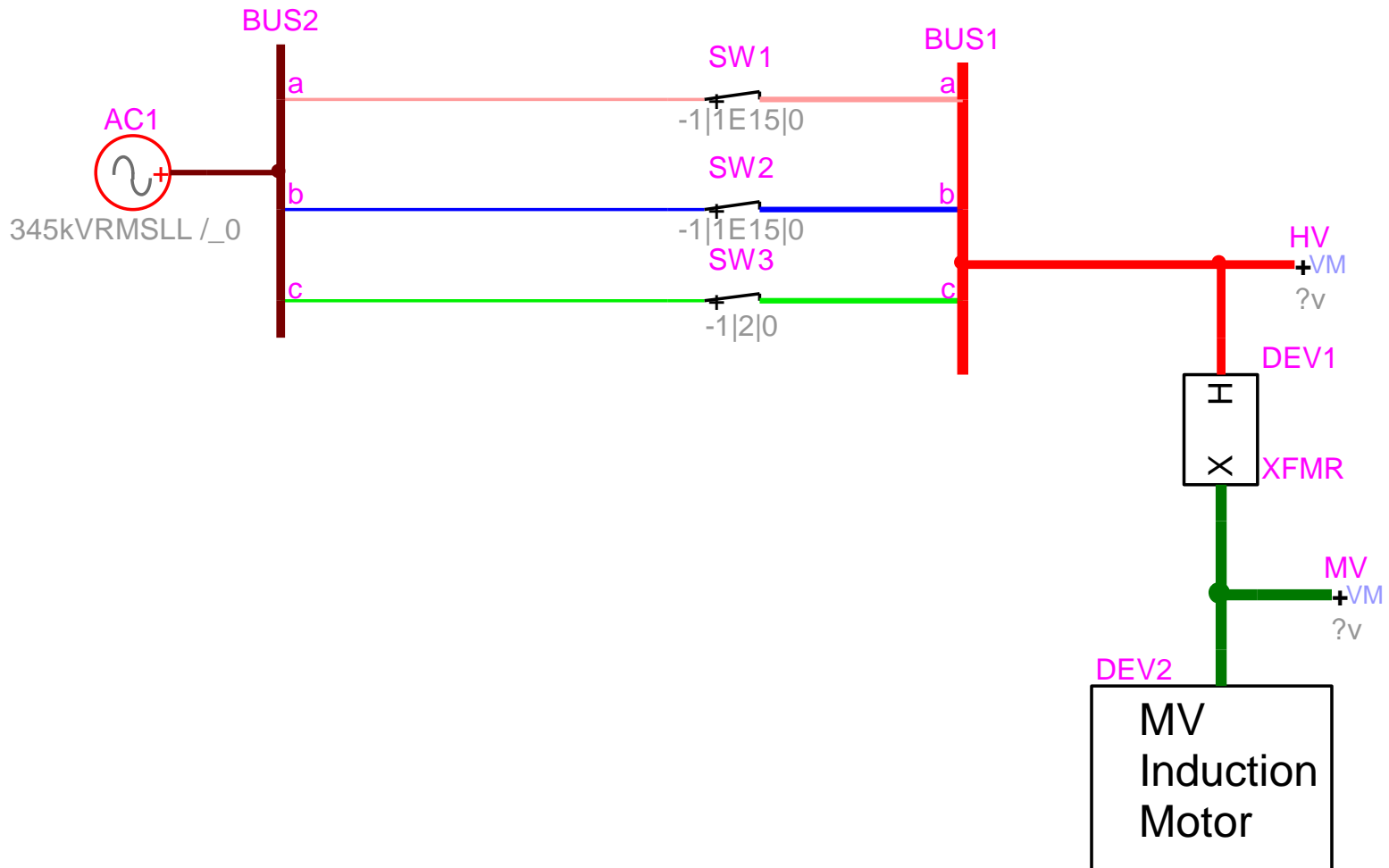
- Load torque curves allow proper modeling of motor stalling behavior



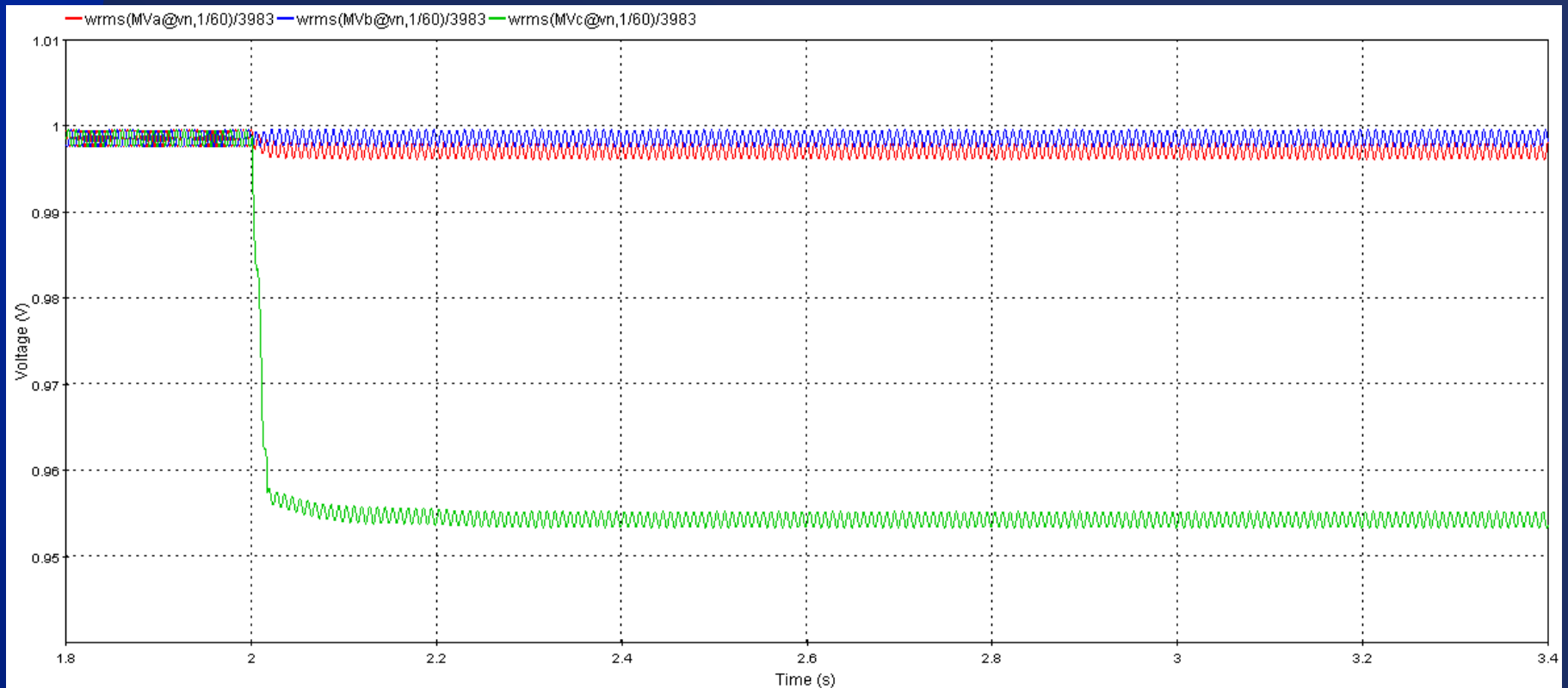
Scripting

- Due to large number of case runs, it is necessary to write scripts to automate batch runs
- Utilize built-in as well as custom Javascript functions
- Divide case runs to multiple processors on a multi-core machine

Example



Results – Light Load



Results – Heavy Load

