A Solution to Sensitivity Challenges for the Protection of Large Fuseless Capacitor Banks

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Sometimes you need to do things a bit differently

Agenda

- Introduction
- The sensitivity challenge for fuseless capacitor banks
- Studied cases
- Relay implementation
- Standardization of the solution
- Conclusions

Introduction

- Hydro-Québec
  - Government owned utility - province of Québec, Canada
  - Generates (mainly large hydro-electric with wind & biomass plants), transmits and distributes electricity
  - Carries out construction projects
  - Conducts R&D in energy-related fields, including energy efficiency

Introduction

- Hydro-Québec TransÉnergie
  - Operates extensive transmission network
    - 530 substations
    - Over 34,187 km (21,243 miles) of transmission lines
  - 15 interconnections with neighboring provinces and states
    - 6,025 MW import capacity
    - 7,974 MW export capacity

Introduction

Voltage	Number of in-service banks			Planned additions
	Externally fused / MVARs	Internally Fused / MVARs	Fuseless / MVARs	Fuseless / MVARs
315 kV	N/A	3 / 1,123.2	9 / 3,024	N/A
230 kV	14 / 1,968	N/A	5 / 1,224	1 / 216
161 kV	4 / 34.5	N/A	2 / 360	2 / 360
120 kV	52 / 3,912.8	13 / 1,100.2	21 / 1,683	9 / 702
Total	**70 / 5,915.3**	**16 / 2,223.4**	**37 / 6,291**	**12 / 1,278**
Total reactive power of 15,707.7 MVARs				

Capacitor banks on Hydro-Québec's transmission network

- Fuseless capacitor banks first added in 2004
  - Neutral current unbalance - ungrounded wye banks
  - Voltage differential - grounded wye banks

The Fuseless Sensitivity Challenge

- Sensitivity of protection:
  - The ability of a protection system to reliably distinguish an internal fault from other system anomalies
    - Environmental variations
    - External faults
    - Loading
    - Noise

We will need more than duct tape to fix this one!

The Fuseless Sensitivity Challenge

- Principal protection signal for voltage differential on wye-grounded capacitor banks is the difference voltage:
  - $V_{dif} = V_{bus} - K^*V_{tap}$
  - Per-phase "K" compensates for the <u>static</u> variations in capacitance of healthy cans
  - Inherently compensated for static and dynamic bus voltage phase imbalances

The Fuseless Sensitivity Challenge

- Dynamic variations in capacitance of individual elements will cause dynamic difference voltages
  - Varying temperatures
    - Some cans are in the sun and some are in the shade
    - Some cans are in the wind and some are sheltered
  - Drift in capacitance caused by ageing
  - Harmonics and noise measured by or induced on the voltage inputs of the relay
    - Fundamental filtering removes most but not 100% if noise/harmonics are rapidly changing

The Fuseless Sensitivity Challenge

- Difference voltage on typical externally fused banks makes a significant step change when a fuse blows
  - Alarm and trip settings significantly larger than the difference voltage generated by dynamic capacitance changes and noise/harmonics
  - Adequate reliability and sensitivity of voltage differential protection

The Fuseless Sensitivity Challenge

- Difference voltage on fuseless banks makes small step changes as individual elements short within the cans
  - Required alarm and trip settings often in the range of dynamic difference voltage
  - Required primary differential voltages often lower than the reliable accuracy range of the voltage transformers used to measure them
  - Challenges increase with bank size

The fuseless sensitivity challenge

- Design approaches can increase the required differential voltage protection alarm and trip settings for fuseless banks
  - Larger KVAR rated cans
  - Higher individual can and bank voltage ratings
  - Split-wye designs
  - Breaking larger banks into multiple smaller banks
- May not be adequate for very large banks

The Fuseless Sensitivity Challenge

- Hydro-Québec’s large banks are standardized
  - Not an option to change bank size
- Forced to find an alternative protection method that would allow for secure and sensitive alarm and trip settings

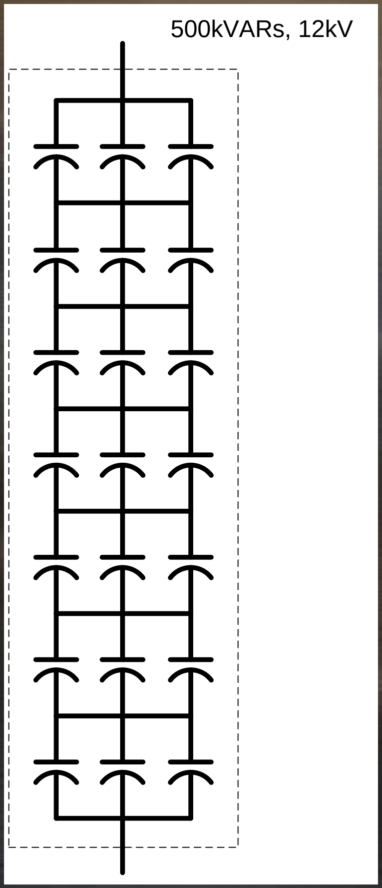
Let’s run some tests to be sure we are headed in the right direction

Studied Cases

- Studied a 180 MVARs, 161 kV capacitor bank using specialized transient simulation software
  - 120 fuseless capacitors per phase
    - 15 strings of eight (8) series cans
    - Each can rated 12 kV, 500 kVARs with 7 elements in series by 3 in parallel
  - The 7 series elements of a can were shorted one at a time and the voltage increase was measured across the remaining healthy elements in the string

Studied Cases

- Bus VT ratio = 1400:1 V
- Step-down circuit with protection module (PM) to measure the tap voltage
  - One 167 kVARs, 825 V monitoring capacitor per 100 A of load
  - 1250:250 V (5:1 ratio) VT
  - 100 Ω, 100 W resistance
- Alarm before 5% OV
- Trip before 10% OV



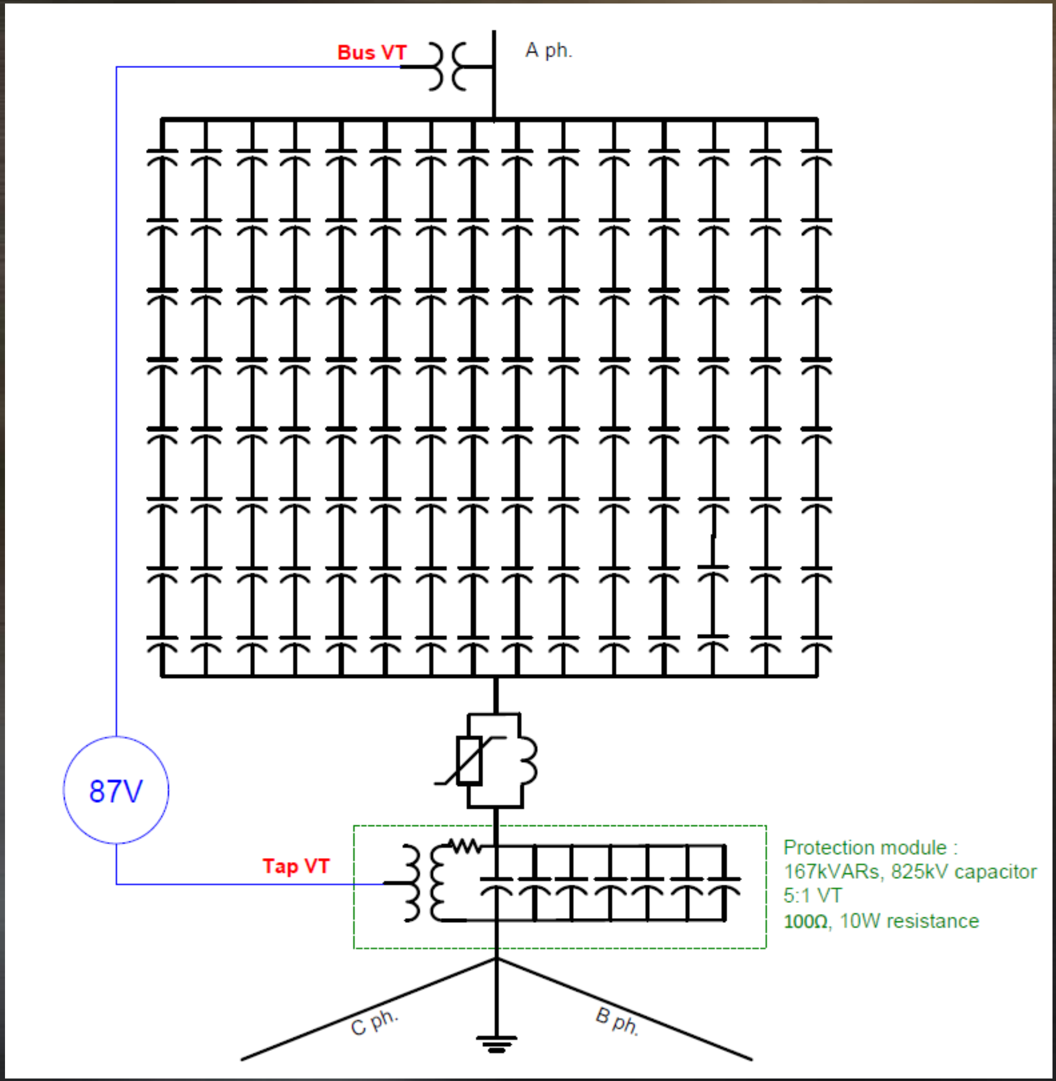
Internal configuration of individual cans for study

Studied Cases

- 3 physical arrangement cases were studied
  - 1 voltage differential covering the entire bank
  - Split-wye arrangement with 2 independent voltage differentials
  - Split in smaller wye-connected zones -- each one monitored by an independent voltage differential

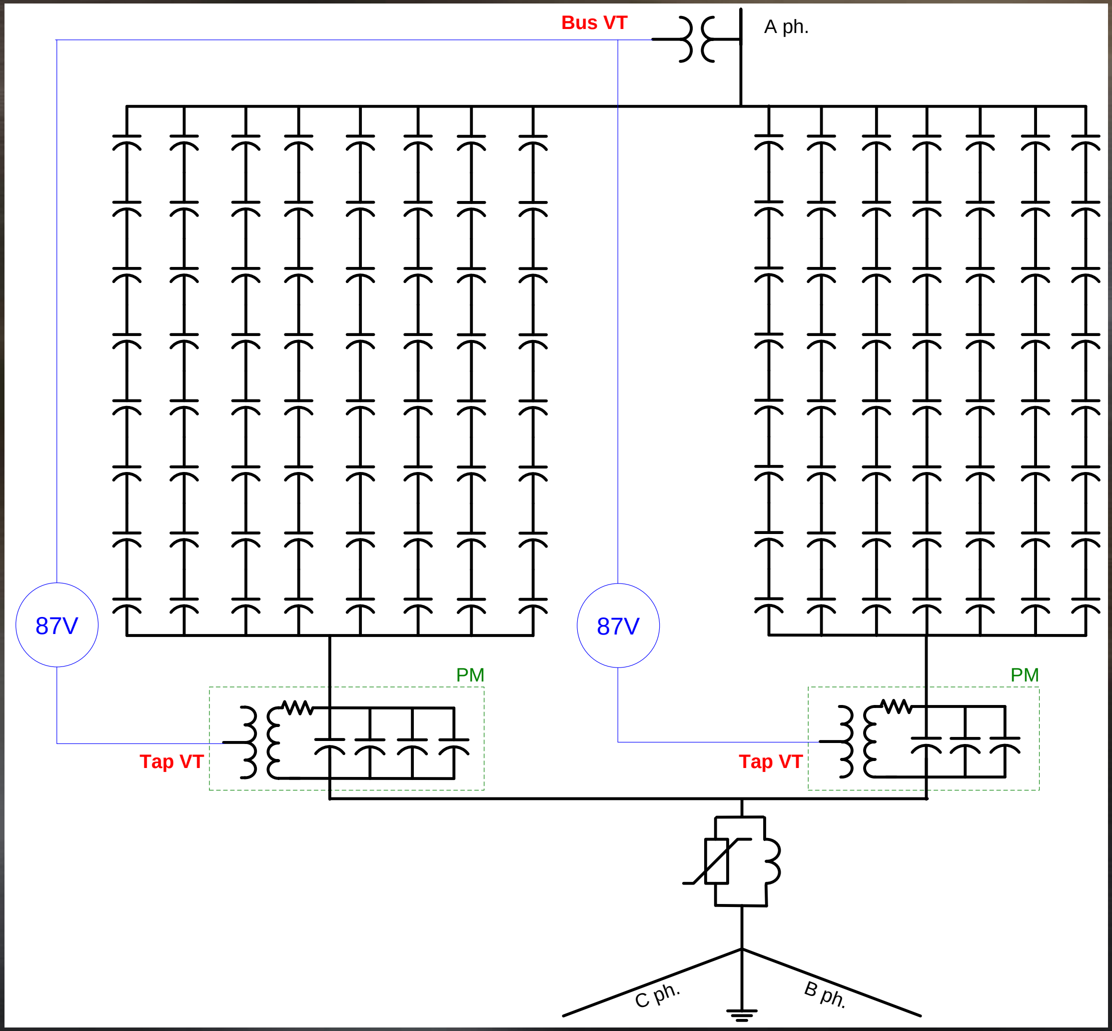
Studied Cases – Case 1

Single voltage differential protection on a 180 MVARs, 161kV capacitor bank

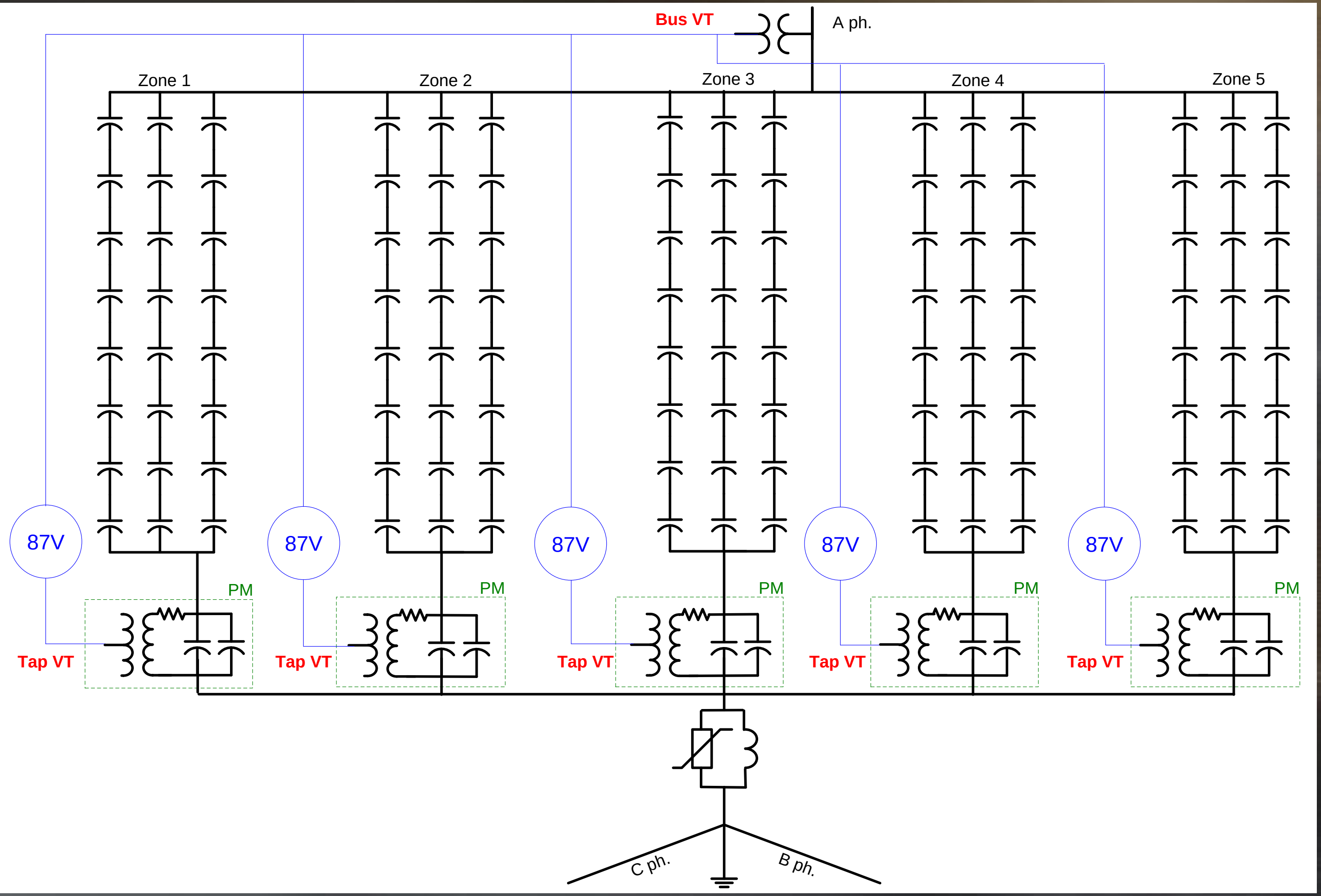


Studied Cases – Case 2

Voltage differential protection for a 180 MVARs, 161kV capacitor bank in split-wye arrangement



Studied Cases – Case 3



Multiple voltage differential protections on a 180 MVARs, 161kV capacitor bank

Studied Cases –Comparison

	Alarm Setting	Trip Setting
Case 1 (8 S X 15 P)	Loss of 2 elements 0.22 V sec	Loss of 5 elements 0.50 V sec
Case 2 (8 S X 8 P)	Loss of 2 elements 0.40 V sec	Loss of 5 elements 0.94 V sec
Case 2 (8 S X 7 P)	Loss of 2 elements 0.46 V sec	Loss of 4 elements 0.86 V sec
Case 3 (8 S X 3 P)	Loss of 2 elements 1.00 V sec	Loss of 4 elements 2.00 V sec

Studied Cases –Comparison

- Case 3 setting is nearly 5 times higher than Case 1 and more than twice Case 2
- Fault location is optimal in Case 3
- Expect less alarms for Case 3
- Hydro-Québec field experience
  - Minimum threshold of 1V to avoid false alarms
  - Minimum threshold of 2V for secure tripping

Relay Implementation

- Relay implementation is challenging
  - Large number of three-phase voltage inputs
  - Large number of 87V functions
- Each relay should handle as many zones as possible
- Modular and customizable relay desirable

If one is good ..... 3 (or 8?) is better!

Relay Implementation

- 1 three-phase current input (including A, B, C and ground) per relay

Save Restore Default Res

PARAMETER	CT F1
Phase CT Primary	2000 A
Phase CT Secondary	5 A
Ground CT Primary	5 A
Ground CT Secondary	5 A

C70-1_87V_TTbarre_vhomologuee.urs | System Setup

- 5 three-phase voltage inputs (including A, B, C and auxiliary) per relay

Save Restore Default Reset VIEW ALL mode

PARAMETER	VT F5	VT M1	VT M5	VT U1	VT U5
Phase VT Connection	Wye	Wye	Wye	Wye	Wye
Phase VT Secondary	66.4 V	49.1 V	49.1 V	49.1 V	188.0 V
Phase VT Ratio	1400.00 :1	5.00 :1	5.00 :1	5.00 :1	5.00 :1
Auxiliary VT Connection	Vag	Vag	Vag	Vag	Vag
Auxiliary VT Secondary	66.4 V	66.4 V	66.4 V	66.4 V	66.4 V
Auxiliary VT Ratio	1.00 :1	1.00 :1	1.00 :1	1.00 :1	1.00 :1

C70-1_87V_TTbarre_vhomologuee.urs | System Setup: AC Inputs | Screen ID: 168

Relay Implementation

- 3 Voltage differential functions per relay

Save Restore Default Reset VIEW ALL mode

SETTING	PARAMETER
Voltage Differential 1 Function	Enabled
Voltage Differential 1 Bus Source	Bus (SRC 2)
Voltage Differential 1 Tap Source	Tap V1 (SRC 3)

SETTING	PARAMETER
Voltage Differential 2 Function	Enabled
Voltage Differential 2 Bus Source	Bus (SRC 2)
Voltage Differential 2 Tap Source	Tap V2 (SRC 4)

SETTING	PARAMETER
Voltage Differential 3 Function	Enabled
Voltage Differential 3 Bus Source	Bus (SRC 2)
Voltage Differential 3 Tap Source	Tap V3 (SRC 5)

Standardization of The Solution

- 4 banks modeled and divided into smaller wye-connected zones to determine the number of strings per zone that provide sufficient reliability and sensitivity
  - 108 MVARs, 120 kV (Vrated = 124.7 kV), 216 cans (6 S x 12 P)
  - 216 MVARs, 230 kV (Vrated = 249 kV), 432 cans (12 S x 12 P)
  - 288 MVARs, 230 kV (Vrated = 249 kV), 576 cans (12 S x 16 P)
  - 384 MVARs, 315 kV (Vrated = 333 kV), 768 cans (16 S x 16 P)

If one's too big, just chop it into smaller parts

Standardization of the solution

Standardization Study Results	Strings per zone	Number of zones	Alarm (V)	Trip (V)	Number of relays
124.7kV, 108MVARs (6 S X 12 P)	4	3	1.0	2.0	1
166.3kV, 180MVARs (8 S X 15 P)	3	5	1.0	2.0	2
249kV, 216MVARs (12 S X 12 P)	3	4	1.0	2.0	2
249kV, 288MVARs (12 S X 16 P)	3 (for zones 1 to 4) 2 (for zones 5 & 6)	4 2	1.0 1.5	2.0 3	2
330kV, 384MVARs (16 S X 16 P)	3 (for zones 1 to 4) 2 (for zones 5 & 6)	4 2	1.0 1.5	1.5 ** 2.25	2

** Violates standard minimum Vtrip solution. Dividing bank into 8 zones of 2 strings would require 3 relays. Decision to compromise on 6 zones with lower trip.

Conclusions

- Hydro-Québec needed a solution to sensitivity problems on large fuseless shunt capacitor banks
- Industry standard solutions were not adequate
- Multi-zone approach was chosen and implemented in the field
- Doesn’t necessarily require more relays
- Offers higher protection sensitivity
- Improved fault location
- Bank becomes more fault tolerant (less alarms over time)

Thank You

Questions?