Flicker Analysis and Case Studies

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August 2008

Voltage Drop Creating Visible Light Flicker

Voltage Flicker Is:

- Voltage Drop as Seen by Others
- Visible With Incandescent lights and some CFLs
- Complaints Normally From Residential Customers
- Much lower in magnitude than a fault related voltage sag – usually only a few volts on 120-V system
- Noticeable at low levels and downright annoying at higher levels

Voltage Flicker Does Not:

- Normally does not cause equipment downtime
- Does not damage other folks equipment

Flicker is Perceived Voltage Drop
Voltage Drop is Graphically Shown Below
Drawing Copied from IEEE 141

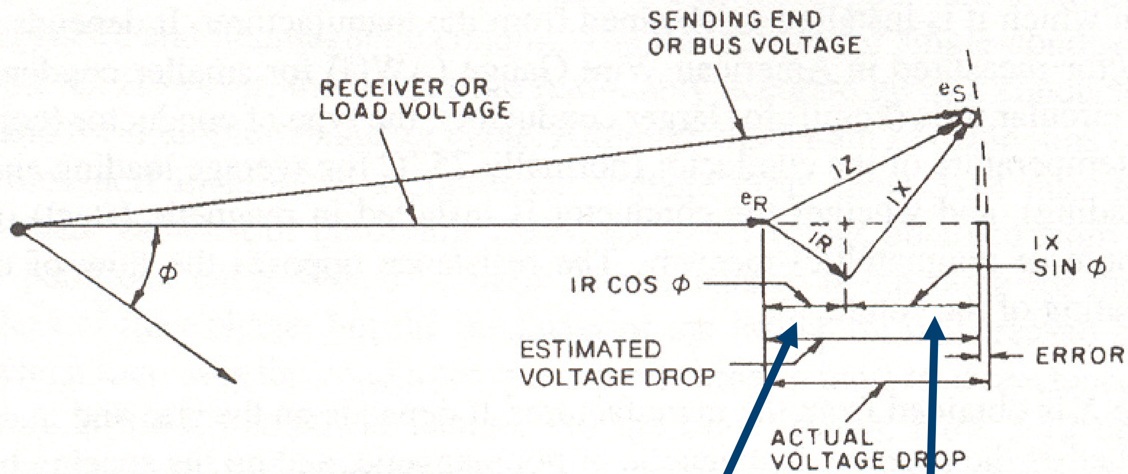


Figure 3-11—Phasor diagram of voltage relations for voltage-drop calculations

$$Vdrop \cong IR\cos\Phi + IX\sin\Phi$$

Per Unit Approach to Calculating Flicker

$$Vdrop \cong IR\cos\Phi + IX\sin\Phi$$

Hand calculations often work best in percent on an MVA base
TVA uses 100-MVA as our base so the following is the same approach but written on a percent basis:

$$\%Vdrop \cong \frac{MWswing\ (\%R1)\ +\ MVARswing\,(\%X1)}{100}$$

Example: Large motor draws 25-MW and 40-MVAR on startup. With a system Thevenin equivalent
Of Z= 0.988% +j 7.170% (100-MVA base), What is the expected voltage swing on startup?

$$Vdrop \cong \frac{25MW\,(0.988\%) + 40MVAR\,(7.170\%)}{100} = 3.1\%$$

Perceived Voltage Drop in Lights
GE Flicker Curves
Copied From IEEE 141

IEEE
Std 141-1993

CHAPTER 3

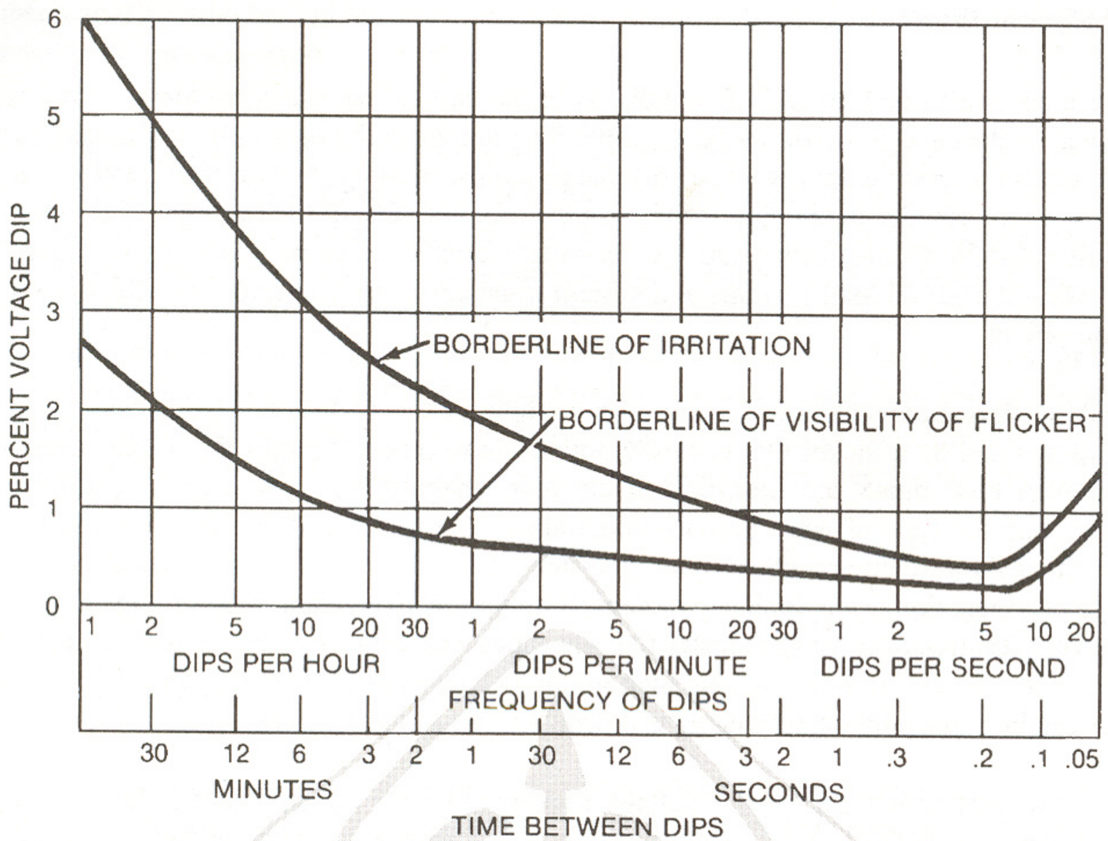
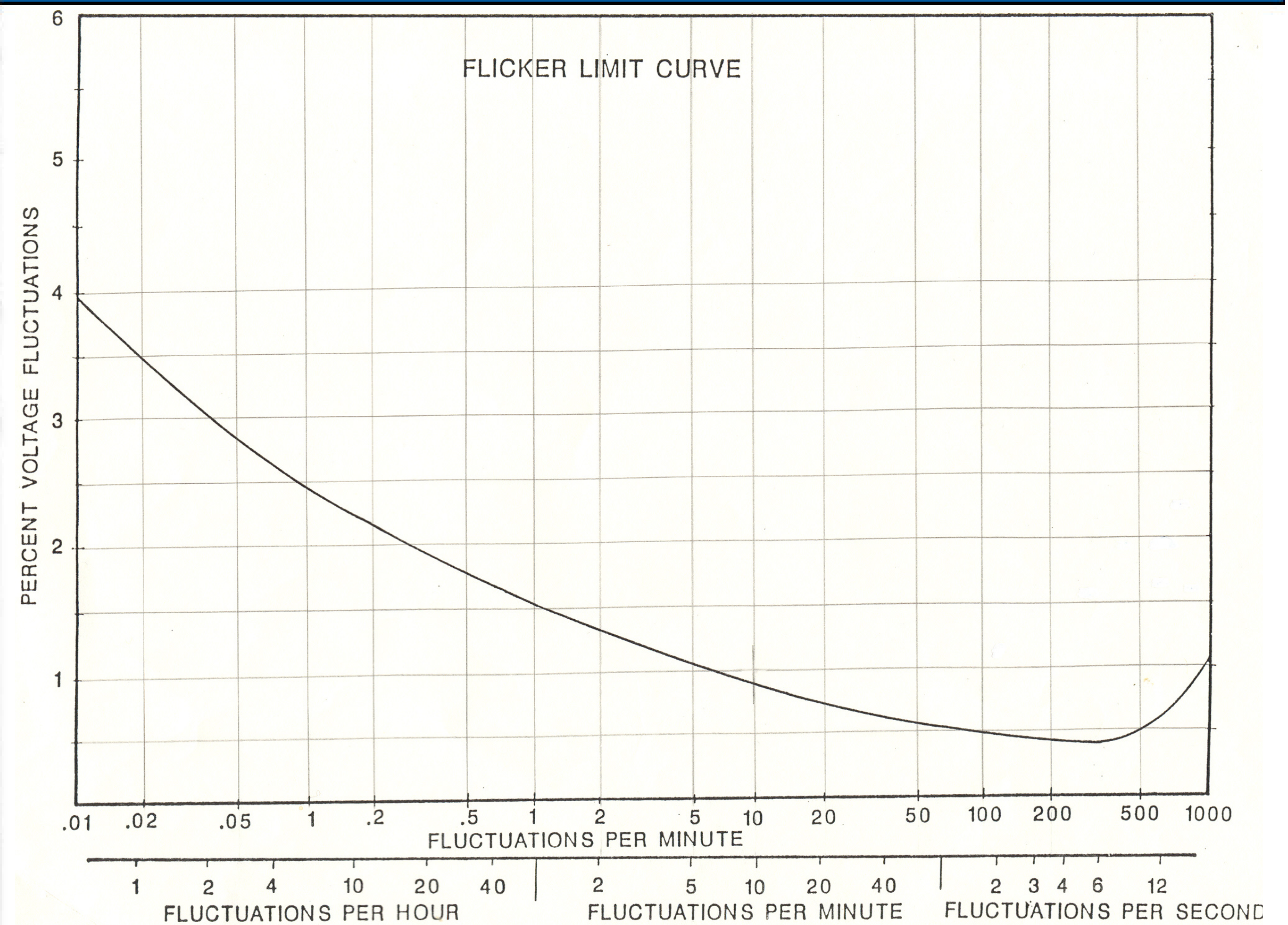


Figure 3-8—Range of observable and objectionable voltage flicker versus time

TVA Flicker Curve



Flicker Curves
IEEE 141 and TVA

IEEE
Std 141-1993

CHAPTER 3

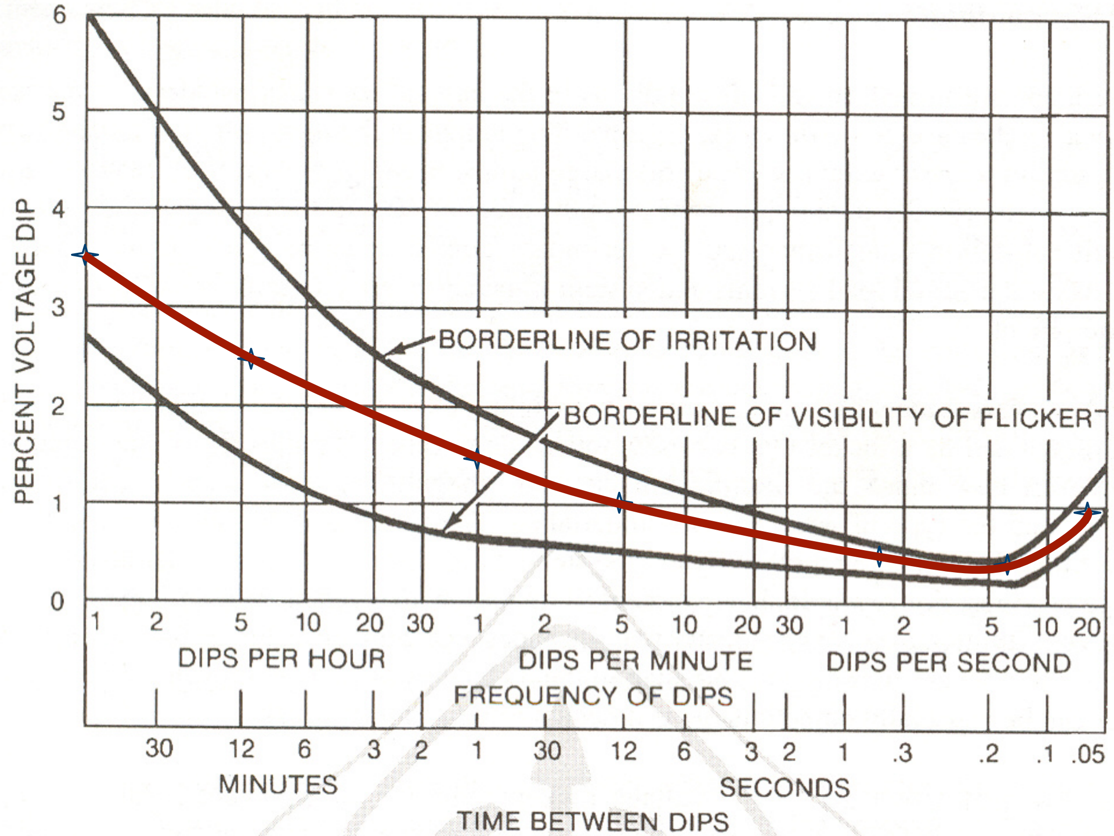


Figure 3-8—Range of observable and objectionable voltage flicker versus time

TVA
Curve
In
Red

Three Key Flicker Components

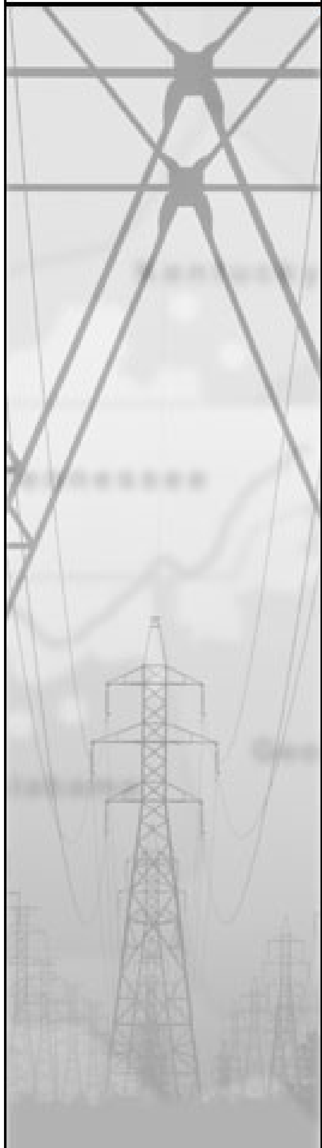
Recipe for Complaints:

1. Start with - Varying load/generation equipment
2. Serve from a - High System Impedance
3. Repeat variations until annoying

Component 1: Equipment with Load Swings Leading to Possible Flicker Issues

- Motors and Compressors
  - Rock Crushers
  - Saw Mills
  - Large Motors (Car Shredders, pumping systems)
  - HVAC systems
- Welders
- Process ARC Furnaces
- Process Induction Furnaces
- Wind Generators
- Others

Mitigation Systems Reducing Load Swings



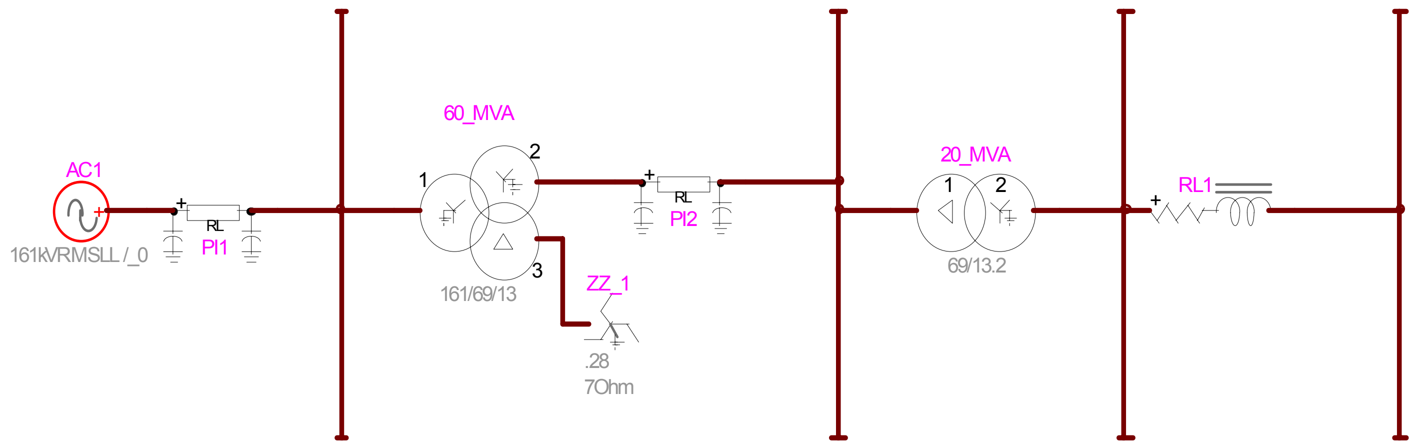
Dynamic Var Systems
- Static Var Compensators
- Dstatcom
- Intellivar
- Thyristor-Controlled Capacitor Systems

Motor Impact Reduction
- Reduced Voltage Starters
- Wound Rotor Motor Resistors
- DC Motor Systems

Sequencing Multiple Welder Systems

Arc Furnace Reactors

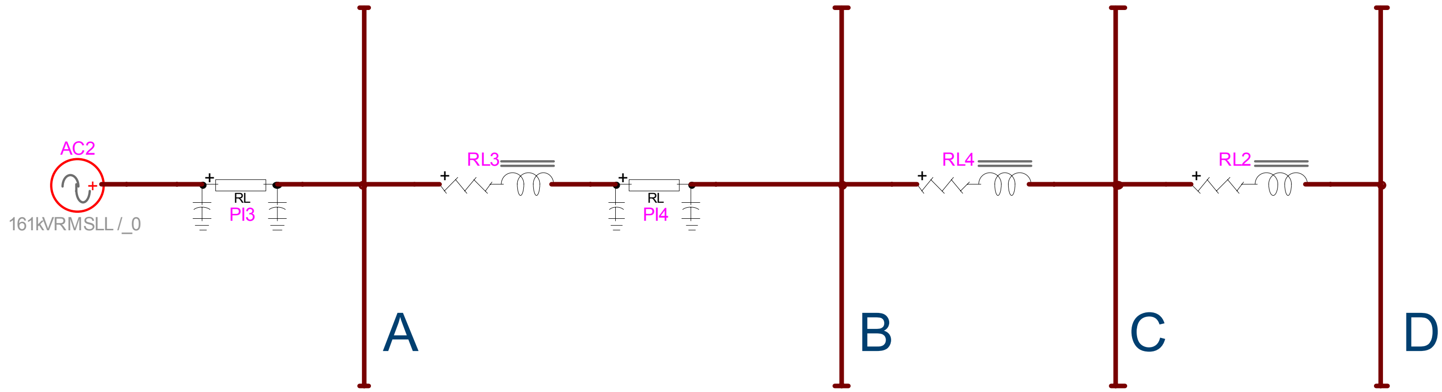
Component 2: Impedance Issues Important to Flicker Critical Point of Common Coupling (PCC) for Flicker Studies



Transmission Level	Sub-transmission Circuit Level	Distribution Bus Level	Distribution Circuit Level

My PCC Definition:
Closest Interconnection Location Where Another Customer Can See The Voltage Drop From The Disturbing Load

Component 2:
Series Impedance to PCC –
Shown in Percent (100-MVA Base)



Possible PCC Interconnection		% Series Circuit Impedance 100-MVA base
Transmission – 161-kV	A	(0.70+j4.82)% – total to A
Sub-transmission – 69-kV	B	(1.08+j12.6)% – total to B
Distribution Bus – 13-kV	C	(1.75+32.6)% – total to C
Distribution Circuit – 13-kV	D	(30.47+j138.9)% – total to D

Hopkinsville, KY Facility - Services Went From 13-kV to 161-kV

Mitigation Approaches With Impedance Reductions

Historical Solution to Flicker Problems – Reduce Impedance and percent voltage drop by Moving PCC upstream:

- General Distribution to Dedicated Distribution Feed
- Dedicated Distribution Feed to Sub-transmission Feed
- Sub-transmission Feed to Transmission Feed

Add Series Capacitors In Line

Component 3: Frequency of Voltage Variation Swings

- Startup Related (once per season, month, week, day)
  - Pump Motors
  - Process Systems
  - Energizing Transformers
- Low Frequency Process cyclic (multiple times per day or hour)
  - Air compressors
  - Refrigeration Compressors
- High Frequency Process cyclic (many times per hour of second)
  - Rock crusher cycling
  - Shredders
  - Welders
  - Arc Furnaces

GE Flicker Curves
Copied From IEEE 519

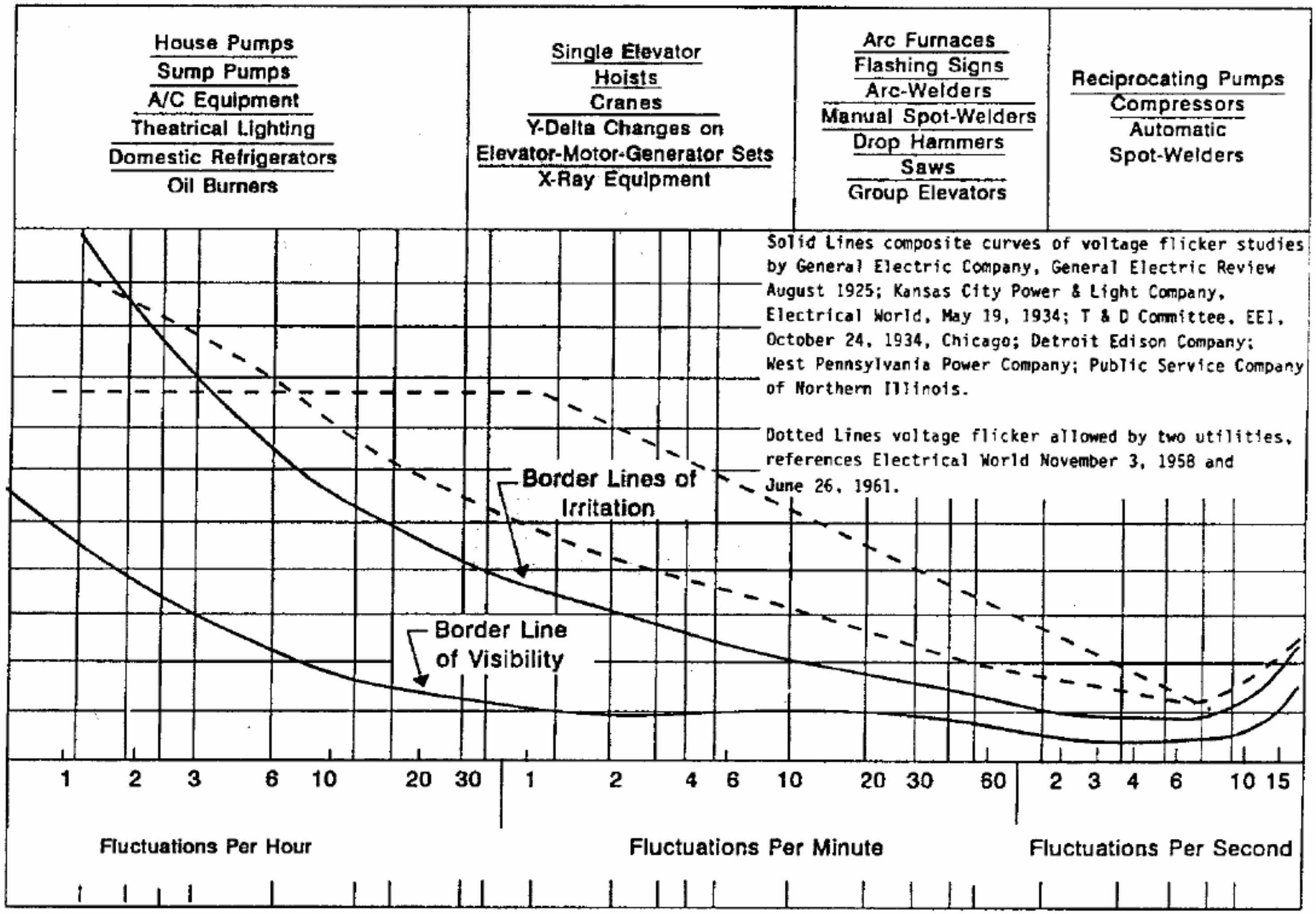
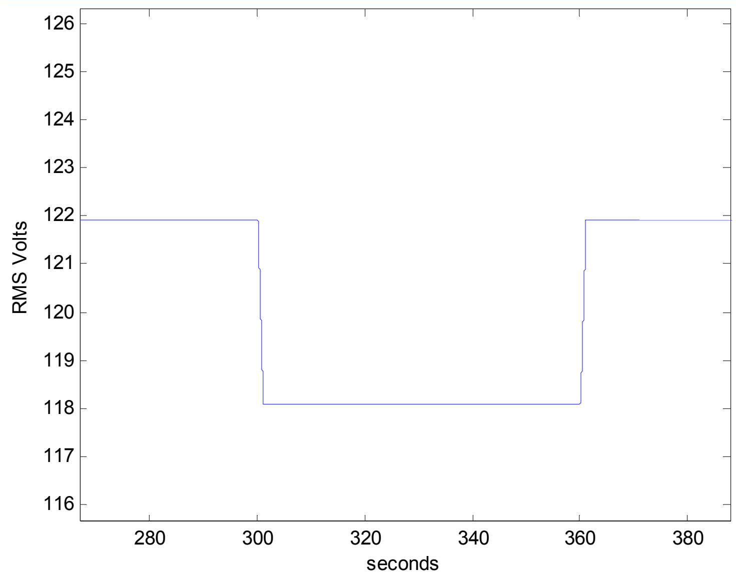
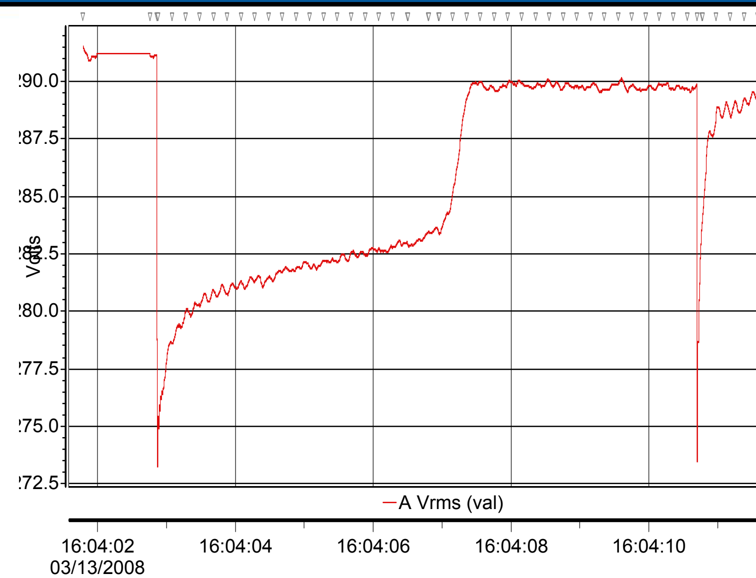
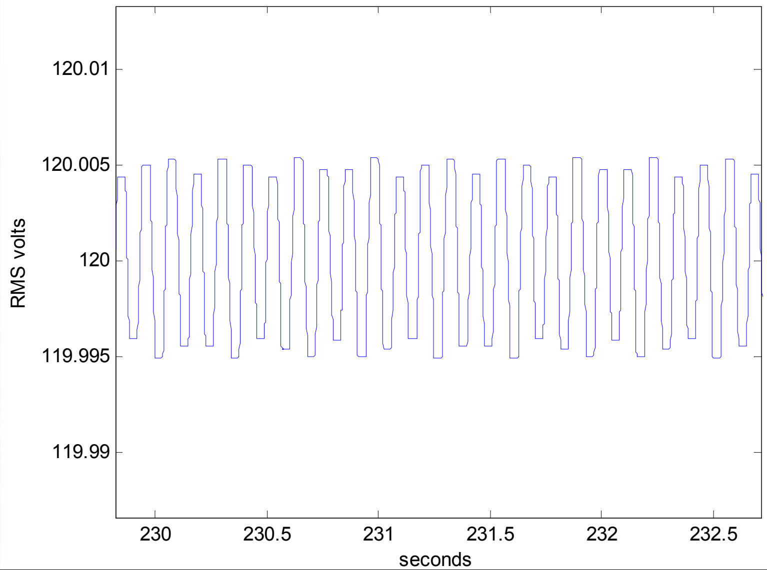


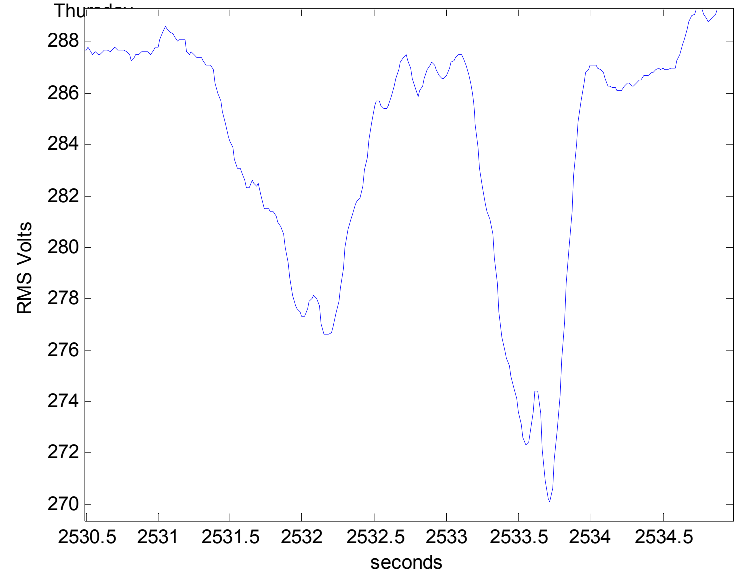
Figure 10-3—Maximum Permissible Voltage Fluctuations

Drawbacks of IEEE 141/519 Curve









IEEE 1453

- Based on IEC 61000-4-15 (adopts the IEC standard).
- Provides specifications for the measurement of flicker based on IEC 61000-4-15.
- Provides recommended flicker limits on medium-voltage, high-voltage, and extra-high voltage systems based on IEC 61000-3-7.

Advantages of using IEEE 1453 over IEEE 141/519 curves

- Measurement that directly represents flicker level in terms of human perception.
- Provides a way of measuring flicker when voltage fluctuation is anything but a rectangular change.
- Impact of modulations caused by modern solid-state converters (interharmonics) on voltage fluctuations taken into account.
- Can be incorporated into simulation models to provide future flicker estimates and the effectiveness of various flicker mitigation options.

UIE/IEC Flickermeter

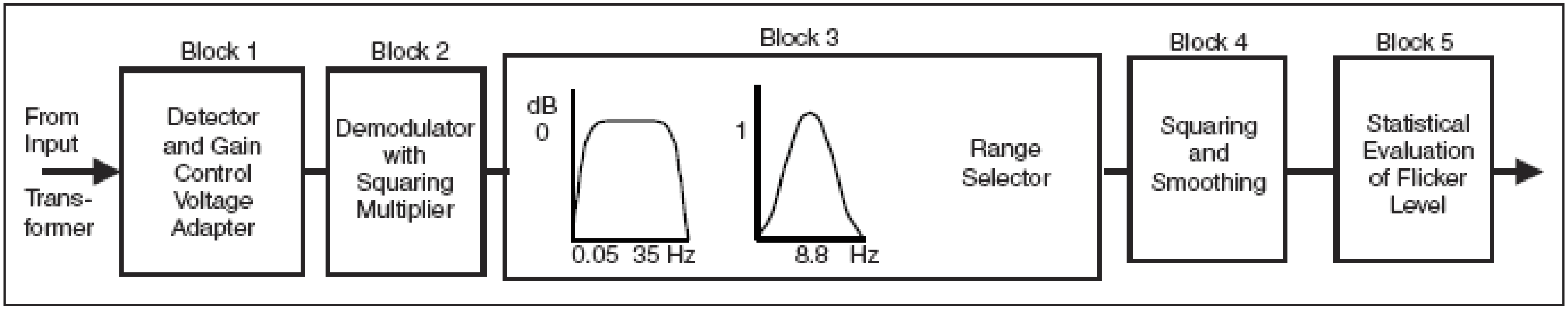


Figure 1. Functional block diagram of the UIE flicker meter

First 4 blocks produce a signal that collectively represent:

- Response of a lamp to a supply voltage variation.
- Perception ability of the human eye
- Memory tendency of the human brain.

Block 5 is a statistical calculation that emulates human irritability to the flicker level.

Figure Source: J.C. Gomez, M.M. Morcos, “Flicker Measurement and Light Effect”, Power Engineering Review, Nov. 2002.

IEEE 1453 Definitions

- **Pst – "A measure (statistical) of short-term perception of flicker obtained for a ten-minute interval. "**
- **Plt – "A measure (statistical) of long-term perception of flicker obtained for a two-hour period. This value is made up of 12 consecutive Pst values per the following formula." - Necessary when duty cycle varies or multiple loads operating simultaneously.**

$$\mathrm{Plt} = \sqrt[3]{\frac{1}{\mathrm{N}} \times \sum_{j=1}^{\mathrm{N}} \mathrm{Pst}_j^3}$$

where N = The nunber of Pst readings.

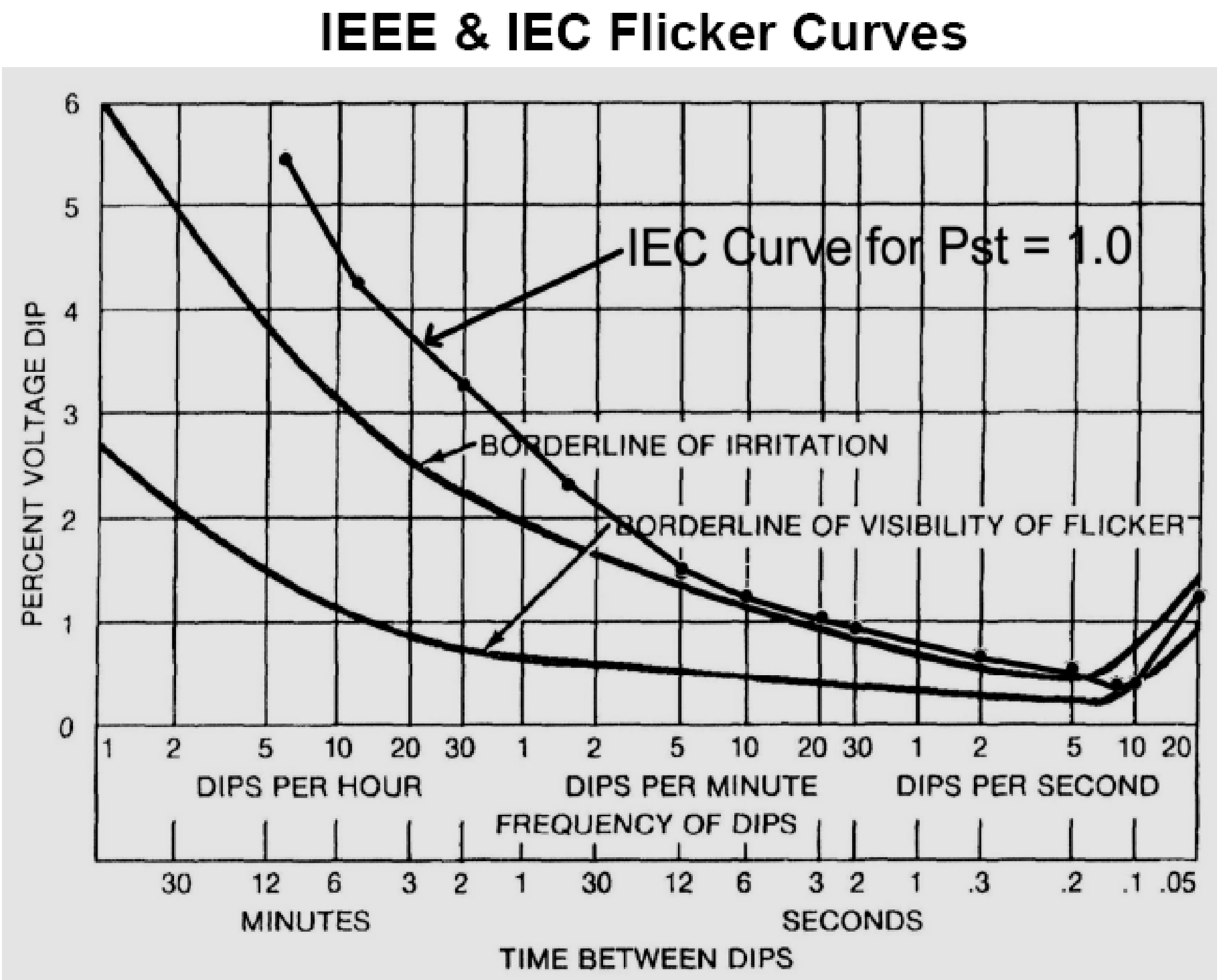
N should be based on the duty cycle of the fluctuating load. If exact duty cycle is unknown, assume N=12 to represent 2 hours.

IEC Flickermeter

- Pst of 1.0 represents a magnitude and frequency of voltage fluctuation that is generally considered to be objectionable.

- Measurement based on luminous fluctuation associated with 60-watt, 60-Hz 120-VAC or 50-Hz 240-VAC incandescent lamps.

Comparison of IEEE 141 and IEC Flickermeter Curves



*1 dip = 2 changes

IEEE 1453 Recommended Flicker Levels

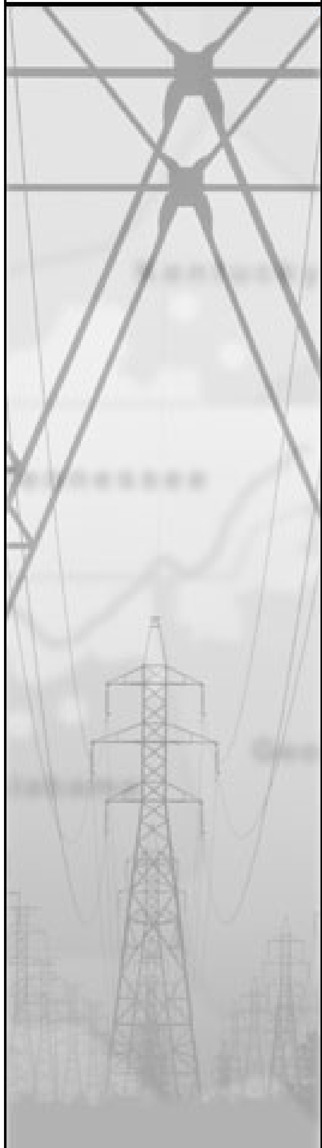


Table 1—Planning levels for Pst and Plt in MV, HV, and EHV power systems

	Planning levels	
	MV	HV–EHV
Pst	0.9	0.8
Plt	0.7	0.6

Table 2—Compatibility levels for Pst and Plt in LV and MV power systems

	Compatibility Levels
Pst	1.0
Plt	0.8

Represents the levels below which complaints are not generally received.

However, levels that are not objectionable may still be perceivable.

1453 Statistical Guidelines

- As a general guideline, when designing, Pst and Plt should not exceed the planning levels more than 1% of the time (99% probability level), with a minimum assessment period of one week.
- IEEE 1453 recommends that Pst and Plt not exceed 1.0 pu 5% of the time in existing low voltage and medium voltage systems (95% probability level.

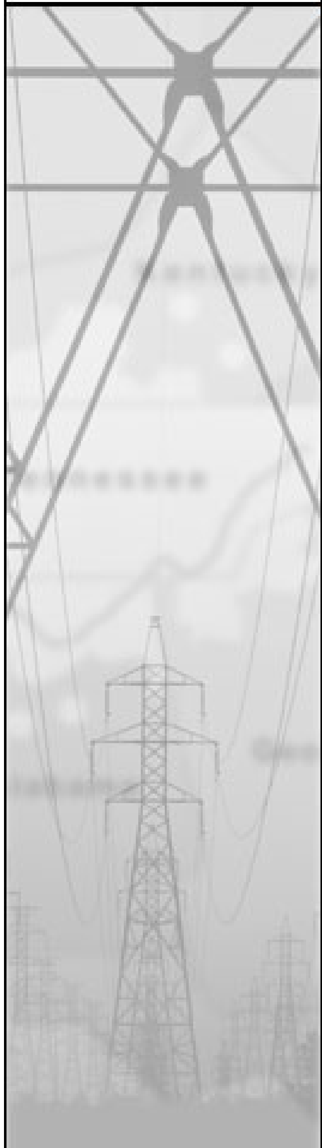
Other Points To Note About Flicker

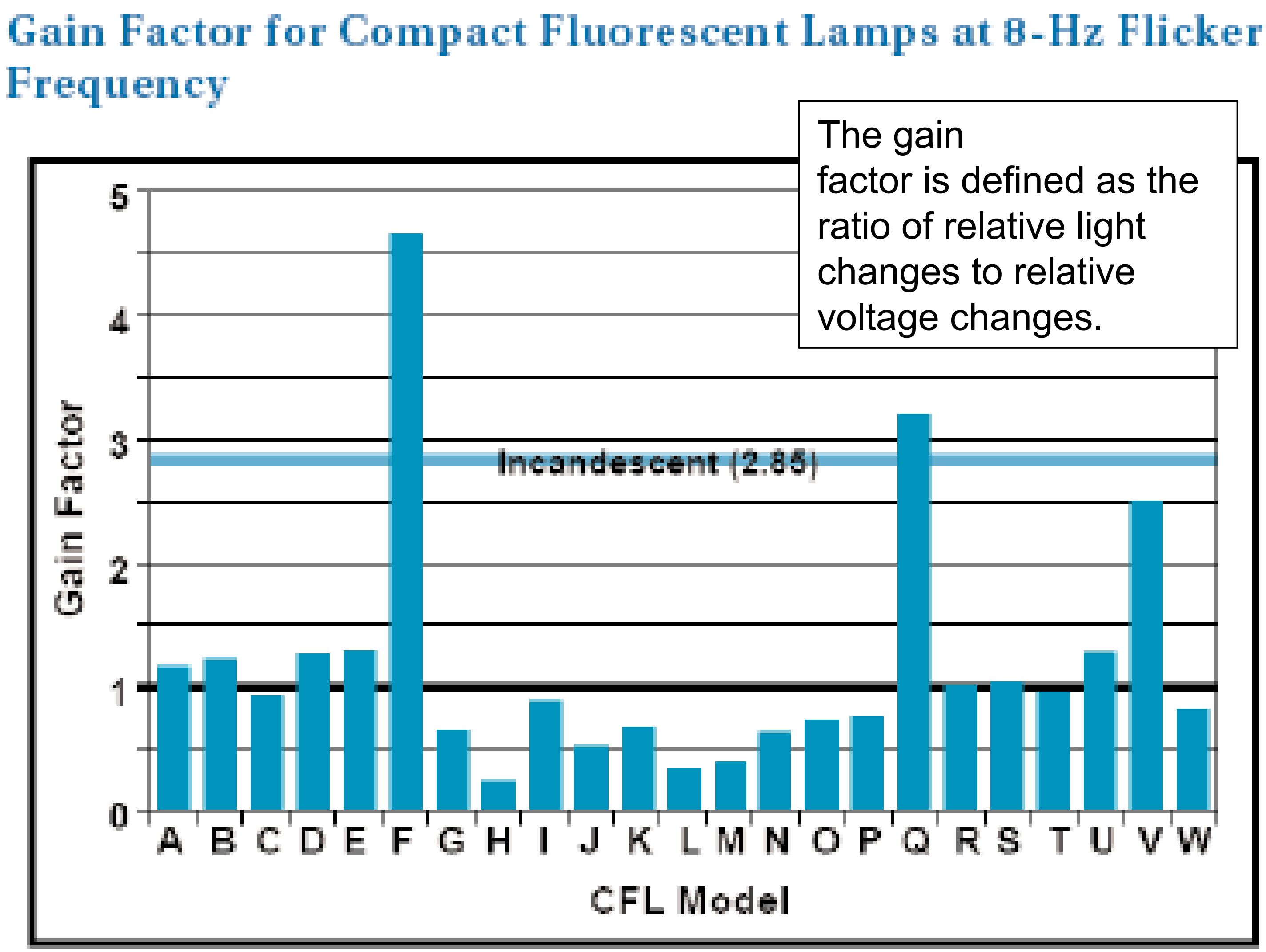
- People most sensitive to fluctuation frequency of 2 to 10 Hz with flicker visible up to 35 Hz.
- Any change in voltage 6.0 % or greater results in objectionable flicker, regardless of frequency. [1]
- Lower-wattage incandescent bulbs produce more flicker for a given change in voltage. At the same rated wattage, a 230-volt bulb will flicker more than a 120-volt bulb for a given change in voltage.
- Dimmers can exacerbate the flicker problem because flicker becomes more perceptible as baseline lumen levels are reduced.
- Fluorescent lamps typically flicker less for a given voltage input [2].

[1] R.Dugan, et al., *Electrical Power Systems* Quality, 2nd Ed., 2002.

[2]T.A. Short, *Electric Power Distribution, 2005.*

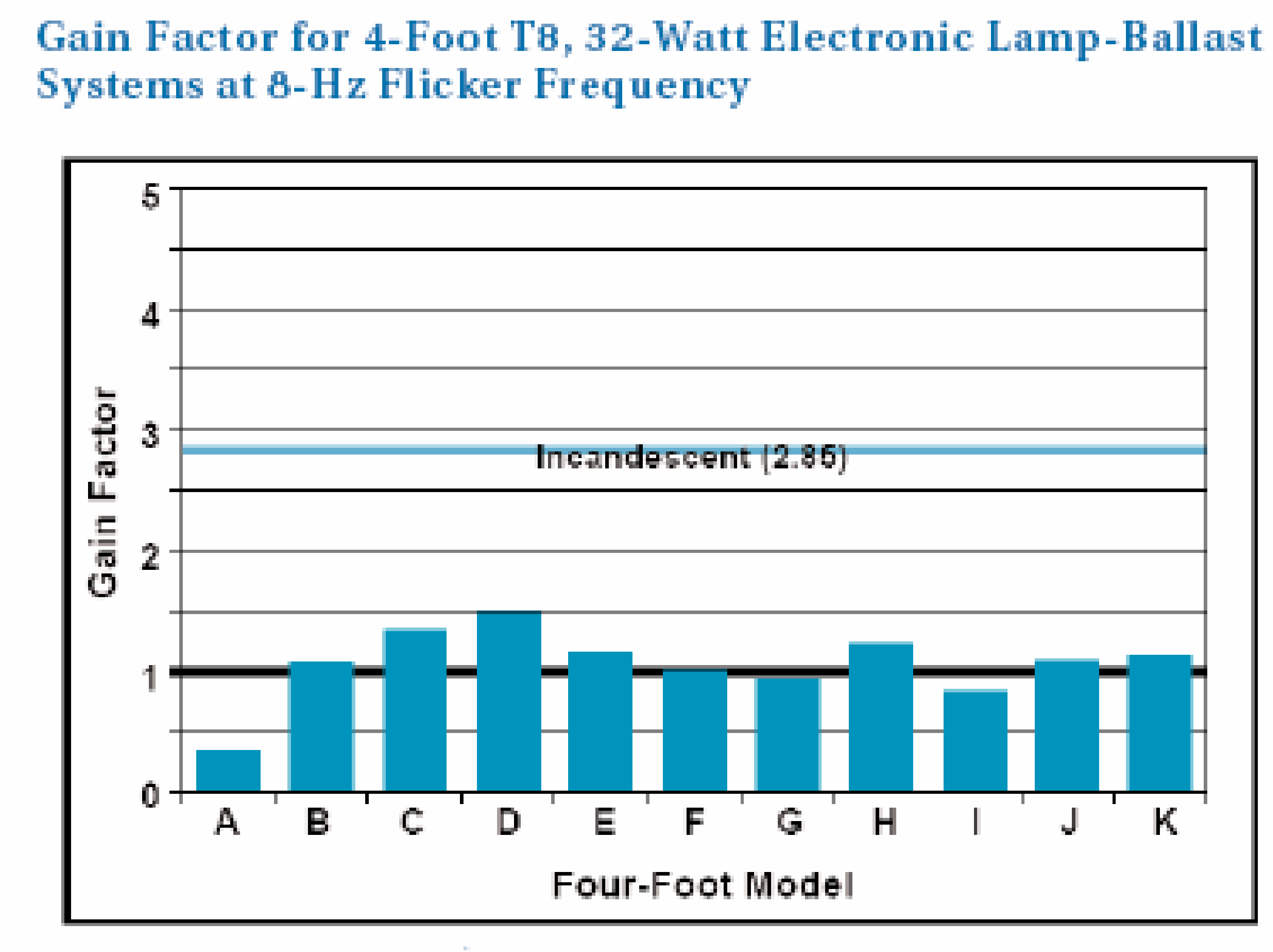
EPRI Studies of Compact Fluorescent Lamp Gain Factors

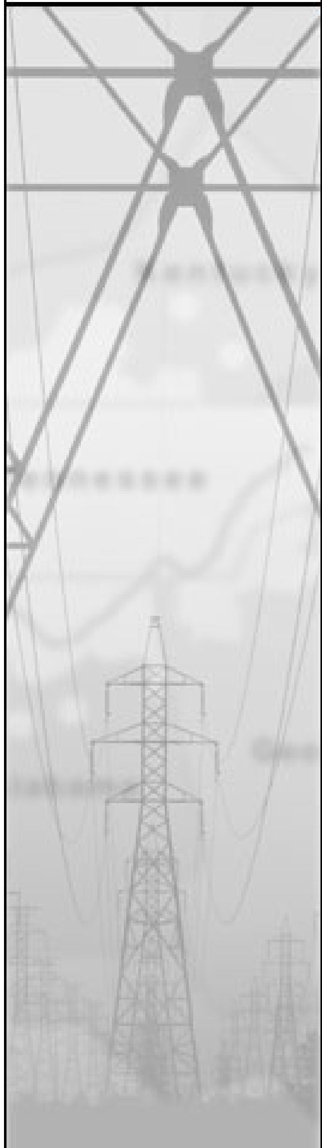




The gain factor is defined as the ratio of relative light changes to relative voltage changes.

EPRI Studies of Linear T8 Fluorescent Lamp Gain Factors

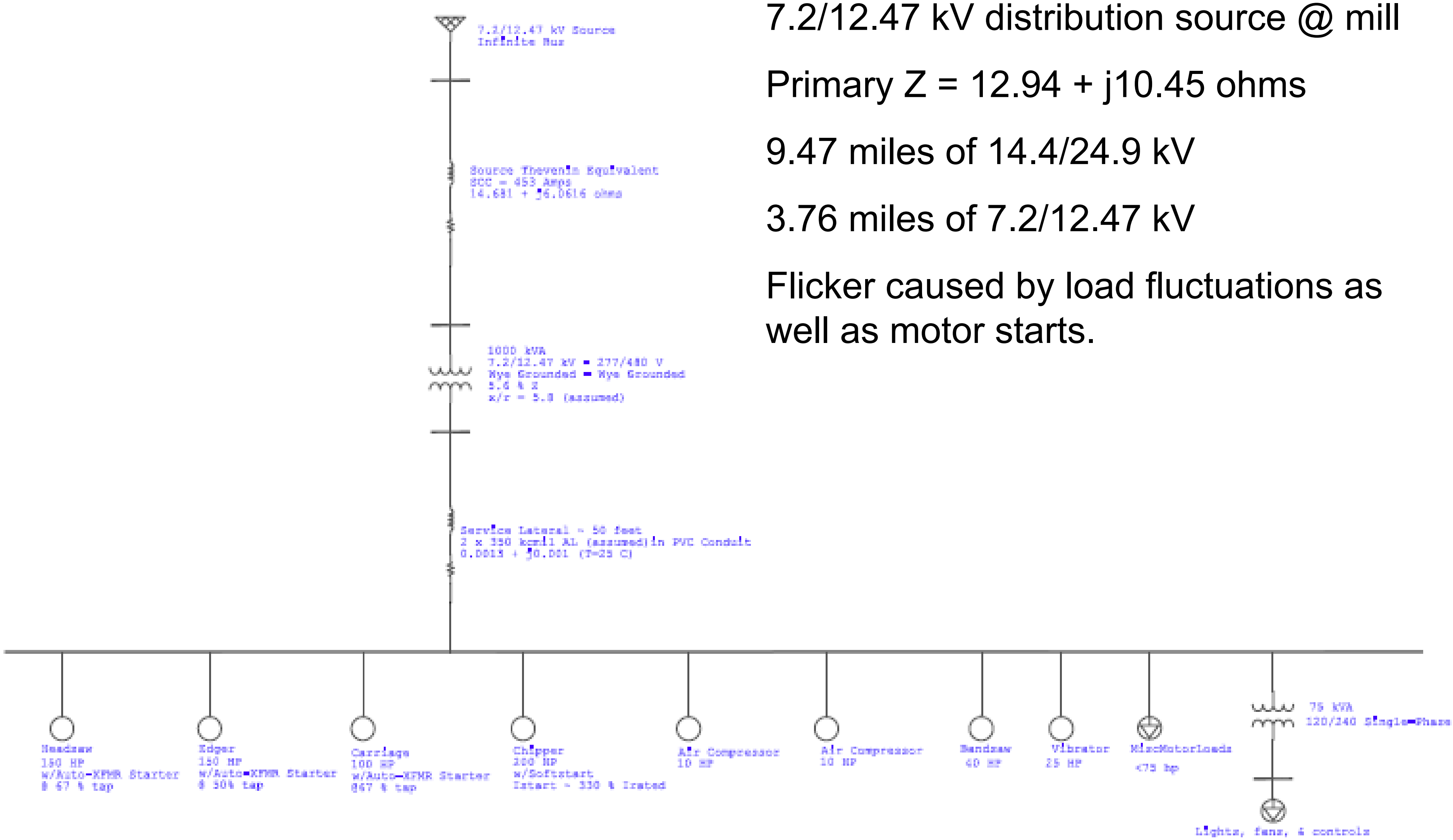




How About a Break!

Lets Keep It to 15 Minutes – The Best is Yet to Come!

Case #1 Sawmill on Rural Feeder



7.2/12.47 kV distribution source @ mill

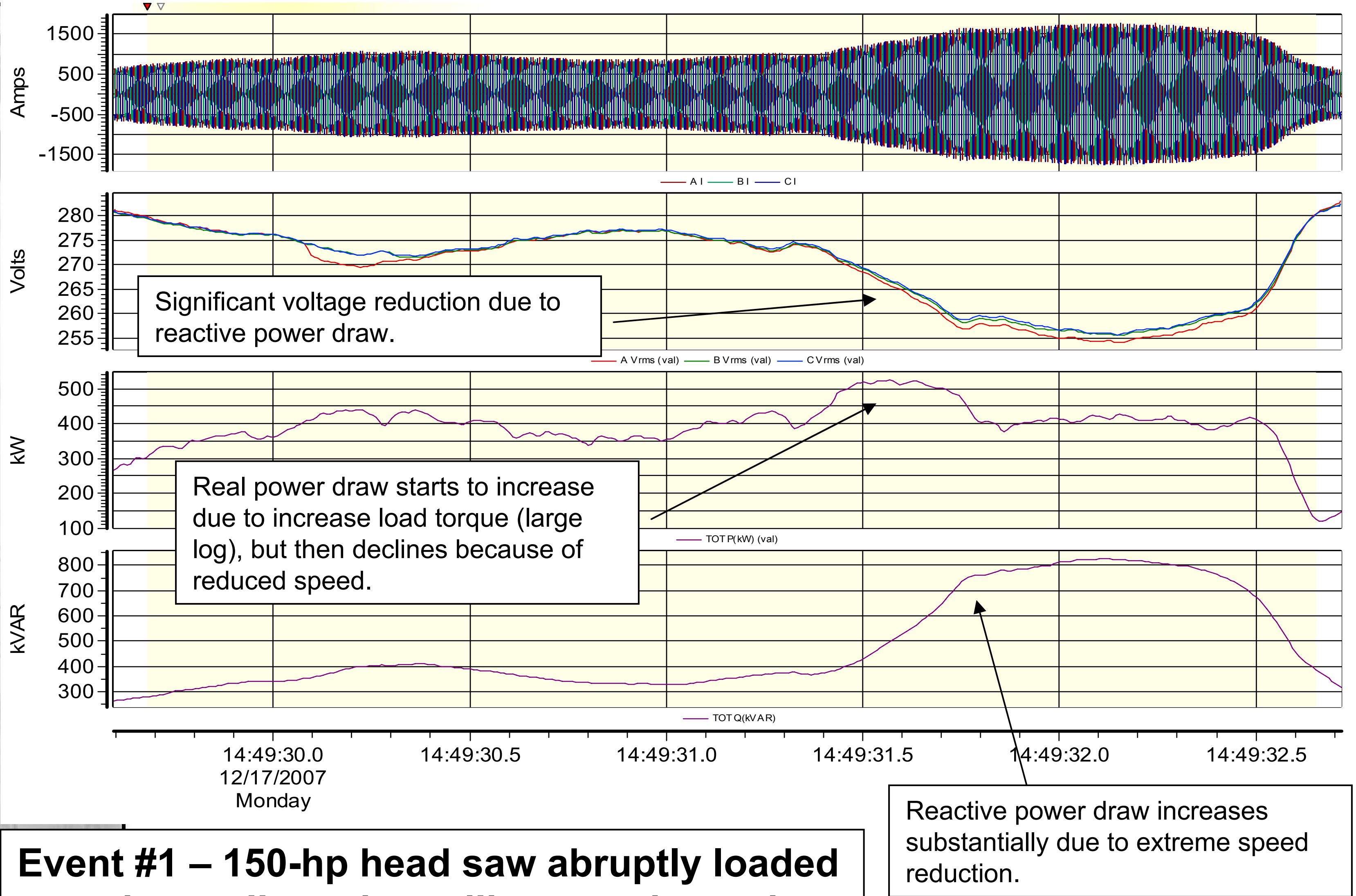
Primary Z = 12.94 + j10.45 ohms

9.47 miles of 14.4/24.9 kV

3.76 miles of 7.2/12.47 kV

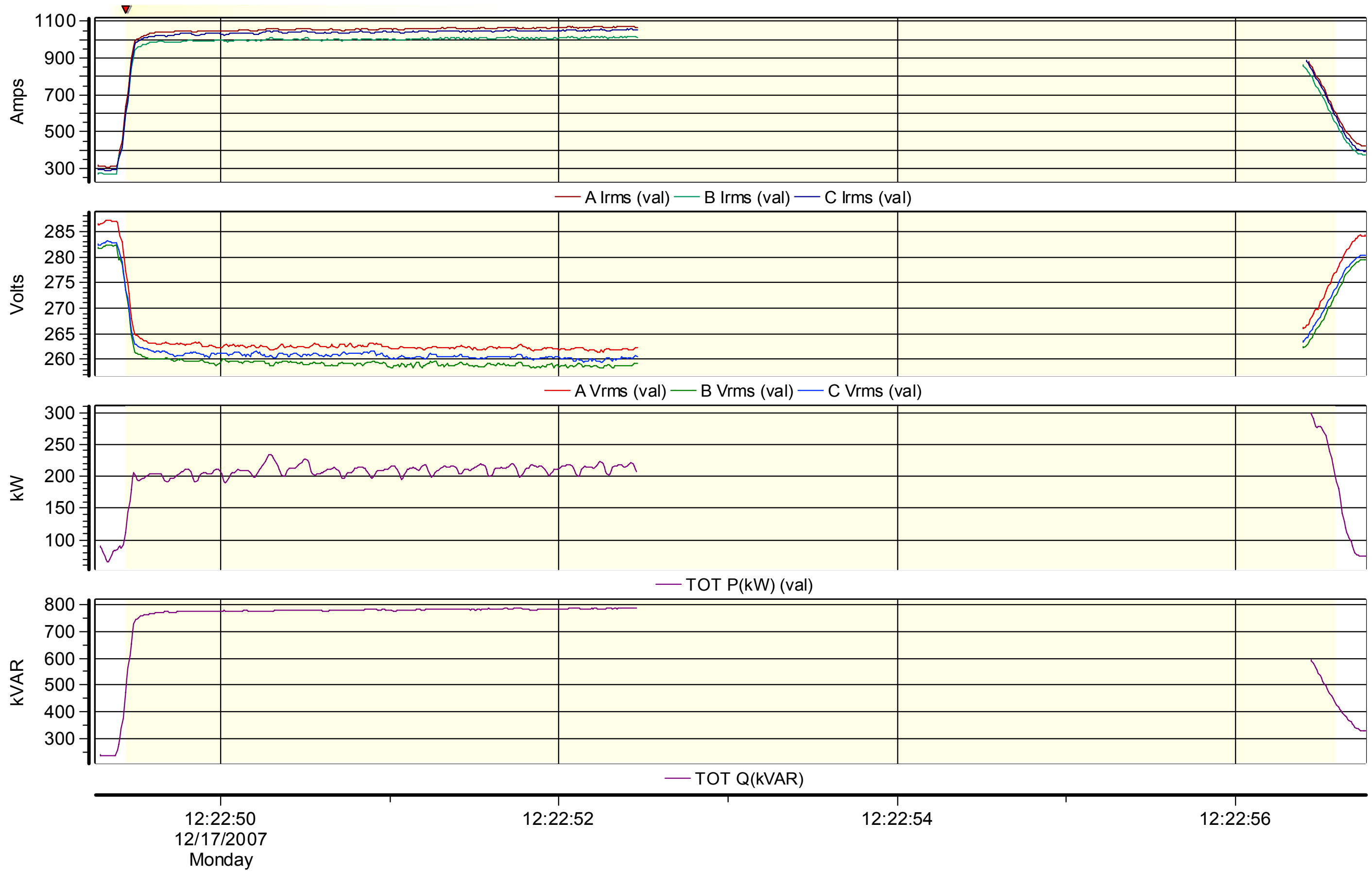
Flicker caused by load fluctuations as well as motor starts.

Case #1 - Head-Saw Load Up – 9.6% Vdrop @ Mill Secondary and 6.6 % Vdrop On Primary



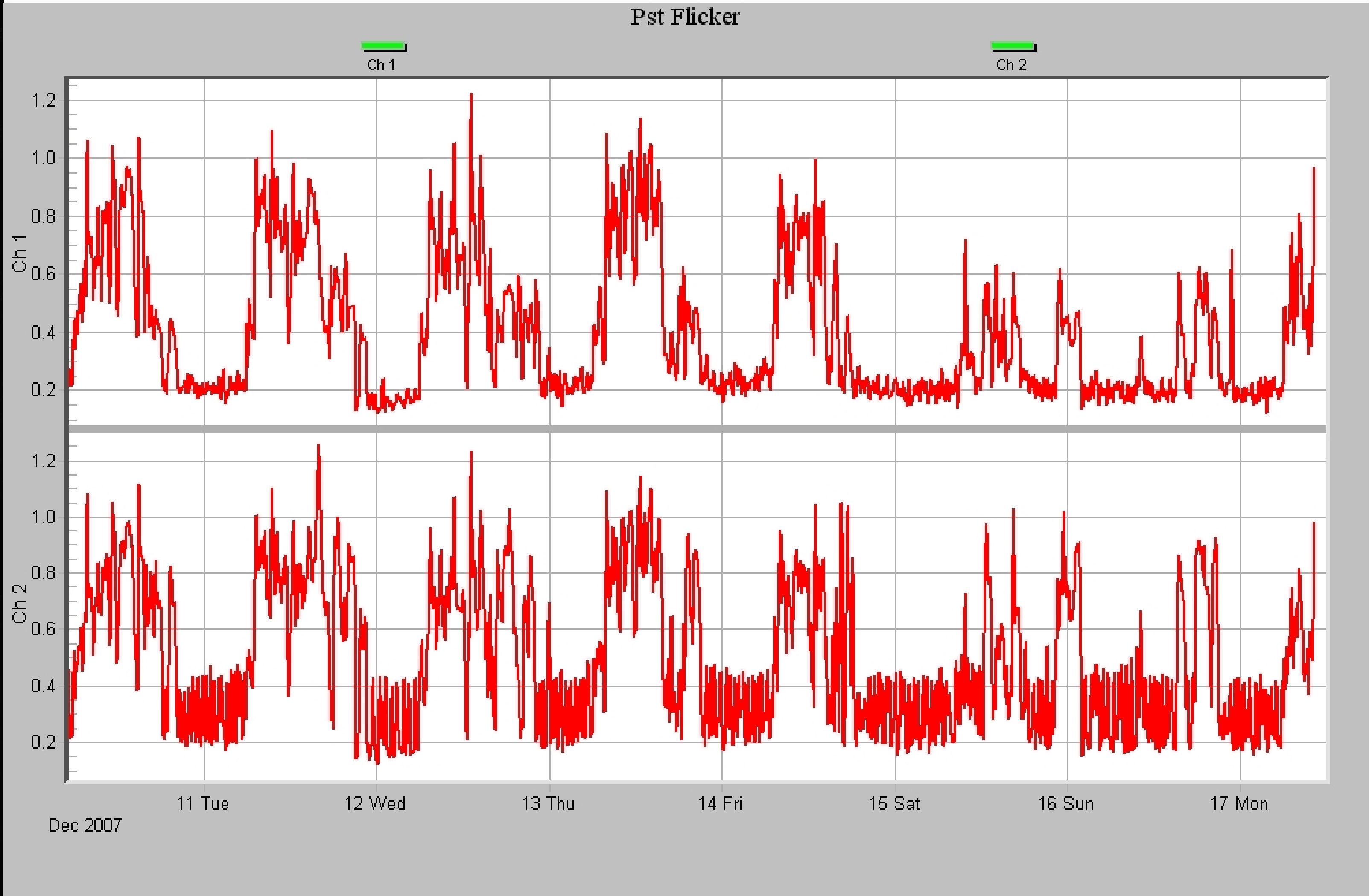
Event #1 – 150-hp head saw abruptly loaded up – data collected at utility metering point

Case #1 – 200 hp Chipper Startup w/softstart 7.5 % instantaneous Vdrop at Sawmill and app. 5 % corresponding drop at residence



Softstart programmed to start motor @ 330 % FLA

Initial 1-Week Pst Profile



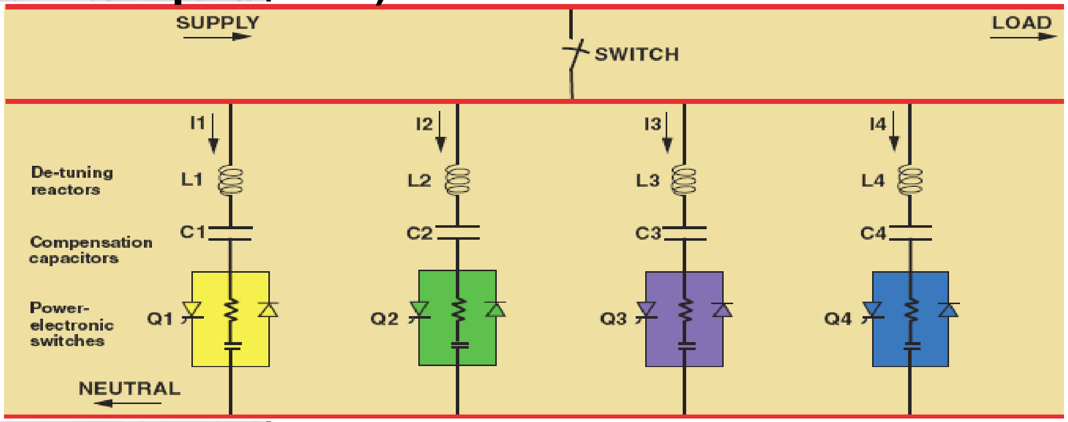
Initial Goals

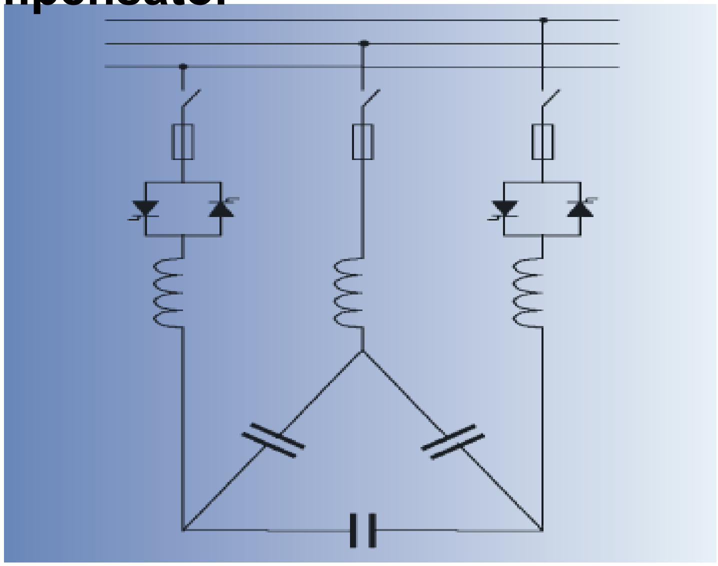
- Reduce flicker Pst on utility system to < 1.0.
- Reduction in voltage sags caused by sawmill operations on utility system to no more than 2.0 percent.
- Mitigation mechanisms must not cause greater than 2.0 percent voltage rise on utility system.

Examples of Products Providing Fast Reactive Power Compensation

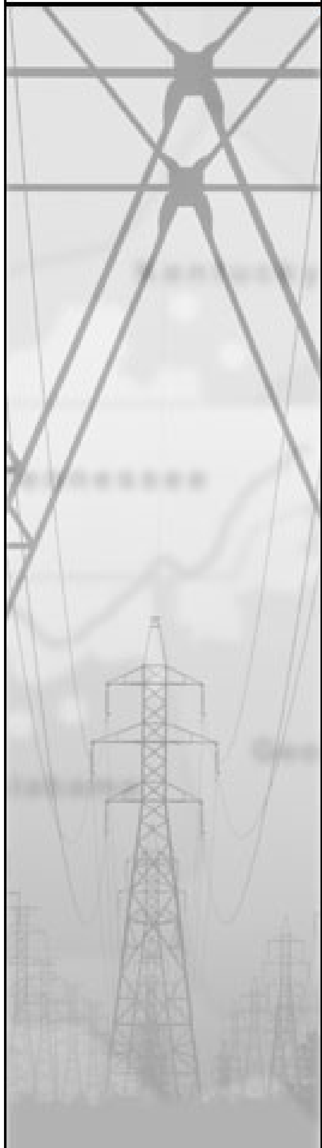
ABB's DynaComp (Dynamic-Var Compensator

S & C's AVC (Adaptive Var Compensator)





More Examples of Products Providing Fast Reactive Power Compensation



CLASS 5890
REACTIVAR™ Hybrid VAR Compensator (HVC)
Real Time Infinitely Variable Reactive Compensation System

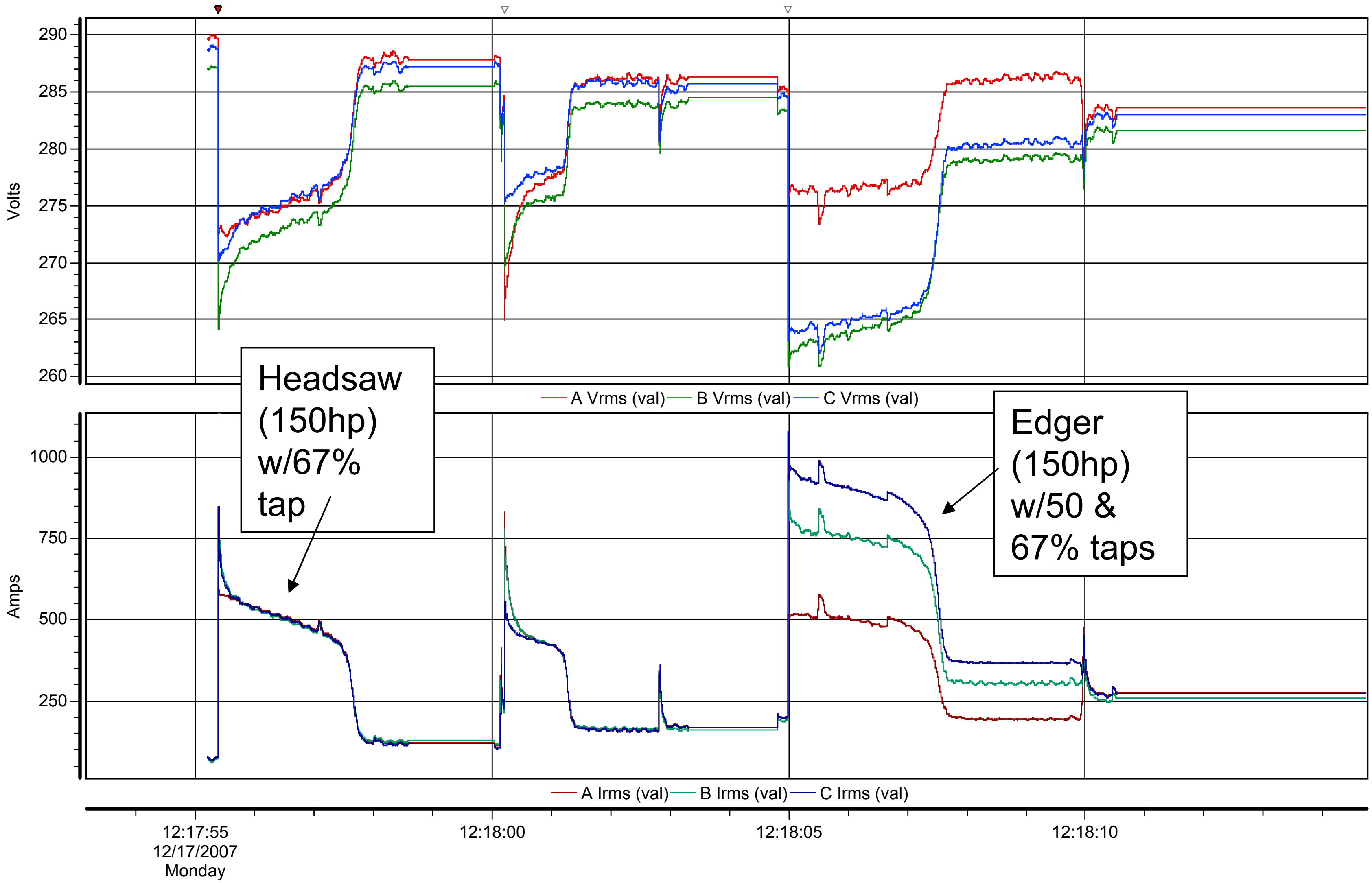
Square-D Hybrid-Var Compensator

Eaton-CH Active Filter

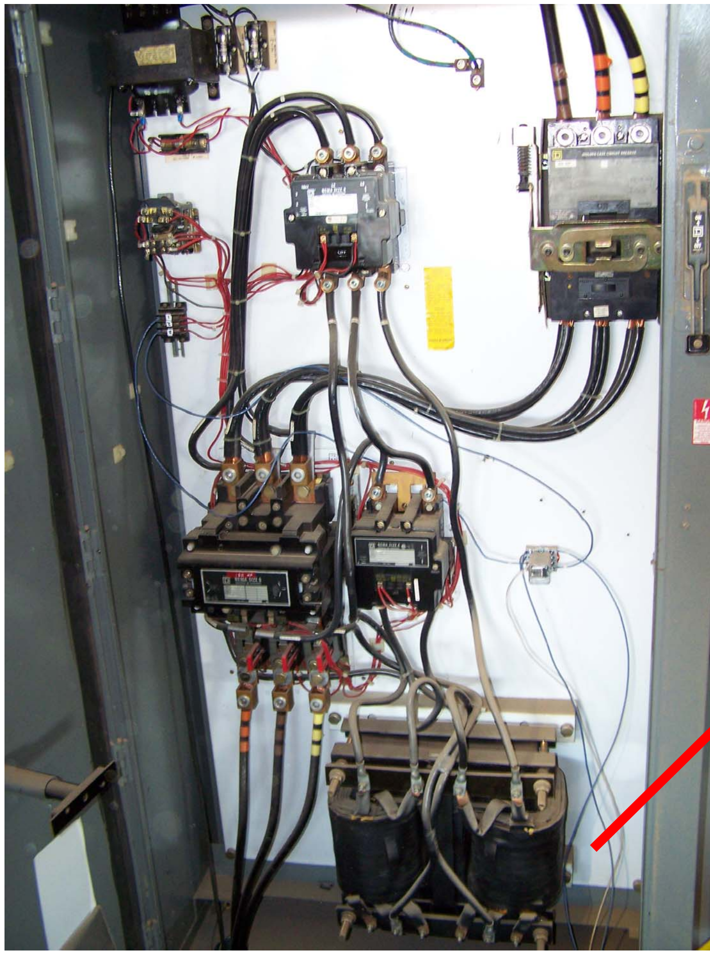
CLASS 5820
ReactiVar™ AccuSine® PCS
Power Correction System

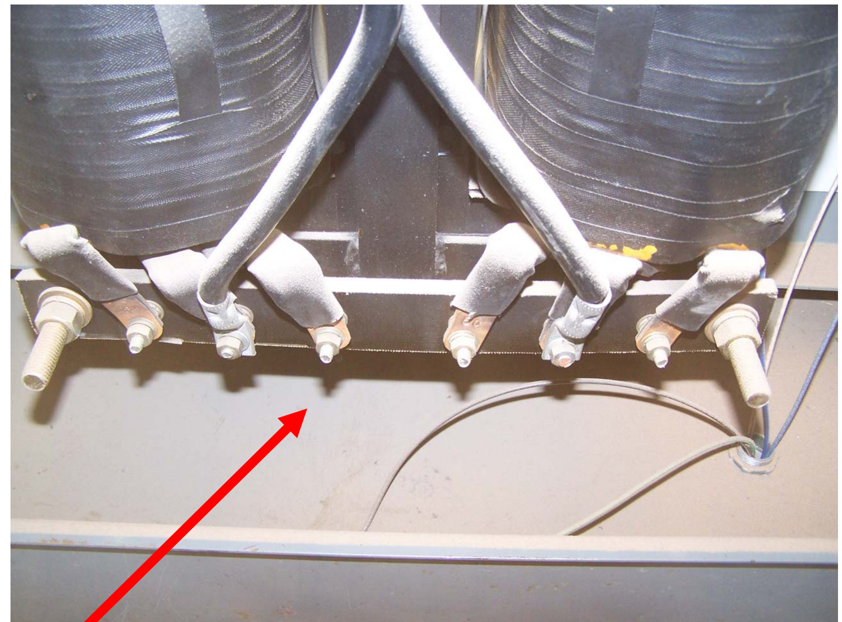
Square-D Active Filter

Case Study #1 – Examples of Motor Starts with AutoXFMR starters



Starter Modifications



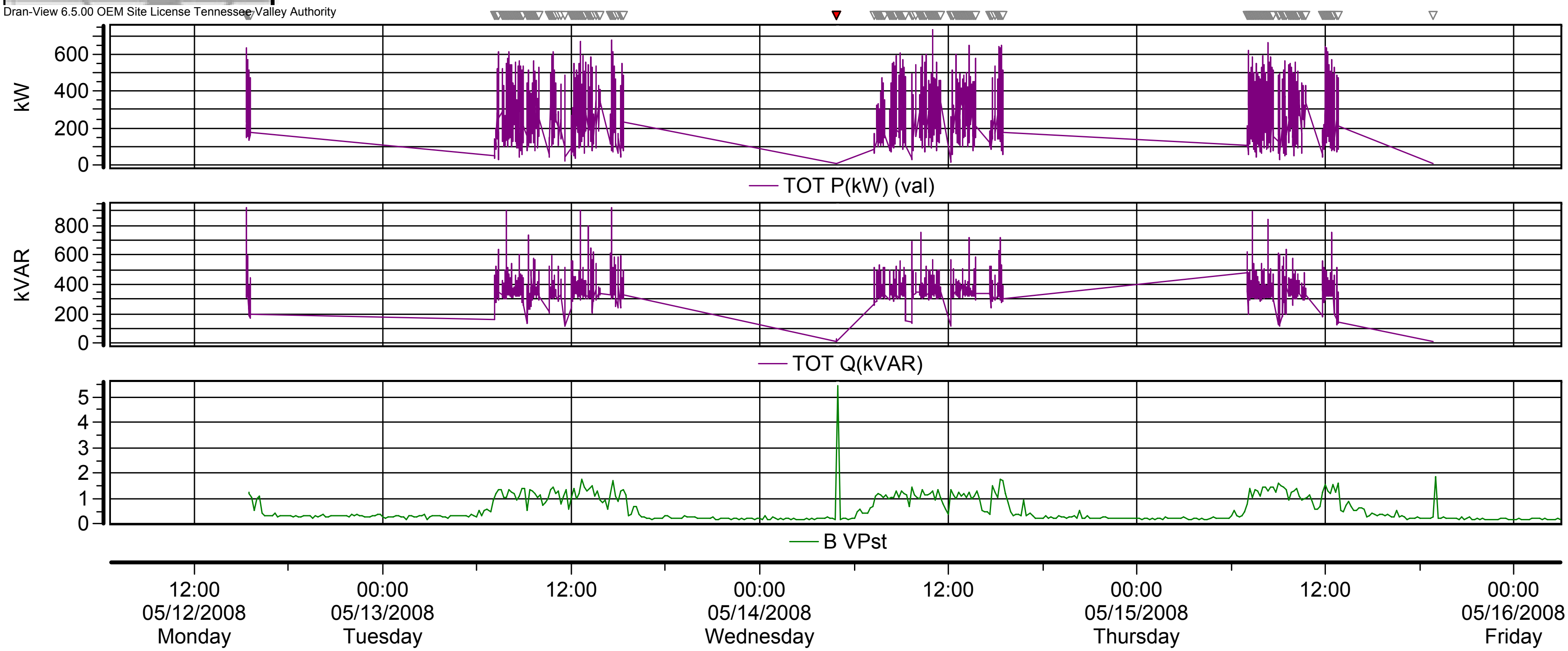


Set all taps to 50% on all autotransformer starters.

Programmed 200hp softstart to start at 250 % of FLA.

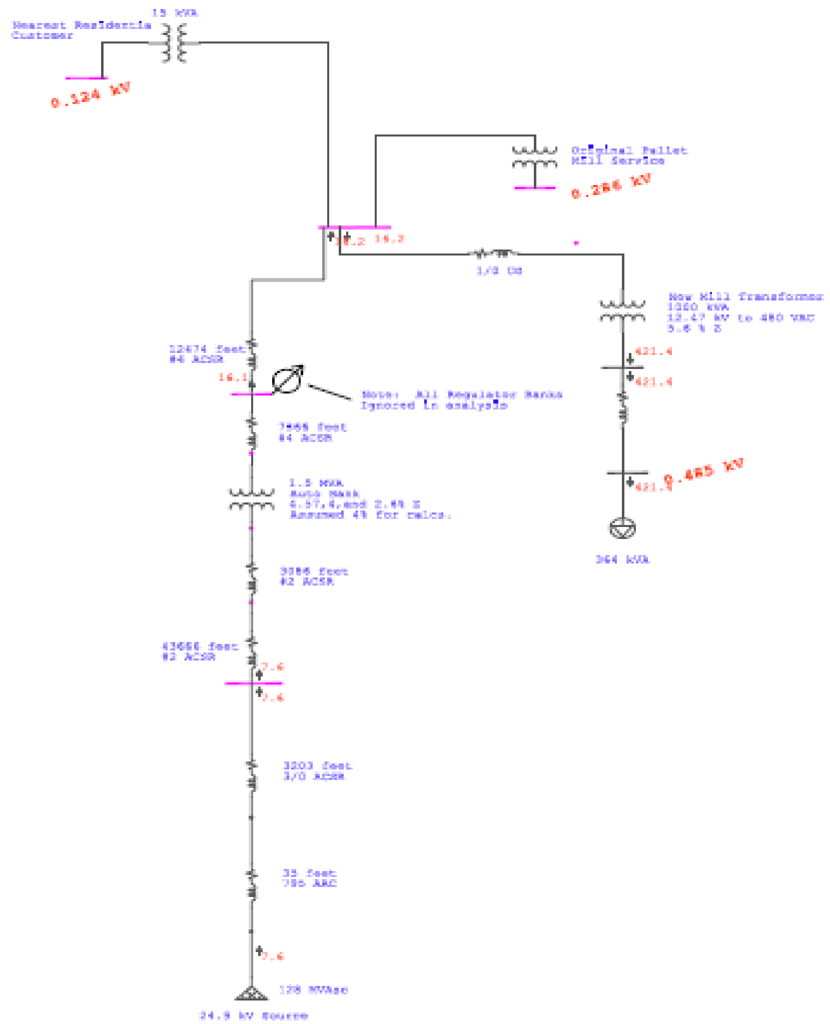
After starter modifications, Max starting Vdrop on primary ~3%

Findings of Additional Recording at the Sawmill

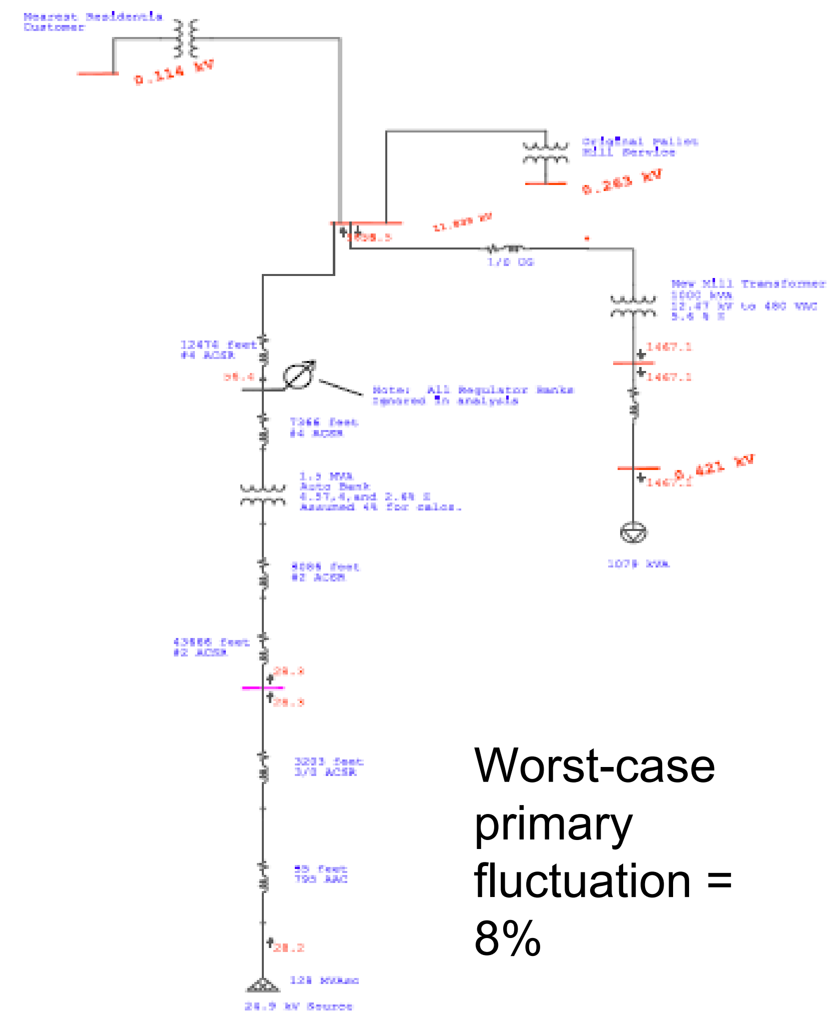


Fluctuations were more frequent and of higher magnitude overall due to type of wood being sawed.

Case Study #1 – Sawmill on Rural Feeder



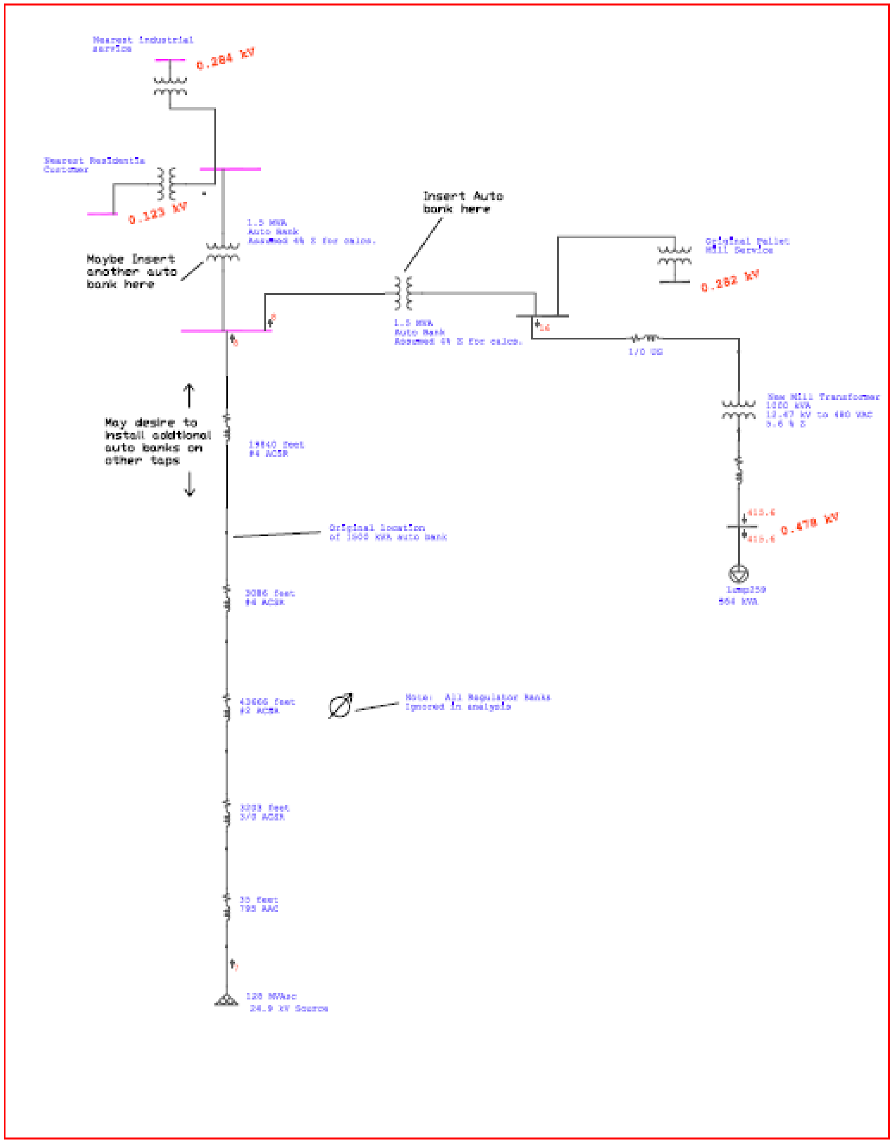
Immediately Before Example Load Surge

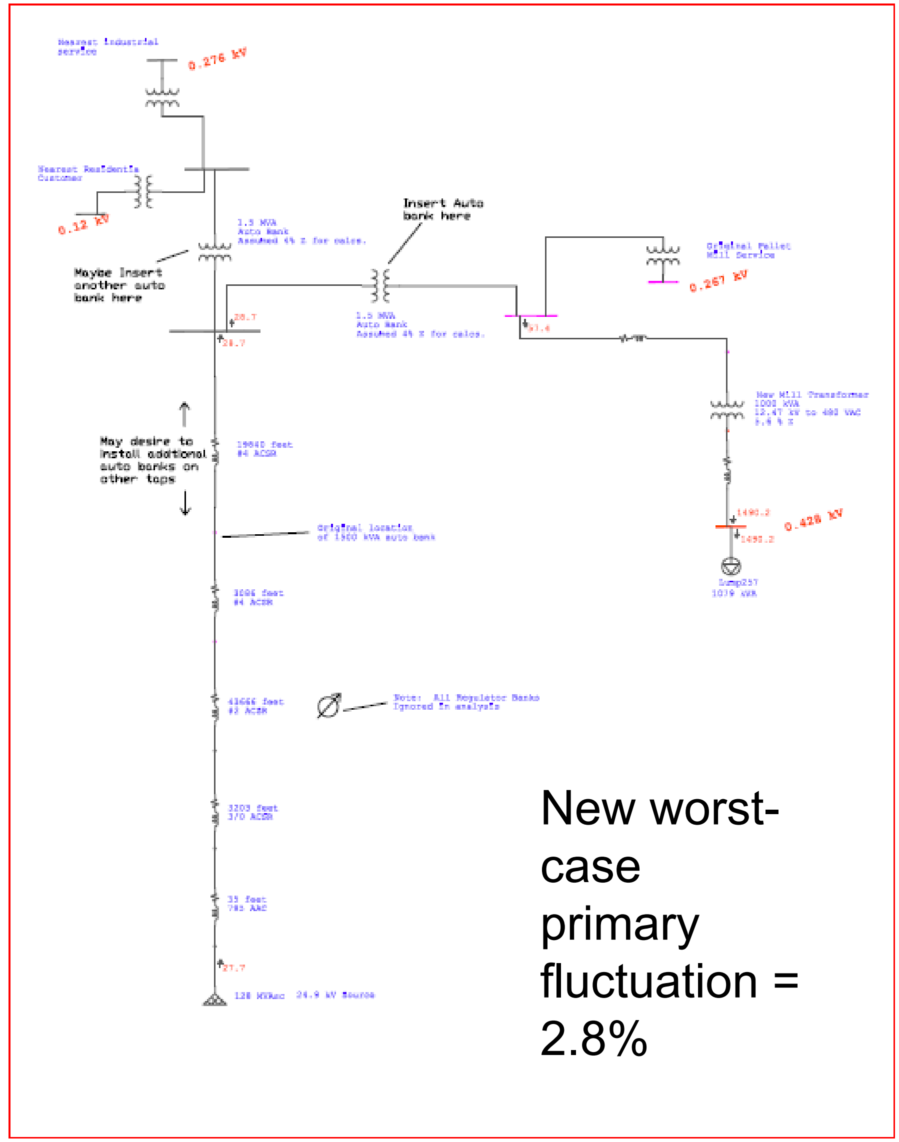


During Example Load Surge

Worst-case primary fluctuation = 8%

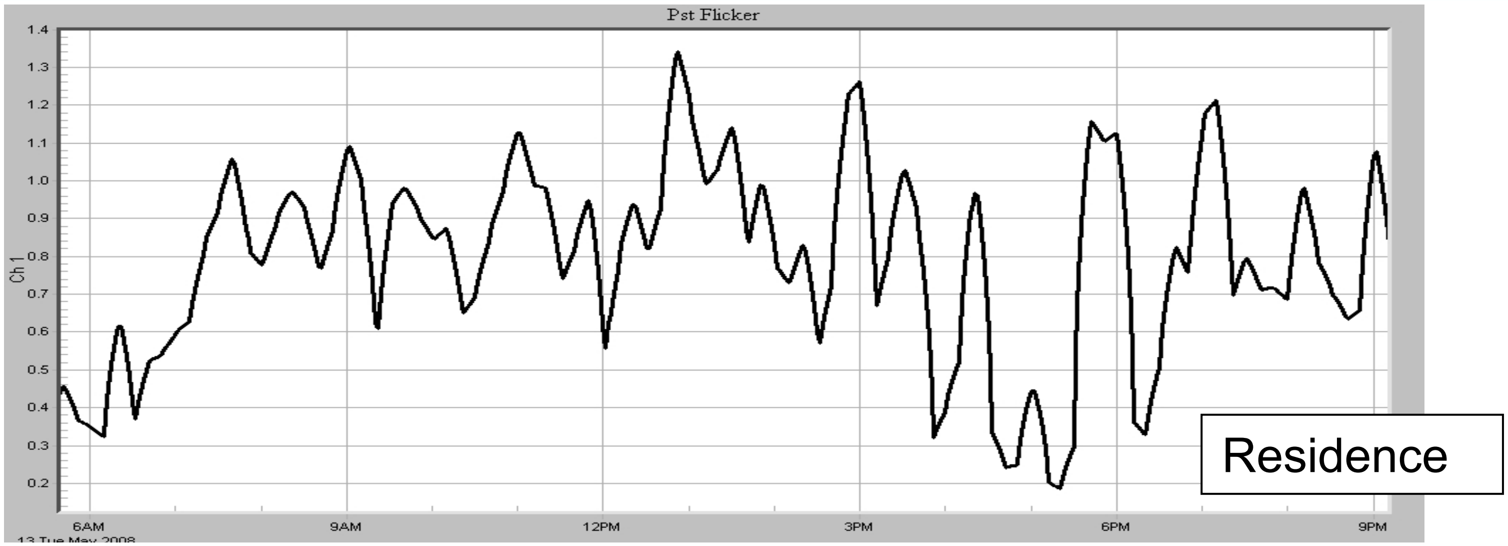
Calculations - Converting 3.9 miles to 14.4/24.9 kV

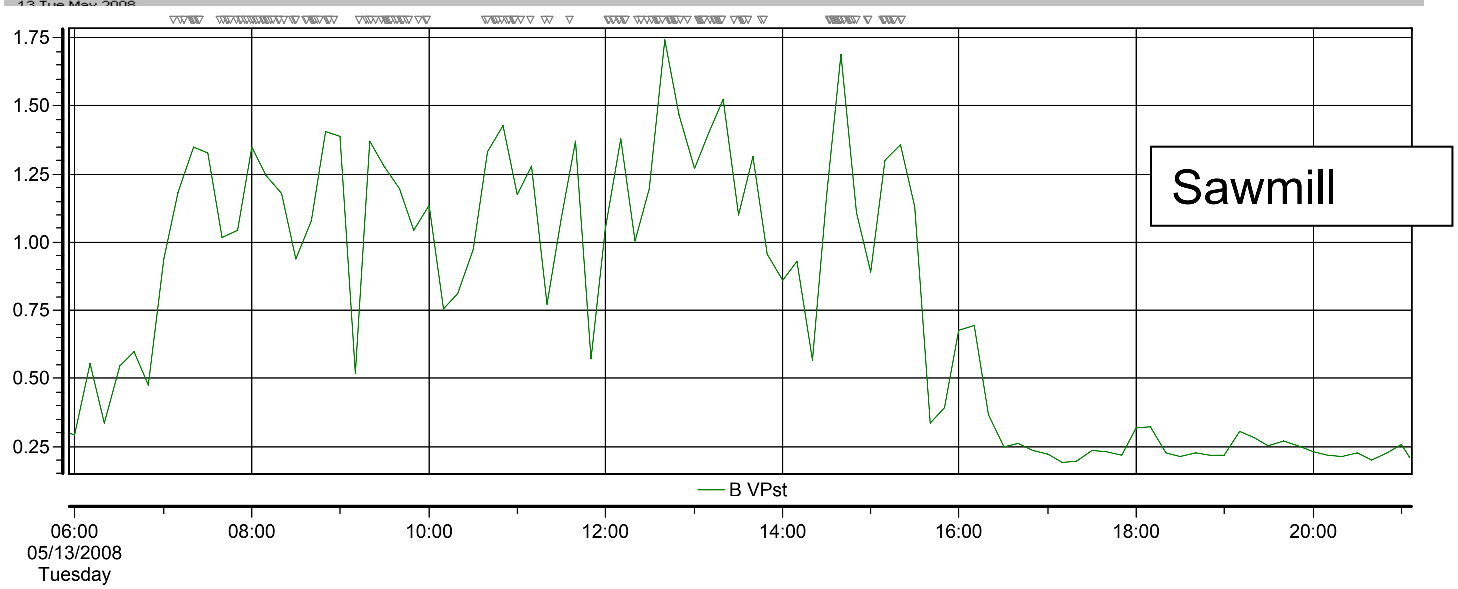




New worst-case primary fluctuation = 2.8%

Pst Calculations and Estimated Pst with Voltage Conversion





Estimating Future Pst After Voltage Conversion

- Max Pst at residence for day shown = 1.34
- Corresponding Pst at sawmill secondary metering point = 1.74

$$\frac{Pst_{Max@residence}}{Pst_{Corresponding@sawmill}} = \frac{1.34}{1.74} = 0.77$$

- Typical ratio "every other interval" ~ 0.7-0.75
- Impedance Ratio =

$$\frac{Z_{To\_XFMR\_Sawmill\_Primary}}{Z_{To\_XFMR\_Sawmill\_Secondary}} = \frac{0.1070}{0.1535} = 0.7$$

- By converting last 3.76 miles to 14.4/24.9 kV

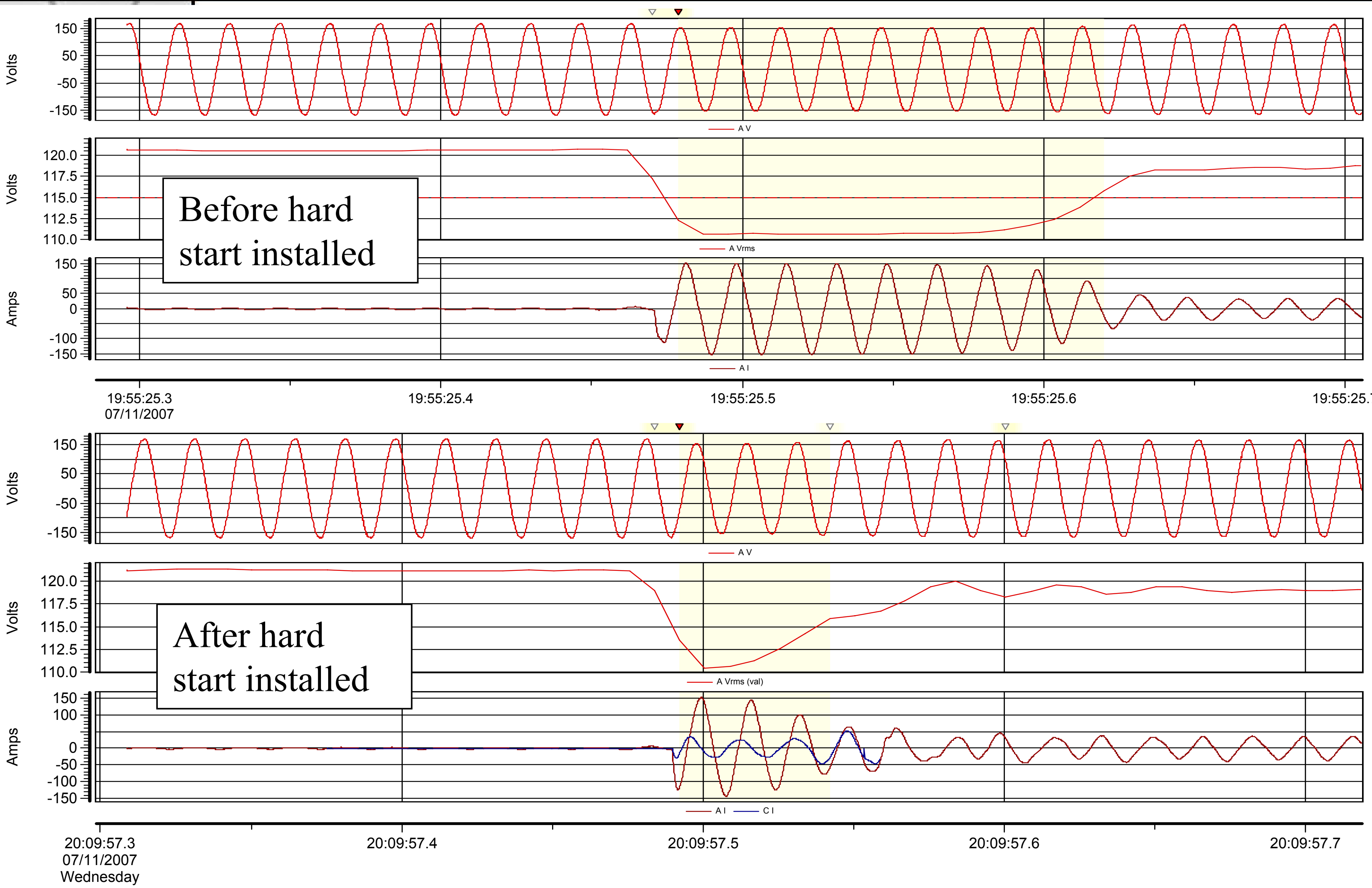
$$\frac{Z_{To\_XFMR\_Sawmill\_Primary}}{Z_{To\_XFMR\_Sawmill\_Secondary}} = \frac{0.0448}{0.0933} = 0.48$$

With Impedance Ratio = 0.48 PstMax @ Residence Due to Sawmill Load = 0.84

Case Study #2a & #2b – Residential Air-Conditioning Starting

- Customer complaints at their worst have resulted in service drop/lateral changeout or possibly even transformer upsizing
- HVAC technicians often install “hard start” kits
- On average, electric consumers understand that flicker is simply going to occur when their A/C starts.
- Members sharing secondary conductors and sometimes transformer may result in one member seeing another member’s A/C startup.

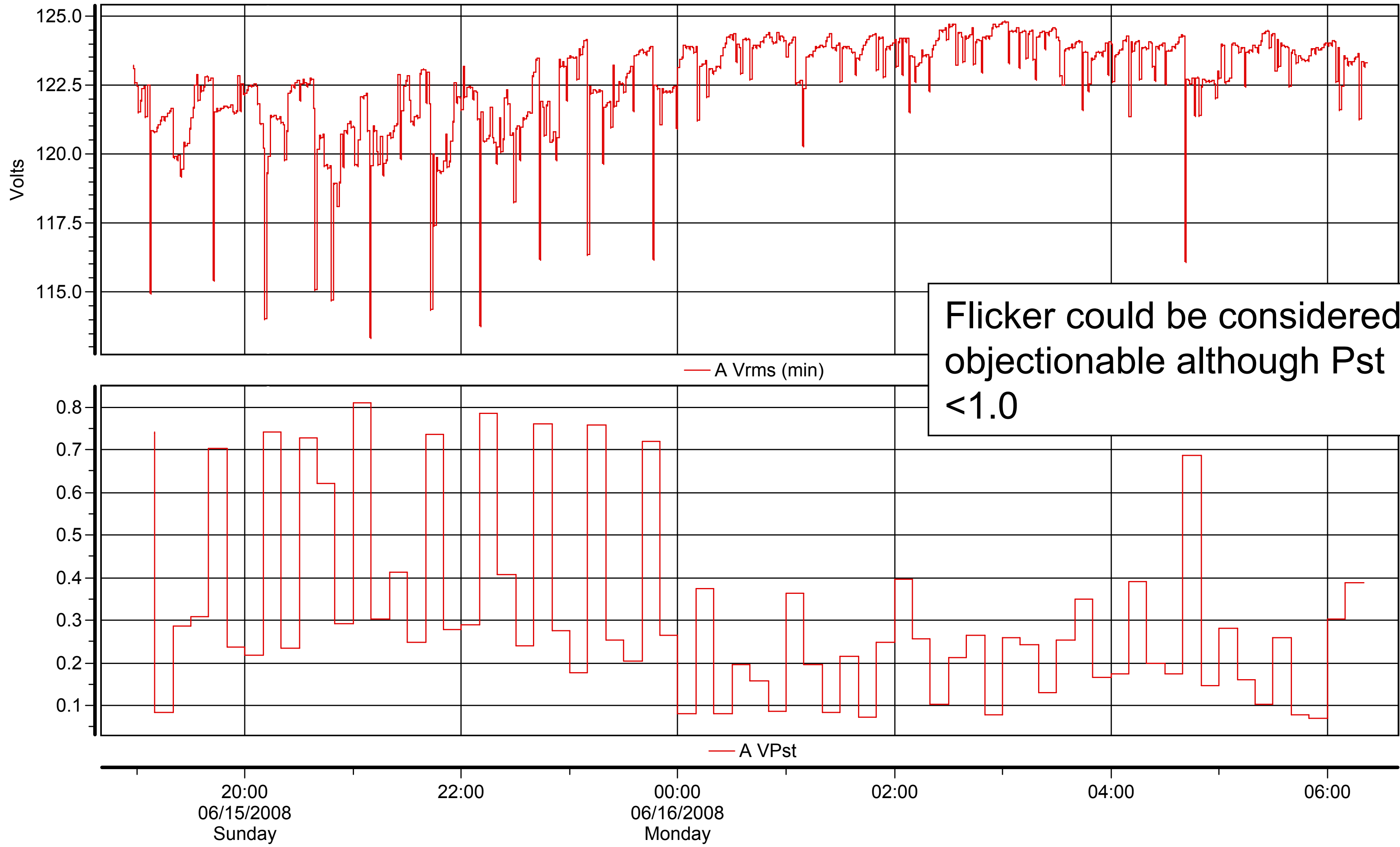
A/C Starting Case Study #2a



Results of Using Hard Start Devices

- Hard start results in increased starting torque
- Compressor accelerates to full speed more quickly, thereby reducing startup duration
- Magnitude of initial inrush current and voltage drop still the same as before – capacitor provides phase shift but no voltage rise

Minimum Voltage Magnitude Profile and Corresponding Pst for A/C Startups Case Study



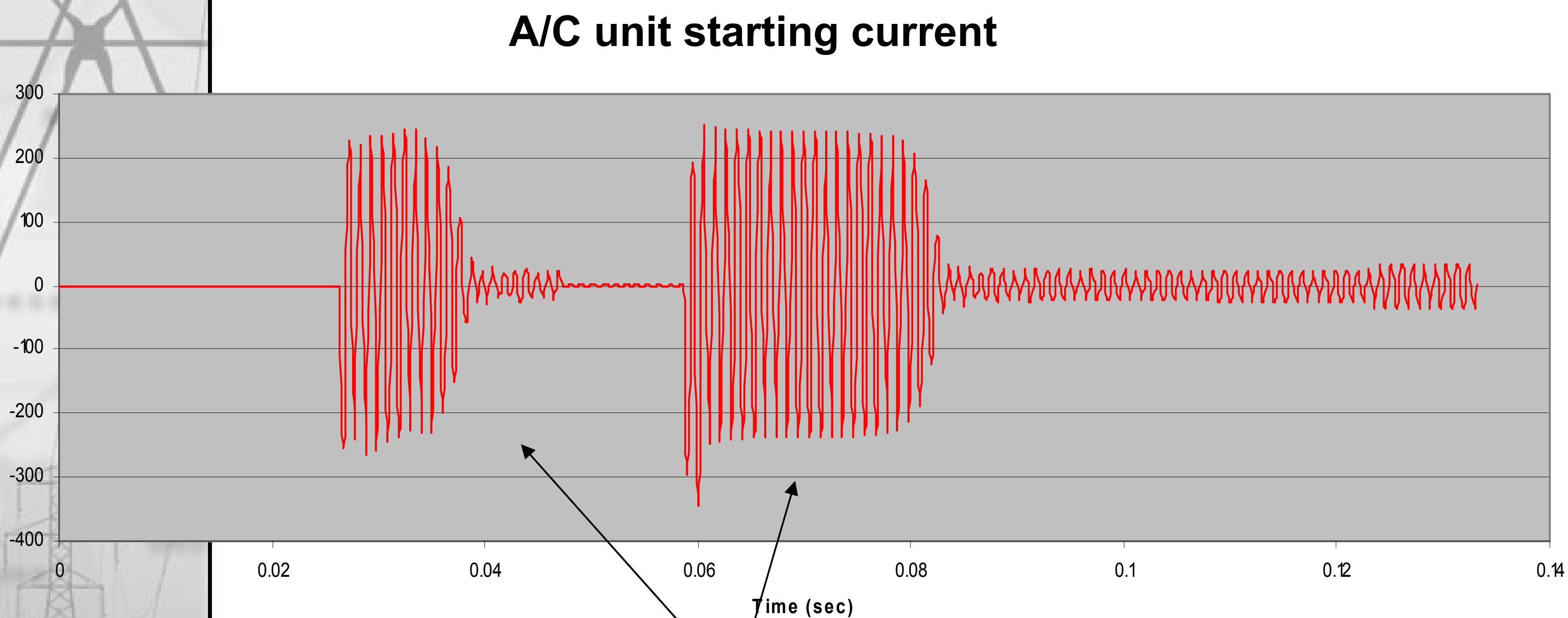
Flicker could be considered objectionable although Pst <1.0

	Min	Max	95%	99%
AVrms	113.3	124.8	N/A	N/A
AVPst	0.06869	0.8114	0.7575	0.8114

A/C Startup Case Study #2b

- Customer complained about flickering lights, number of interruptions occurring, and damaged electronics.
- Distributor power-quality monitoring revealed nothing problematic.
- Distributor changed 50 kVA to 75 kVA transformer and concerns were not resolved.
- Relationship between customer and distributor was tense and customer wondered why the transformer had been changed out if no problem could be detected.
- HVAC technician told customer that the A/C unit needed a “booster” (hard-start kit).

A/C Startup Case #2b Power Quality Monitoring



Switchbounce associated with the mercury-bulb thermostat resulted in multiple A/C starts

Case Study - Raw Water Pumping Station – Original Design

- Original study began in 2004
  - Design incorporated 1 pump driven by 1250 hp 4,160 V AC induction motor
  - Provision for additional pump installation
  - 4,160 VAC Electronic softstarter
  - 2,125 kVAr 2-stage capacitor bank switched simultaneously on with motor (electromechanical contactor-switched)
  - 1,800 kVAr switched off just as motor about to reach full speed

Original Design – Circuit Characteristics

- Fed from 161/69/12.47 sub off of 12.47-kV system
- App. 3.5 miles with 8 line sections of distribution line
- 12.47 kV to 4,160 V 2,500 kVA padmount XFMR
- 0.1 miles from riser pole to XFMR, but distributor wanted PCC to still be at primary terminals of XFMR

Original Objectives and Constraints

- Determine if original design with both electronic softstart and simultaneously-switched cap bank:
  - Result in less than 2.0 % voltage drop at PCC during motor start?
- Use softstart manufacturer's stated inrush current values for calculations
- Perform calculations by hand and/or using steady-state type analysis program

Original Calculations from 2004-2005

Table 2 - Voltage Drop at PCC and Transformer Secondary During Motor Starting Assuming 2,125 kVAr Switched On in 1 Step and Then 1,800 kVAr Switched Off

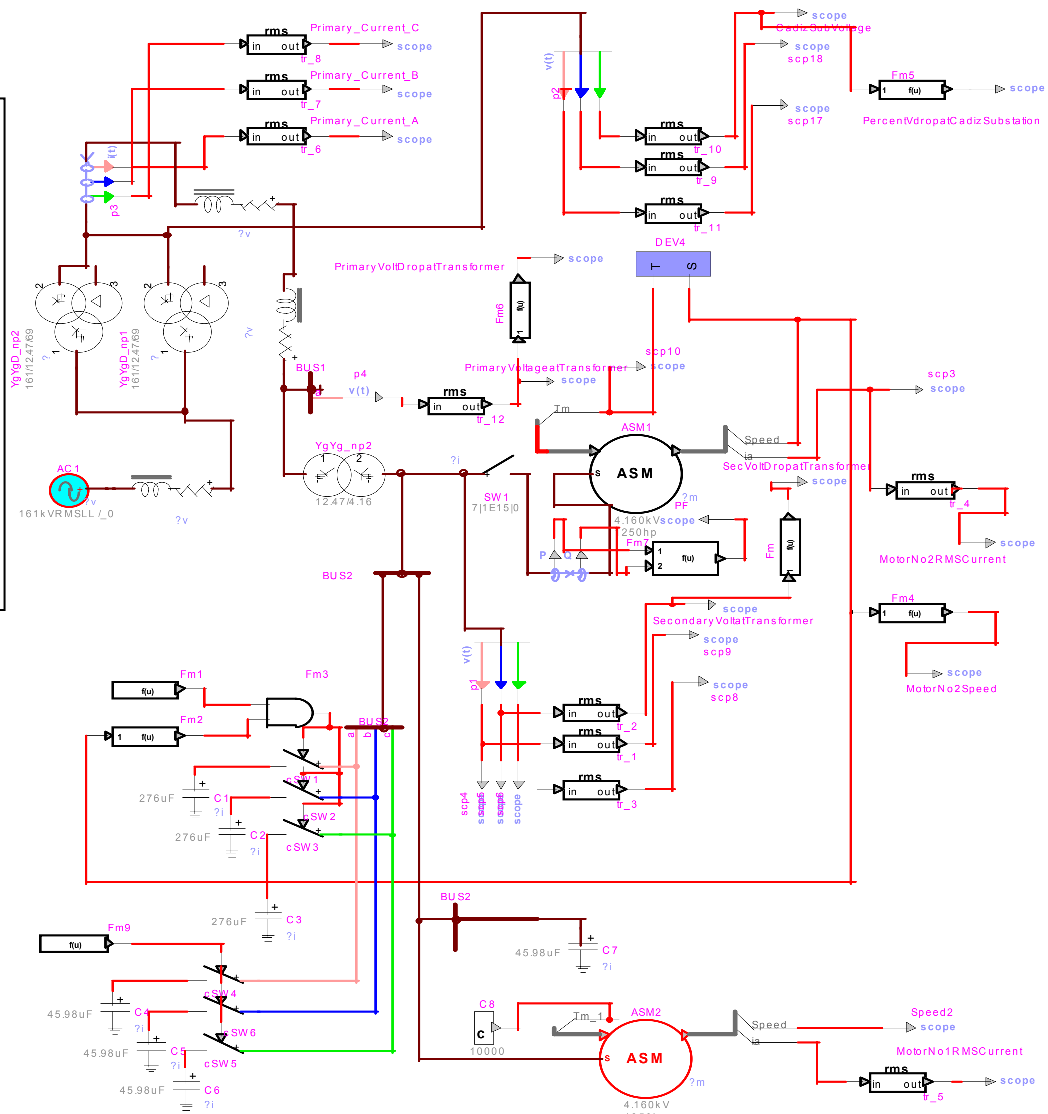
	PCC Relative to Previous State %	PCC Relative to No Load %	1800 kVA XFMR Sec Terminals Relative to No Load %
Beg of Startup	- 1.81%	- 1.81 %	- 4.57 %
2 sec (20%Rated Speed)	- 0.5 %	- 2.16 %	- 5.81 %
5 sec (54% Rated Speed)	- 0.8 %	- 3.04 %	- 7.76%
10 sec (83 % Rated Speed)	- 0.00 %	- 3.04 %	- 7.76%
Immediately After Startup Before Caps Deenergized	+ 4.89 %	+ 1.85 %	+ 5.11 %
1800 kVAr OFF	- 2.79 %	- 0.94 %	- 2.20 %

2.0 % limit exceeded but distributor willing to go to 3.0 % with understanding that pump not started more than once per week

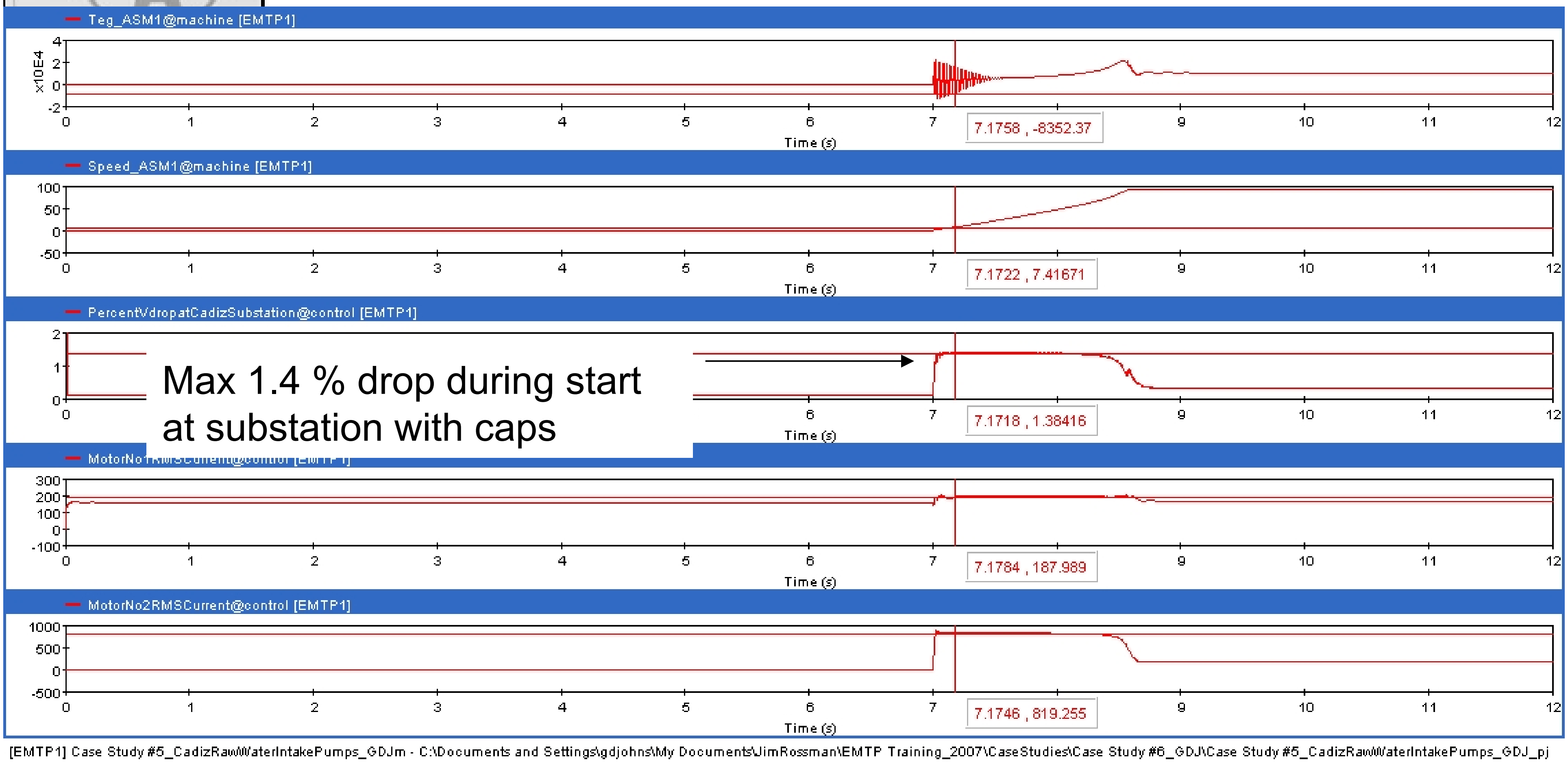
2006 Design Changes

- Latest starter mfr/consultant analysis indicated voltage drop will exceed 4.0 percent at PCC during startup.
- New design called for 2 pumps operating simultaneously
- Increased runtime/# of startups
- Customer contemplating generator because distributor does not want to allow more than 3% fluctuation under any circumstances

- EMTP used to simulate motor start using dedicated feed from substation
- Analysis of across-the-line start with and without simultaneous cap switching

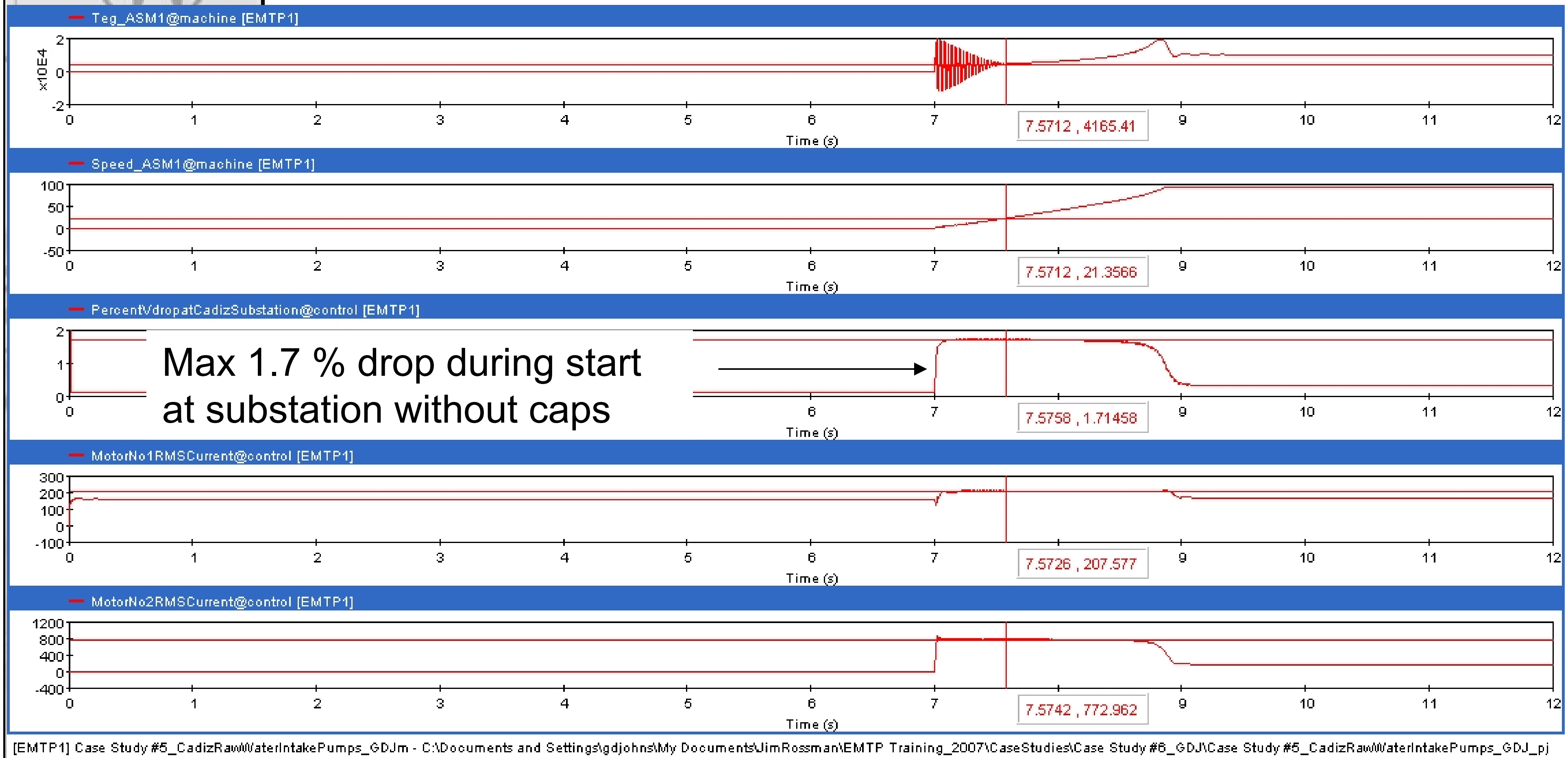


With Cap Bank Switched - Results

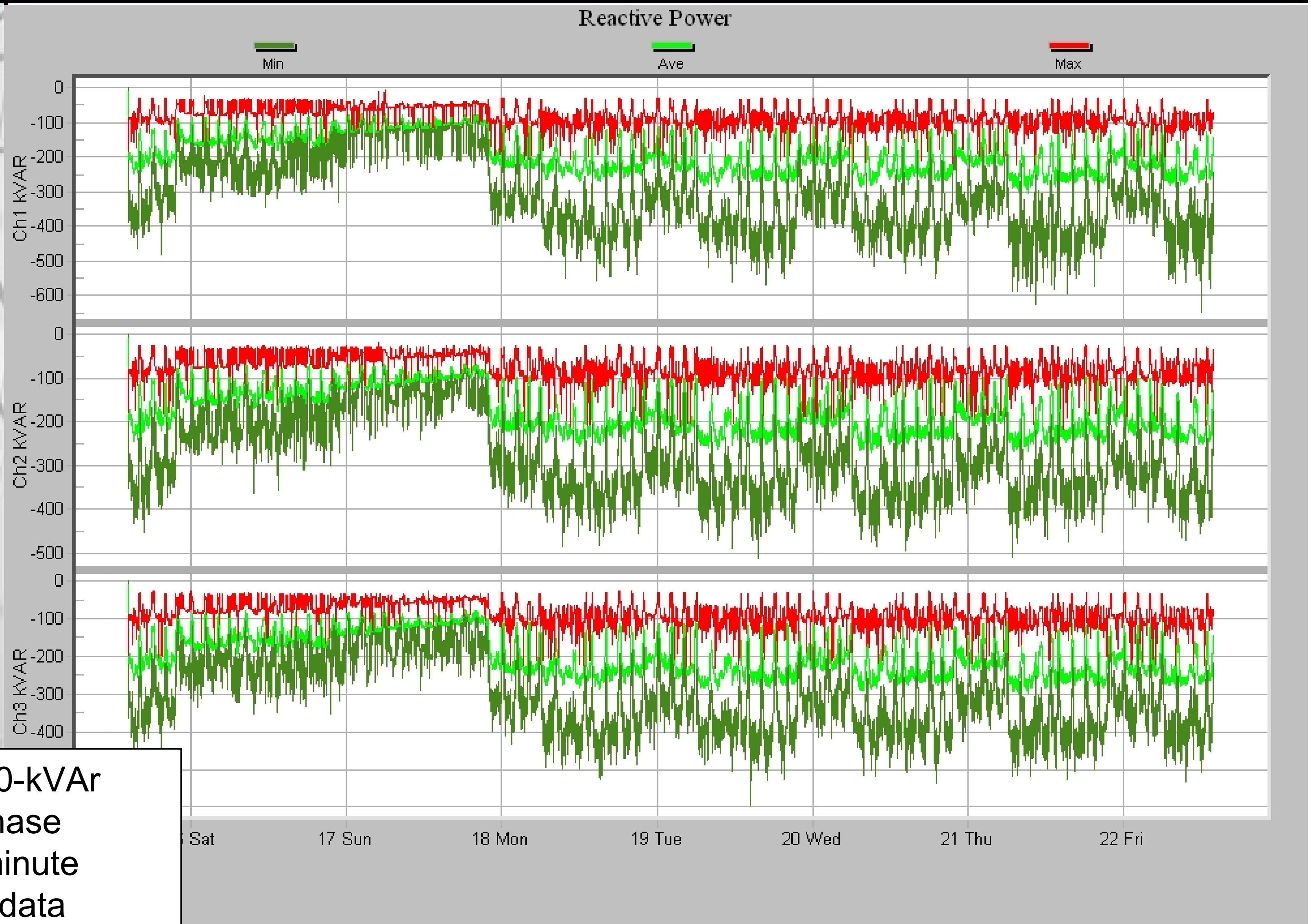


Max 1.4 % drop during start at substation with caps

Without 1,800 kVAr Cap Bank Switched - Results

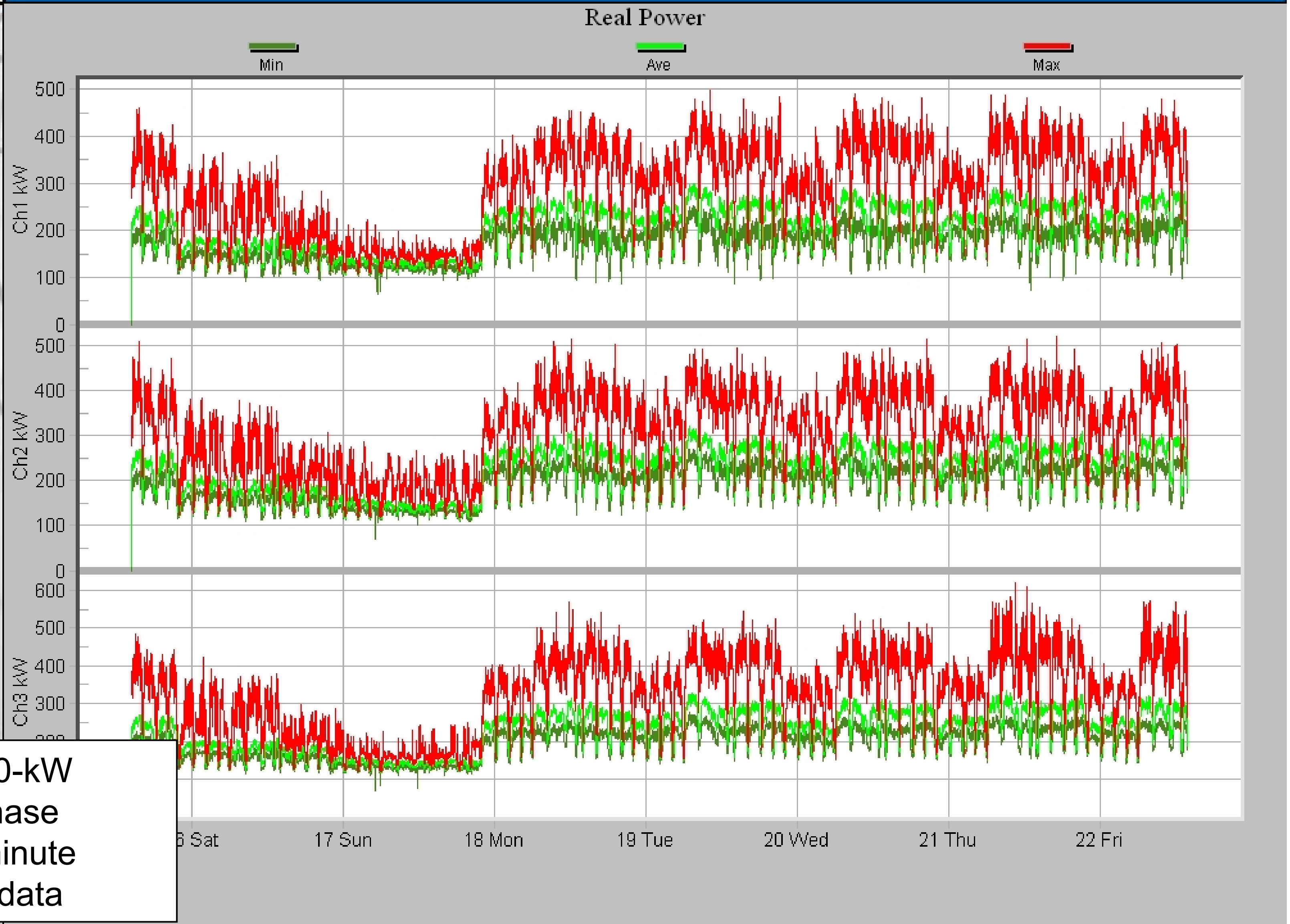


Case Study #4 – Automotive Component Manufacturer with Welders (Reactive Power)



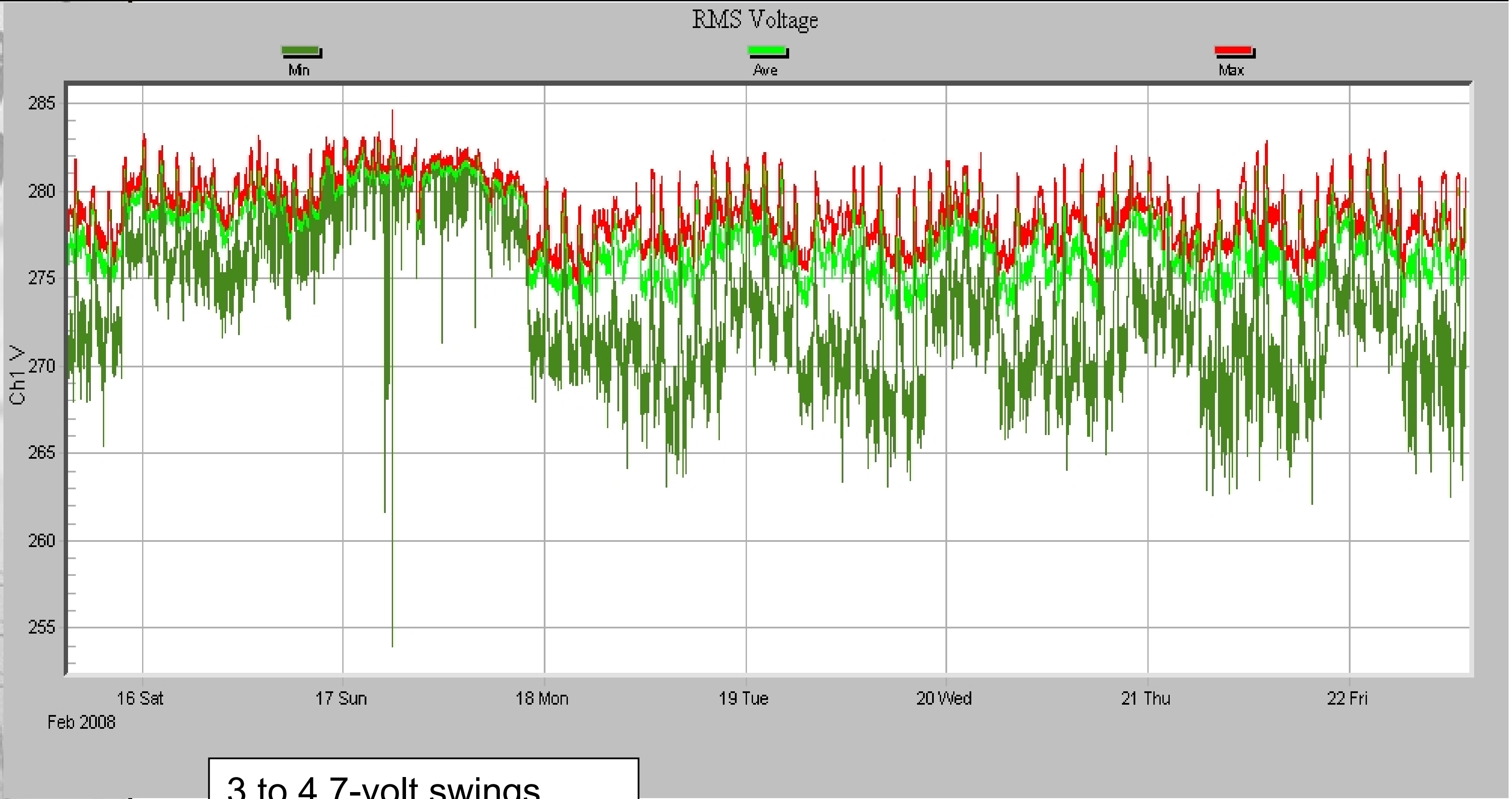
Estimated 400-kVAr swings per phase based on 1-minute max/avg/min data

Case Study #4 – Automotive Component Manufacturer with Welders (Real Power)



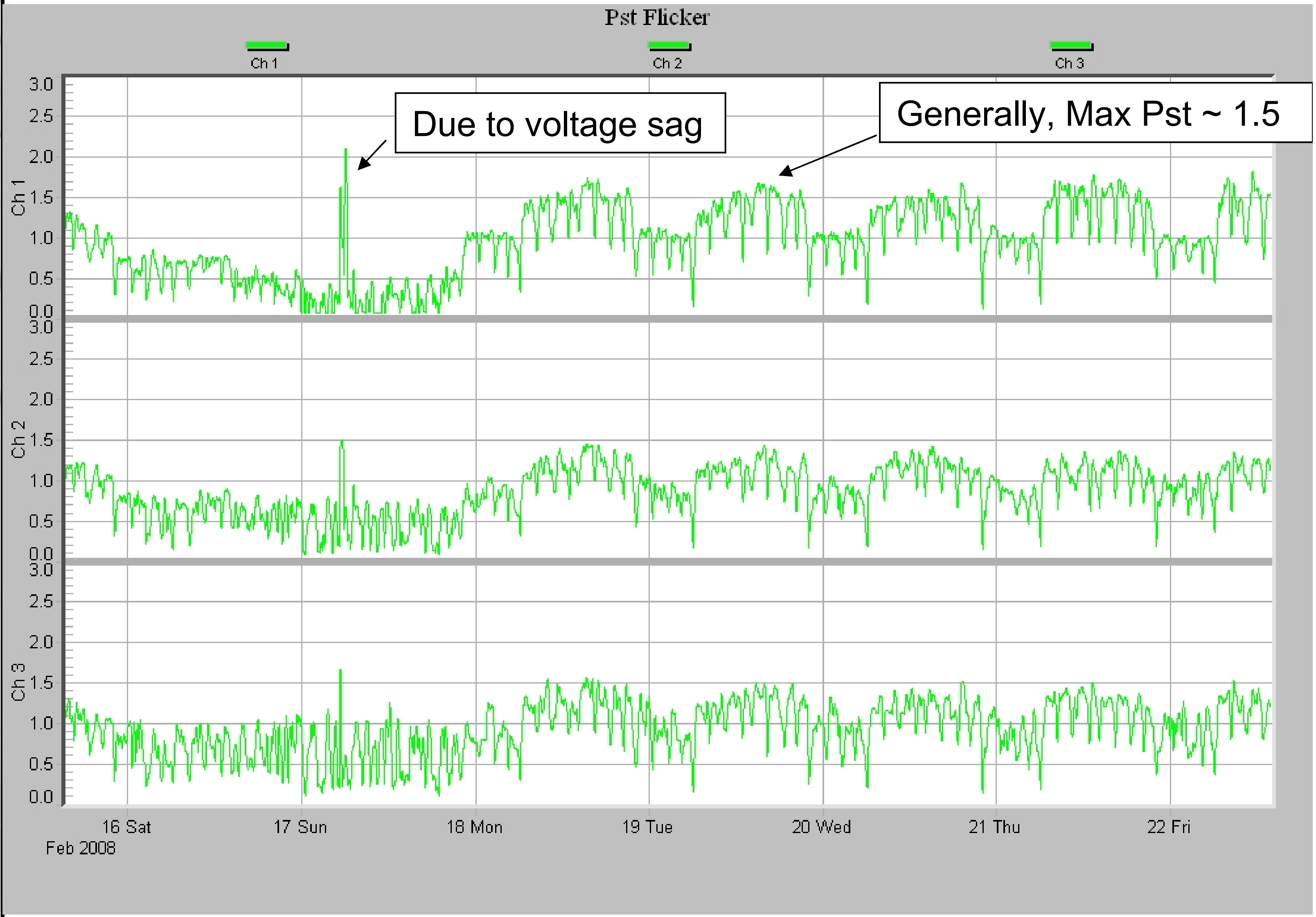
Estimated 200-kW swings per phase based on 1-minute max/avg/min data

Case Study #4 – Automotive Component Manufacturer with Welders (Voltage)

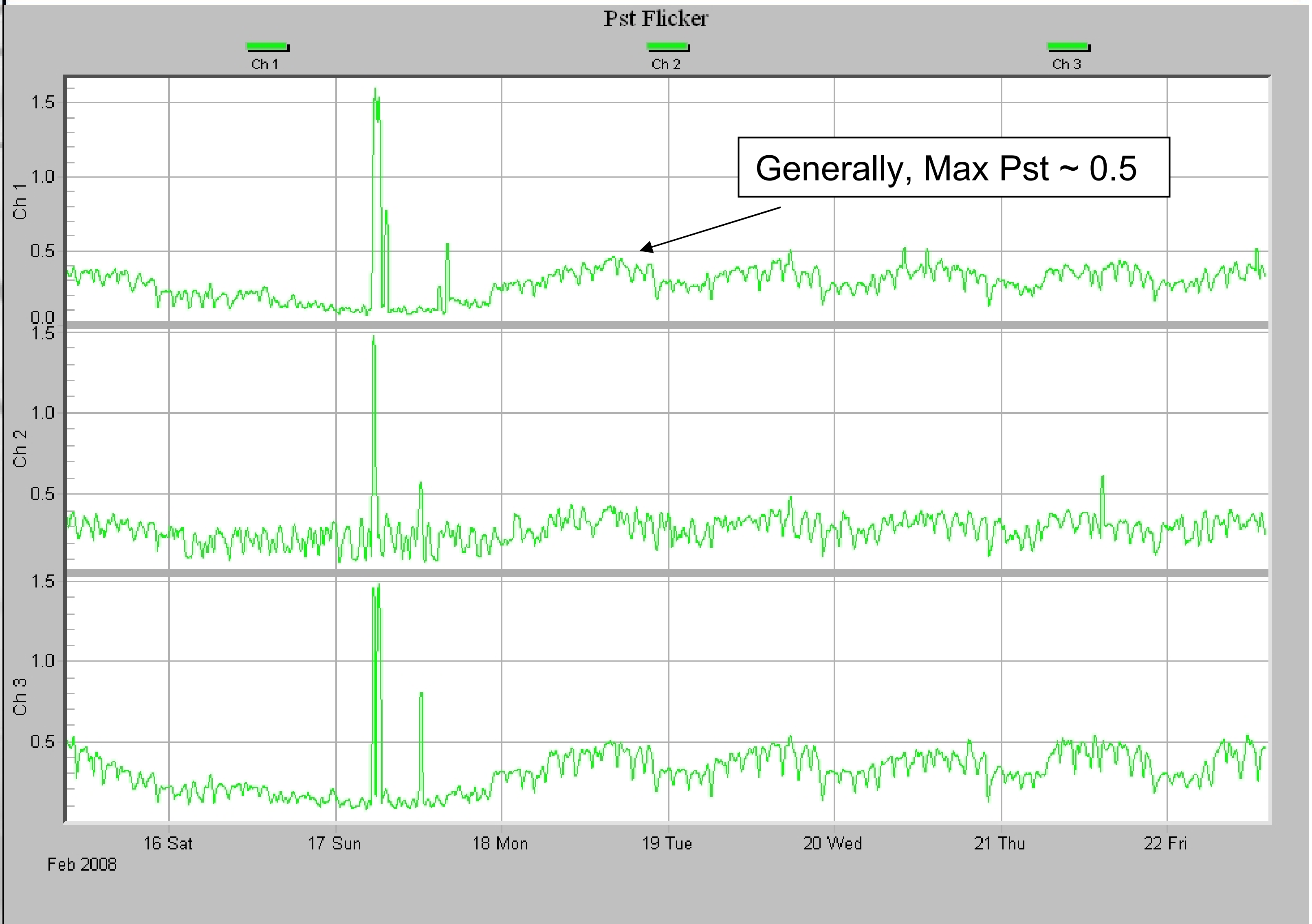


3 to 4.7-volt swings based on 1-minute max/avg/min data

Case Study #4 – Corresponding Pst on Bus Feeding Welders (Dirty Feed)



Case Study #4 – Corresponding Pst on Bus Fed By Separate Transformer Bank (Clean Feed)



Vdrop Calculation and Comparison of Welder Bus Pst to That of Separately Fed Bus

- Max Pst on welding bus = 1.5
- Max Pst on separately fed bus = 0.5
- Utility-supplied SCC = 4,127 A @ 7.2/12.47 kV
- Welding bus XFMR %Z = 6 %
- Assume X/R of utility circuit = 7 and X/R of XFMR = 12

$$\frac{7200}{4127}\times(\cos(\tan^{-1}(7))+j\sin(\tan^{-1}(7)))=0.25+1.73\text{ ohms}$$

$$\text{On 100 MVA base, } Z_{\text{source}}=\frac{0.25+j1.73}{\frac{12470^2}{10^8}}=16+j111.3\text{ percent}$$

$$\text{Transformer Z (on 100-MVA base)}=20+j239\text{ percent}$$

$$\text{Expected \%Voltage Drop}=\frac{0.6\times(16+20)+1.2\times(111.3+239)}{100}=4.4\%$$

$$\frac{\text{Separately Fed Bus Pst}}{\text{Welding Bus Pst}}=\frac{0.5}{1.5}=0.3$$

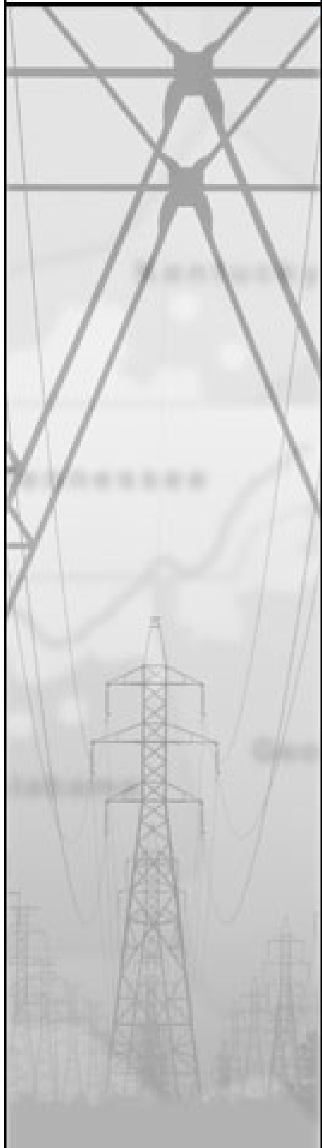
$$\frac{\text{Common Source Z}}{\text{Total Z to Welding Bus}}=\frac{|16+j111.3|}{|36+j350|}\approx\frac{111}{350}\approx 0.32$$

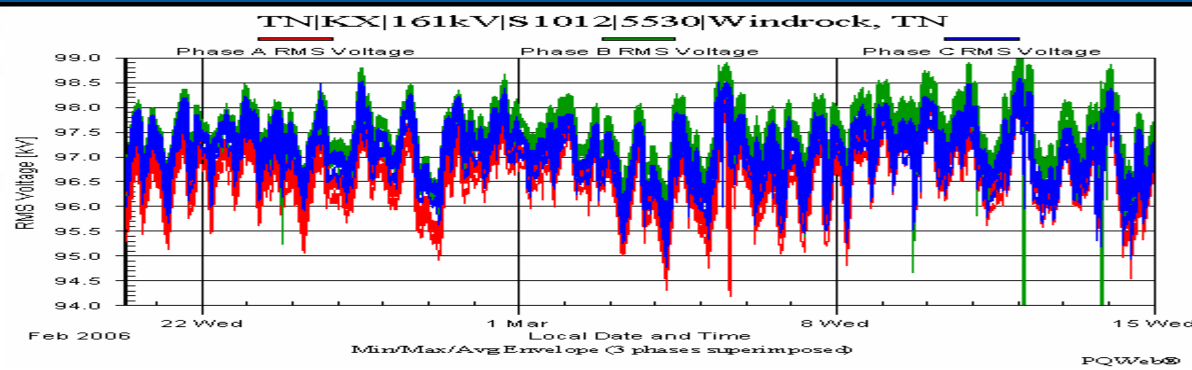
Case 5 – Wind Generation

Buffalo Mountain Wind Farm Generation - Flicker Case

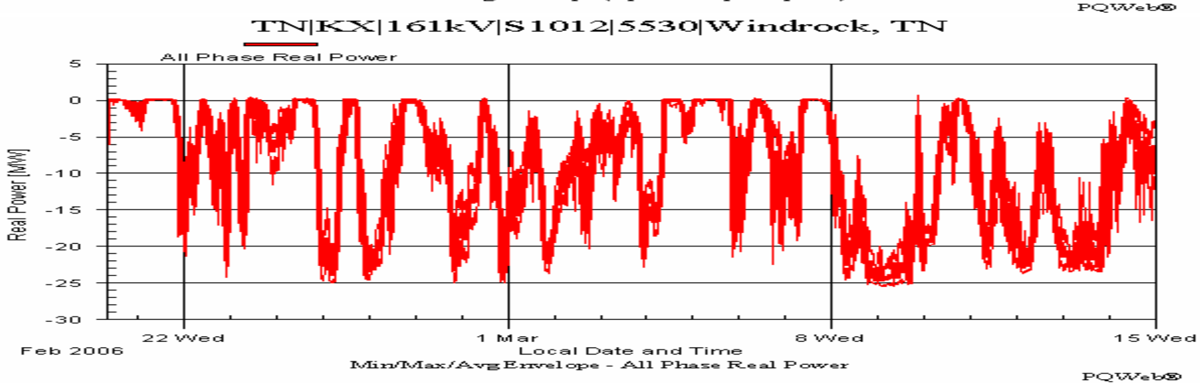
TVA originally contacted for three small windmills to be fed from a local distributor's 13-kV system. Occasionally during windmill startup, the distributor received flicker complaints. When the 15-1.8-MW units went in service, it was decided to serve the new load at 161-kV.

Aggregate Load Swings for 15-1.8-MW Wind Generators

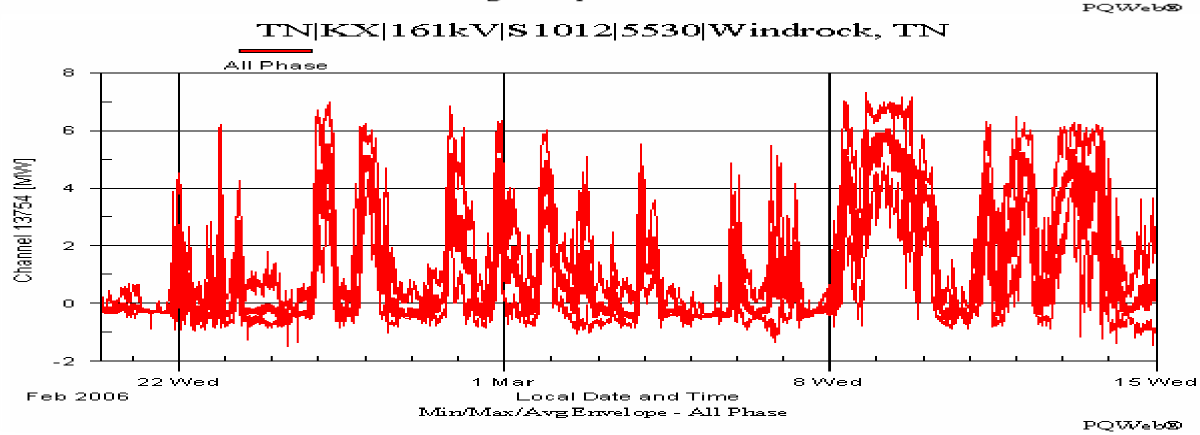




Voltage



MW



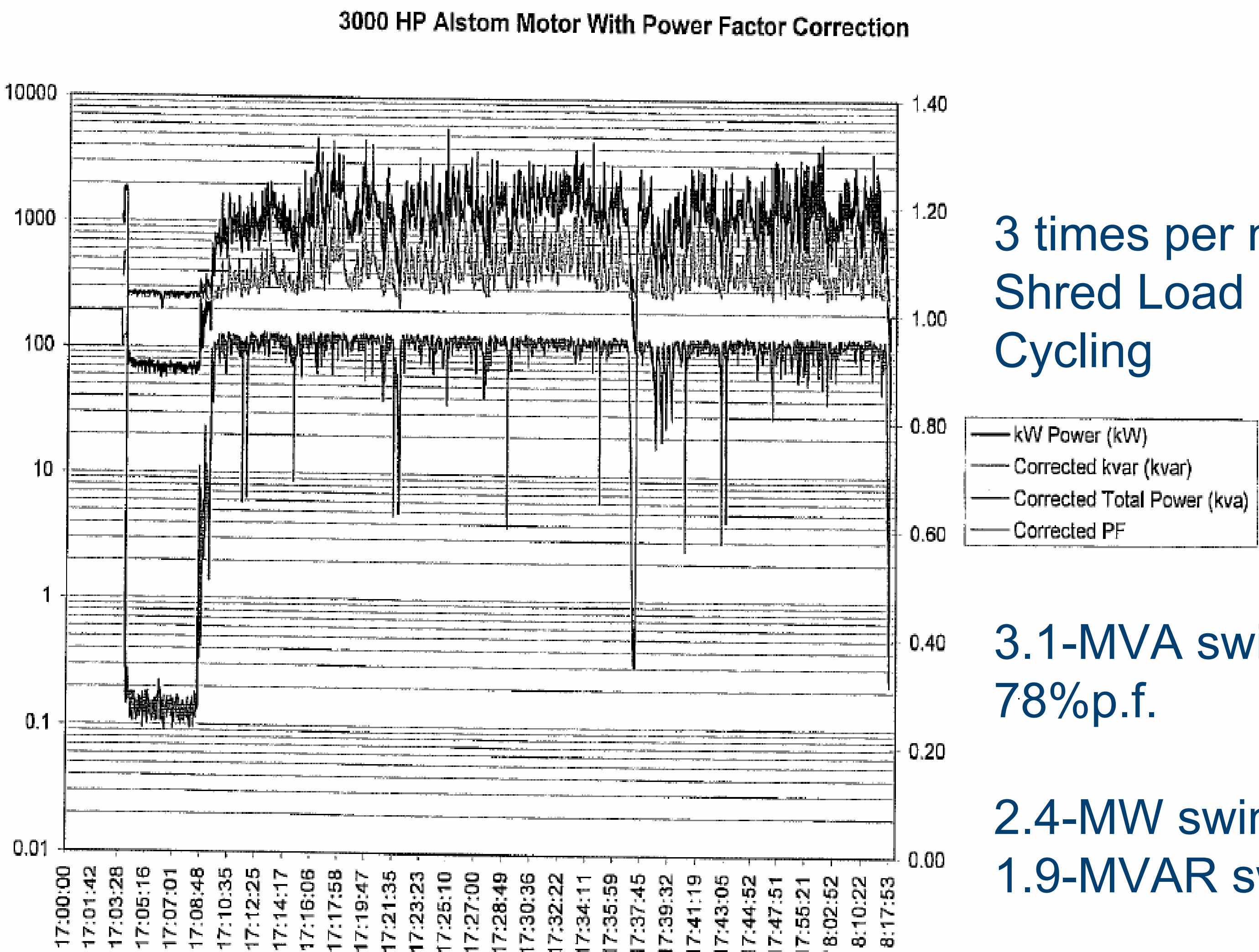
MVAR

Case 6 – Large Motor System

Evaluate Possibility of
Serving a 3000-hp Wound Rotor Motor
Metal Shredder
At Two Possible Locations

- XXX 69-kV: Z1 = 23.989 + j 52.618%
- YYY 161-kV: Z1 = 1.559 + j 9.048%

Characteristics of Shredder Provided by Vendor



3 times per minute Shred Load Cycling

3.1-MVA swings at 78%p.f.

2.4-MW swing
1.9-MVAR swing

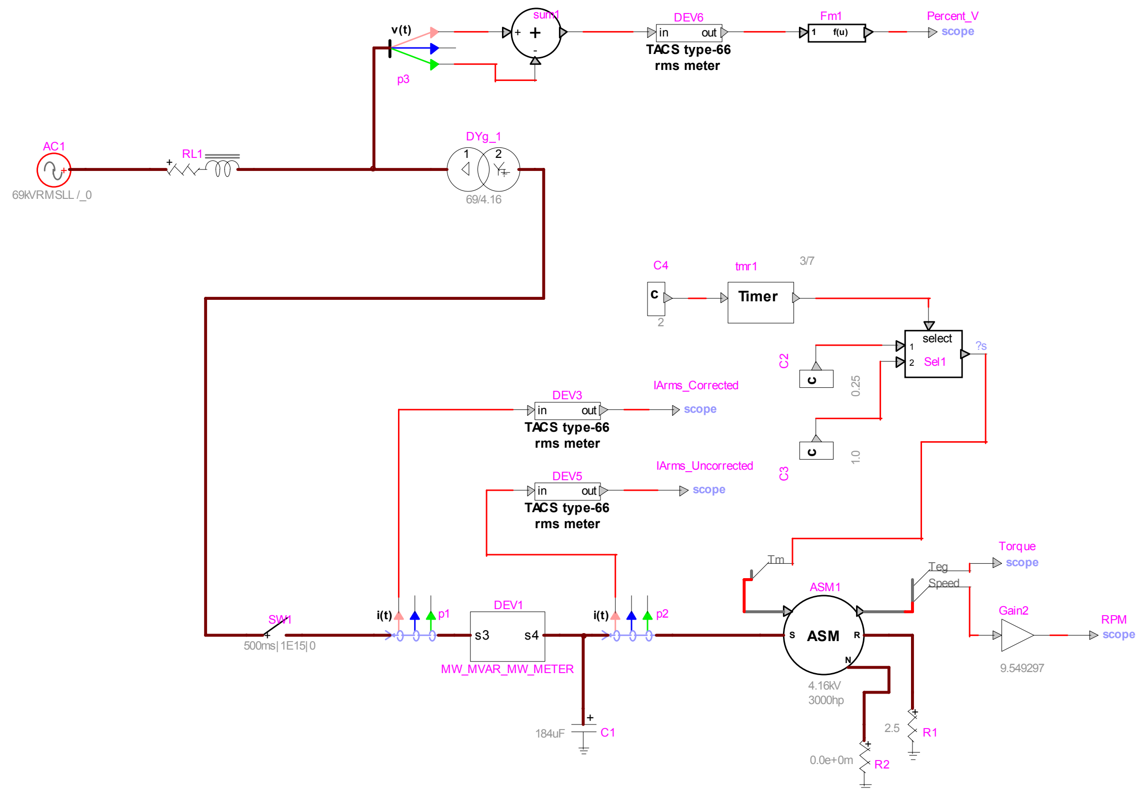
Hand Calculation Used for Approximation and EMTP Model Used for More Exact Solution

Site XXX Hand Calculation:

Z1 = 23.99 + j 56.6 % (100-MVA base)

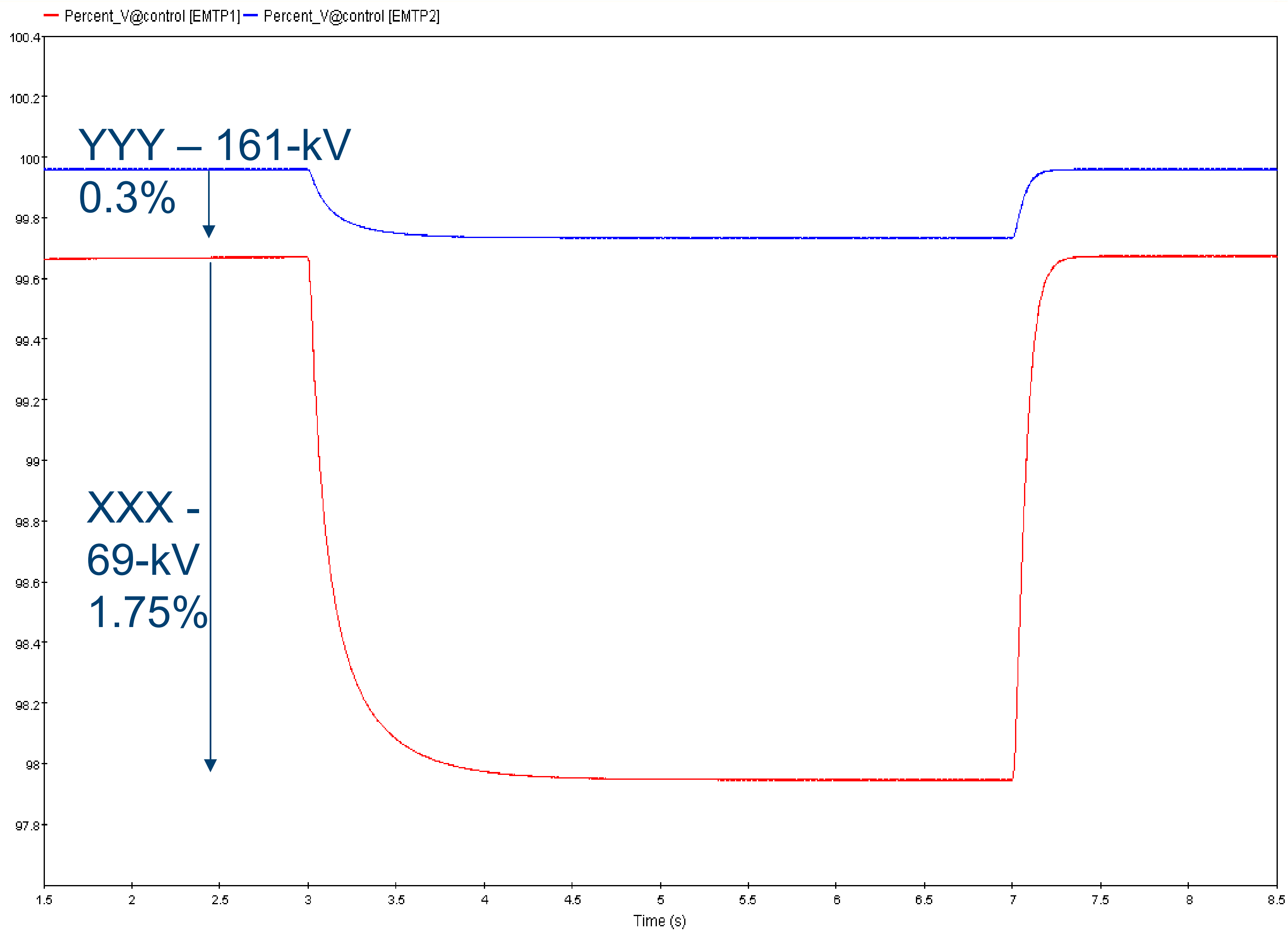
MVA swing = 2.4 + j1.9

%VDrop ≅ 2.4-MW (23.99)/100 + 1.9-MVAR (56.6)/100 = 1.65%

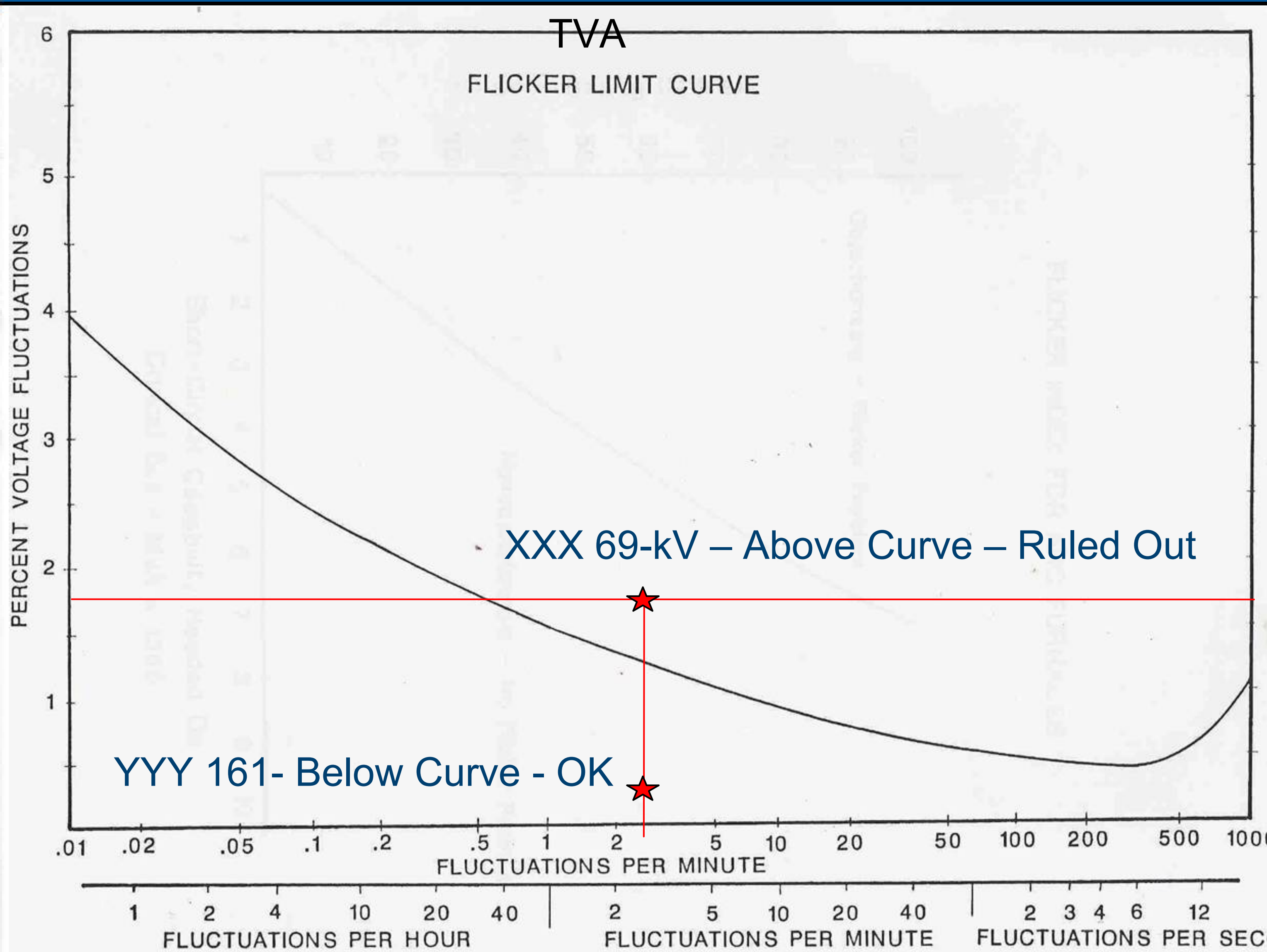


Use EMTP Modeling For More Exact Solution

EMTP Simulation Results
Voltage Drops As Shredder Cycles



Applying Results to TVA Flicker Curve Shows YYY is OK and XXX is Not Recommended



Case 7

My Town Needs a Steel Rolling Mill

What do we need to do to allow us to run this mill?

Remote Community Fed at 46-Kv – Impedance to Substation - Z1 = 74.9 +j113.5%

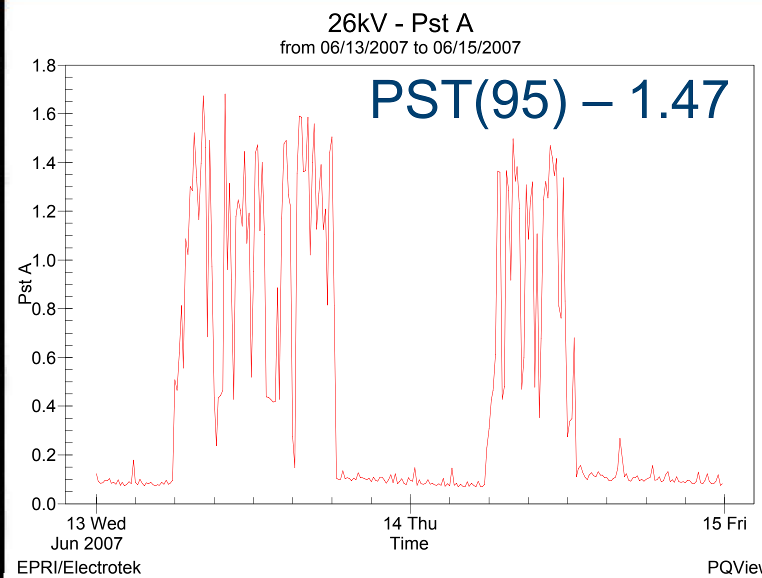
At 26-kV Substation Transformer Secondary (PCC) - Z1=76.3 +j169.0%

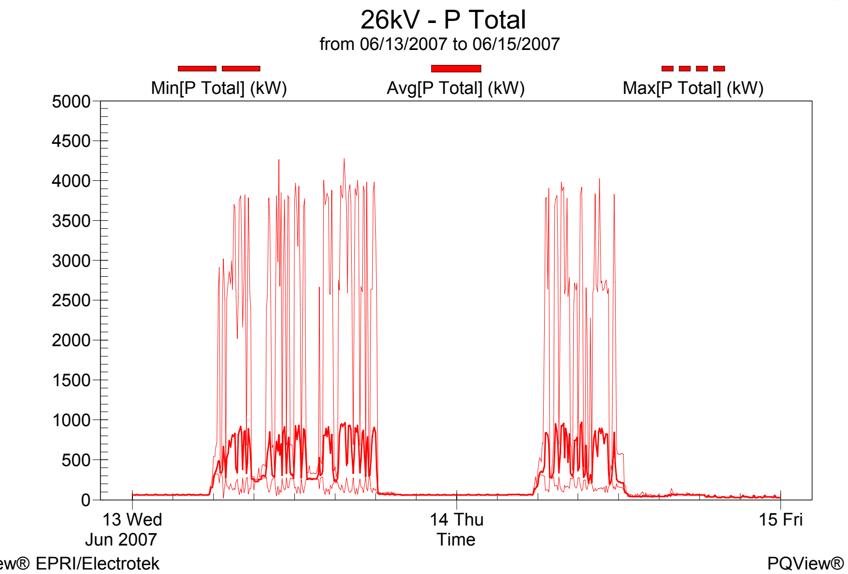
Company Choose IntelliVar as Mitigation System

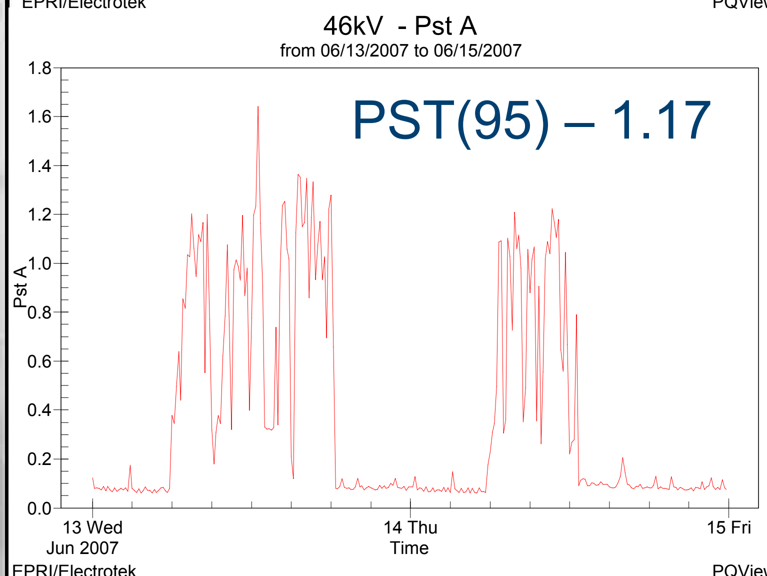
Not actual Installation But Shows All Major Components

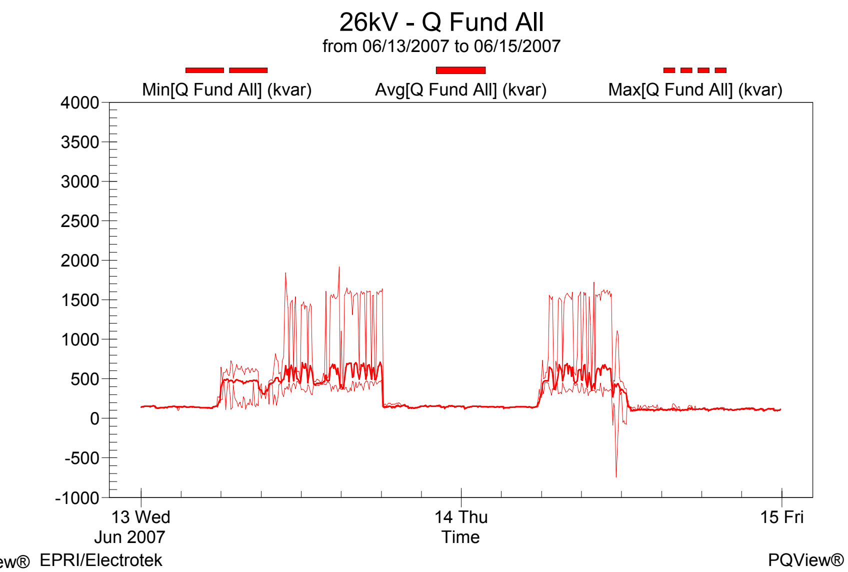
Transformers
Valves
Filters
Controls

IntelliVAR System at 1500-KVAR Controls Not Working Properly

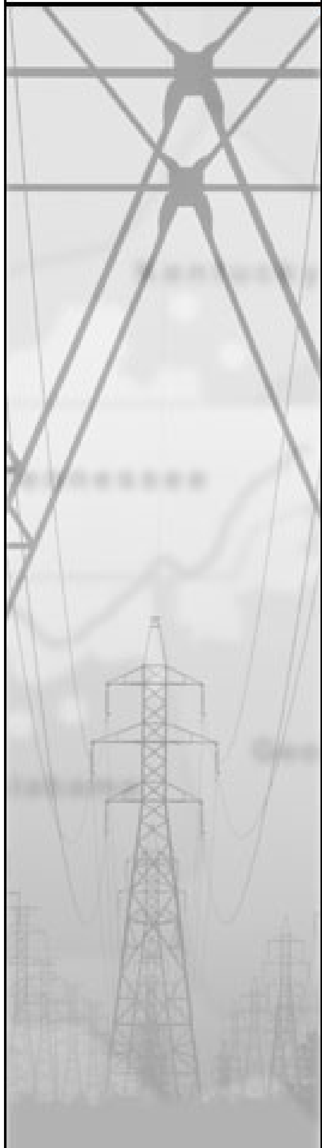


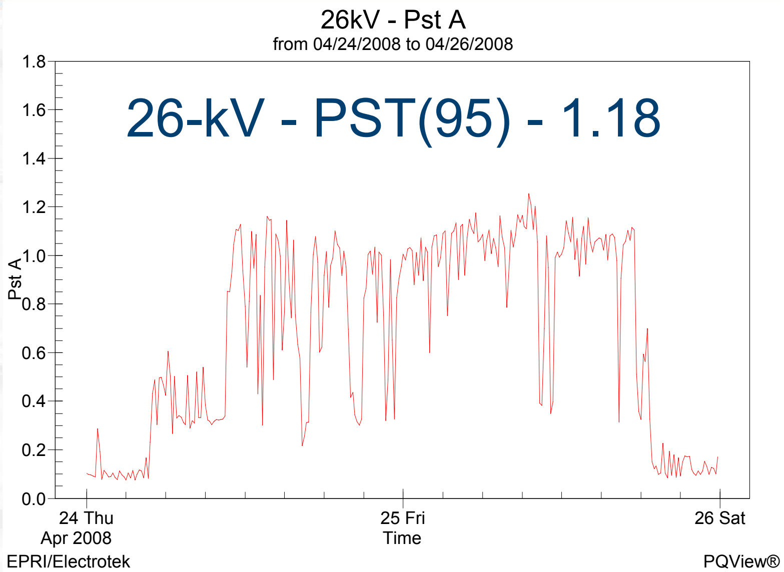


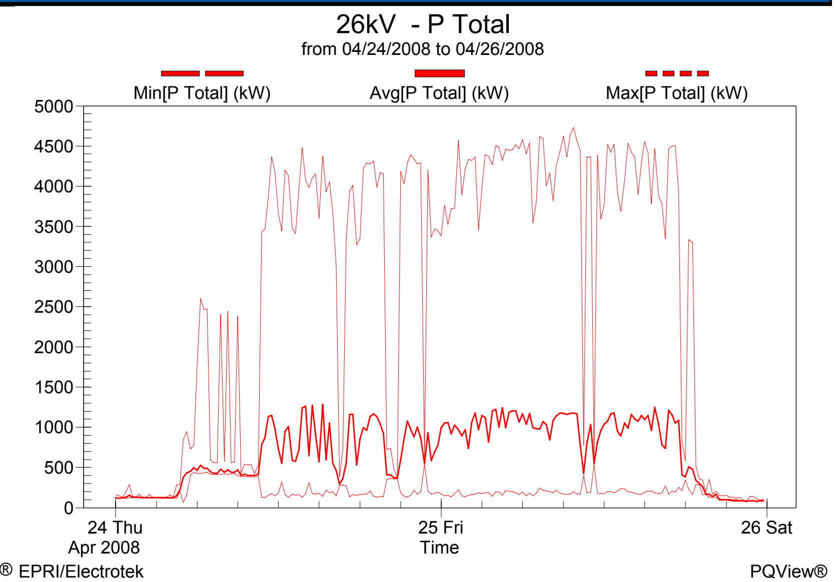


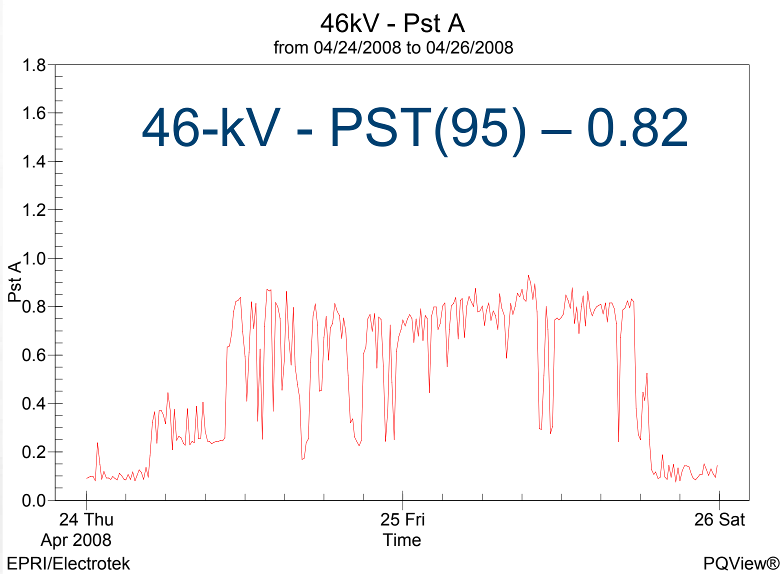


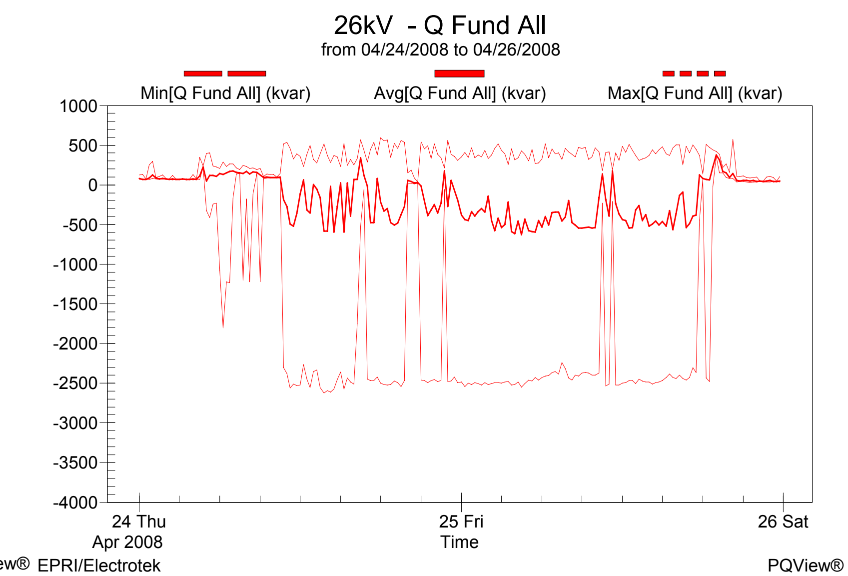
IntelliVAR Sizing Doubled to 3000-KVAR Control System Finally Tuned



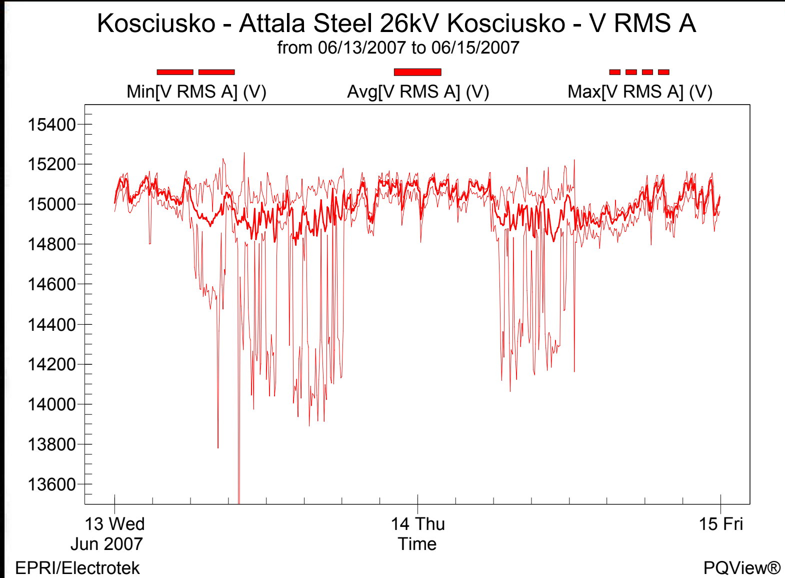


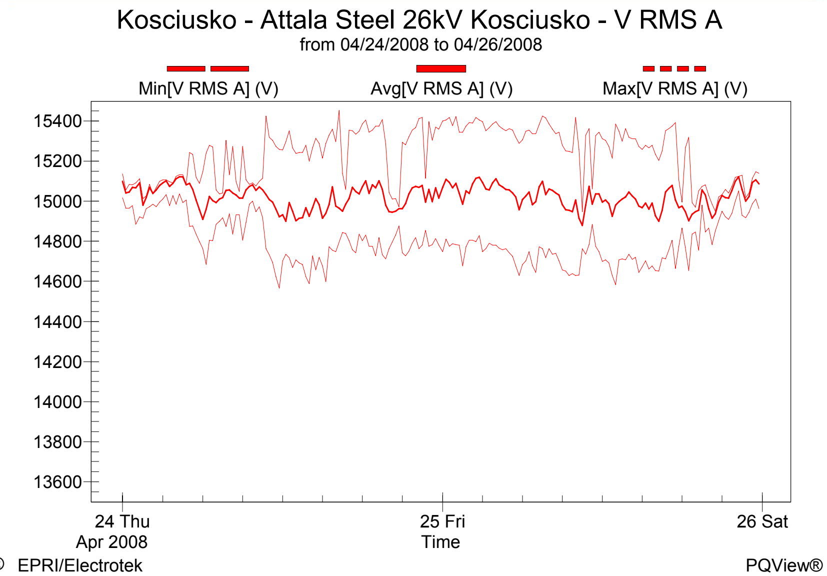


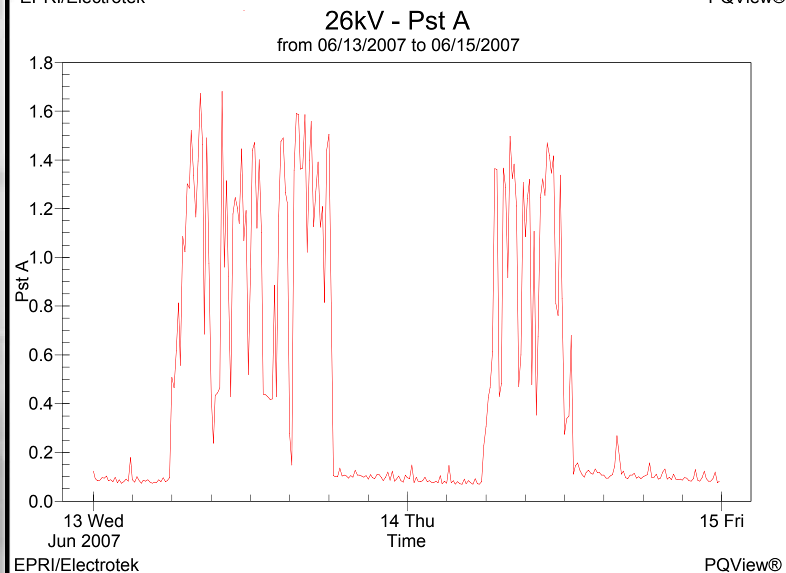


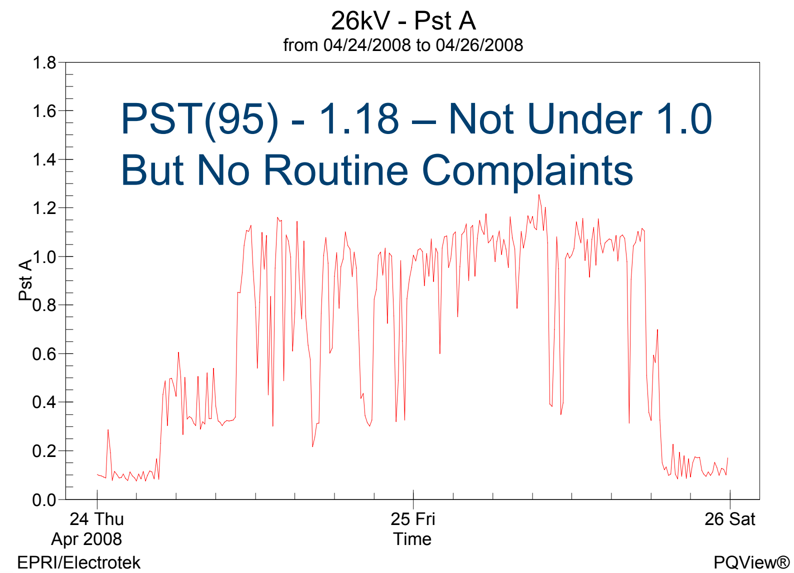


Before and After Intellivar Changes





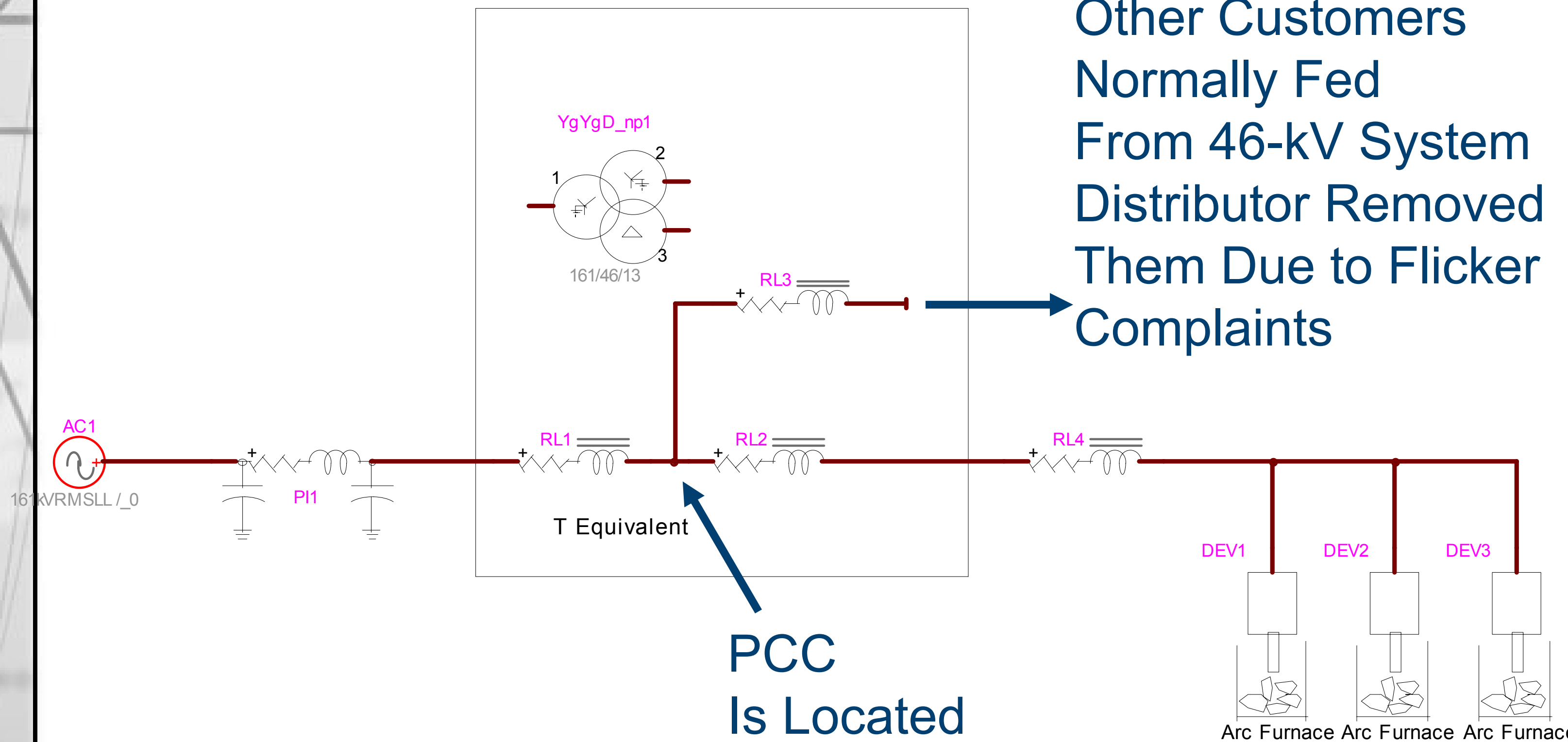




Case 8

My Largest Industry Has Us in a Bad Situation Due to Flicker, What Are Our Options?

Distributor Not Routinely Serving Any Customer From 46-kV Winding Due to Flicker Complaints



Other Customers Normally Fed From 46-kV System Distributor Removed Them Due to Flicker Complaints

PCC Is Located Within Transformer At T Equivalent Tie Point

Site Fed From Dedicated 13-kV Winding 161/46/13 Transformer

PST Estimate – Traditional Hand Calculation

161-kV MVAsc at Sub – 1558 MVAsc or 3.85% at 60 MVA Base

161-kV:46-kV:13:kV Transformer Nameplate:
Z161-46 = 9.7% at 60-MVA,
Z161-13 = 5.8% at 21-MVA (16.57% at 60-MVA)
Z46-13 = 2.1% at 21-MVA (6.0% at 60-MVA)
Convert to T equivalent
Z161 = ½ (9.7% +16.57%-6.0%) = 10.135% at 60 MVA
Z46 = ½ (9.7% + 6.0% -16.57%) = -0.435% at 60 MVA
Z13 = ½ (16.57%+6.0% -9.7%) = 6.435% at 60-MVA

PCC Includes TVA plus 161-kV portion of winding to 46/13-kV T point
PCC = 3.85% + 10.135% = 13.985% = 429-MVAsc

Estimated AF Swing = 2 x 4-MW = 8-MVA
Swing with 3 AF = $\sqrt[3]{3}$ x 8-MVA = **11.54-MVAsc for 3 units operating**

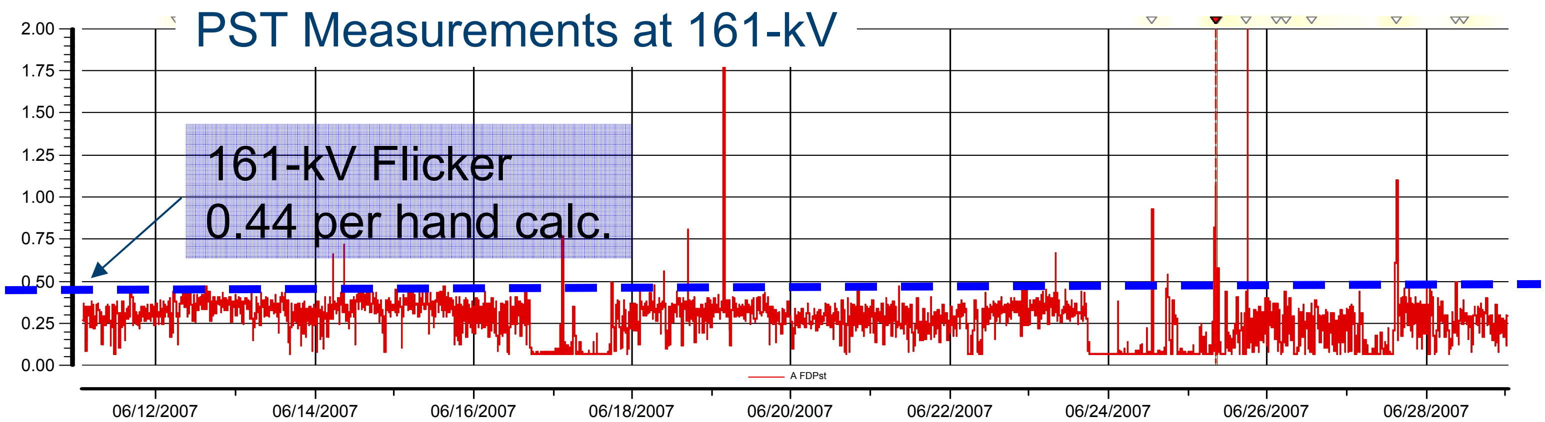
46-kV Short Circuit Voltage Depression (SCVD) = 11.54/429 = 0.0269
161-kV Short Circuit Voltage Depression (SCVD) = 11.54/1558 = 0.0074

46-kV PST Estimate = 0.0269 x KST = 0.0269 x 60 = 1.61

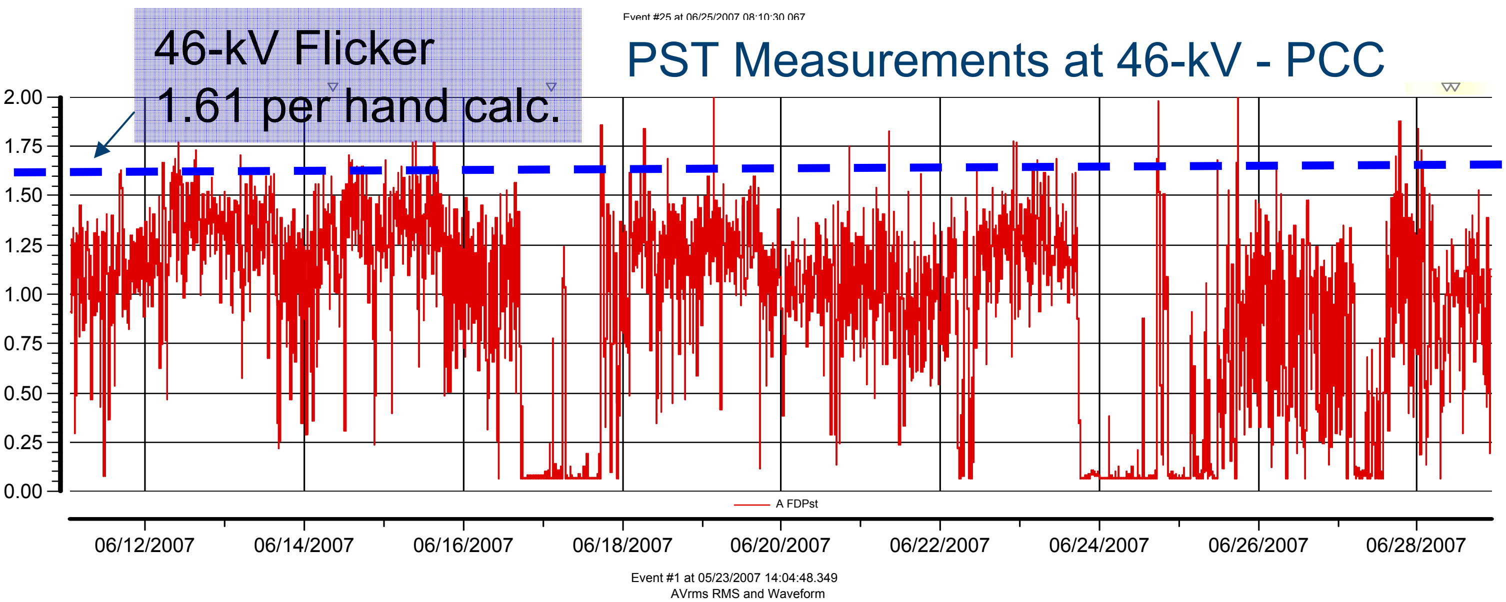
161-kV PST Estimate = 0.0074 x KST = 0.0074 x 60 = 0.44

PST Measurements of 46-kV and 161-kV Bus Confirm Hand Calculations - Target – PST Under 1.0 Moving to 161-kV Accomplishes This Objective

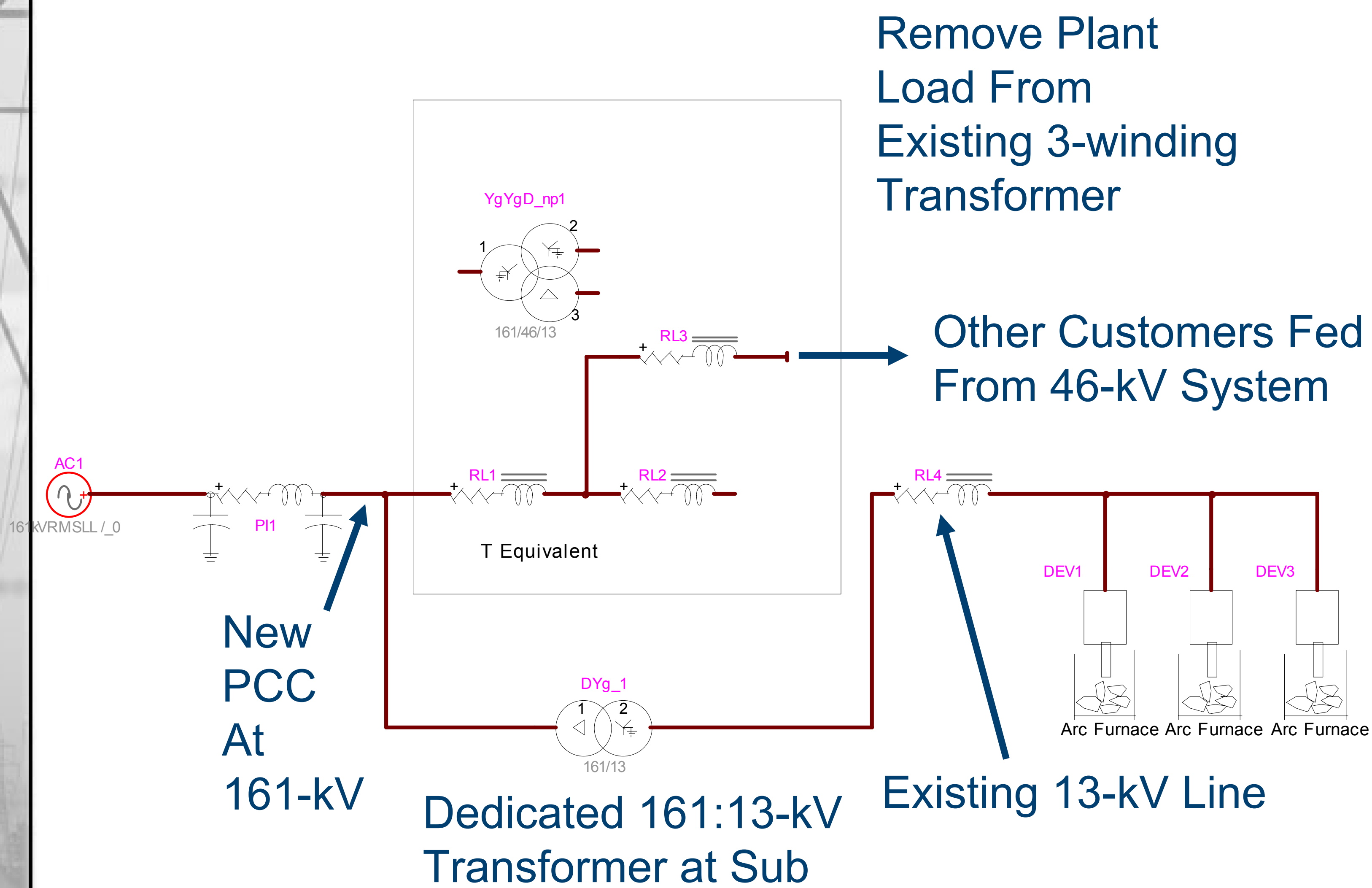
161-kV PST
(a phase)



46-kV PST
(a phase)



Option 1 – Add Transformer at Substation Use Existing 13-kV Feed to Plant



Move PCC Up to 161-kV
Option 1 - Install Dedicated Transformer

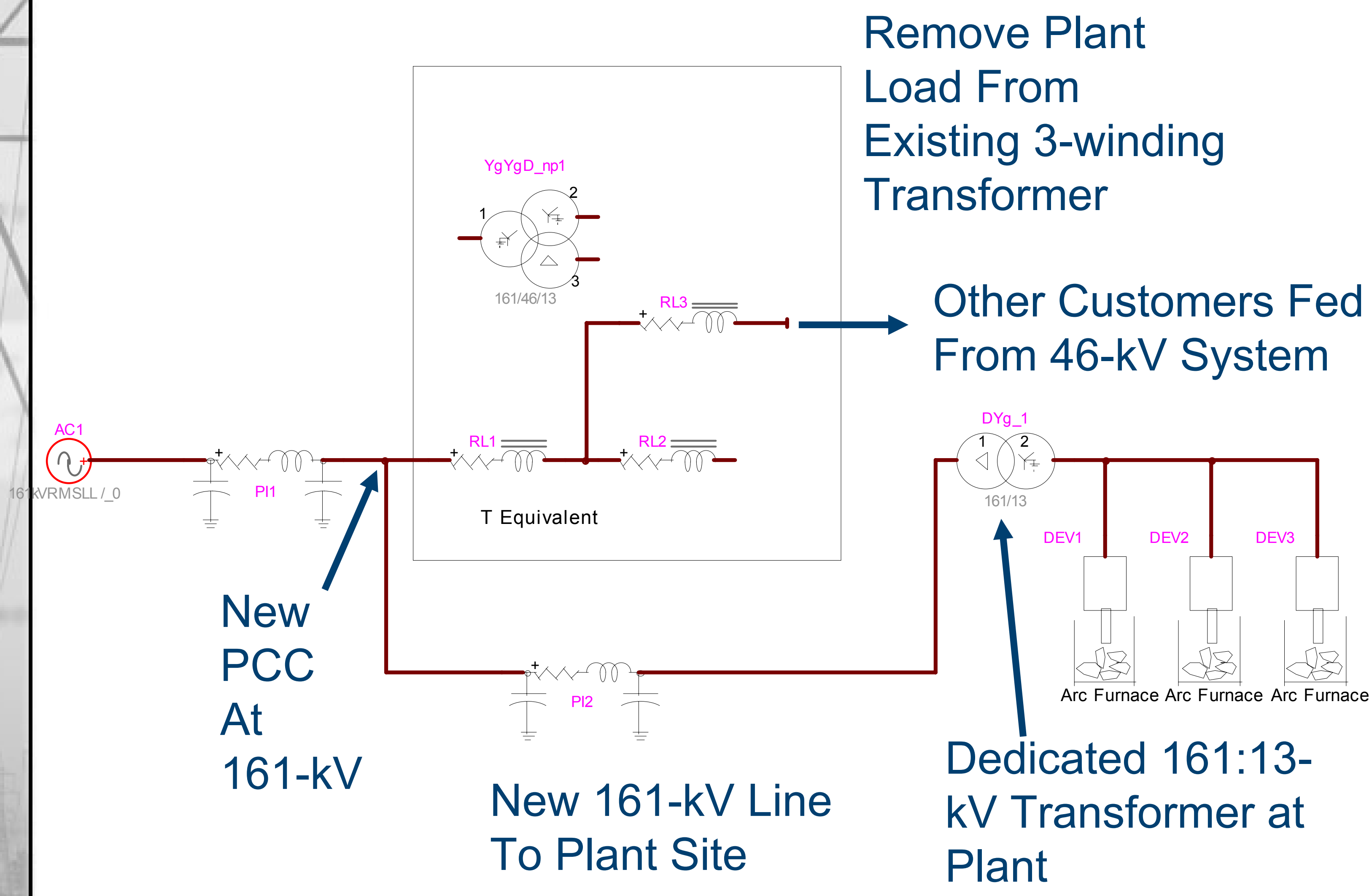
Option

1 **Move PCC up to 161-kV System at Substation**

All cost below in $1000s

		Equip.	Install	Total
1a	New 16-MVA Transformer, oil containment, foundations, bus	$850	$150	$1,000
1b	161-kV SF-6 breaker w/ bay and relays	$250	$150	$400
1c	13-kV Distribution Breaker with relays	$50	$25	$75
1d	Routing Existing 13-kV Wiring to New System	$10	$10	$20
1e	Two-Step - 4.5 (4.0 effective) -MVAR Harmonic Filter	$100	$23	$123
	Misc. cost not currently identified - 20% of cost (excluding transformer)			$124
	Grand Total - New Transformer System			**$1,742**

Option 2
Build 161-kV Line to Plant Site and Add Transformer at That Site



Move PCC to 161-kV
Option 2 - Install Dedicated 161-13-kv Substation at Plant Site

Option

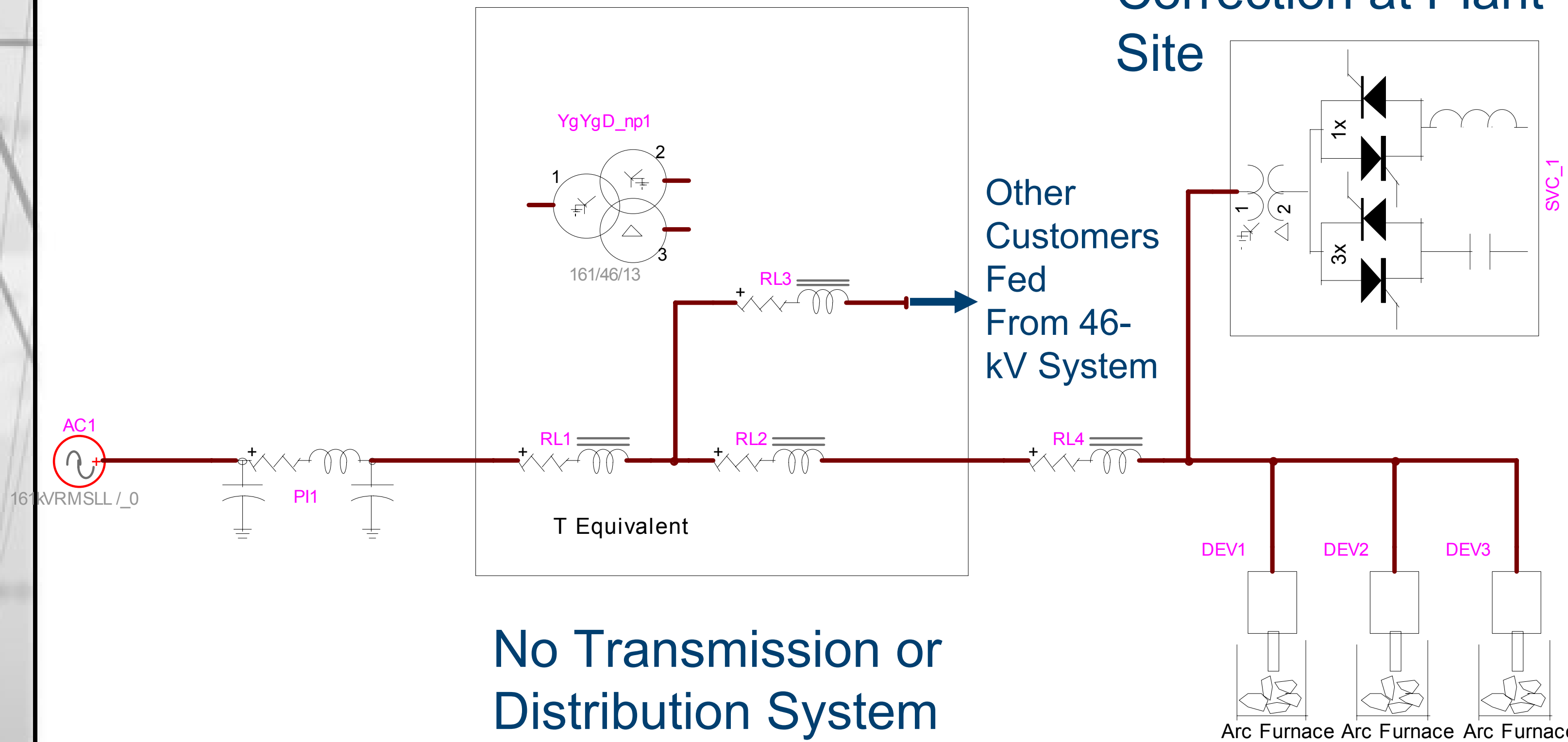
2 Move PCC Up to 161-kV System at Plant

All cost below in $1000s

		Equip.	Install	Total
2a	New 16-MVA Transformer, oil containment, foundations, bus	$850	$75	$925
2a	Used 18-MVA Transformer, oil containment, foundations, bus	$350	$75	$425
2b	161-kV SF-6 breaker w/ bay and relays	$250	$75	$325
2c	161-kV Feed to Plant (existing row - big unknown ??)			$400
2d	161-kV Circuit Switcher at Plant with relays	$100	$25	$125
2e	13-kV Distribution Breaker at Plant with relays	$50	$25	$75
2f	Two-Step - 4.5 (4.0 effective) -MVAR Harmonic Filter	$100	$23	$123
	Misc. cost not currently identified - 20% of cost (excluding transformer)			$210
	Grand Total - New Transformer System			**$2,183**
	Grand Total - Used Transformer System			**$1,683**

Option 3 - Install Quick, Dynamic VAR Correction and Harmonic Filter System at Plant Site

Add Dynamic Var Correction at Plant Site



Other Customers Fed From 46-kV System

No Transmission or Distribution System Changes Needed!

Fix Flicker at Plant 13-kV Bus
Option 3 - Install Quick, Dynamic VAR Correction and Harmonic Filter System at Plant Site

Option

3 **Install ABB Mincomp or S&C Purewave Dstatcom**

All cost below in $1000s

		Equip.	Install	Total
3a	Install +10 /- 2-MVAR Var Compensator	$1,000	$100	$1,100
3b	Two Step - 6.6/6.3 (6.0 effective)-MVAR Harmonic Filter	$120	$25	$145
3c	13-kV Switchgear Integrated Into Existing System	$100	$25	$125
	Misc. cost not currently identified - 10% of cost			$125
	Grand Total			**$1,370**

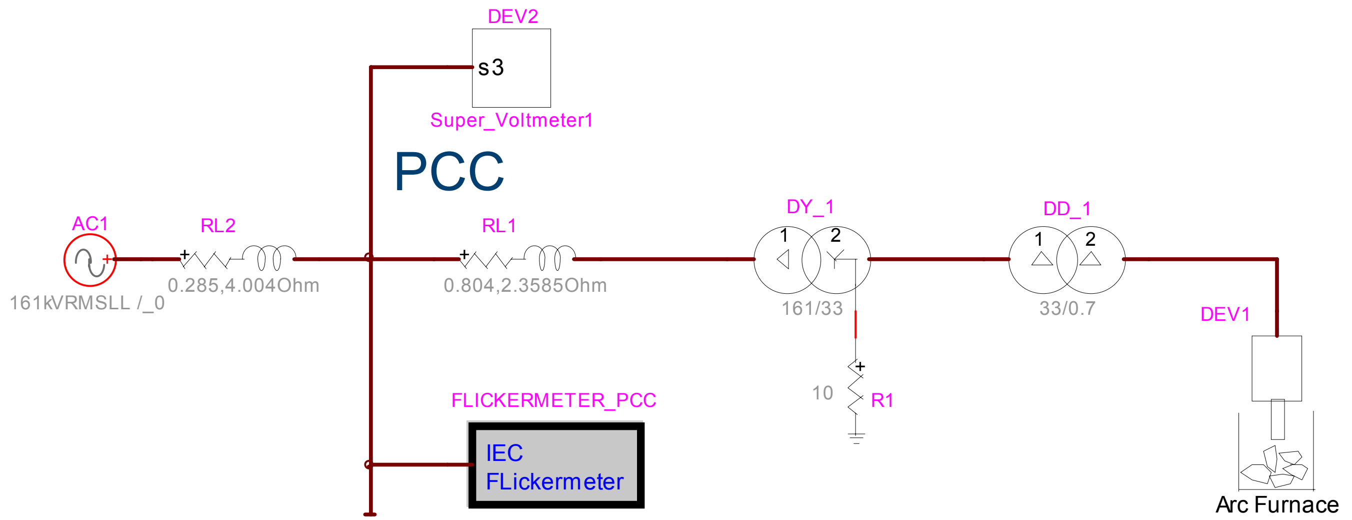
Economic Summary: Installing Dynamic Var Compensation is Best Choice

Option #	Power Factor Correction Savings (1000s)	Electronic Equip. Savings (1000s)	Production Profit Increase (1000s)	Total Savings (1000s)	Total Cost (1000s)	Simple Payback (years)
Option 1	$32.8	$31.6	$0	$64.4	$1,742	27.0
Option 2	$32.8	$31.6	$0	$64.4	$2,183	33.9
Option 3	$32.8	$31.6	$415.0	$479.4	$1,370	2.9

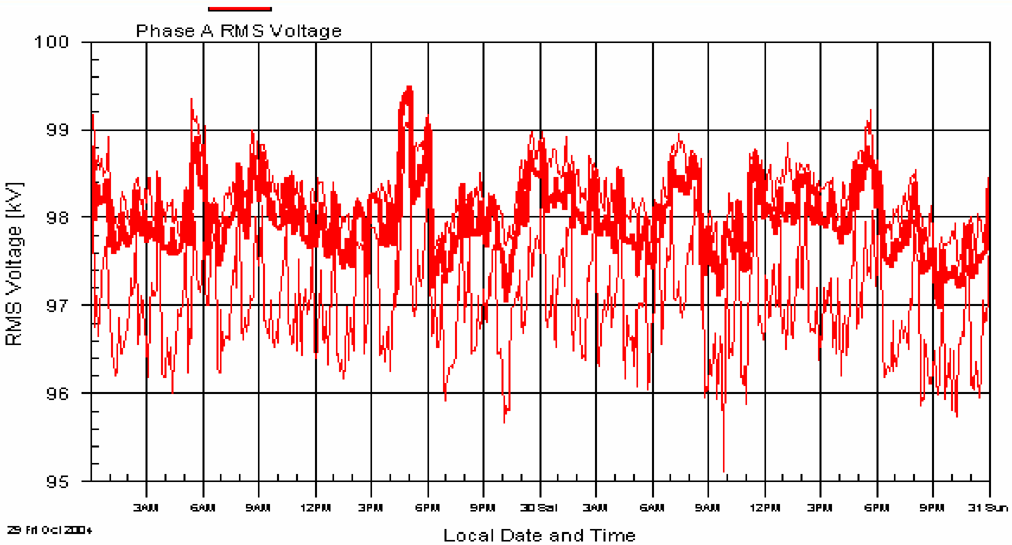
Option 1 – Transformer Isolation at Substation, filter at Plant
Option 2 – Transformer Isolation at Plant, filter at Plant
Option 3 – Install Filter/Dynamic VAR Compensation at Plant

Case 9

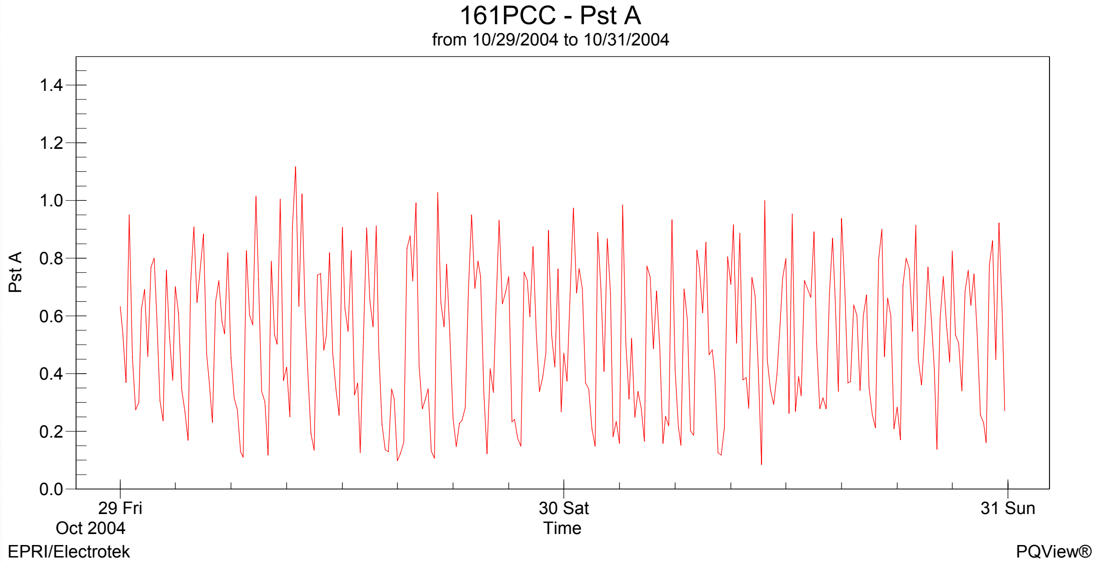
A Large Steel Mill Has an SVC, Why is it Creating More Flicker When On Compared to When its Off?



Base Case Without SVC System Operating 2 Days



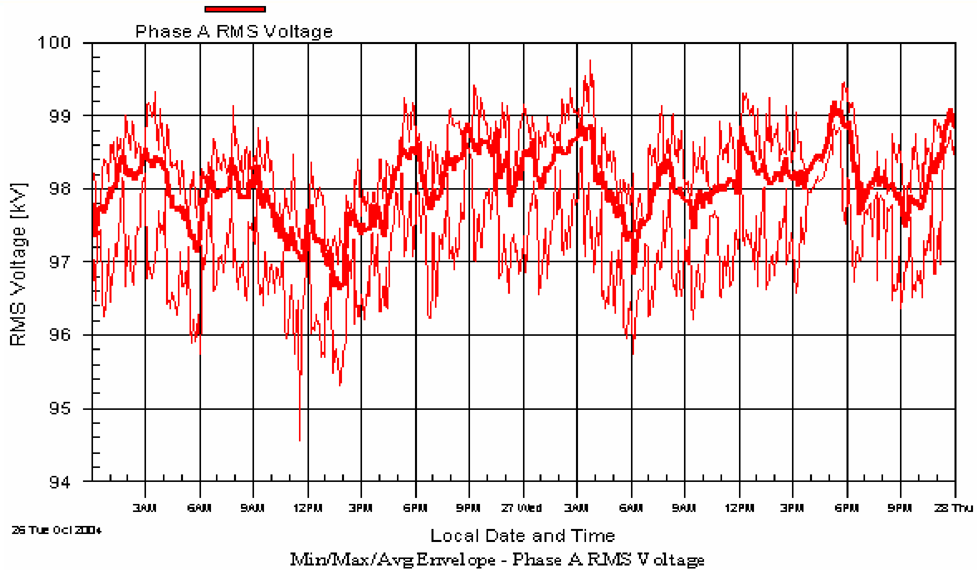
Min/Max/Avg Envelope - Phase A RMS Voltage

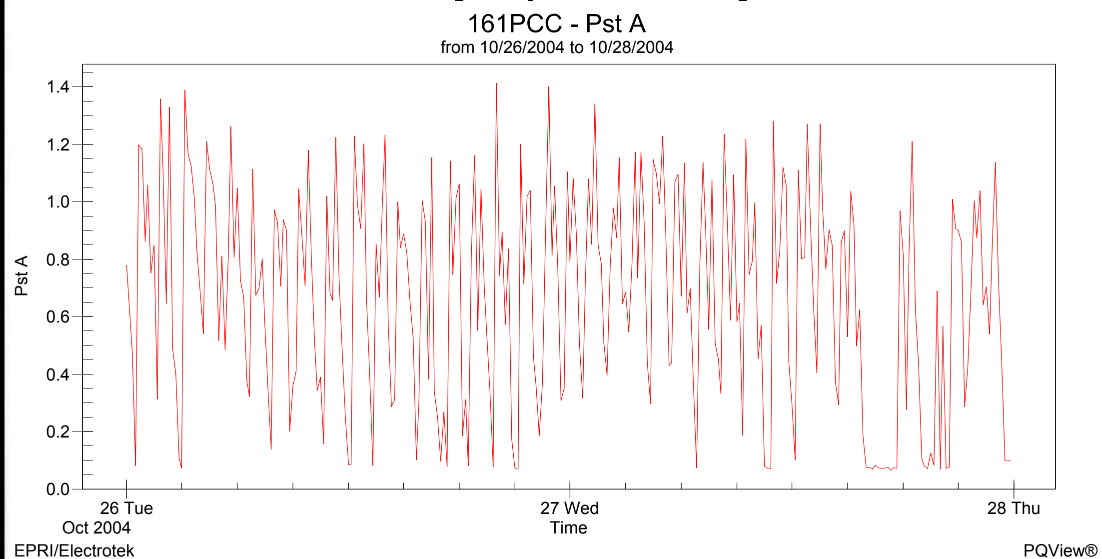


Phase A Voltage (Max, Min, Avg)

Flicker Summary
PCC Monitor Site
Without SVC/ Filters
PST(95) = 0.93

Base Case With SVC System Operating 2 Days





Phase A Voltage (Max, Min, Avg)

Flicker Summary

PCC Monitor Site

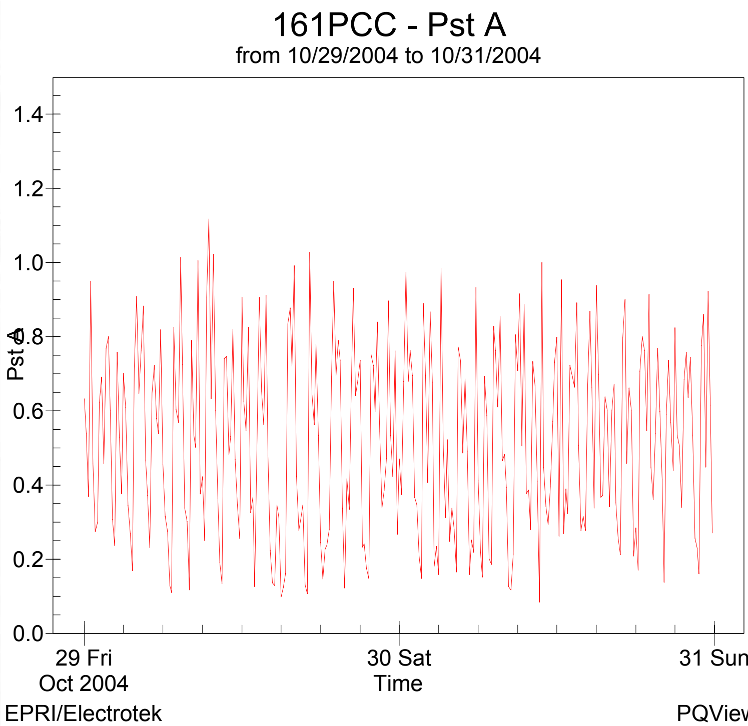
Without SVC/ Filters

PST(95) = 1.22

Flicker Reduced by Approximately 24% by Switching Off SVC/Filters

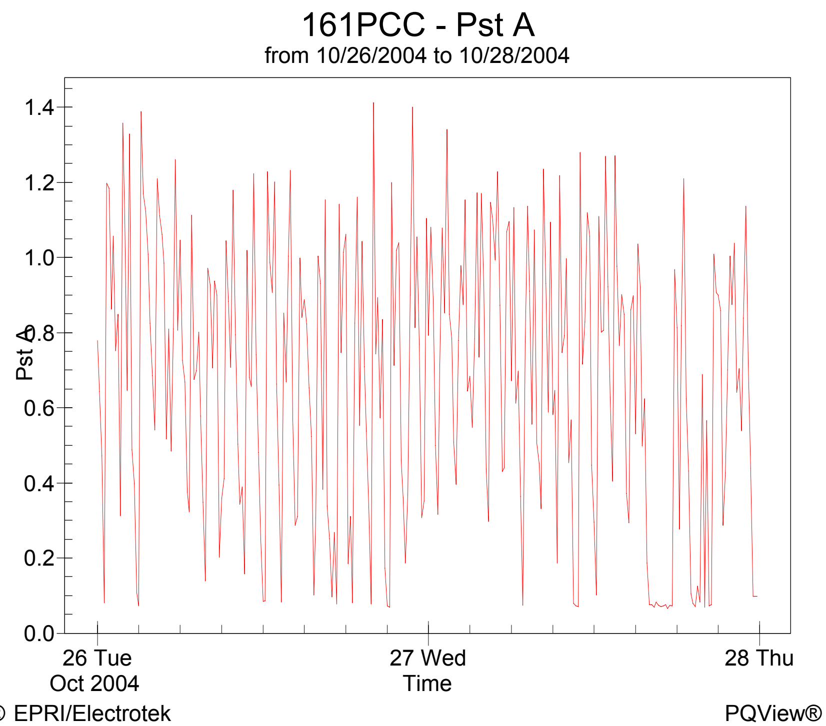
What is the reason for lower flicker levels with the SVC out of service?

Without SVC



PST (95) – 0.93

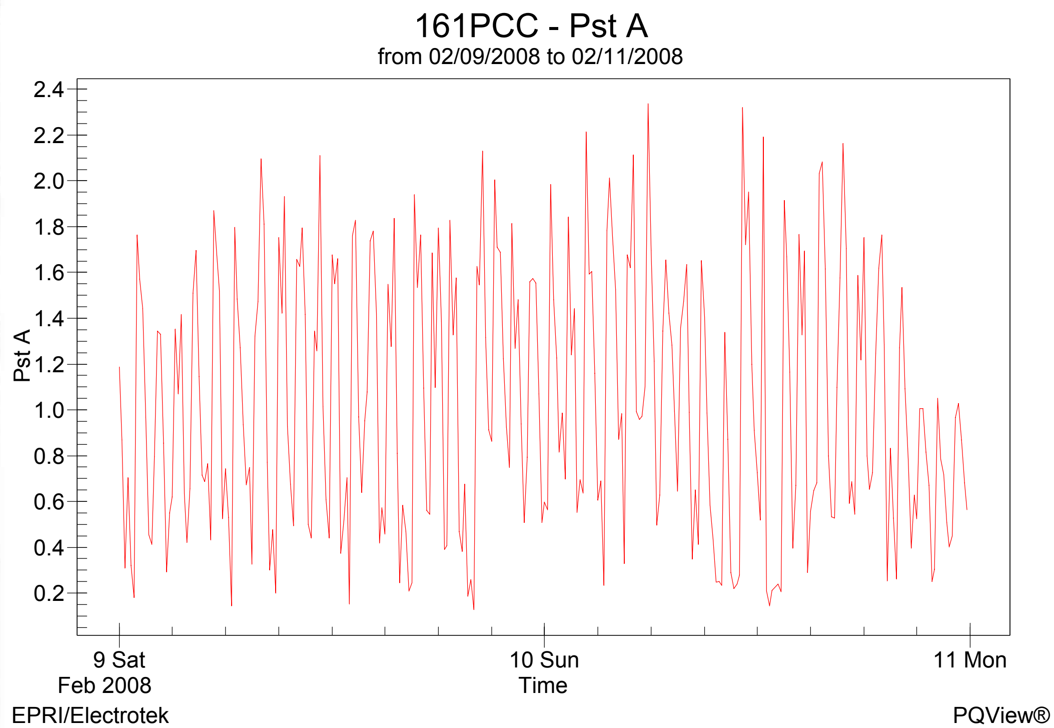
With SVC



PST (95) – 1.22

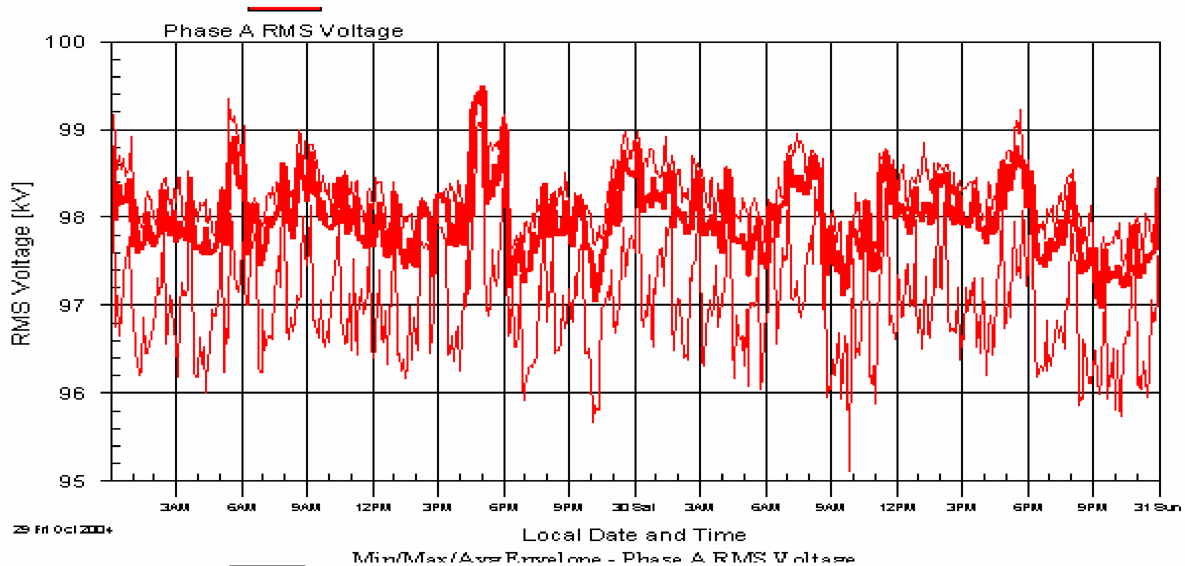
Base Case With SVC System Operating - Weakened TVA System - 2 Days

Complaints Ramped Up During This Period

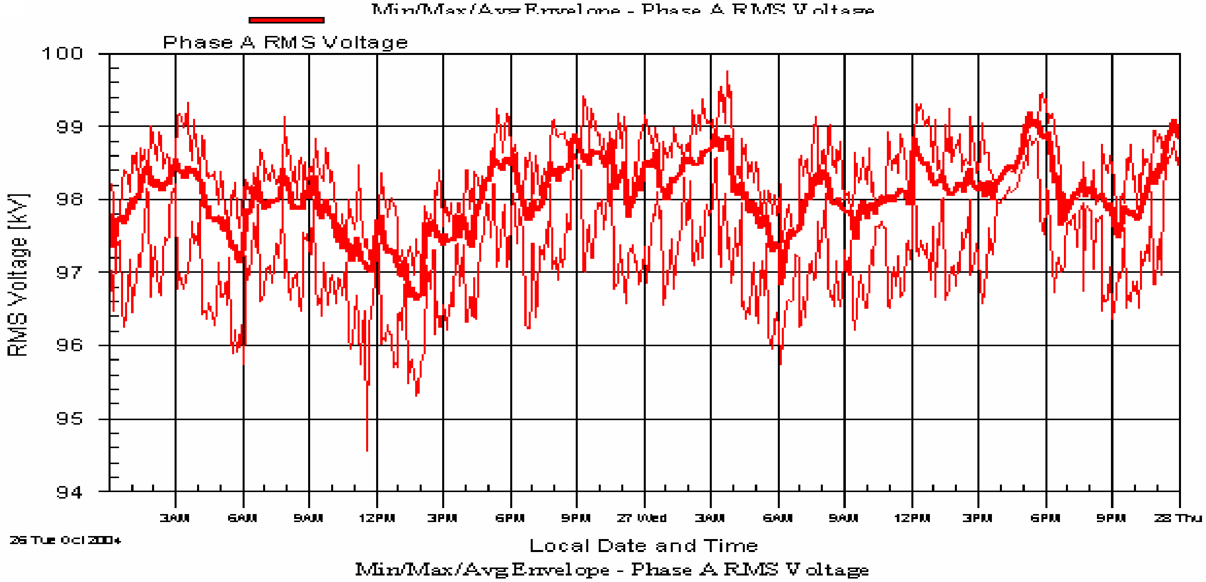


Flicker Summary
PCC Monitor Site
Without SVC/ Filters
PST(95) = 1.86

Comparison of Voltage Swings at PCC Both With and Without SVC Operation



No SVC



SVC

Controls Overshoot – One Possibility For Flicker Swing

GE Flicker Curves
Copied From IEEE 519

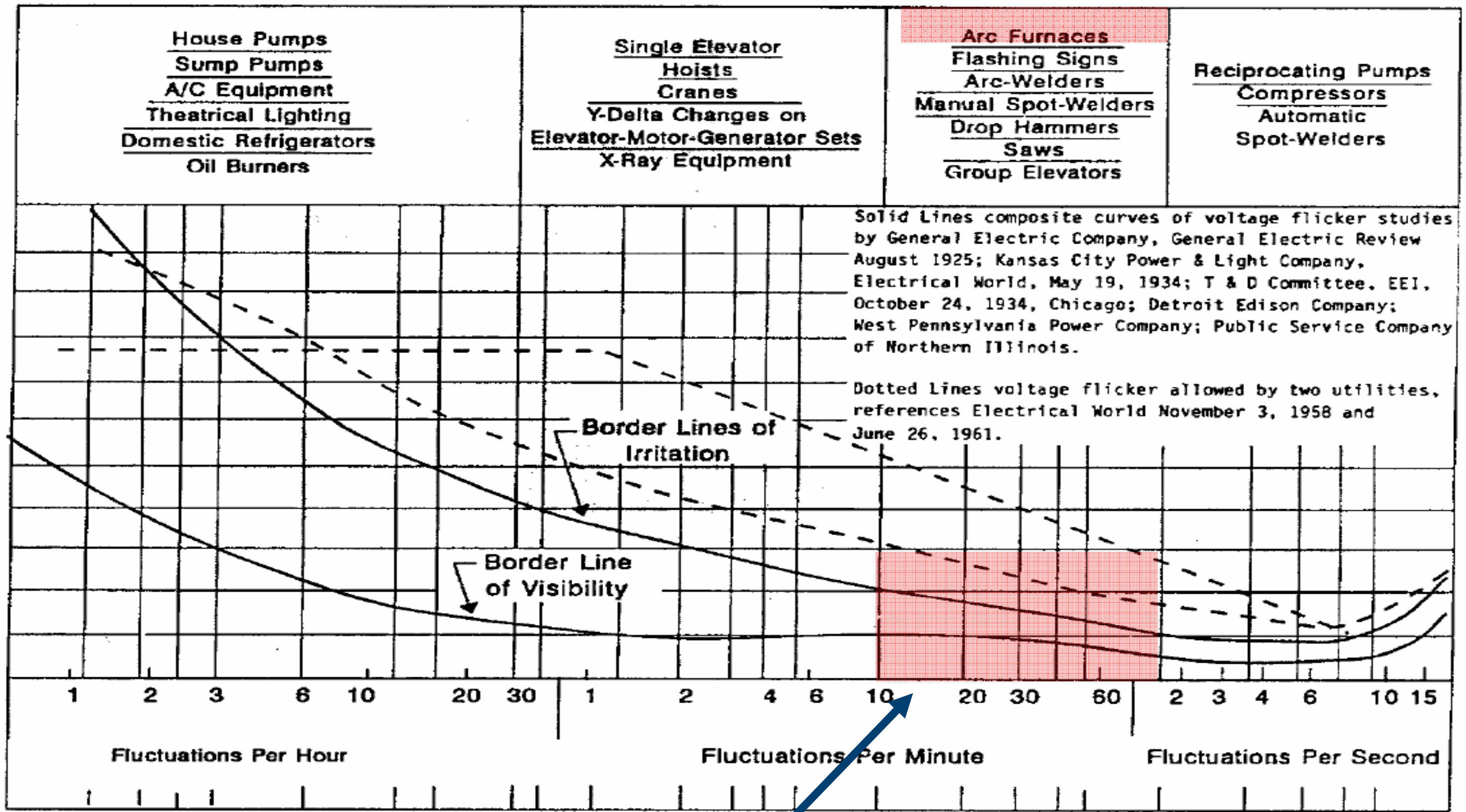


Figure 10-3—Maximum Permissible Voltage Fluctuations

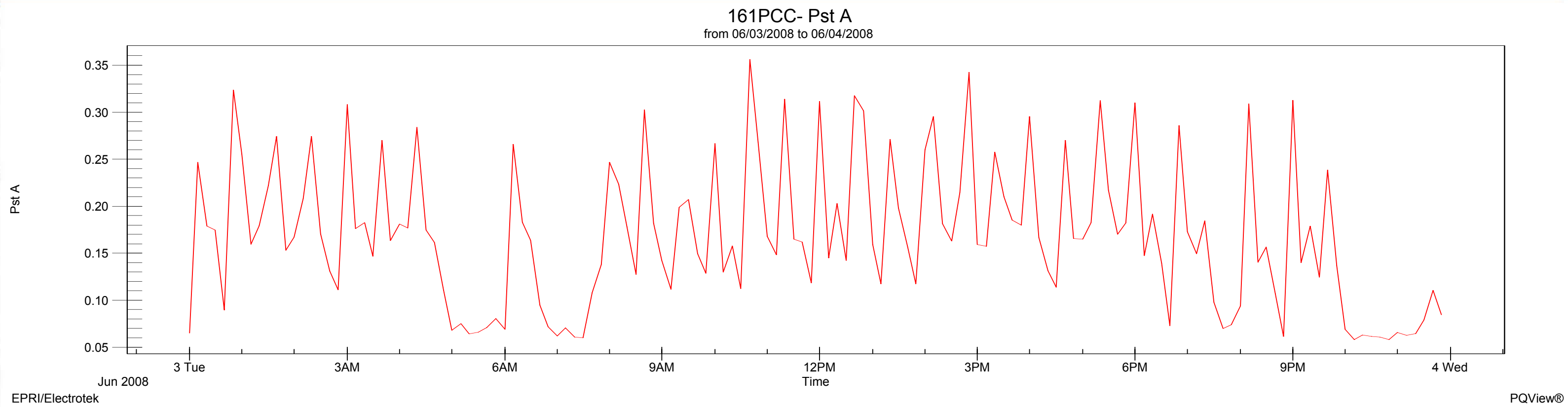
Voltage Swing Possible By TCR Overshoot = 1.1%

Case 10

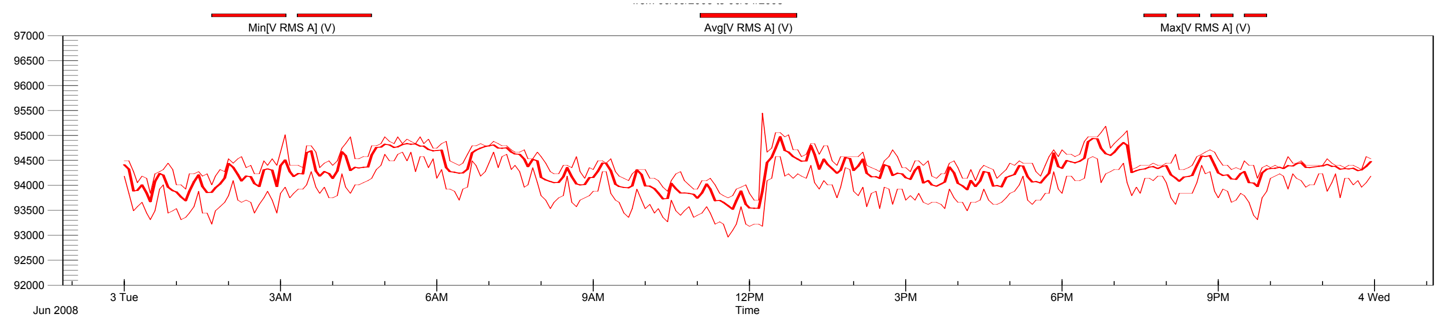
A Large Steel Mill Has an SVC and DC Electric Arc Furnace, Here is The Way Things Should Operate!

EAF Operation with Great SVC Control Performance

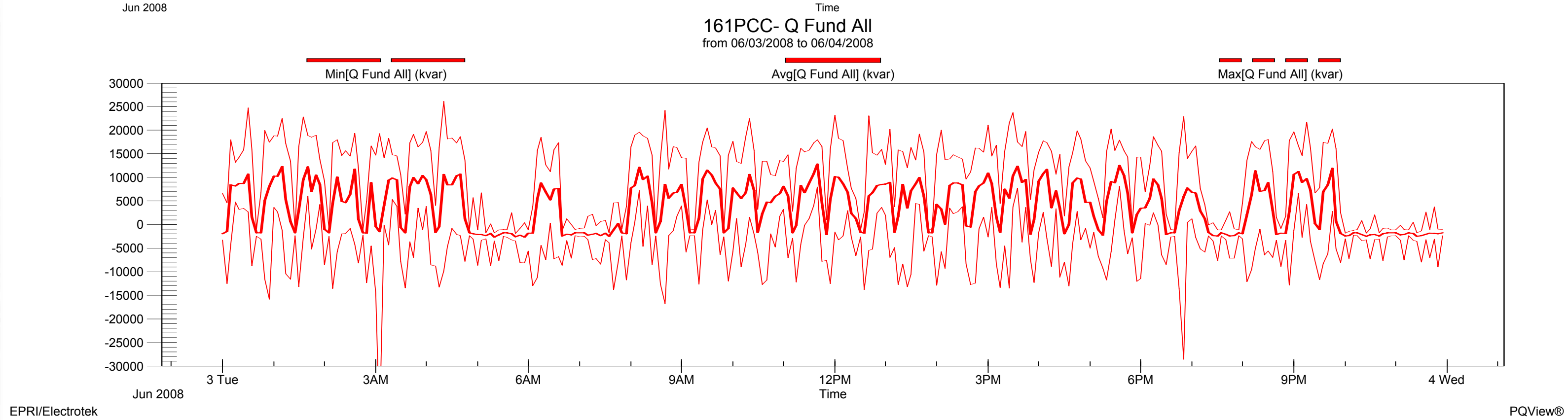
PST



VOLTAGE



REACTIVE POWER



Questions/Comments

If not, then lets eat!!