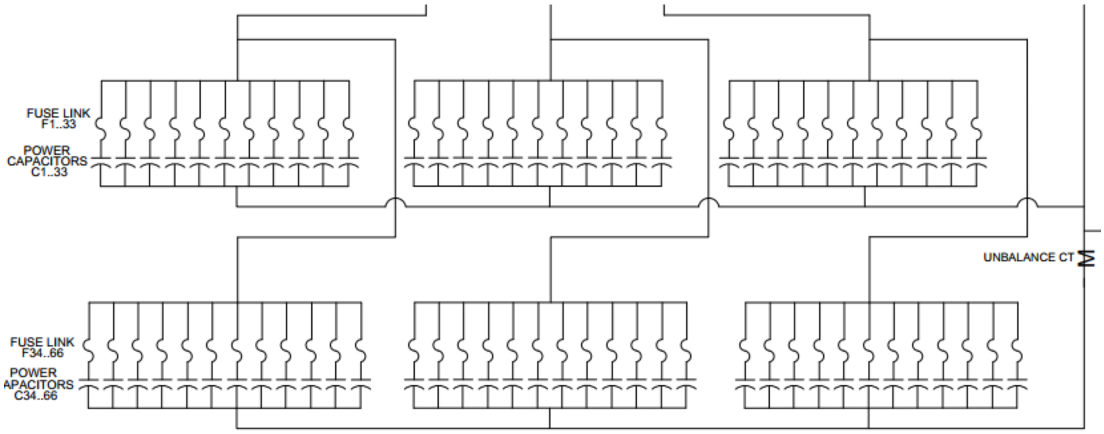
Capacitor Bank Configuration & Unbalance Protection

Ref.-PIC/001

Capacitor Bank Configuration

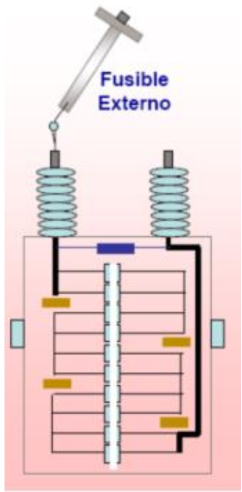
One capacitor bank will be supplied for this project, the capacitor bank has a reactive power of 33000kVAr @ 37.4kV (28080kVAr @ 34.5kV), in an ungrounded double wye configuration. The Capacitor Bank will be manufactured with 66 capacitor units.

The configuration will be 1 series group and 22 parallel capacitor units per phase, 11 capacitors in the left wye and 11 capacitors in the right wye according to the next diagram:



It is very important to mention that in normal operating conditions, each neutral of each wye will have zero volts and zero amperes because each wye is balanced with the same number of capacitor units and the capacitor units have the same reactive power, same voltage, and same capacitance.

For externally fused capacitor banks, the entire capacitor units are constructed with several series-parallel combinations. A typical externally fused capacitor bank design is as shown in the image below.



Unbalance protection has the function of sending the trip signal of the Capacitor Bank when fuses have operated or there is some abnormality of current or voltage in the neutral of the capacitor bank.

The functions of a neutral unbalance protection are the following:

a) Perform the opening quickly of the capacitor bank if the unbalance indicates that a fuse has operated. With this action, the following is avoided:

a.1) Damage to the capacitors or remanent elements of undesirable surges, since each capacitor only supports 10% of overvoltage, and when a capacitor fails in a phase the rest of the boats will be over-stressed.

a.2) Inappropriate operation of a harmonic filter, since when losing capacitance, the filter could lose the tuning for which it was designed.

a.3) Bad operation or operation of fuses and avoid cascading failures of the capacitor bank fuses.

b) Depending on the design and if the bank supports it, it will send the alarm signals without making the opening, in case of a fuse failure and the remaining capacitors do not have an overvoltage of above 10%.

c) Shoot the capacitor bank in case the imbalance indicates the possible presence of external arcs or cascading faults inside the capacitor bank.

If the neutral unbalance protection is not adequate, the following may be presented, among other things:

1. Excessive damage in the capacitors and in general in the equipment that makes up the capacitor bank.
2. Propagation of damage to equipment near the capacitor bank.
3. Possible case/tank rupture and leakage of the dielectric liquid causing explosions and/or fire.
4. Adverse effects on the power system where the capacitor bank will be connected.

In accordance with **ANSI C37.99 - Guide for protection of Shunt Capacitors Banks**, it is recommended to use an unbalance CT and with this information to be able to calculate the neutral unbalance settings, it is required to know the following data:

n – Blown fuses
S – Capacitor Series groups per capacitor bank
Pt – Capacitor parallel units per phase
Pa – Capacitor parallel units in left wye
G – 0 (Grounded wye) 1 (Ungrounded wye)

Column title	Formula and comment	G	Number of blown capacitor fuses *n* (The number of fuses that have blown in one parallel group of capacitor units. $n = 0$ is the system normal condition n)					
			0	**SU**	**1**	**2**	**3**	**4**
Parallel group per-unit capacitance *Cg*	$Cg = \frac{Pa - n}{Pa}$ The capacitance of the parallel group of capacitors that includes the blown fuse(s).	0	1.0000	SC	0.8750	0.7500	0.6250	0.5000
		1	1.0000	SC	0.8750	0.7500	0.6250	0.5000
Affected wye capacitance *Cs*	$Cs = \frac{S \times Cg}{Cg \times (S-1) + 1}$ The per-unit phase-to-neutral capacitance of the series/parallel group of capacitor units that includes the blown fuse(s). For the group including the affected unit, the per-unit capacitance is Cg. For all other groups, the per-unit capacitance is 1.	0	1.0000	1.3333	0.9655	0.9231	0.8696	0.8000
		1	1.0000	1.3333	0.9655	0.9231	0.8696	0.8000
Per-unit capacitance, phase with blown fuses *Cp*	$Cp = \frac{(Cs \times Pa) + Pt - Pa}{Pt}$ The per-unit capacitance of the phase (both wyes) that includes the blown fuse(s). For single wye banks, $Pa = Pt$ and $Cp = Cs$.	0	1.0000	1.1905	0.9803	0.9560	0.9255	0.8857
		1	1.0000	1.1905	0.9803	0.9560	0.9255	0.8857
Neutral-to-ground voltage (per-unit of *Vlg*) *Vng*	$Vng = G \times \left(\frac{3}{2 + Cp} - 1\right)$ For grounded banks ($G = 0$), this voltage is always 0. For ungrounded wye banks, the calculation is made assuming the affected phase has a capacitance Cp and the other two phases each have a per-unit capacitance of 1.	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		1	0.0000	−0.0597	0.0066	0.0149	0.0255	0.0396
Voltage on affected phase *Vln*	$Vln = Vng + 1$ The voltage line to neutral across the phase that includes the blown fuse(s). The operation of the fuse(s) reduces the capacitance of that phase and increases the voltage across the affected phase; therefore, the numbers are always greater than one except before the operation of the fuse on a faulted capacitor unit.	0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
		1	1.0000	0.9403	1.0066	1.0149	1.0255	1.0396
Voltage on affected series group *Vcu*	$Vcu = \frac{Vln \times Cs}{Cg}$ (If $Cg = 0$, $Vcu = Vln \times S$) The per-unit voltage on the capacitor units in the group with the blown fuse(s), based on the capacitance division of the actual voltage on the affected phase (Vln).	0	1.0000	SC	1.1034	1.2308	1.3913	1.6000
		1	1.0000	SC	1.1107	1.2491	1.4268	1.6634
Current through affected capacitor(s) *Iu*	$Iu = Vcu \times Cu$ The current through the individual capacitor units in the group with the blown fuse(s), per-unit of the value with no fuses blown. Note that for healthy capacitor units $Cu = 1$. The value for SU indicates the power frequency current available to blow the fuse on a faulted capacitor unit. This value may be used to estimate the maximum clearing time of the fuse (assuming no discharge from parallel capacitor units into the faulted one).	0	1.0000	10.667	1.1034	1.2308	1.3913	1.6000
		1	1.0000	10.667	1.1107	1.2491	1.4268	1.6634
Current in affected wye *Iy*	$Iy = Cs \times Vln$ The per-unit current in the series/parallel group with the blown fuse(s). This value may be useful for differential schemes comparing the current in different series/parallel groups.	0	1.0000	1.3333	0.9655	0.9231	0.8696	0.8000
		1	1.0000	1.2537	0.9719	0.9368	0.8917	0.8317
Current in affected phase *Iph*	$Iph = Cp \times Vln$ The current in the phase with the blown fuses. This may be useful for setting protection based on phase current.	0	1.0000	1.1905	0.9803	0.9560	0.9255	0.8857
		1	1.0000	1.1194	0.9868	0.9703	0.9490	0.9208

Column title	Formula and comment	G	Number of blown capacitor fuses *n* (The number of fuses that have blown in one parallel group of capacitor units. *n* = 0 is the system normal condition.n)					
			0	**SU**	**1**	**2**	**3**	**4**
Ground current change *Ig*	$Ig = (1 - G) \times (1 - Iph)$ The change in current to ground, which is used with protective relay schemes utilizing either neutral-to-ground current, or the voltage across a low-voltage capacitor(s) in the neutral or in each phase.	0	0.0000	–0.1905	0.0197	0.0440	0.0745	0.1143
		1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Neutral current between wyes *In*	$In = \frac{3 \times Vng \times G \times (P_t - P_a)}{P_t}$ Unbalance current for ungrounded wye-wye banks. [The current is calculated assuming the neutral-to-ground (zero sequence) voltage is applied at the neutral of the wye with no blown fuses.]	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		1	0.0000	–0.0896	0.0099	0.0223	0.0382	0.0594

According to the capacitor bank configuration and internal construction of capacitor units, we have next information:

CapBank configuration:

Variable	Quantity	Unit
S	1	Groups
Pt	22	capacitors
Pa	11	capacitors
G	1	Ungrounded
Q	28080	kVAr
V	34.5	kV
If	469.91	Amps

Applying last equations we obtain next results:

n	Cp [pu]	Vng [pu]	Vln [pu]	Vcu [pu]	Vrc [pu]	Iu [pu]	Ist [pu]	Iph [pu]	In [pu]	Id [pu]	Iprim	Isec
0	1.000	0.000	1.000	1.000	0.844	1.000	1.000	1.000	0.000	0.000	469.913	0.000
1	0.955	0.015	1.015	1.015	0.857	0.923	0.923	1.031	0.046	0.046	484.483	10.844
2	0.909	0.031	1.031	1.031	0.871	0.844	0.844	1.063	0.094	0.094	499.741	22.027
3	0.864	0.048	1.048	1.048	0.885	0.762	0.762	1.098	0.143	0.143	515.732	33.565
4	0.818	0.065	1.065	1.065	0.899	0.677	0.677	1.133	0.194	0.194	532.503	45.475
5	0.773	0.082	1.082	1.082	0.914	0.590	0.590	1.171	0.246	0.246	550.105	57.776
6	0.727	0.100	1.100	1.100	0.929	0.500	0.500	1.210	0.300	0.300	568.595	70.487
7	0.682	0.119	1.119	1.119	0.944	0.407	0.407	1.251	0.356	0.356	588.032	83.629
8	0.636	0.138	1.138	1.138	0.961	0.310	0.310	1.295	0.414	0.414	608.484	97.223
9	0.591	0.158	1.158	1.158	0.978	0.211	0.211	1.341	0.474	0.474	630.022	111.295
10	0.545	0.179	1.179	1.179	0.995	0.107	0.107	1.389	0.536	0.536	652.723	125.870
11	0.500	0.200	1.200	1.200	1.013	0.000	0.000	1.440	0.600	0.600	676.675	140.974

Reviewing the last table, we can develop a summary regarding currents in Amperes, with the next results:

		CT	
n	Iph [Amps]	Iprim [Amps]	**Isec [Amps]**
0	469.913	0.000	0.000
1	484.483	10.844	1.084
2	499.741	**22.027**	**2.203**
3	515.732	**33.565**	**3.357**
4	532.503	45.475	4.548
5	550.105	57.776	5.778
6	568.595	70.487	7.049
7	588.032	83.629	8.363
8	608.484	97.223	9.722
9	630.022	111.295	11.130
10	652.723	125.870	12.587
11	676.675	140.974	14.097

According to the last results when a capacitor fails, the neutral CT primary current will be 10.84 Amperes. When 2 expulsion fuses operate, neutral CT primary current will be 22.02 Amps.

With these results, Arteche recommends a CT ratio of 50:5 Amps.

Alarm setting: **2.20 Amps, time delay 100ms**
Trip setting: **3.35 Amps, time delay 100ms**