SINGLE-WYE NEUTRAL VOLTAGE DETECTION

VarStec Power Solutions
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Abstract - Single-wye neutral voltage detection is a long-established indirect unbalance protection method for ungrounded medium-voltage capacitor banks and harmonic filter banks. The method detects neutral displacement caused by loss of capacitance and can be applied where a split-wye arrangement is not practical or where a simpler single-wye bank is required. This paper reviews the application, topology, relay-setting philosophy, and limitations of the method. Particular attention is given to false-operation exposure, remote ground-fault effects, voltage-transformer application, switching-duty concerns, and the need to treat neutral voltage detection as an indirect unbalance function rather than a substitute for direct fuse sensing.

Index Terms - capacitor bank protection, neutral voltage unbalance, single-wye bank, blown fuse detection, harmonic filter, voltage transformer, transient recovery voltage, direct fuse sensing.

I. INTRODUCTION

Single-wye neutral voltage detection is a long-established indirect unbalance protection method used on medium-voltage power capacitor banks and harmonic filter banks, particularly on ungrounded single-wye arrangements. It is used to detect the loss of capacitance caused by blown fuses, failed capacitor elements, or other internal bank unbalance conditions that can create harmful overvoltage on remaining capacitor units and, in filter applications, shift the tuning characteristics of the bank. Because this method remains widely specified and widely applied, it is important for engineers, consultants, and users to understand how the scheme works, where it is appropriate, and what limitations must be recognized during application and setting.

II. TECHNICAL DISCUSSION

A. What the Single-Wye Neutral Voltage Detection Scheme Is Used For

The single-wye neutral voltage detection scheme is used to detect internal capacitor bank unbalance caused by blown fuses, failed capacitor elements, or other conditions that change the capacitance of one phase of an ungrounded single-wye bank. Its primary purpose is to identify loss of capacitance early enough to prevent damaging overvoltage on the remaining healthy capacitor units and to allow the bank or filter to be removed from service before a more serious failure develops.

Blown fuse detection and prevention of cascading failures

When a fuse operates and removes a capacitor unit or element from service, the capacitance of the affected phase changes. In an ungrounded single-wye bank, the neutral is free to shift, and that shift produces a measurable neutral-to-ground voltage. If the condition is not detected and cleared in time, the resulting increase in voltage across the remaining healthy capacitor units in the affected phase or series group can lead to additional fuse operations, further capacitor failures, and in severe cases a cascading failure of the bank. IEEE C37.99-specifically treats the single-wye neutral voltage protection scheme as one of the standard unbalance detection schemes used in medium-voltage open-air and metal-enclosed capacitor banks (MECB).

Prevention of harmonic filter detuning

In harmonic filter banks, loss of capacitance is especially important because the capacitor bank works with the reactor to establish the intended tuning point. When a capacitor unit is lost, the effective capacitance of the filter changes, which shifts the tuning frequency upward. That can degrade filtering performance and can increase the likelihood of resonance or harmonic amplification, depending on the filter design and system conditions. For that reason, unbalance detection in harmonic filters is not only a capacitor protection function, but also an important part of maintaining intended filter performance and avoiding abnormal harmonic behavior.

Maintain intended reactive power compensation

Shunt capacitor banks are installed to provide reactive power support, improve power factor, reduce system losses, and support voltage. When a capacitor unit is lost, the bank no longer delivers its intended kvar output. Single-wye neutral voltage detection helps identify that degraded operating condition so that it does not remain unnoticed in service.

From an engineering standpoint, filter applications should be reviewed not only for capacitor overvoltage following fuse operation, but also for the effect of lost capacitance on filter tuning and system resonance exposure.

B. Topology of the Split-Wye Neutral Current Detection Scheme

IEEE C37.99-2012 presents the basic neutral voltage unbalance protection method for a single-wye ungrounded bank. In this arrangement, as shown in figure 1, the bank is configured as a single ungrounded wye, and a voltage-sensing device is connected between the bank neutral and ground. IEEE notes that the sensing device may be a voltage transformer, capacitive potential device, or resistive potential device. The basic protection concept is to measure the neutral-point displacement (neutral-to-ground voltage) that appears when the bank becomes electrically unbalanced.

A practical advantage of the single-wye neutral voltage method is that it does not require the bank to be split into two separate wye sections. That can make it more attractive where a simpler single-wye arrangement is desired, especially on banks that otherwise could be built with only three capacitor units per stage rather than six in a split-wye configuration. In that sense, the single-wye neutral voltage method can reduce capacitor count, enclosure size, and cost relative to a double-wye neutral current arrangement.

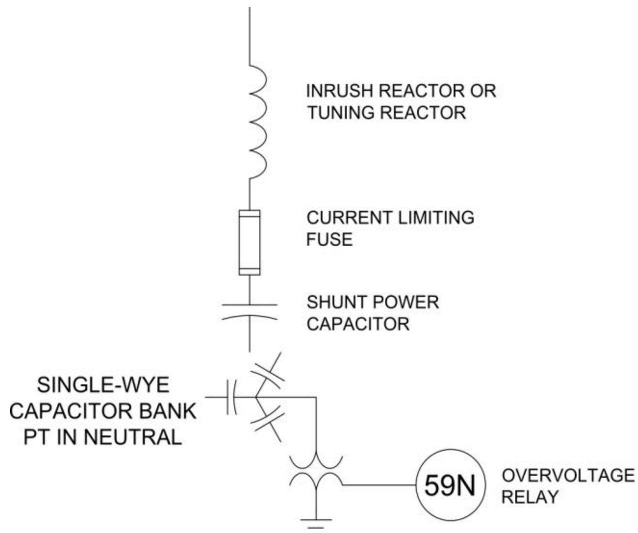

Fig. 1. Diagram associated with Single-Wye Neutral Voltage Detection.

C. How the Scheme Operates Under Balanced and Unbalanced Conditions

Balanced Conditions

When the capacitor bank is healthy and the phase capacitances remain substantially balanced, the neutral point stays near its expected position and the neutral-to-ground voltage remains very small, near 0 voltage.

Unbalanced Conditions

When a capacitor element fails, a fuse operates, or another internal condition changes the capacitance of one phase, the electrical balance of the bank is disturbed. The neutral point shifts, creating a measurable neutral-to-ground voltage. The protection relay uses that signal to detect internal bank unbalance and to initiate an alarm or trip as required. The objective is to identify the condition before the resulting voltage rise on the remaining healthy capacitor units leads to further fuse operations, capacitor damage, or loss of intended bank or filter performance.

D. Advantages and Limitations of the Single-Wye Neutral Voltage Detection Scheme

Single-wye neutral voltage detection is an established and widely used indirect unbalance protection method for ungrounded single-wye capacitor banks. IEEE C37.99 describes it as a standard neutral-voltage unbalance method and provides both the theory and application comments for single-wye ungrounded banks. One of its practical advantages is simplicity: it can be applied on a single-wye bank without requiring a split-wye or double-wye arrangement.

The method does, however, have important limitations. As the Direct Blown Fuse Detection brief already states, neutral voltage unbalance detection can be susceptible to false tripping caused by system voltage unbalance, unequal phase-to-ground capacitance, or neutral voltage shift resulting from remote line-to-ground faults, and protective coordination must be evaluated carefully for those conditions

A second important limitation is the switching-duty concern associated with the neutral PT. IEEE states that a voltage transformer used in this application should be rated for full system voltage because the neutral voltage can, under some conditions, rise to as high as 2.5 per-unit during switching; an underrated voltage transformer can be driven into deep saturation. This concern aligns with the position already stated in the Split-Wye Neutral Current Detection brief and the Direct Blown Fuse Detection brief: in VarStec's field experience, neutral PT applications can contribute to switching-related problems, including PT saturation during discharge events, elevated transient recovery voltage on the switching device, and an increased risk of restrike.

A third limitation is that this remains an indirect method. Like split-wye neutral current detection, it does not directly monitor the physical status of the fuse. It infers fuse operation from the electrical unbalance that follows loss of capacitance, and it does not directly detect fuse thermal failure. For that reason, its use does not eliminate the value of direct fuse sensing in metal-enclosed capacitor bank and harmonic filter applications.

E. Engineering Considerations and Setting the Relay

To properly apply split-wye neutral voltage detection, relay settings should be based on the actual capacitor bank topology and on calculated unbalance quantities for the loss of one or more fuses. IEEE C37.99 provides the accepted methodology for this work and should be used as the governing reference for alarm, trip, and coordination calculations.

F. Setting Philosophy

Alarm stage. The alarm setting should be sensitive enough to identify the first practical loss of capacitance while remaining secure against standing unbalance, instrument error, and normal operating variation. IEEE notes that the alarm level should ideally detect failure of a single capacitor unit, but should not assert nuisance alarms due to system unbalance, and that it is good practice to monitor the unbalance signal over time before finalizing the setting. IEEE also notes that, for externally fused banks, the alarm set point will typically be 50% to 75% of the signal associated with one fuse having operated.

Trip stage. The trip setting should be coordinated so that the bank trips and locks out before the voltage on the remaining healthy capacitor units in the affected series group exceeds 110% of rated voltage, or the specific contingency limit recommended by the capacitor manufacturer. IEEE states that the trip level should be set halfway between the critical step and the next lower step, where the critical step is the number of blown fuses or shorted elements that causes overvoltage on healthy units in excess of 110% of rated voltage or the manufacturer's recommended maximum continuous operating voltage.

Time delay. A short intentional time delay should be applied so that damaging internal conditions are cleared promptly while still providing security during inrush, system ground faults, nearby switching, and nonsimultaneous pole operation if those conditions affect the chosen unbalance principle. IEEE notes that for most applications, 0.1 s should be adequate, but longer delays increase the probability of catastrophic bank failure.

Harmonic filter banks. In harmonic filter applications, the normal practice is often to trip the affected filter bank or filter stage at the first fuse operation rather than alarm and continue operation, because continued operation in a detuned condition may create unacceptable harmonic performance or resonance risk. That same philosophy used in the Split-Wye Neutral Current Detection brief applies equally here.

G. IEEE C37.99 Calculation Method for an Ungrounded Double-Wye Bank

For a single wye-connected capacitor bank, IEEE C37.99 gives the step-by-step per-unit method for calculating the capacitance change, neutral shift, and overstress on the affected capacitor units.

The simplified approach uses as shown in Table 1 below. Here, n is the number of blown capacitor fuses in one affected parallel group, Pt is the number of parallel capacitor units in that group, S is the number of series groups per phase, and G = 1 for an ungrounded bank and 0 for a grounded bank. In practice, the most important outputs are Vng, because it is the neutral-voltage quantity used for the relay setting, and Vcu, because it determines when the remaining healthy capacitor units become overstressed.

H. Practical Application Notes

In practice, the procedure is straightforward: calculate the one-fuse condition, then calculate the two-fuse, three-fuse, and higher-loss conditions as needed. Determine the step at which Vcu exceeds the allowable capacitor-unit voltage limit, and then place the trip setting between that step and the previous step. IEEE's example for a single-wye bank explicitly illustrates this approach by placing the trip threshold halfway between the one-fuse and two-fuse neutral-voltage levels.

The neutral sensing device is a critical application detail. IEEE states that the voltage-sensing device should be selected for the lowest practical ratio while still being able to withstand transient and continuous overvoltage, and that a VT used in this application should be rated for full system voltage because the neutral voltage can rise to as high as 2.5 per-unit during switching. This is not a minor detail. It is one of the most important practical limitations of the scheme.

IEEE also notes that de-energized ungrounded wye capacitor banks can have induced voltage from nearby energized objects, which has on occasion caused nuisance alarm or trip even with the bank de-energized. To avoid this, IEEE recommends using an auxiliary contact of the capacitor switch to short the output of the neutral-to-ground transformer or otherwise disable the unbalance protection when the bank is open.

As with other indirect unbalance methods, inherent bank unbalance must be considered. IEEE states that compensation may be beneficial when the inherent unbalance exceeds one half of the desired setting for detecting failure of a capacitor unit. Relays that compensate for inherent bank unbalance can therefore facilitate more sensitive and reliable protection.

Finally, the calculated settings should be verified during testing and initial energization. The relay installation should be calibrated to confirm proper pickup and time delay, and the measured signal should be checked against the calculated values. Excessive trip delay can result in severe damage to the capacitor bank and associated equipment.

III. VARSTEC PERSPECTIVE

VarStec recognizes single-wye neutral voltage detection as a widely used indirect unbalance protection method for medium-voltage capacitor banks and harmonic filter banks. However, despite its popularity, it is not VarStec's recommended approach.

VarStec does not favor single-wye neutral voltage detection because its disadvantages are significant and well established in practical application. These include susceptibility to false operations caused by remote line-to-ground faults, added coordination complexity, and sensitivity to system voltage unbalance. In addition, neutral voltage schemes that rely on a neutral PT introduce switching-duty concerns that VarStec considers especially important. Based on direct field and application experience by VarStec engineers, neutral PTs can be exposed to saturation during capacitor discharge and switching events, which can contribute to elevated transient recovery voltage (TRV) on the switching device and increase the risk of restrike. For these reasons, VarStec does not recommend this method where a better alternative is available.

VarStec's preferred indirect unbalance protection method remains split-wye neutral current detection whenever the bank can practically be arranged as a split wye. This method avoids many of the limitations associated with neutral voltage detection and provides a more robust and dependable approach for medium-voltage applications.

Table 1 – Calculation Method for an Ungrounded Single-Wye Connected Capacitor Banks

Quantity	Equation
Parallel group per-unit capacitance	Cg = (Pt - n) / Pt
Affected wye capacitance	Cp = (S x Cg) / [Cg x (S - 1) + 1]
Neutral-to-ground voltage shift (per unit of Vlg)	Vng = G x [3 / (2 + Cp) - 1]
Affected phase voltage	Vln = 1 + Vng
Voltage on the affected series group	Vcu = Vln x Cp / Cg If Cg = 0, then Vcu = Vln x S

VarStec's recommendation also extends beyond the selection of the preferred indirect method. Wherever practical, VarStec recommends direct fuse sensing, because it does more than infer a fuse event from electrical unbalance. It directly monitors fuse operation and can also detect fuse-failure conditions associated with thermal overload operation in the prohibited zone, which indirect neutral current and neutral voltage schemes do not directly detect. Accordingly, where single-wye neutral voltage detection is applied, it should be treated strictly as an indirect electrical unbalance method, not as a substitute for direct fuse sensing.

VarStec applies IEEE C37.99 calculation methods to establish alarm and trip settings based on the actual bank design. During routine factory testing, VarStec verifies the intended operation of the protection scheme so that the bank performs as designed under blown-fuse conditions and related loss-of-capacitance events.

IV. CONCLUSIONS

Where indirect fuse sensing is desired, VarStec recommends split-wye neutral current detection over single-wye neutral voltage detection. Neutral voltage schemes introduce greater switching-duty concerns, can contribute to higher TRV on the switching device, and increase restrike risk. For that reason, VarStec recommends avoiding neutral voltage detection whenever a more robust alternative is practical.

Even where an indirect method is used, VarStec still recommends direct fuse sensing wherever practical as the more complete and dependable protection approach. Direct fuse sensing remains VarStec's preferred method because it directly detects fuse operation, provides protection against fuse failure, is more cost-effective, and is easier to set and commission.

When neutral voltage detection is specified or preferred for a particular project, VarStec can still provide the equipment accordingly, with alarm and trip settings determined from the actual bank design in accordance with applicable industry standards, including IEEE C37.99.

V. REFERENCES

[1] IEEE Std C37.99 (Guide for the Protection of Shunt Capacitor Banks): Provides the foundational theory, mathematical formulas, and application comments for neutral-voltage unbalance protection, including single-wye ungrounded banks.

[2] IEEE Std 1036 (Guide for the Application of Shunt Power Capacitors): Provides broader application guidance for shunt capacitors, including grounding, rating, and overvoltage considerations.

[3] VarStec Engineering Brief - Split-Wye Neutral Current Detection: Explains why split-wye neutral current detection is generally VarStec's preferred indirect method when a double-wye configuration is practical.

[4] VarStec Engineering Brief - Direct Blown Fuse Detection: Explains direct fuse-status detection and why it complements indirect neutral current and neutral voltage schemes.

[5] VarStec Technical Resources: VarStec provides tools to calculate neutral current, neutral voltage, and unit overvoltages for blown fuse conditions in accordance with IEEE C37.99.

[6] Kojovic et al., "Application of Three-Phase Vacuum Reclosers for Capacitor Bank Switching": Relevant to capacitor-bank switching-duty considerations, including how neutral voltage transformer applications can increase TRV severity during switching.

VI. VITAE

Paul B. Steciuk is Co-Founder and President of VarStec Power Solutions, Inc. He specializes in medium-voltage reactive compensation and power quality systems, including metal-enclosed capacitor banks and harmonic filter banks. He previously co-founded and served as President of Northeast Power Systems, Inc. He holds a B.S. in Electric Power Engineering from Rensselaer Polytechnic Institute and has authored more than 30 technical papers and articles on harmonic analysis, reactive compensation, and filter applications.

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