

# Transformer Modeling Using Simulator

PowerWorld Program Users Work Group

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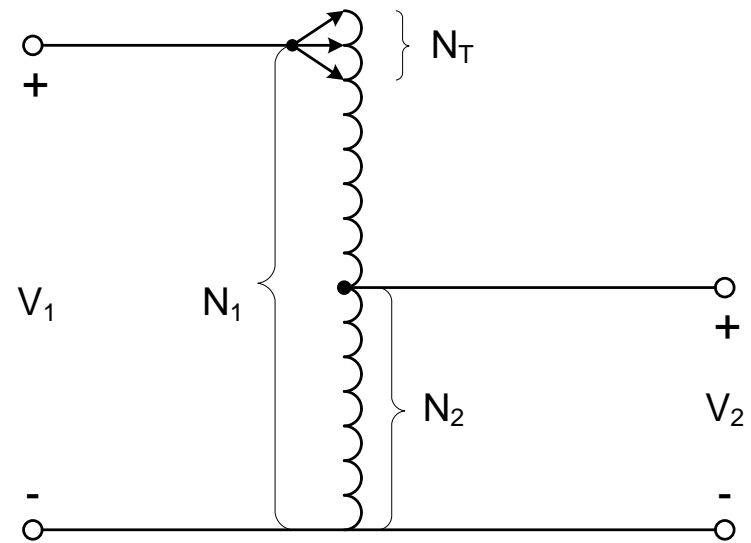
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## General Purpose and Operation

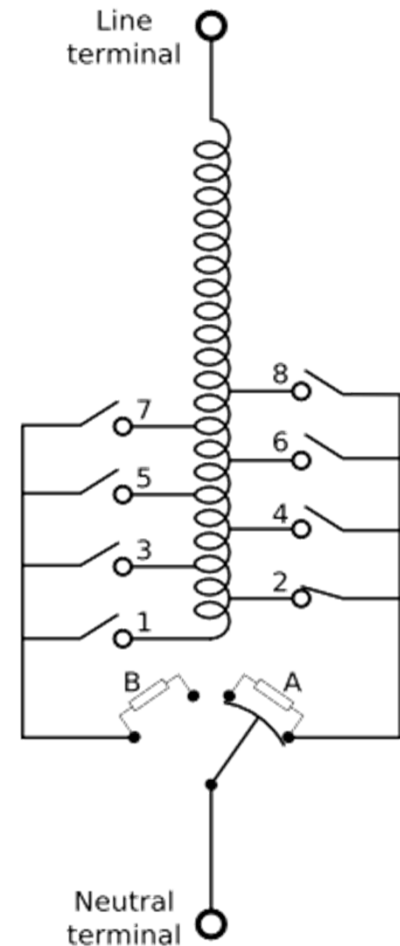
- Maintain near constant secondary voltage with a variable primary voltage
- $N_1$  and  $N_2$  are fixed turns ratios determined by connected positions ( $N_2$  can be changed with transformer out of service)
- $N_T$  represents the LTC which adds or subtracts windings to the  $N_1$  turns ratio
- Avista's 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

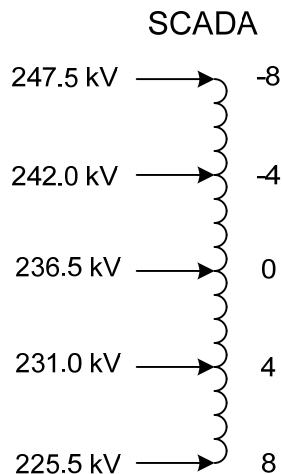
- Various methods/devices are used for LTC
- Example at right:
  - Tap selector switches numbered 1 to 8
  - Diverter resistors A and B prevent high circulating current
  - Change from tap position 2 to 3
    - Close switch 3 under no load
    - Rotary switch causes load current to flow through resistor 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

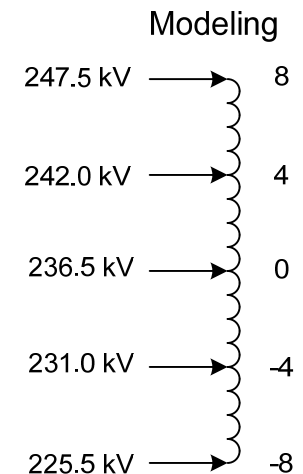
- Positive tap position **increases** secondary voltage, total tap ratio is **decreased**
- Negative tap position **decreases** secondary voltage, total tap ratio is **increased**



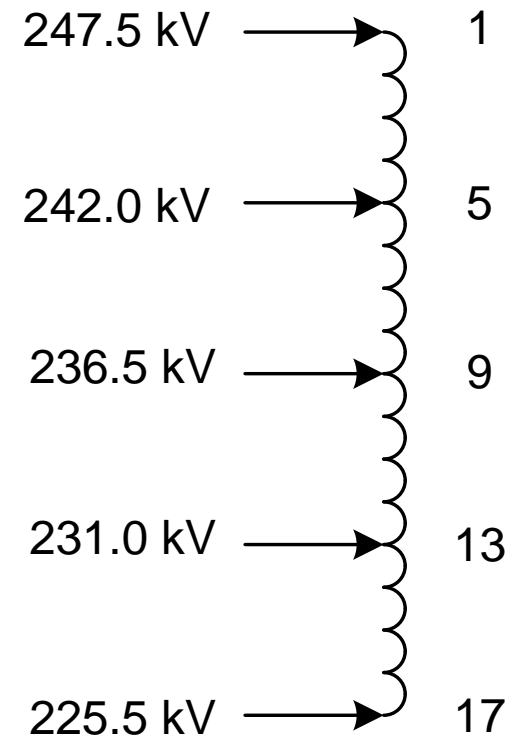
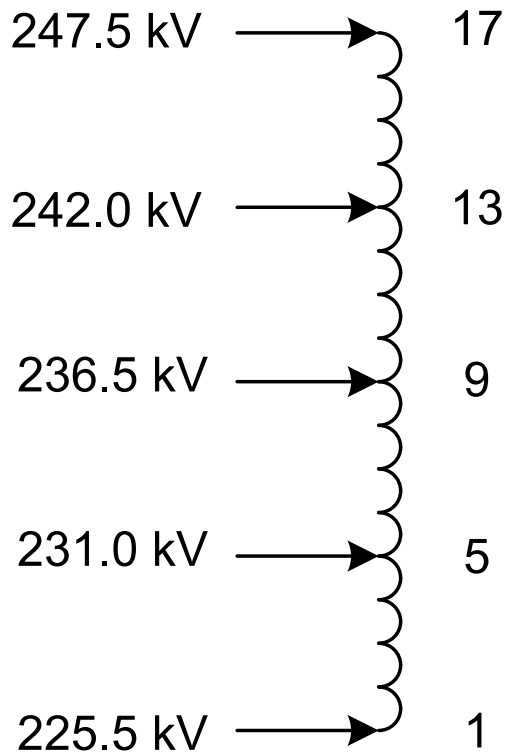
$$a = (236.5 + 1.375x - 8) / 112.75 = 2$$
$$a = (236.5 + 1.375x + 8) / 112.75 = 2.195$$

## Modeling Convention

- Positive tap position **decreases** secondary voltage, total tap ratio is **increased**
- Negative tap position **increases** secondary voltage, total tap ratio is **decreased**



## 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

Maintenance: \$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**

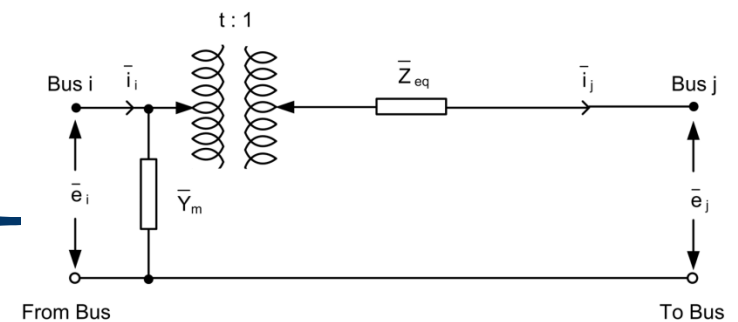


## Where do you start?

❑ 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

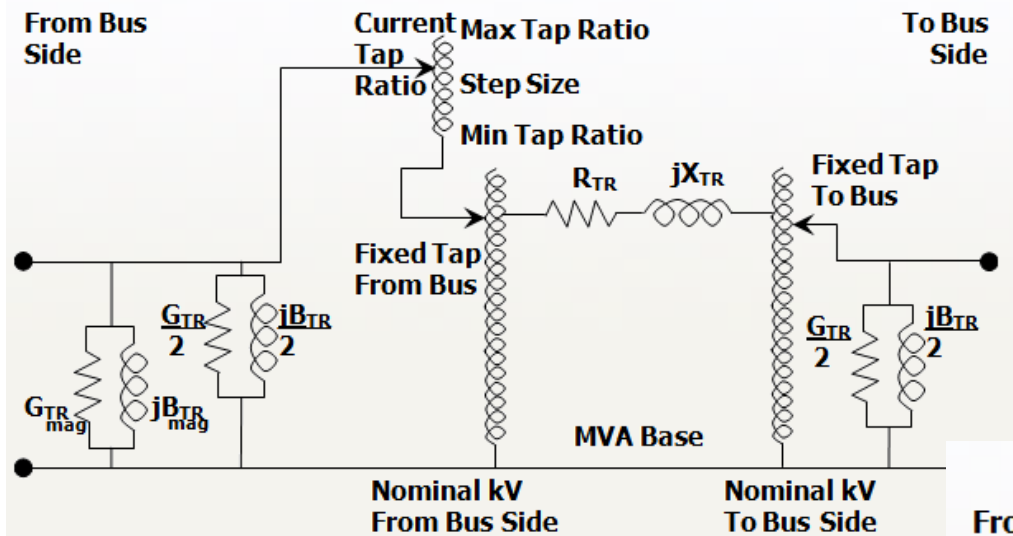


## What base values should you use?

- 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!

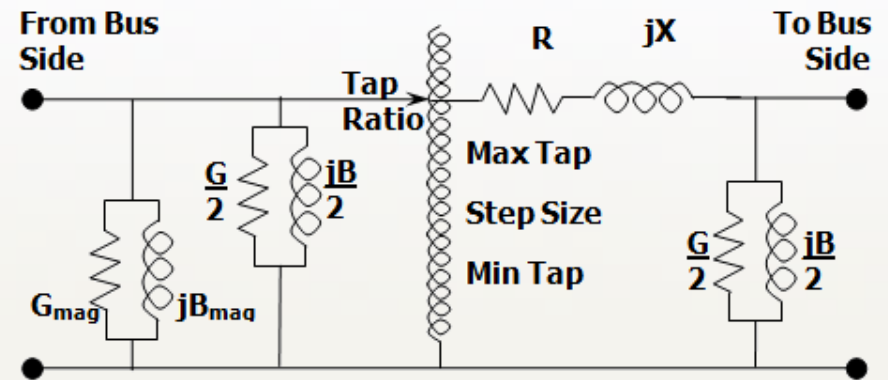
# The Transformer Model

## 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

Test Date: JULY 10 - 26, 2006

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		90 % PF		80 % PF		
					0.15 / 0.35		1.97 / 3.36		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.

Ambient Temperature °C

Pounds



# Example Data Entry

**Branch Options**

Transformer Number	From Bus	To Bus	Circuit
48524	48524	48522	2

Transformer Name: BOULDER  
 Area Name: NORTHWEST (40)  
 Nominal kV: 230.0

Labels: no labels

Transformer Information:  
 Off-nominal Turns Ratio: 1.01188  
 Phase Shift (degrees): 0.0

Automatic Control Type:  
 Transformer Control is Voltage Regulation (AVR)

Automatic Control Enabled

(Note, tap and/or phase shift is always on the From Bus side)

Specify Transformer Bases and Impedances...

**Transformer Parameters**

Transformer Base Parameters | Transformer Base Model | System Model | Conversion Equations

The values at the right are derived from:  
 1. The transformer bases (below)  
 2. Fixed taps (below)  
 3. System bases (system MVA base, and bus nom kV)  
 4. A corresponding value stored on the system bases

By changing these values along with the bases on this dialog, you will modify the values stored on the system bases.

Data Specified on the Transformer Bases	
R	0.001115
X	0.070584
B	0.000000
G	0.000000
Magnetizing B	0.000000
Magnetizing G	0.000000
Current Tap Ratio	0.988357
Minimum Tap Ratio	0.953500
Maximum Tap Ratio	1.046500
Step Size	0.005810

Transformer Base Values and Fixed Taps

Fixed Tap From Bus	1.000000
Fixed Tap To Bus	1.024400
Nominal kV From Bus	236.50
Nominal kV To Bus	112.75
MVA Base:	250.00

System State: 48522, 1.0115 pu, 116.32 KV

# 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%),  $Z = Z_{\text{nom}}(1.0244)^2$
  - Measured impedance may differ by ~ ±8% or ~ 0.5 ohms

# Conversion to System Base

**Transformer Parameters**

Transformer Base Parameters | Transformer Base Model | System Model | Conversion Equations

The following equations convert the tap, minimum tap, maximum tap, and step size from the transformer base to the system base.

$$TapMult = \frac{1}{FixedTapTo_{TR} * NomKVTo_{SYS} * NomKVFrom_{TR}}$$

$$MinTap_{SYS} = (MinTap_{TR} + FixedTapFrom_{TR} - 1) * TapMult$$

$$MaxTap_{SYS} = (MaxTap_{TR} + FixedTapFrom_{TR} - 1) * TapMult$$

$$Tap_{SYS} = (Tap_{TR} + FixedTapFrom_{TR} - 1) * TapMult$$

$$StepSize_{SYS} = (StepSize_{TR}) * TapMult$$

The following equations convert the impedance and admittance parameters from the transformer base to the system base.

$$ImpedanceRatioSysOverTran = \frac{MVABase_{SYS}}{MVABase_{TR}} * \left( \frac{FixedTapTo_{TR} * NomKVTo_{TR}}{NomKVTo_{SYS}} \right)^2$$

$$R_{SYS} = R_{TR} * ImpedanceRatioSysOverTran \quad X_{SYS} = X_{TR} * ImpedanceRatioSysOverTran$$

$$AdmittanceRatioSysOverTran = \frac{MVABase_{TR}}{MVABase_{SYS}}$$

$$G_{SYS} = G_{TR} * AdmittanceRatioSysOverTran \quad B_{SYS} = B_{TR} * AdmittanceRatioSysOverTran$$

Let the program do the calculations

**Branch Options**

Transformer: From Bus (48524) To Bus (48522) Circuit (2)

Name: BOULDER BOULDERE

Area Name: NORTHWEST (40) NORTHWEST (40)

Nominal kV: 230.0 115.0

Labels: no labels

Buttons: Find By Numbers, Find By Names, Find ..., From End Metered, Default Owner (Same as From Bus)

Display | Parameters | Transformer Control | Fault Info | Owner, Area, Zone, Sub | Custom | Stability

Status:  Open  Closed

Branch Device Type: Transformer

Allow Consolidation:

Length: 1.00

Buttons: Calculate Impedances >, Convert Transformer to Line

**Per Unit Impedance Parameters**

Series Resistance (R)	0.00045
Series Reactance (X)	0.02848
Shunt Charging (B)	0.00000
Shunt Conductance (G)	0.00000
Magnetizing Conductance	0.000000
Magnetizing Susceptance	0.000000
<input type="checkbox"/> Has Line Shunts	Line Shunts

**MVA Limits**

Limit A	278.000
Limit B	278.000
Limit C	381.000
Limit D	381.000
Limit E	313.000
Limit F	313.000
Limit G	313.000
Limit H	313.000

Buttons: OK, Save, Cancel, Help

# 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