TVA Transmission Voltage Unbalance Evaluation

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October 23, 2017

Overview

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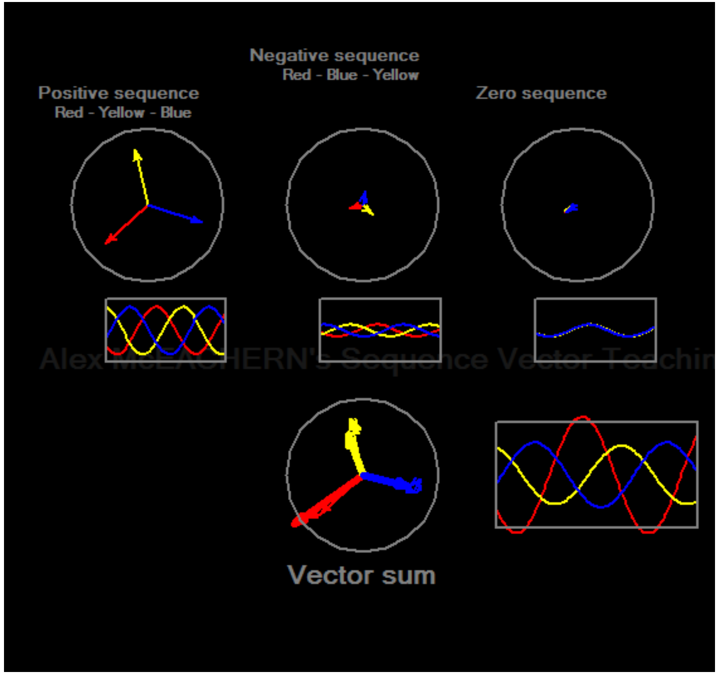
TVA Overview

We are 10,000 men and women proud to be carrying on TVA's long tradition of service. We are privileged to be able to make life better for the people of the Valley by providing safe, clean, reliable and affordable power; by being good stewards of the resources that have been entrusted to us; and by helping to bring new investments and good jobs to the region and helping keep them here.

Energy
Environment
Economic Development

Voltage Unbalance Introduction



Typically, voltage unbalance creates problems for 3 phase motor load. The unbalance condition induces heating in motors. Protection elements within industrial plants are generally set to identify this condition and trip off the motor load.

Trends in Distribution - CVR

Per phase monitoring employed at distribution substations to facilitate CVR. This monitoring shows that the voltage on all 3 phases is different.

PROBLEM?

Concern Reported…An Example

Phase	Voltage
A	13.2 kV
B	13.2 kV
C	13.0 kV

Reported Voltage Unbalance – 1.5%

Standards

- There are 3 standards that provide standard definitions / guidance on limits for voltage unbalance:
  - ANSI C84.1
    - > Computation: Max Deviation From 3 Phase Average / 3 Phase Average
    - > Limit of 3% measured at PCC under no load conditions
  - NEMA MG-1
    - > Computation: Max Deviation From 3 Phase Average / 3 Phase Average
    - > Limit of 5% at motor terminals
  - IEC 61000-3-13 (Selected Method)
    - > Computation: Ratio of the modulus of the negative-sequence to the positive-sequence components of the voltage at fundamental frequency.
    - > 95% Cumulative Probability limit of 1.4% at 161kV.

Concern Revisited…An Example

Phase	Voltage
A	13.2 kV
B	13.2 kV
C	13.0 kV

ANSI Unbalance Calculation Method – 1.0%

IEC 61000-3-13

3.26.6
voltage unbalance factor (u)
defined as the ratio of the modulus of the negative-sequence to the positive-sequence components of the voltage at fundamental frequency, expressed as a percentage

$$u_2 = \frac{|\underline{U}_2|}{|\underline{U}_1|}.100 = \frac{|\underline{U}_a + \mathbf{a}^2\underline{U}_b + \mathbf{a}\underline{U}_c|}{|\underline{U}_a + \mathbf{a}\underline{U}_b + \mathbf{a}^2\underline{U}_c|}.100 \quad \%$$

NOTE Phase-to-phase voltages may also be used instead of line to neutral voltages

NOTE For simplicity in this document u has been used to denote the voltage unbalance factor instead of u_2.

An equivalent formulation is given by [3]:

$$u_2 = \sqrt{\frac{1-\sqrt{3-6\beta}}{1+\sqrt{3-6\beta}}}.100\% \text{ with } \beta = \frac{|\underline{U}_{ab}|^4 + |\underline{U}_{bc}|^4 + |\underline{U}_{ca}|^4}{\left(|\underline{U}_{ab}|^2 + |\underline{U}_{bc}|^2 + |\underline{U}_{ca}|^2\right)^2}$$

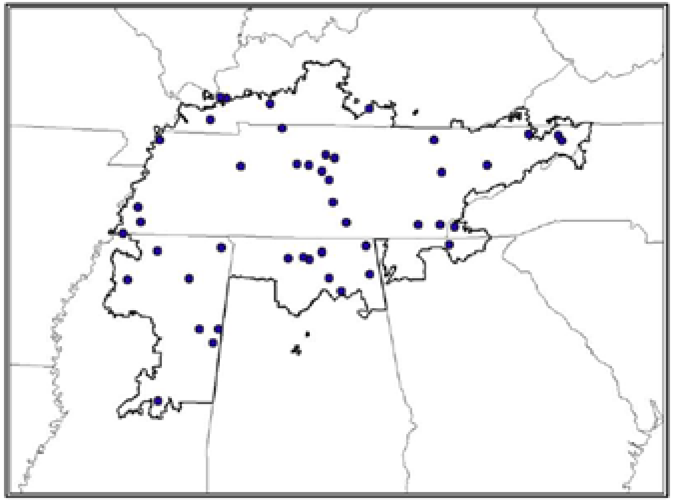
IEC 61000-3-13 (Continued)

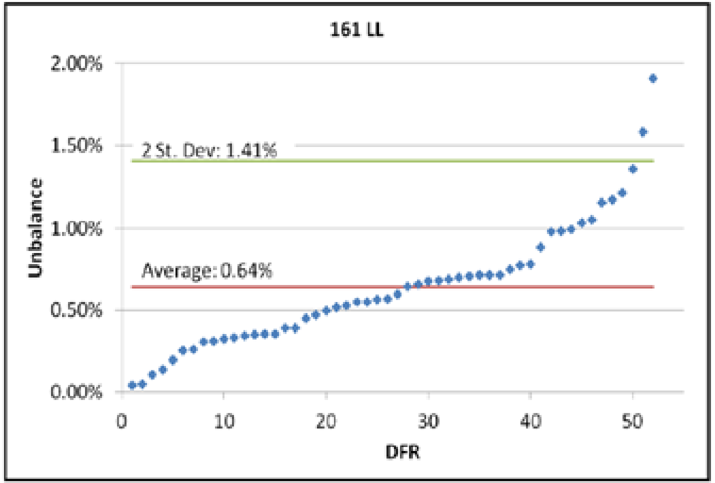
The minimum measurement period is one week with normal business activity. The monitoring period should include some part of the period of expected maximum voltage unbalance levels.

The 95 % weekly value of voltage unbalance factor at fundamental frequency over "short" 10 min periods should not exceed the planning level.

Voltage level	Planning level L_{u2} (%)	
MV	1,8	
HV	1,4	161 kV
EHV	0,8	

Measurements





Voltage Unbalance Sources

- Measurement device calibration
- Long untransposed transmission lines
- Blown capacitor fuses
- Open-Delta Regulators
- Open-Delta Transformers
- Uneven single-phase load distribution
- Single-phasing in distribution lateral feeders due to blown fuses or faulty equipment (LTCs with phases out of step, Cap Banks, etc.)

4 Sites with High Voltage Unbalance

161-kV System

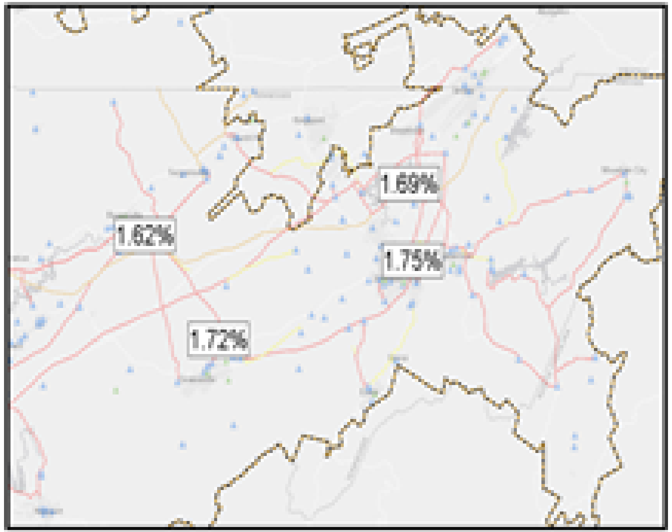
17 Month Study Period

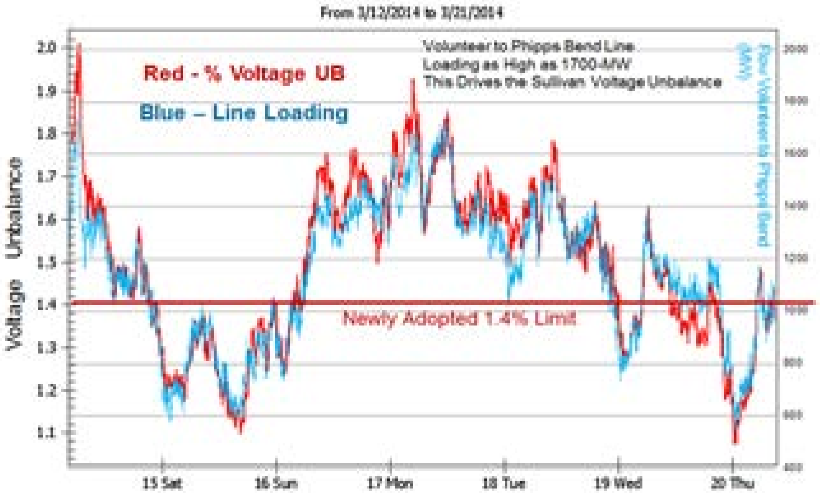
10/1/2012 – 3/1/2014

IEC Unbalance Method

CP 95

Weekly Aggregation





Voltage Balancing

- Transpose long transmission lines
- Balance single phase load
- Repair faulty equipment

- Additional generation
- 3 phase motor load

Conclusions

- No customer equipment was affected.
- Standards are critical to measure and establish reasonable limits.
- Measurements can be a significant cause of error.
- Long un-transposed lines can be a cause for voltage unbalance. However, a more typical cause is load balance and equipment malfunction.
- Not a widespread problem, but very localized.

TVA