Transformer Modeling Using Simulator

PowerWorld Program Users Work Group

August 23, 2011

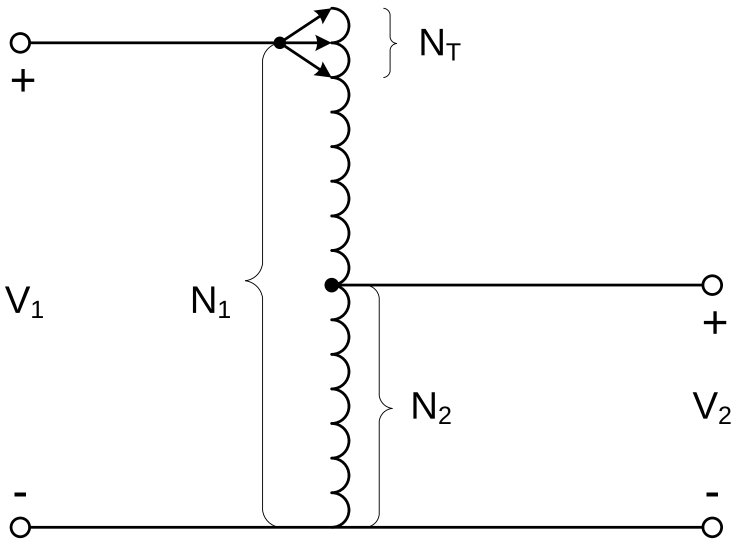
Presented by John Gross

Phone: 509-495-4591

Email: john.gross@avistacorp.com

General Purpose and Operation

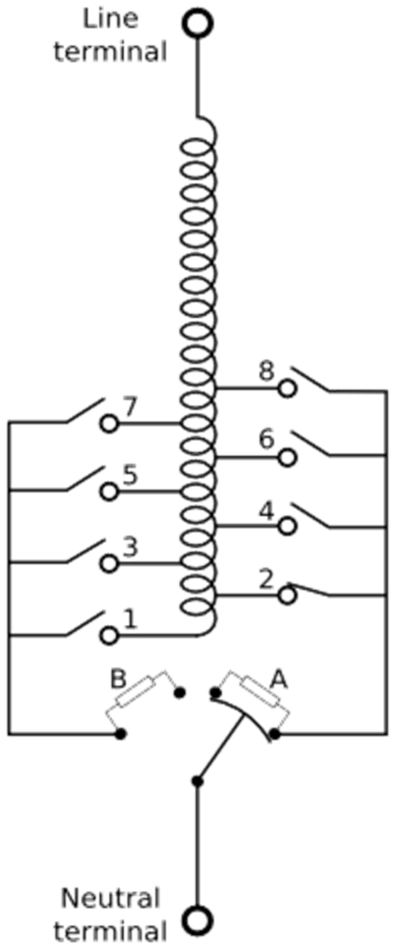
- Maintain near constant secondary voltage with a variable primary voltage
- N_1 and N_2 are fixed turns ratios determined by connected positions (N_2 can be changed with transformer out of service)
- N_T represents the LTC which adds or subtracts windings to the N_1 turns ratio
- Avista's typical LTC on Autotransformers has 17 positions; range 247.5 kV to 225.5 kV with nominal at 236.5 kV



$$V_1 = \frac{N_1 + N_T}{N_2} V_2 = a \cdot V_2$$

Mechanical Operation

- Various methods/devices are used for LTC
- Example at right:
  - Tap selector switches numbered 1 to 8
  - Diverter resistors A and B prevent high circulating current
  - Change from tap position 2 to 3
    - Close switch 3 under no load
    - Rotary switch causes load current to flow through resistor A, then momentarily through both resistor A and B with switches 2 and 3 closed
    - Once resistor B is shorted, load current flows through switch 3
    - Switch 2 now opens under no load



SCADA vs. Modeling Labeling Convention

SCADA Convention

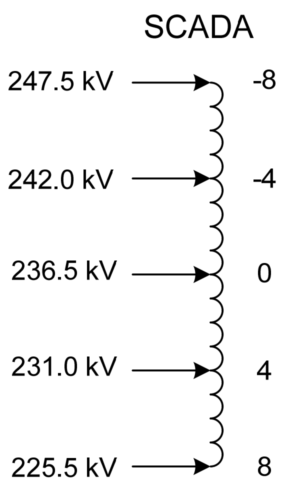
•Positive tap position **increases** secondary voltage, total tap ratio is **decreased**

•Negative tap position **decreases** secondary voltage, total tap ratio is **increased**

Modeling Convention

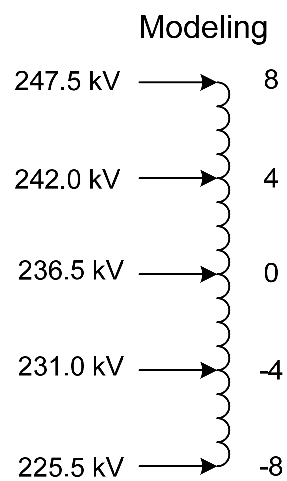
•Positive tap position **decreases** secondary voltage, total tap ratio is **increased**

•Negative tap position **increases** secondary voltage, total tap ratio is **decreased**

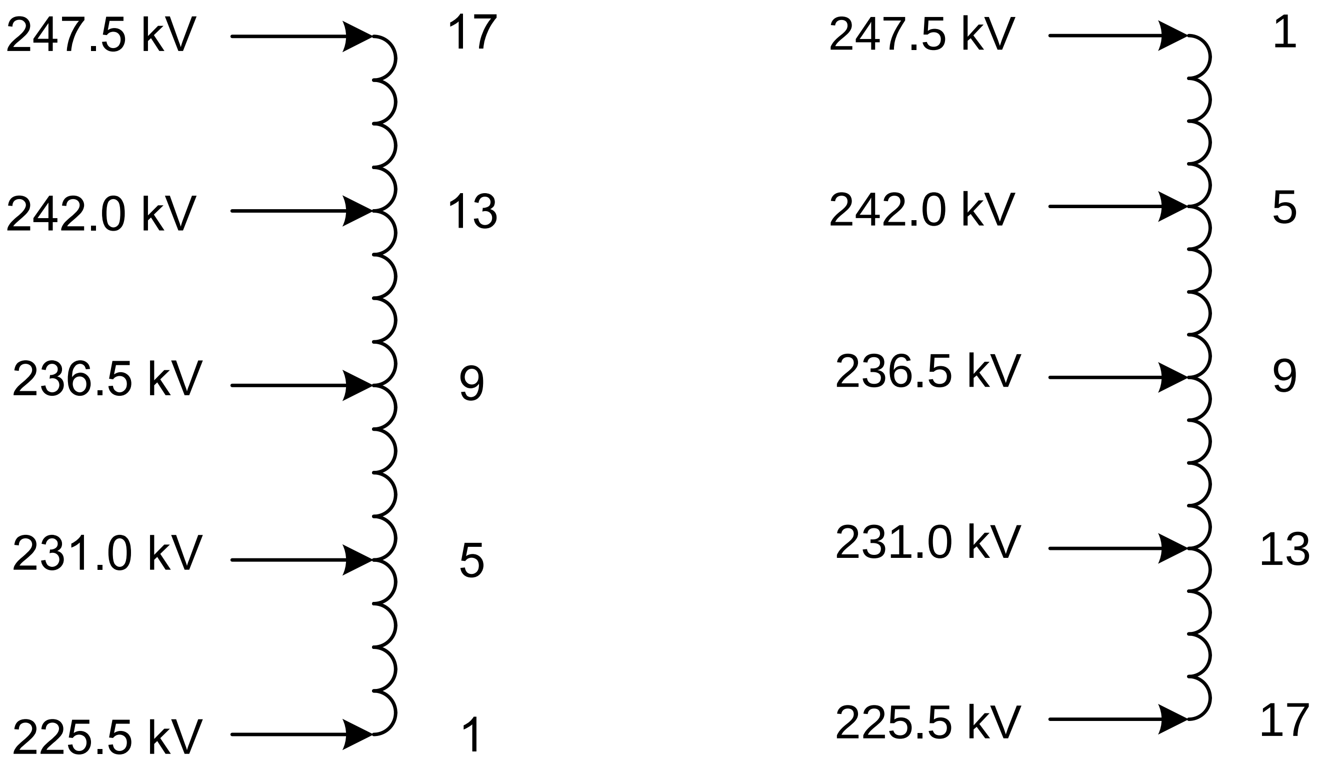


$a = (236.5+1.375x\mathbf{-8})/112.75 = 2$

$a = (236.5+1.375x\mathbf{+8})/112.75 = 2.195$



Other Labeling Conventions



Any labeling convention works so long as it is consistent and documented!

LTC Discussion

- **LTC Advantages:**
  - Voltage control
  - Added flexibility
- **LTC Disadvantages:**
  - Costs: Adds ~15-18%
  - Maintenance issue:
    - Moving parts
    - Increased outages
  - Failure probability higher with LTC
  - LTCs generally not utilized today (confirm with PI data)

LTC Discussion Cont.

- PJM has analyzed and recommends NO LTC on 500/230 kV banks
- Alternatives to LTC's:
  - Capacitor banks: distribute MVAR to optimum location
    - Approximately 3 tap positions is equivalent to one cap bank:
      - 22 MVAr at 115 kV or
      - 67.1 MVAr at 230 kV
    - No flexibility for high voltages
  - Move generation (not likely for Avista)
  - Specify LTC's on lower voltage transformers
  - Specify LTC for special situations

Taps vs Caps

LTC
Initial cost: ~$390k
- Assume 250 MVA transformer
- 15-18% of total transformer cost

Maintenace: $20k, 5-7 years
- 70,000 operations
- Requires outage coordination

Life expectancy: 50 years
Total life cycle costs:
~$500k

Capacitors
Initial cost: ~$750k
- 3 – 70 MVAr banks at 230 kV
- Land acquisition will add to cost

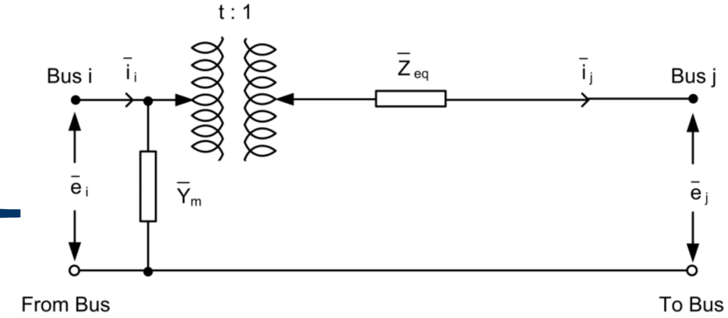
Maintenance: $20k, 5-6 years
- 4000 operations

Life expectancy: 14 years for CB
- Circuit breaker mechanism will require parts: $300k

Total life cycle costs (50 years):
~$2 million

Where do you start?

- ❑ Transformer test reports and other company records
- ❑ Collect the following data:
  1. Impedance (%Z and full load loss)
  2. Primary nominal voltage
  3. Secondary nominal voltage
  4. MVA rating
  5. NLTC fixed tap position
  6. LTC min & max tap
  7. LTC step size

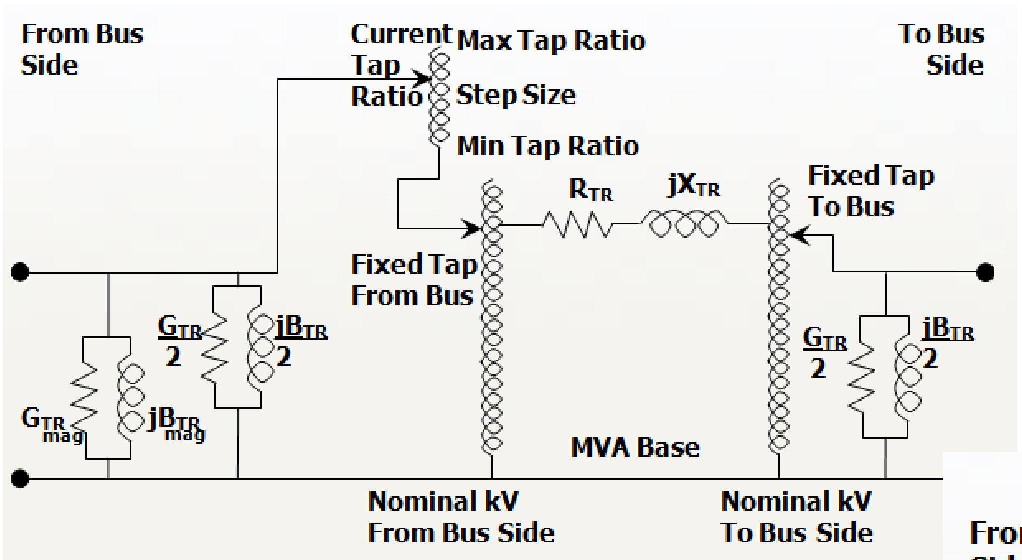


What base values should you use?

- ❑ System MVA base (100 MVA) & system voltage base
  - i.e. 500 kV, 230 kV, 115 kV
- ❑ System MVA base & transformer voltage base
- ❑ Transformer MVA base & system voltage base
- ❑ Transformer MVA base & transformer voltage base
  - Read directly from test report
  - Less calculations!

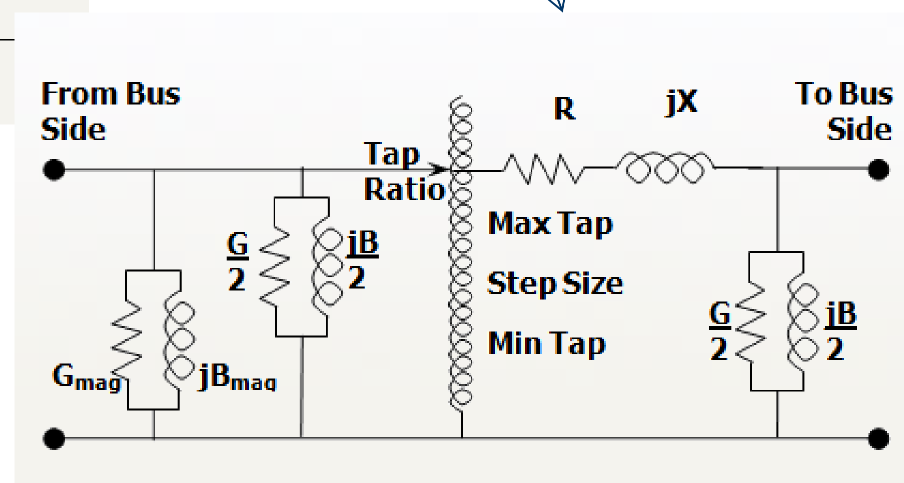
The Transformer Model

Transformer Base Model



Let the software do the base conversion

System Base Model



Example Test Report

VA TECH Ferranti-Packard de México, S.A. DE C.V

Report of Transformer Tests

Customer: **AVISTA CORPORATION** Cust. Order #: 030413 FPT Order #: ------- FP S/N: **TP - 543**

st Date: JULY 10 - 26, 2 006 Cooling: ONAN / ONAF1 / ONAF2 Hz: 60 Phases: 3 Insulating Fluid: OIL Temp rise: 55°C // 65°C

Winding	HIGH VOLTAGE	LOW VOLTAGE	TERTIARY VOLTAGE
MVA	150 / 200 / 250 // 280.0	150 / 200 / 250 // 280.0	33.3 / 44.4 / 55.5 // 62.2
kV	236.5 / 136.543 (Y)	112.75 / 65.096 (Y)	13.80 (Δ)
Taps,OC	**±4.65 % in 16 Steps**	**+4.88 - 5.23 % in 4 Steps**	------

Resistance, Exciting Current, Losses and Impedance

Based on normal rating, unless otherwise stated. Losses and regulation are based on wattmeter measurements.

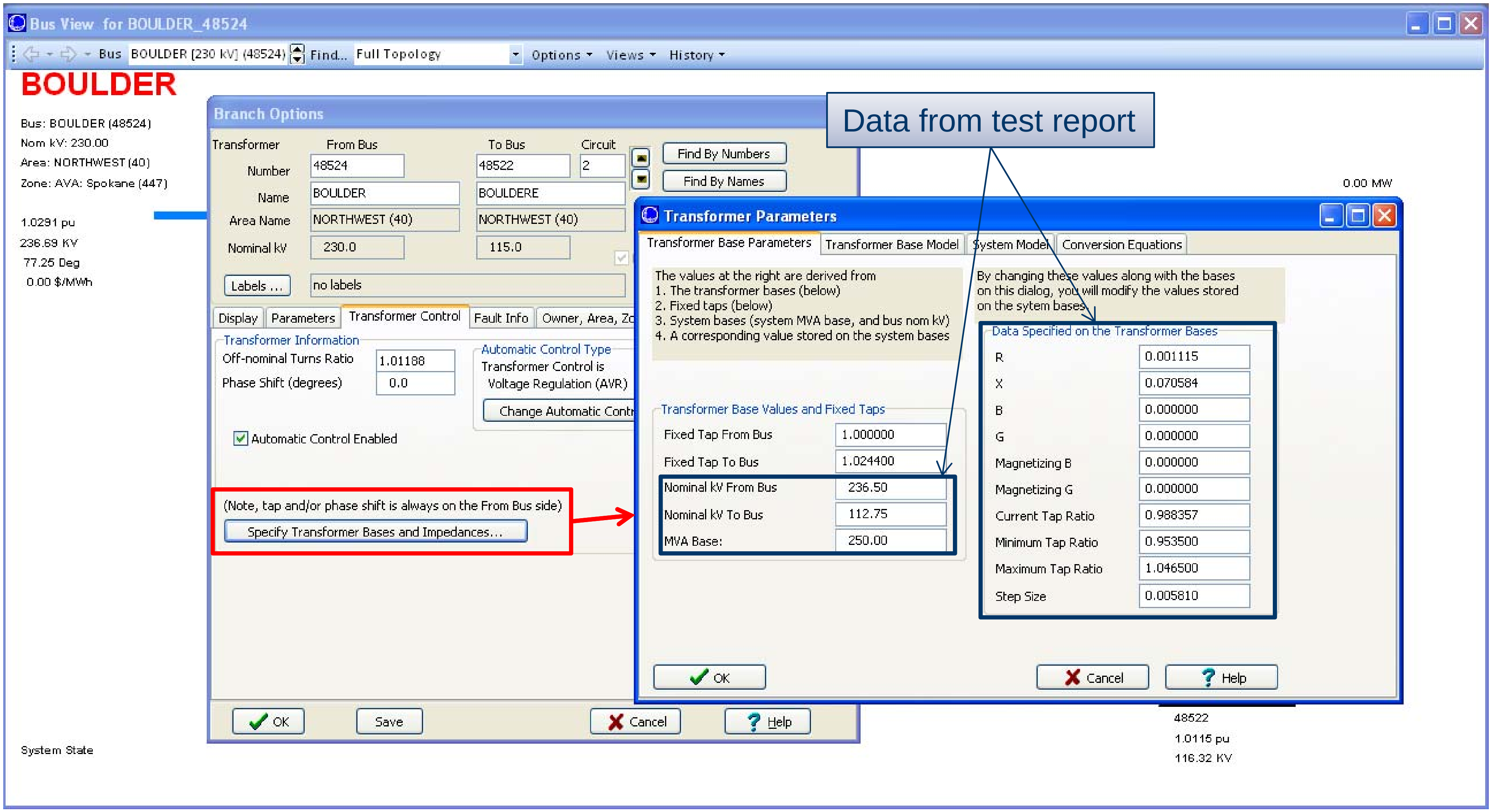
For three-phase transformers the resistances are the sum of the three phases in series.

SERIAL NUMBER	Resistance in ohms at 75°C			% exciting current at 100% rated voltage @MVA: 150	No-load kW at 100% rated voltage 20°C	HV: 236.5 KV LV: 112.75 KV 250.0 MVA		HV: 236.5 KV TV: 13.8 KV 250.0 MVA		LV: 112.75 KV TV: 13.8 KV 250.0 MVA	
	HV (H-X)	LV (X - H0X0)	T.V.			Load loss kW, 75°C	% IZ	Load loss kW, 75°C	% IZ	Load loss kW, 75°C	% IZ
TP-543	0.42667	0.12843	0.040498	0.0544	75.977	276.71	7.06	1944.78	48.05	1864.31	39.00
	Calculated			0.16	73.5	302.08	7.13	2136.60		2098.04	
	Guarantee				**74.0**	**311.11**	**6.8**		**45.0**		**37.0**
	% Regulation at 75°C, H.V. TAP N, L.V. TAP 3 150 / 250 MVA, Lagging				100 % PF 0.15 / 0.35		90 % PF 1.97 / 3.36			80 % PF 2.65 / 4.47	

Temperature Rises Average rise in degrees C, corrected to instant of shutdown, with windings connected and loaded as follows, until constant temperature rise was reached.

Pounds

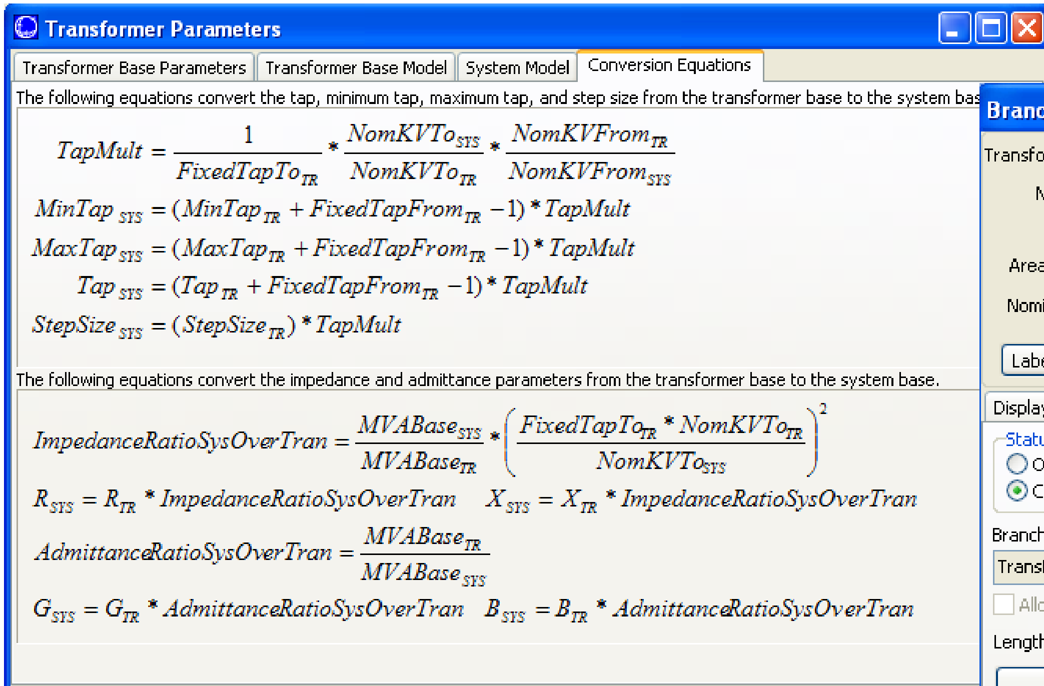
Example Data Entry

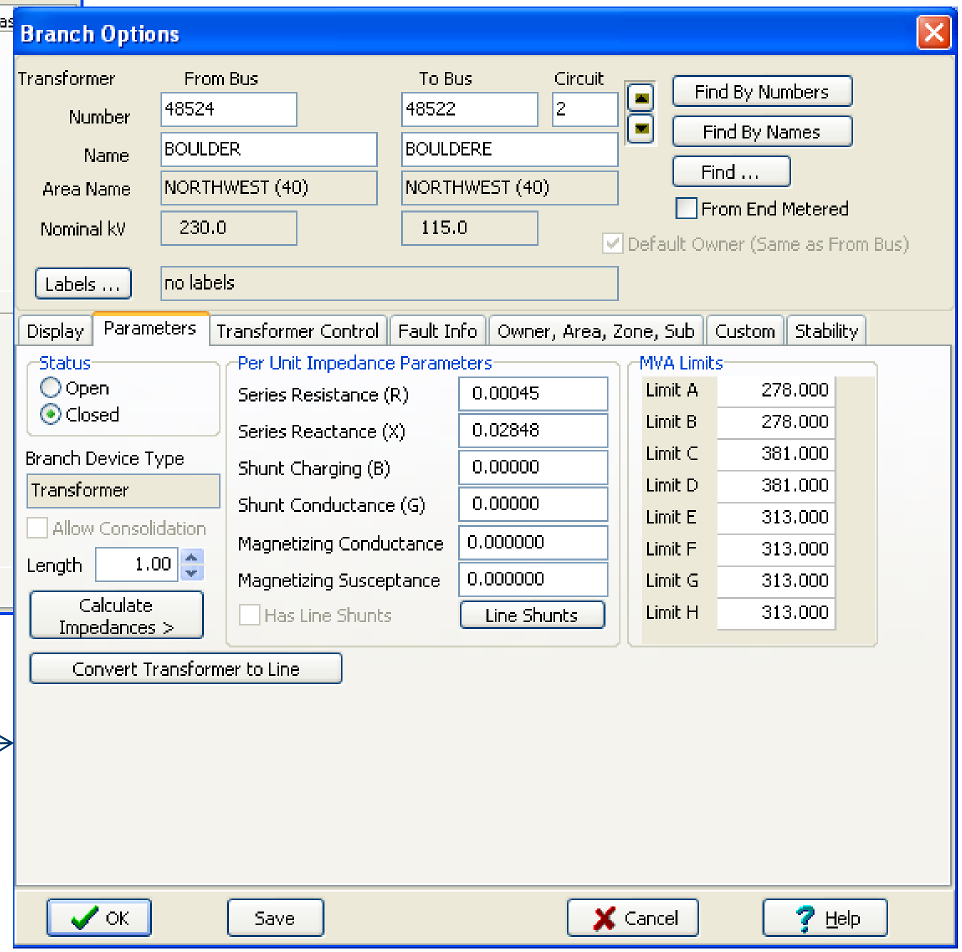


Modeling Assumptions

- ❑Magnetizing impedance is neglected
  - Magnetizing current ~ 0.5% of rated current
  - Less than 20% xfmrs in WECC cases model B and G
- ❑Impedance is proportional to number of turns squared
  - If NLTC is off nominal (i.e. + 2.44%), $Z = Z_{nom}(1.0244)^2$
  - Measured impedance may differ by ~ ±8% or ~ 0.5 ohms

Conversion to System Base





Let the program do the calculations

Conclusions

- Hand Calculations should be avoided
  - Computers excel at repetitive mathematical operations
  - IF a bug exists that causes a math error when fixed all of the errors will be corrected
    - This is NOT the case with hand calculations
- Data needs to be easily traced back to a proper source
  - If you enter data off the test sheets (as much as possible) then there is NO DOUBT as to the accuracy of the data.

- Avista Procedure