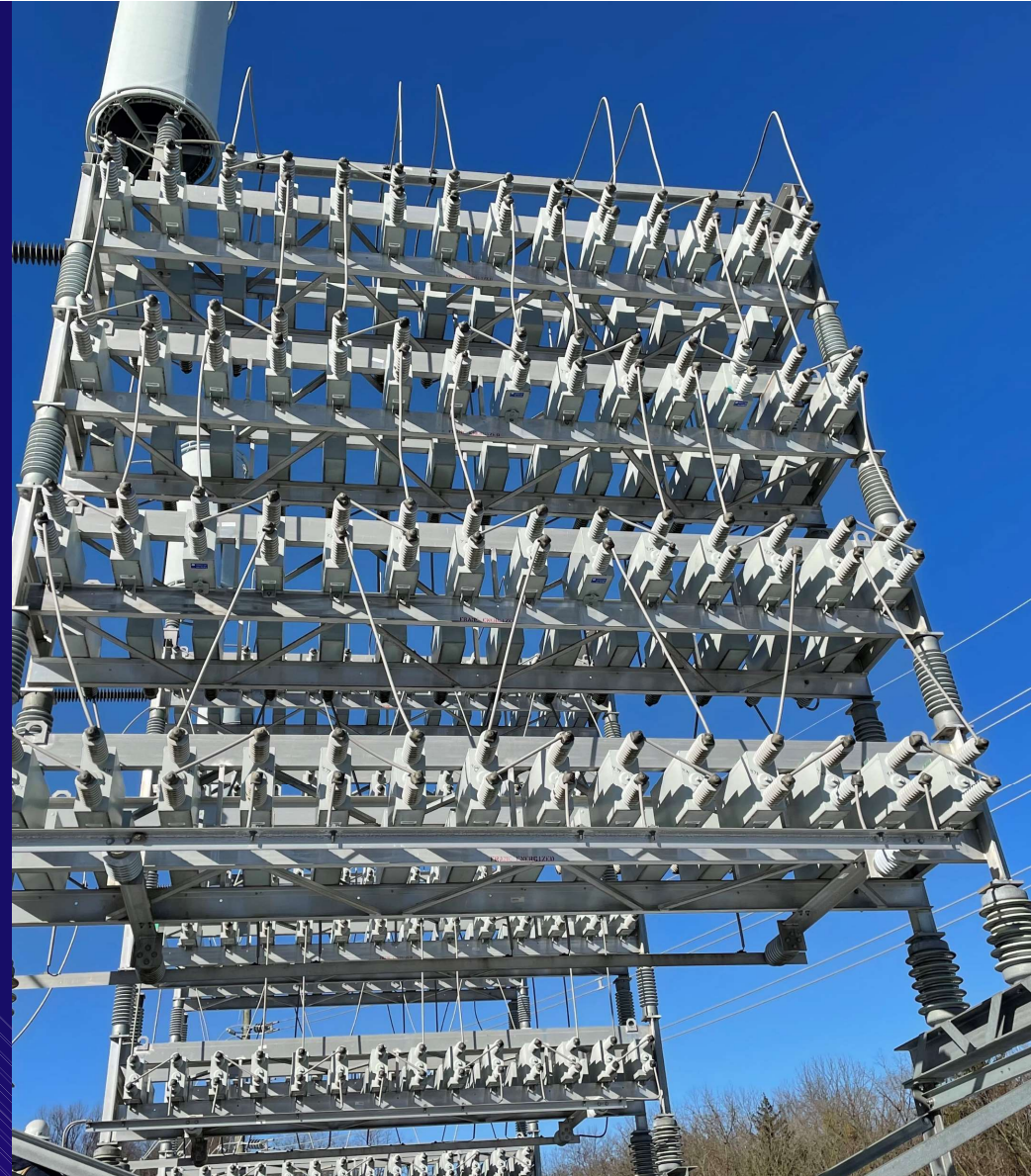




PECO Capacitor Bank Event Analysis

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Confidential Information – For Internal Use Only

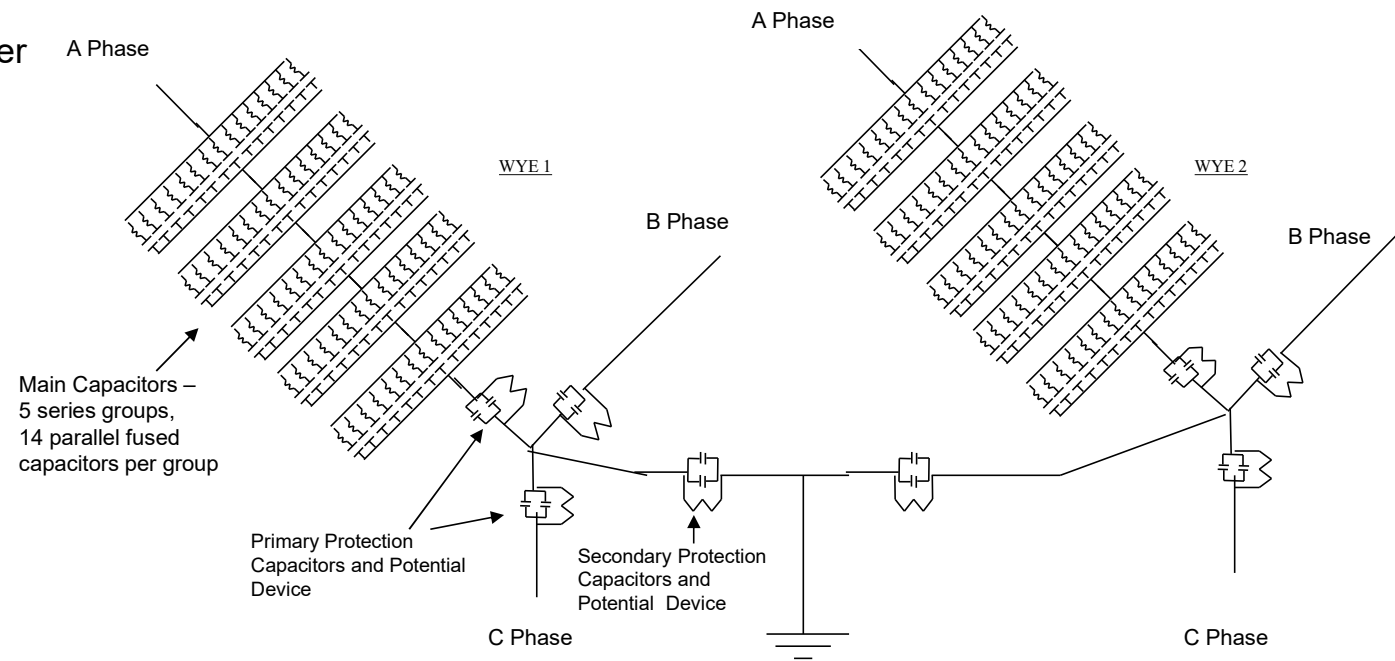


Outline Of The Presentation

1. Capacitor Bank Designs
2. Capacitor Bank Protection Schemes
3. Event Analysis
4. Learning From The Event Analysis

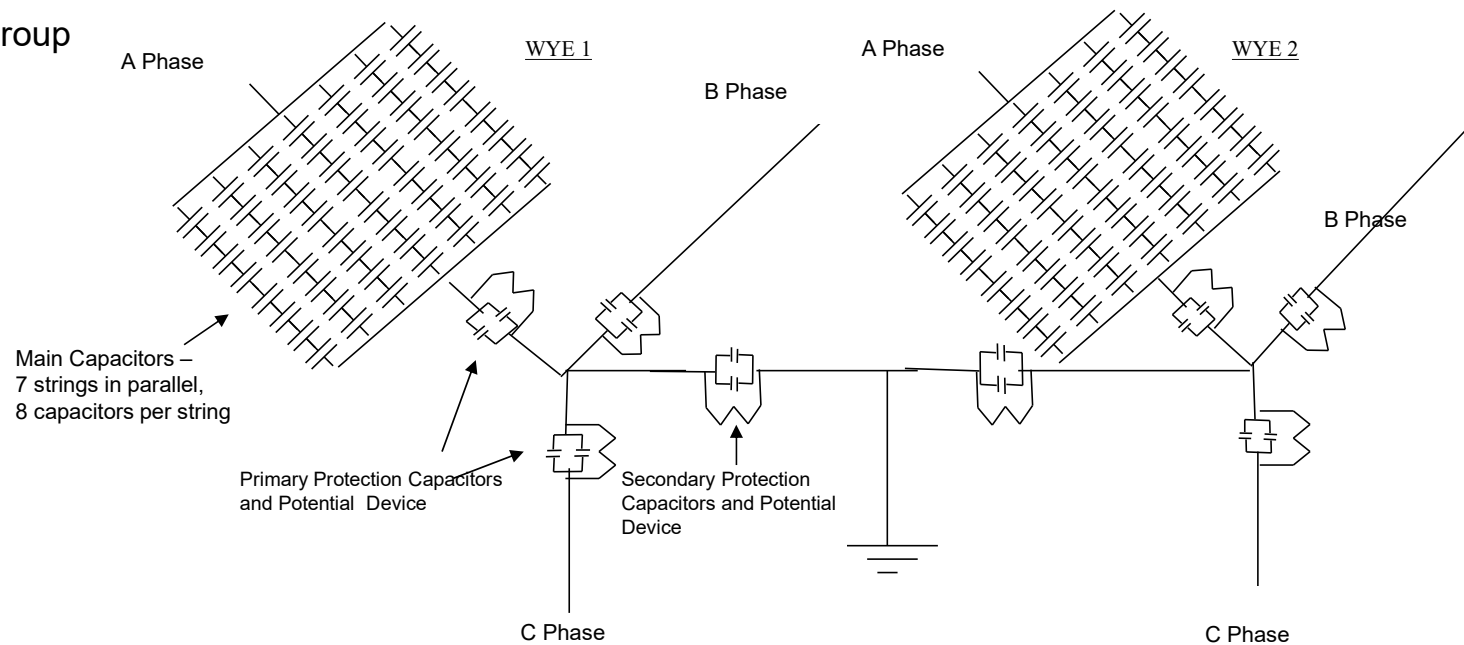
PECO's 230 kV Capacitor Bank Designs – Old Design

- Old Design last installed in 1992
- With 840 capacitor units.
- 14 parallel fused (15A) capacitors per group
- 10 series group per phase
- Required larger footprint 65x65'
- Required fencing.



PECO's 230 kV Capacitor Bank Designs – New Design

- New Design began installing in 1992
- With 336 capacitor units.
- 8 series fuseless capacitors per group
- 7 paralleled group per phase
- Requires smaller footprint 22x50'
- No fencing is required.



PECO's 230 kV Capacitor Protection Scheme

Voltage Differential Protection

1. $|dV| = |V_x| - k_n * |V_y|$ per phase
2. $|dV_n| = |V_{nx}| - k_n * |V_{ny}|$ for neutral
3. $k\text{-factor} = |V_x| / |V_y|$
4. $k\text{-factor}$ is set differently for each phase and neutral

PECO's 230 kV Capacitor Protection Scheme

Protection Philosophy

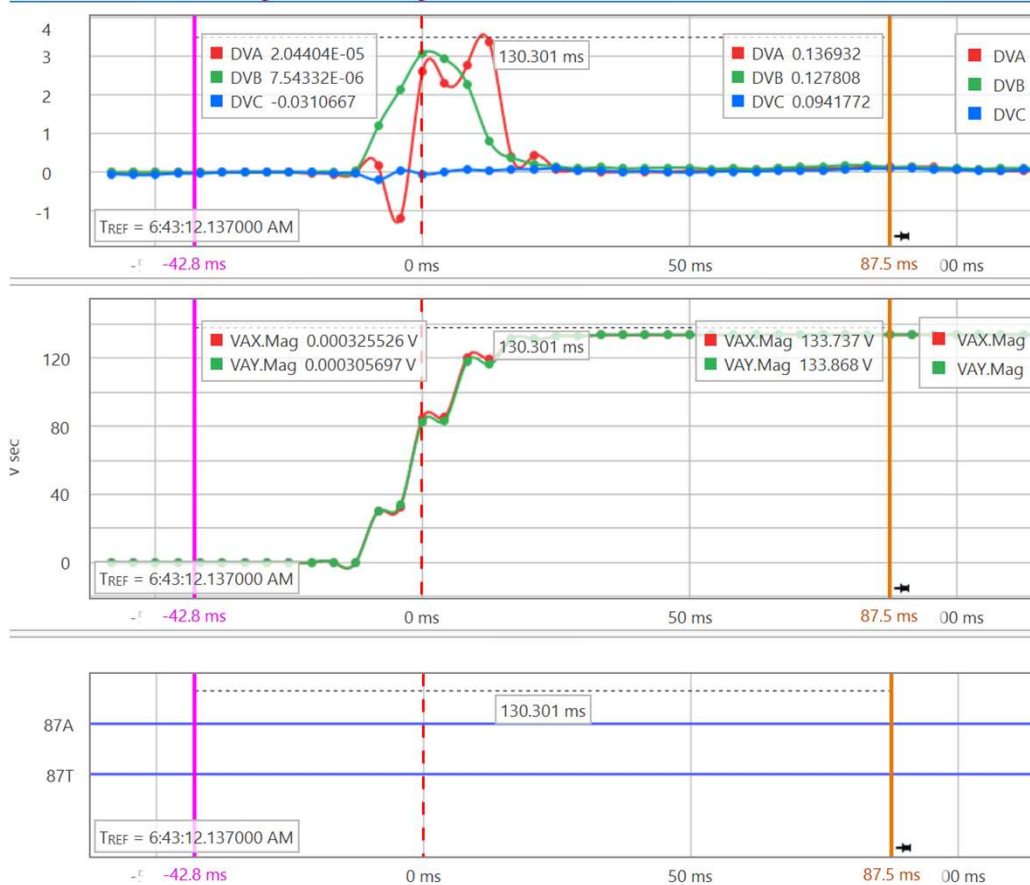
1. Alarm for $|dV| \geq 0.44$ volt
 - Roughly when 2 units (or cans) become defective
2. Trip for $|dV| \geq 1.41$ volt
 - Roughly when 4 units become defective
3. Capacitance can drift due to ambient temperatures and ages

Capacitor Voltage (kV)	Capacitor KVAR	Nominal Capacitance microfarads	Questionable microfarads	Defective microfarads
8.32	100	3.83	3.06 to 3.45 4.21 to 4.60	< 3.06 > 4.60
	150	5.75	4.60 to 5.18 6.33 to 6.90	< 4.60 > 6.90
	200	7.67	6.14 to 6.90 8.44 to 9.20	< 6.14 > 9.20
	300	11.50	9.20 to 10.35 12.65 to 13.80	< 9.20 > 13.80
9.96	100	2.68	2.14 to 2.41 2.95 to 3.22	< 2.14 > 3.22
	150	4.01	3.21 to 3.61 4.41 to 4.81	< 3.21 > 4.81
13.80	200	2.79	2.23 to 2.51 3.07 to 3.35	< 2.23 > 3.35
19.92	200	1.34	1.07 to 1.21 1.47 to 1.61	< 1.07 > 1.61
	300	2.01	1.61 to 1.81 2.21 to 2.41	< 1.61 > 2.41
17.47	521	4.53	3.62 to 4.08 4.98 to 5.44	< 3.62 > 5.44
21.60	200	1.14	0.91 to 1.03 1.25 to 1.37	< 0.91 > 1.37

PECO's 230 kV Capacitor Tripping Event

- On 2/22/2-21, the 230 kV cap bank tripped, by the neutral relay, but not the primary relay.
- No capacitor units were found defective.

Primary Relay Event



PECO's 230 kV Capacitor Tripping Event

- The voltage difference between V_x and V_y is about, 0.2 volt (DVAA = 0.2).
- But the Voltage Differential Element (DVA) is about 1.5 volt, above the trip threshold of 1.4 volt.

Neutral Relay Event



PECO's 230 kV Capacitor Lesson Learned

Neutral Relay Setting

```
Event   :TRIP  TARGETS: EN,87A
X27L = 0.00   X59I = 150.00   Y27L = 0.00   Y59I = 150.00   3Y59D= 0
X59PU= 150.00 X59D = 0        Y59PU= 150.00 Y59D = 0        VSS   = X
59P1 = 150.00 THP1 = 0        THD1 = 0
27P1 = 0.00   TLP1 = 0        TLD1 = 0
59P2 = 150.00 THP2 = 0        THD2 = 0
27P2 = 0.00   TLP2 = 0        TLD2 = 0
KA    = 1.998  KB    = 1.000  KC    = 1.000
87AA = 0.44   87BA = 150.00  87CA = 150.00  87T   = 1.41    87H   = 4.81
87APD= 1000   87TPD= 45       87HPD= 30      87DO  = 0
A1PD = 0       A2PD = 0        A3PD = 0        A4PD = 0        A5PD = 0
TDUR = 10      LTCHE= N        LOPE1= N        LOPE2= N        LOPD  = 60
TIME1= 5       TIME2= 30      AUTO  = 3        RINGS= 5
```

- It turns out $KA = 1.998$ on the neutral relay.
- It was PECO's practice to set K-factor automatically during commissioning of cap relay

PECO's 230 kV Capacitor Lesson Learned

- During Commission of a new cap bank, each units are measured and placed accordingly so each phase is balanced between the X and Y section, and between all three phases on same section.
- However, it can't never be 100% balanced.
- Use k-factor to zero out the voltage difference at time of commissioning.

Strings	1	2	3	4	5	6	7
TIER 1	4.860	4.750	4.730	4.710	4.770	4.770	4.700
TIER 2	4.700	4.680	4.740	4.690	4.750	4.820	4.770
TIER 3	4.790	4.770	4.720	4.730	4.730	4.780	4.740
TIER 4	4.730	4.770	4.780	4.850	4.750	4.750	4.810
TIER 5	4.710	4.700	4.700	4.740	4.840	4.810	4.700
TIER 6	4.750	4.680	4.740	4.840	4.740	4.710	4.760
TIER 7	4.760	4.750	4.730	4.780	4.730	4.770	4.730
TIER 8	4.780	4.710	4.710	4.730	4.770	4.720	4.730

A ↻ WEST SIDE (Cap CB is on your Left)

*** All results measured in uF ***

Strings	1	2	3	4	5	6	7
TIER 1	4.770	4.770	4.780	4.760	4.830	4.820	4.760
TIER 2	4.840	4.710	4.740	4.760	4.750	4.790	4.740
TIER 3	4.770	4.740	4.730	4.720	4.810	4.780	4.680
TIER 4	4.730	4.750	4.640	4.860	4.740	4.710	4.780
TIER 5	4.700	4.740	4.730	4.760	4.810	4.720	4.820
TIER 6	4.760	4.730	4.770	4.710	4.710	4.760	4.790
TIER 7	4.770	4.750	4.770	4.750	4.710	4.780	4.750
TIER 8	4.720	4.790	4.790	4.710	4.730	4.800	4.760

A ↻ EAST SIDE (Cap CB is on your Left)

PECO's 230 kV Capacitor Lesson Learned

- K-factor is calculated by $K_A = |V_{AX}|/|V_{AY}|$, for each phase and neutral.
- At the time of commissioning the nominal voltage for each phase is about 132 volts, however, we can have $V_{ax} = 132.2$ volts, and $V_{ay} = 132.4$ volts, then k-factor would be 0.998.
- For the neutral, if the system is relatively balanced, we could end up having $V_{nx} = 0.4$ and $V_{ny} = 0.2$, then k-factor would be 2.

PECO's 230 kV Capacitor Lesson Learned

- Having a k-factor of 2 at low neutral voltage is not an issue.
- As the neutral voltage rises, the voltage difference becomes more significant.
- In other word, the voltage differential element becomes more sensitive for any k-factor that deviates from 1.

Vx	Vy	K-factor	DV
0.4	0.2	2	0
0.6	0.4	2	0.2
0.8	0.6	2	0.4
1	0.8	2	0.6
1.2	1	2	0.8
1.4	1.2	2	1
1.6	1.4	2	1.2
1.8	1.6	2	1.4
2	1.8	2	1.6

PECO's 230 kV Capacitor Lesson Learned

- PECO no longer set k-factor automatically for neutral relays. Manually set at 1.
- For phase relays, after setting k-factor automatically, if k-factor deviates from 1 for more than 20%, report it back to relay engineers for further analysis.