# Distribution System Analysis

## Panel Session – Induction Machine Modeling

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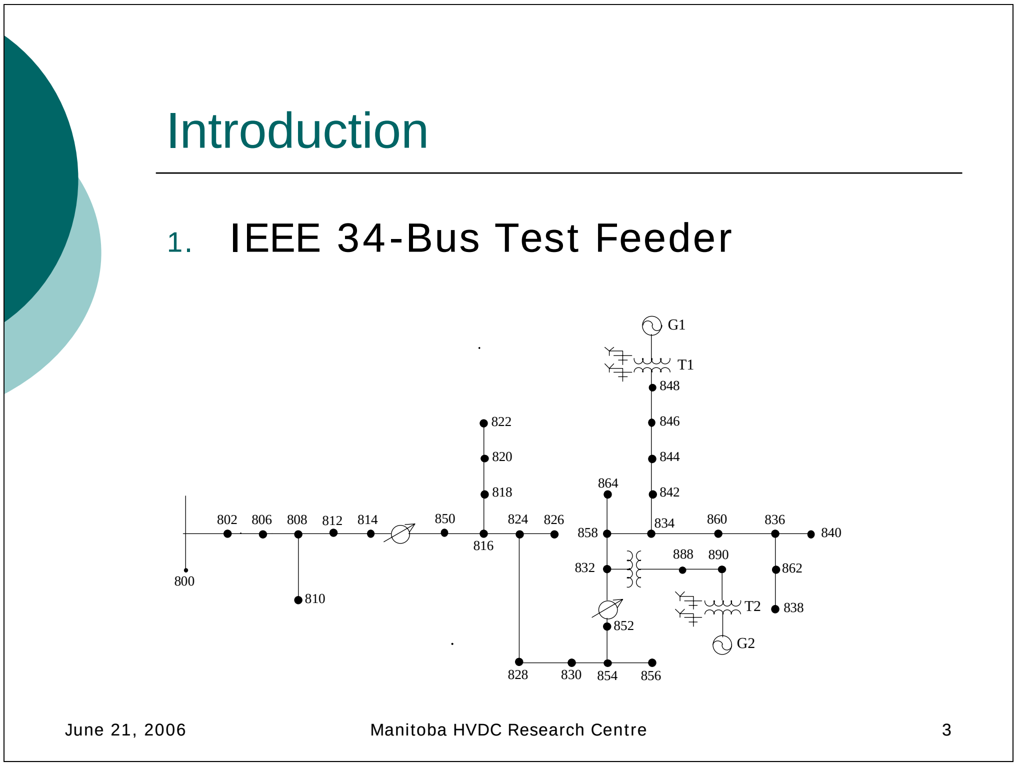
Paul Wilson

Authors: Dr. Santoso, Dr. Muthumuni, Jen Z. Zhou

Manitoba HVDC Research Centre

## Agenda

1. Introduction
2. System Modeling
3. Power Flow Validation
4. Wind Generator Modeling
5. Slip and Power Flow Results
6. Short-Circuit Analysis
7. Conclusions




Key points:

-PSCAD Model was built of the IEEE 34 Bus test system.

-Model include all transformers, regulators plus controls, induction generators, loads, distribution lines, and wind turbines.

-Model power flows are validated against the benchmarks.

-The case was solved in 114s for a 6s run using a time step of 250us (no induction machines). The same case with induction machines solved in 181s.

## Distribution System Modeling

1. Unbalanced Distribution Line
2. Distributed loads
3. Phase load (constant pq, Z, and I)
4. Phase to Phase load
5. Regulators and controls



Key points:

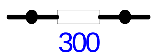
-The first test case included these elements to validate against a power flow.

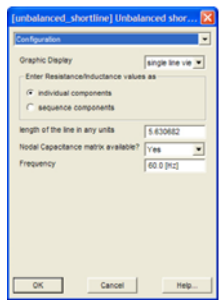
-Subsequent slides document what was done for each element.

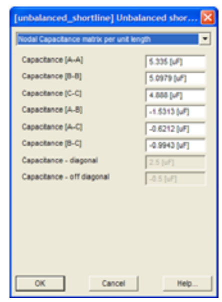
System Modeling

# 1. Unbalanced Distribution Line

- A mutually coupled wires are used
- Z & B matrices are directly entered

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Key points:

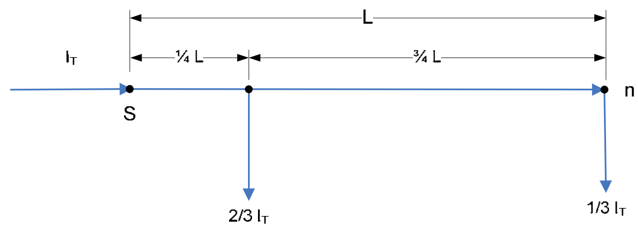
-Each type of standard construction was modeled. Six types of construction models included 300, 301, 302, 303, 304 and 305.

-Specification of Susceptance (B) values precluded use of standard models, thus a new component was created to address the tightly coupled unbalanced distribution line.

-The lack of long transmission lines enforces a large and tightly couple matrix in this analysis.  This makes it difficult for an efficient solution in the time domain when transmission line boundaries can not be used to form subsystems.

## 2. Distributed loads

- One-third of the load is placed at the end of line
- Two-thirds of the load be placed one-forth of the way from the source end






Key points:

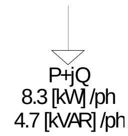
-Distributed load was modeled as above. This is based on a reference (Get from Surya)

-Load is connected at the interface points to match its unbalance requirements.

System Modeling

## 3. Phase load (constant pq, Z, and I)

- Constant power
  - Np=Nq=0
  - Kpf=Kqf=0
- Constant Z
  - Np=Nq=2
  - Kpf=Kqf=0
- Constant Current:
  - Np=Nq=1
  - Kpf=Kqf=0




$$P = P_0 \cdot \left(\frac{V}{V_0}\right)^{NP} \cdot (1 + K_{PF} \cdot dF)$$

$$Q = Q_0 \cdot \left(\frac{V}{V_0}\right)^{NQ} \cdot (1 + K_{QF} \cdot dF)$$

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Key points:

-A standard PSCAD model was used for phase to ground loads, formulas is widely used in industry

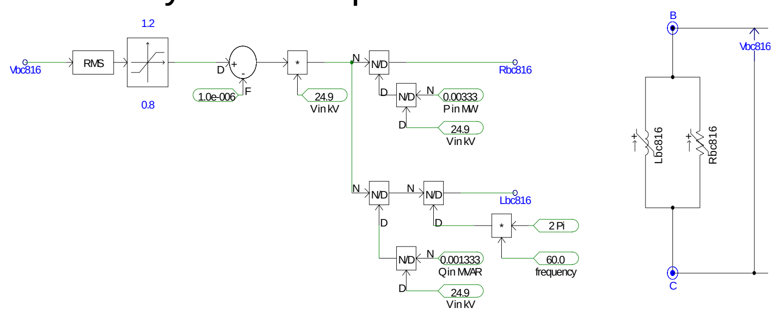
-Constant PQ, constant impedance, constant current is modeled depending on the parameters entered.

-Frequency variability in the load is not considered.

System Modeling

# 4. Phase to Phase load

- The phase to phase load is represented by a variable resistor and inductor whose values are updated at every time-step.

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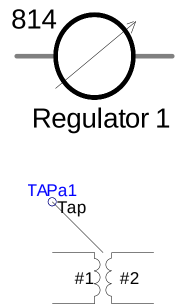
Key points:

-Phase to phase load modelled as R//L circuit adjusted with voltage every time step.

-More research work is required accurate load modeling in a time domain algorithm.

# 5. Regulators and controls

- 1-Phase 2-Winding Transformer with online tap changer
- Regulator controls include
  - Set voltage
  - Initial tap setting
  - Bandwidth
  - Out-of-band detector
  - Control time delay
  - Tap position calculator
  - Timer reset
  - Line compensation






Key points:

-A regulator model needed to be built to accommodate the IEEE benchmark case

-Standard single phase transformers were used with very low leakage reactance and zero losses. No information was available on this but this can easily be added in PSCAD.

-Regulator control built to model a realistic regulator control with V setting, R, X, BW, Timer reset and Time delays.

-Regulators sequenced in time similar to a real regulator voltage control application.

# PSCAD Power Flow Results

| Node Voltage pu | | | |
|---|---|---|---|
| Node | A-N | B-N | C-N |
| 800 | 1.05 | 1.05 | 1.05 |
| 802 | 1.047 | 1.048 | 1.048 |
| 806 | 1.046 | 1.047 | 1.047 |
| 808 | 1.014 | 1.03 | 1.029 |
| | | | |
| 810 | | 1.029 | |
| 812 | 0.9769 | 1.01 | 1.006 |
| 814 | 0.9474 | 0.9943 | 0.9887 |
| 850 | 1.018 | 1.025 | 1.02 |
| 816 | 1.018 | 1.025 | 1.019 |
| | | | |
| 818 | 1.017 | | |
| 820 | 0.9941 | | |
| 822 | 0.9912 | | |
| 824 | 1.009 | 1.016 | 1.011 |
| | | | |
| 826 | 1.016 | | |
| 828 | 1.008 | 1.015 | 1.01 |
| 830 | 0.9903 | 0.998 | 0.9929 |
| 854 | 0.9898 | 0.9976 | 0.9925 |
| | | | |
| 852 | 0.9589 | 0.9678 | 0.9627 |
| 832 | 1.037 | 1.034 | 1.035 |
| | | | |
| 858 | 1.034 | 1.032 | 1.033 |
| | | | |
| 834 | 1.032 | 1.029 | 1.03 |
| | | | |

| Power Flow kW/kVR | | | | | | |
|---|---|---|---|---|---|---|
| | P | Q | P | Q | P | Q |
| Node | A | A | B | B | C | C |
| 800 | 757.9 | 174.1 | 666.2 | 87.94 | 620.5 | 31.02 |
| 802 | 756.3 | 169 | 665.2 | 87.8 | 619.6 | 31.04 |
| 806 | 755.2 | 168.8 | 633.3 | 75.46 | 593.3 | 14.78 |
| 808 to 812 | 735.1 | 164.5 | 606.4 | 64.44 | 582.3 | 18.32 |
| 808 to 810 | | | 16.63 | 7.218 | | |
| 810 | | | 0 | 0 | | |
| 812 | 711.6 | 158.8 | 595.4 | 62.79 | 569.4 | 18.06 |
| 814 | 692.8 | 150.5 | 586.7 | 61.8 | 559.1 | 17.45 |
| 850 | 692.8 | 150.5 | 586.7 | 61.8 | 559.1 | 17.45 |
| 816 to 824 | 521.7 | 75.86 | 586.5 | 61.79 | 559 | 17.44 |
| 816 to 818 | 170.8 | 76.62 | | | | |
| 818 | 170.7 | 77.63 | | | | |
| 820 | 132.8 | 66.52 | | | | |
| 822 | 0 | 0 | | | | |
| 824 to 828 | 517.5 | 75.27 | 537.6 | 39.81 | 552.3 | 13.9 |
| 824 to 826 | | | 40.46 | 19.38 | | |
| 826 | 0 | 0 | | | | |
| 828 | 517.1 | 78.47 | 537.3 | 39.79 | 548 | 10.35 |
| 830 | 486.4 | 61.3 | 518.3 | 38.37 | 520 | 9.81 |
| 854 to 852 | 486.2 | 64.46 | 514.2 | 38.08 | 519.8 | 9.81 |
| 854 to 856 | | | 3.887 | -1.915 | | |
| 852 | 472.4 | 65.68 | 498.9 | 40.1 | 503.9 | 6.34 |
| 832 to 858 | 319.6 | -20 | 345.8 | -44.1 | 353.6 | -76.7 |
| 832 to 888 | 152.8 | 85.24 | 153.1 | 82.91 | 150.3 | 82.14 |
| 858 to 834 | 310 | -21.43 | 340.6 | -47.8 | 347.8 | -75.5 |
| 858 to 864 | 2.056 | 0.739 | | | | |
| 834 to 842 | 174.7 | -133.3 | 211.6 | -116.2 | 183.5 | -126.9 |
| 834 to 860 | 127.5 | 106.5 | 116.6 | 67.19 | 149.6 | 45.59 |



Key points:

-PSCAD model validated against published results with small errors. See error slide for comparison.

# PSCAD Power Flow Results

| Node Voltage pu | | | |
|---|---|---|---|
| Node | A-N | B-N | C-N |
| 842 | 1.032 | 1.029 | 1.03 |
| 844 | 1.031 | 1.029 | 1.03 |
| 846 | 1.032 | 1.029 | 1.03 |
| 848 | 1.032 | 1.029 | 1.03 |
| 860 | 1.031 | 1.029 | 1.03 |
| 836 | 1.031 | 1.028 | 1.03 |
| | | | |
| 840 | 1.031 | 1.029 | 1.03 |
| 862 | 1.031 | 1.029 | 1.03 |
| 838 | | 1.028 | |
| 864 | 1.034 | | |
| 888 | 0.9961 | 1.004 | 0.9962 |
| 890 | 0.9134 | 0.9294 | 0.9138 |
| 856 | | 0.9976 | |

| Power Flow kW/kVR | | | | | | |
|---|---|---|---|---|---|---|
| | P | Q | P | Q | P | Q |
| Node | A | A | B | B | C | C |
| 842 | 174.7 | -133.3 | 211.6 | -116.2 | 183.4 | -126.9 |
| 844 | 20.66 | -144.5 | 68.28 | -120.8 | 40.81 | -132.8 |
| 846 | 20.66 | -143.5 | 42.34 | -132.3 | 20.57 | -143.7 |
| 848 | 20.45 | -143.4 | 19.35 | -142.9 | 20.75 | -143 |
| 860 | 55.29 | 28.12 | 76.31 | 44.05 | 47.7 | 23.23 |
| 836 to 840 | 21.31 | 6.48 | 30.6 | 15.91 | 17.13 | 19.29 |
| 836 to 862 | | | 28.07 | 12.88 | | |
| 840 | 9.34 | 7.295 | 9.29 | 7.139 | 9.192 | 7.182 |
| 862 | | | 28.06 | 13.07 | | |
| 838 | | | 0 | 0 | | |
| 864 | 0 | 0 | | | | |
| 888 | 147.8 | 76.53 | 151.4 | 77.8 | 147.3 | 77.07 |
| 890 | 136.8 | 69.55 | 140.8 | 69.56 | 135.6 | 68.3 |
| 856 | | | 0 | 0 | | |

| Voltage Regulator | | | | |
|---|---|---|---|---|
| | Node 814 | | Node 852 | |
| Phase | IEEE | PSCAD | IEEE | PSCAD |
| A | 12 | 13 | 13 | 13 |
| B | 5 | 5 | 11 | 13 |
| C | 5 | 5 | 12 | 13 |



Key points:

-PSCAD results are very close

-Largest real power error <1% without machines.

# Errors

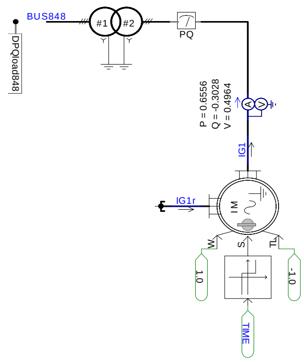
| Node Voltage % | | | |
|---|---|---|---|
| Node | A-N | B-N | C-N |
| 800 | 0.00% | 0.00% | 0.00% |
| 802 | -0.05% | -0.04% | -0.04% |
| 806 | 0.03% | -0.04% | -0.04% |
| 808 | 0.04% | 0.04% | -0.06% |
| | | | |
| 810 | | -0.04% | |
| 812 | 0.06% | 0.00% | -0.09% |
| 814 | 0.07% | -0.02% | -0.06% |
| 850 | 0.04% | -0.05% | -0.03% |
| 816 | 0.08% | -0.05% | -0.10% |
| | | | |
| 818 | 0.07% | | |
| 820 | 0.15% | | |
| 822 | 0.17% | | |
| 824 | 0.08% | 0.02% | -0.06% |
| 826 | | 0.04% | |
| 828 | 0.06% | -0.01% | -0.09% |
| 830 | 0.09% | -0.02% | -0.09% |
| 854 | 0.08% | -0.02% | -0.09% |
| | | | |
| 852 | 0.08% | -0.02% | -0.10% |
| 832 | 0.11% | -0.05% | -0.10% |
| | | | |
| 858 | 0.04% | -0.02% | -0.08% |
| | | | |
| 834 | 0.11% | -0.05% | -0.13% |
| 842 | 0.11% | -0.04% | -0.13% |
| 844 | 0.03% | -0.01% | -0.11% |
| 846 | 0.11% | -0.01% | -0.13% |
| 848 | 0.10% | -0.01% | -0.14% |
| 860 | 0.05% | -0.01% | -0.10% |
| 836 | 0.07% | -0.07% | -0.08% |
| | | | |
| 840 | 0.07% | 0.03% | -0.08% |
| 862 | 0.07% | 0.03% | -0.08% |
| 838 | | -0.05% | |
| 864 | 0.04% | | |
| 888 | -0.36% | 0.57% | -0.38% |
| 890 | -1.37% | 0.03% | 0.07% |
| 856 | | -0.01% | |



Excellent agreement in load flow, generally much less than 0.2%

# Wind Generators

Two induction generators added at buses 848 and 890 to Represent 660 kW wind turbine generators.




- Results agree with steady state calculations.



Key points:

-Squirrel cage induction motors modeled using wound rotor model. Rotor currents are monitored for additional analysis.

# Wind Generators

Two induction generators added at buses 848 and 890 to Represent 660 kW wind turbine generators.

- Results agree with steady state calculations.

| Slip | | | |
|---|---|---|---|
| Node 848 | | Node 890 | |
| IEEE | PSCAD | IEEE | PSCAD |
| -0.00751 | -0.0073 | -0.00912 | -0.0087 |

| | Voltage Regulator | | | |
|---|---|---|---|---|
| | Node 848 | | Node 890 | |
| Phase | IEEE | PSCAD | IEEE | PSCAD |
| A | 6 | 8 | 6 | 5 |
| B | 1 | 1 | 6 | 6 |
| C | 0 | 2 | 5 | 6 |

| Reactive Power (KVar) | |
|---|---|
| Node 848 | Node 890 |
| 312 | 316 |

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Key points:

-PSCAD modeled generator slip agree very closely in steady state.

-Slip error is 2.7%, 4.6% are small.

-Regulator tap position differ slightly in this solved case. This can be due to the differences in dead band control of the regulator, and distributed load modelling differences.

# Wind Generators

- Results agree with steady state calculations.

| Generator Node Voltage (V) | | | |
|---|---|---|---|
| Node 848 | | Node 890 | |
| IEEE | PSCAD | IEEE | PSCAD |
| 282 | 284 | 259 | 262 |
| 281 | 285 | 258 | 265 |
| 282 | 285 | 260 | 263 |

| | Generator currents (A) | | | |
|---|---|---|---|---|
| | Node 848 | | Node 890 | |
| | IEEE | PSCAD | IEEE | PSCAD |
| Positive seq | 871 | 855 | 953 | 925 |
| Negative Seq. | 21 | 12 | 22 | 13 |

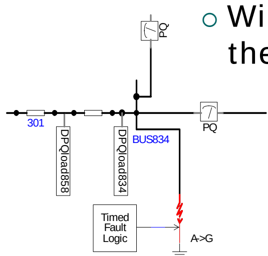


Key points:

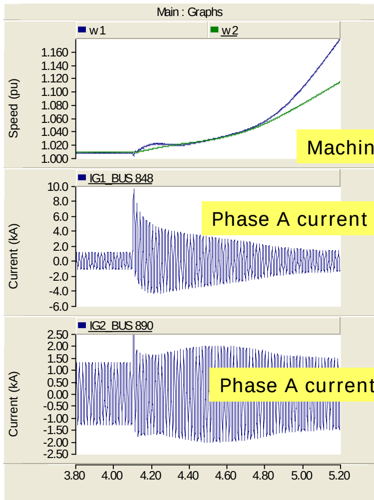
-Error percentages on the generator pos seq currents < 2.9%

# Wind Generators

- Fault on Bus 834
  - A-G Fault (not cleared)
  - A number of factors are important
    - Machine inertia
    - Wind turbine characteristic will determine the input torque variation.



# Wind Generators




Machine speed (Slip)

Phase A current – Gen. 1 at Bus 848

Phase A current – Gen. 2 at Bus 890

Note:
Machine 1(Bus 848) – Smaller inertia – H=1 pu
Machine 2(Bus 890) – Larger inertia – H=2.5 pu

- Fault on Bus 834

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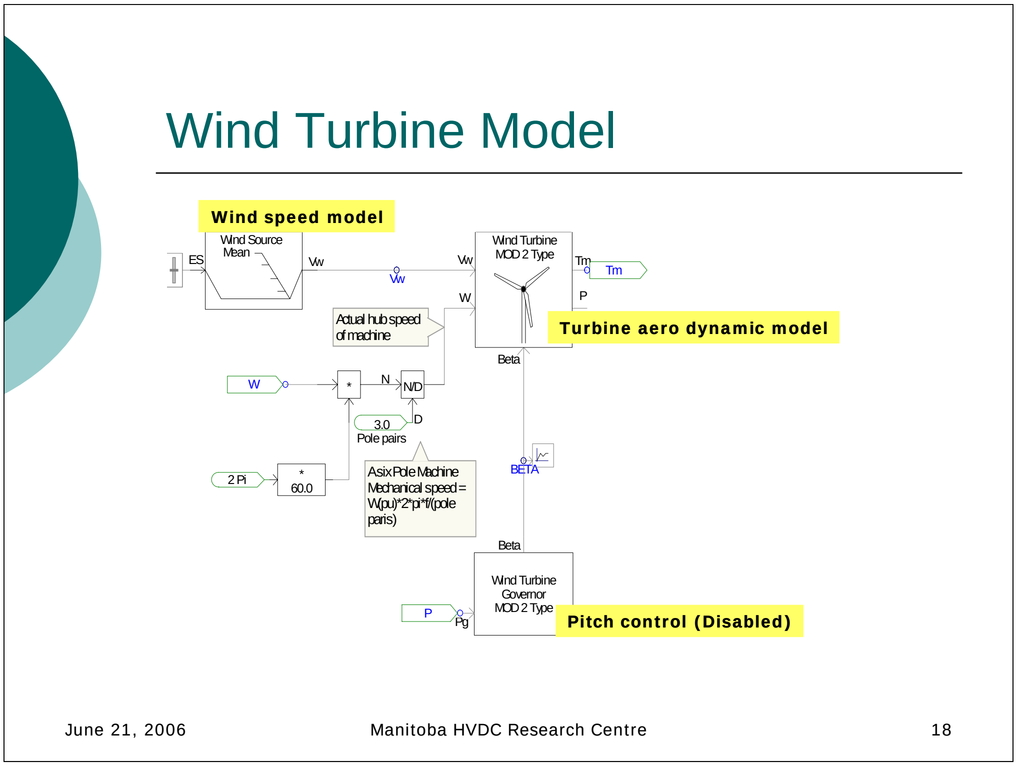
Key points:

-Fault is applied, generator currents vary widely as the fault develops

-Machine speed is dependent on machine inertia (data was not provided so two typical values were assumed H=1, and H =2.5)

-Machine response assume constant Torque, this may not be realistic depending on the machine.

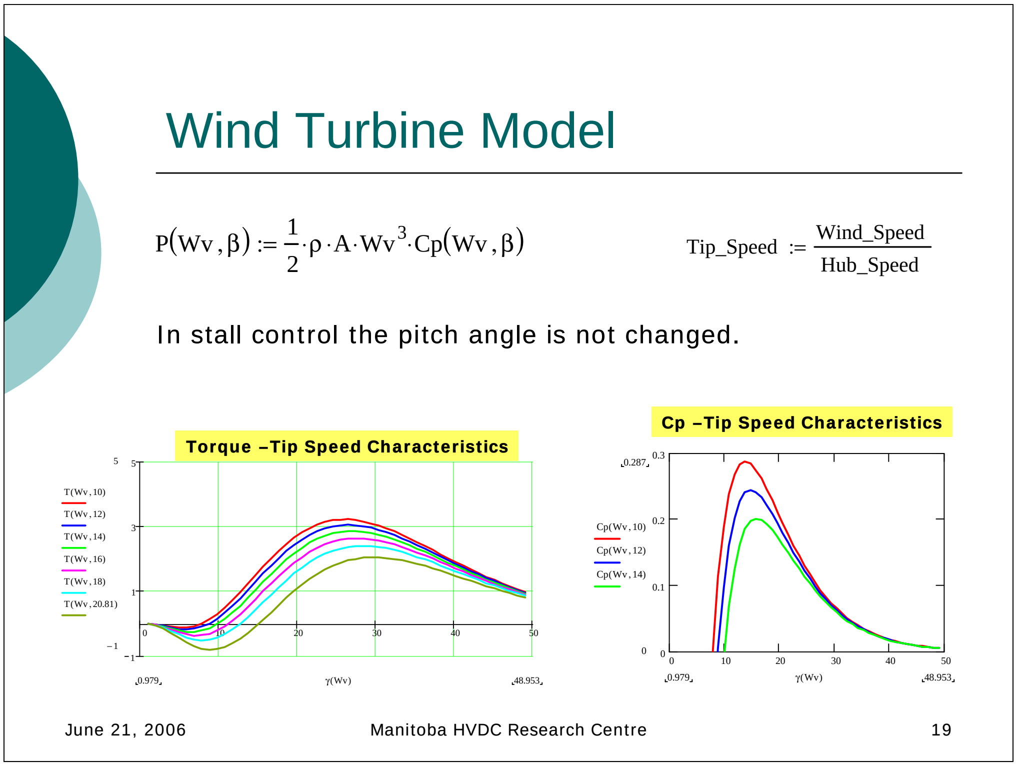



Key points:

-Wind turbine model is pitch stall control

-Based on work done by PhD candidate Rhonda Peters at University of North Dakota and Dr. Muthumuni (HVDC Research Centre)

-Pitch control is disabled. Represents a simple wind turbine.




Key points:

-As the machine speeds up during the fault, tip speed ratio decreases. This changes Tm.

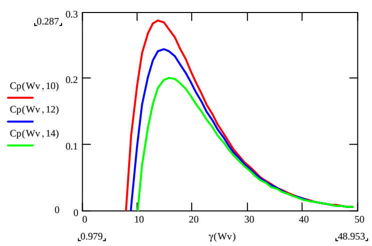
-Simulation is set up at 20 m/s wind speed, providing a 20.81 constant beta.

-Cp is dependent on Tip Speed Ratio.

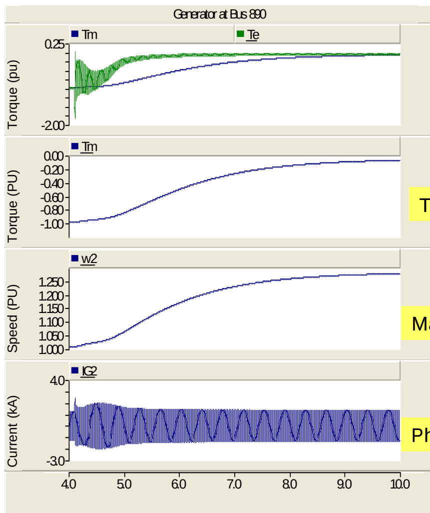
# Wind Turbine Model

- In stall control the pitch angle is not changed.
- Blades designed to have a sharp drop in Cp at wind speed above a design limit (Turbulence effects)

**Cp –Tip Speed Characteristics**



# Wind Generators




Fault on Bus 834

Turbine torque response

Machine speed (Slip)

Phase A current – Gen. 2 at Bus 890

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Key points:

-Negative torque : due to sign convention

## Conclusions

- IEEE 34 bus distribution network is completely modeled in a transient program.
- New models were developed as a result of this effort to meet the challenging needs of the distribution engineer.
- Power, Reactive Power, Voltage, and tap changer results are validated against steady state calculations provided in the test case document.
- Two inductions generators were added to the original model and the steady state results were validated.
- Function of the voltage regulators validated.
- The response of the machine during a system fault was analyzed.
  - Wind turbine characteristics will impact those results.
  - Initial transients and dc offsets in the fault current can be studied.



Additional Points:

-The test case can be made available from the PSCAD.COM Forum.

-This presentation will be made available on the same Forum for general distribution.