

Sudden Pressure Protection for Transformers

**A report to the
Substation Protection Subcommittee of the
Power System Relaying Committee of
the IEEE Power and Energy Society**

Prepared by the K6 Working Group

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Assignment: To complete a technical report to the Substation Protection Subcommittee on the application of sudden pressure relaying in power transformers.

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1.0 Introduction

The use of sudden pressure relays (SPRs) has been a subject of great debate ever since their introduction in the 1950's as a possible component of a transformer protection system. This type of device is also commonly referred to as a fault pressure relay (FPR) and rapid pressure rise relay (RPR). This document proposes to clarify the issues associated with SPRs and to give the reader the information needed to make an informed decision on SPR applications.

Sudden pressure relays are somewhat unique in that they utilize mechanical quantities (sudden changes in internal transformer pressure) to sense low level internal faults that are often not able to be identified by other relays that utilize electrical quantities. Sudden pressure relays are designed to not operate for steady state or non-fault changes in these quantities, but to operate quickly and with an inverse time characteristic, for changes in these quantities due to internal faults. The nature of these devices is such that they are sometimes prone to operation due to external faults and other non-fault events, making their application considerations a trade off between dependability for internal transformer faults and security against other events.

This report provides an overview of sudden pressure relay types, their applications and considerations. A brief history of transformer pressure relay applications is also included in Appendix A and a survey of North American utility practices was performed and the results are included in Appendix B.

2.0 Types of Transformers

For purposes of sudden pressure relay applications, transformers can be classified into two general groups, dry type or liquid filled. The dry type transformers are non-ventilated and use air, nitrogen, or another inert gas for the insulating and cooling media. Gas flow may be circulated naturally, forced, or maintained at zero gauge pressure. Liquid filled transformers use a variety of liquids for the insulating and cooling media. The liquid is typically mineral oil, but may be synthetic oil or a less flammable fluid such as the silicon based polydimethyl siloxane. The fluid flow may be circulated naturally or forced and can be either direct or indirect. Liquid filled transformers typically use external heat exchangers that are cooled by air or water regardless of circulation methods. Some liquid filled transformer designs use a combination gas-liquid system.

Gas-liquid systems are classified as either sealed or non-sealed. While both types maintain liquid volume, only the sealed type maintains gas volume. A single tank transformer with a nitrogen blanket that is supplied from a gas bottle is an example of a simple positive pressure sealed system. If an auxiliary tank is added to the transformer, so as to maintain the complete immersion of the main tank components, the arrangement is still a sealed system. If the auxiliary tank contains a diaphragm that separates the liquid from the gas, the configuration is considered to have a conservator.

Transformers may use a load tap changer (LTC) to regulate voltage. The LTC is usually contained in a separate liquid filled tank. Pressure monitoring of the LTC tank may be desirable and integrated into the sudden pressure relay scheme.

3.0 Types of Sudden Pressure Relays

There are two main types of sudden pressure relays; pressure sensing and flow sensing. The basic principles of operation for each are described below:

3.1 Pressure Sensing

One method is where the sudden pressure sensing relay is located on the top of the transformer such that the sensing connection is located in the gas space of a pressurized transformer. This is known as an “In Gas” sudden pressure relay. The sensing chamber contains a bellows, a micro-switch, and an orifice that connects the sensing chamber to the reference chamber, as shown in Figure 3-1. [5, 10] During normal transformer operations, the internal gas pressure will rise and fall as a function of the transformer temperature. Since this change in pressure is gradual, the orifice allows sufficient flow to keep the sensing chamber and the reference chamber at the same pressure. Consequently, the device does not operate. When an internal arcing transformer fault occurs, the gas pressure in the tank rises rapidly. This high rate of change of pressure is greater than the capability of the orifice and the sensing pressure becomes greater than the reference pressure. Thus, the bellows moves and operates the micro-switch output contacts. The device reset is a function of the pressure inside the transformer but will typically reset in less than 90 seconds.

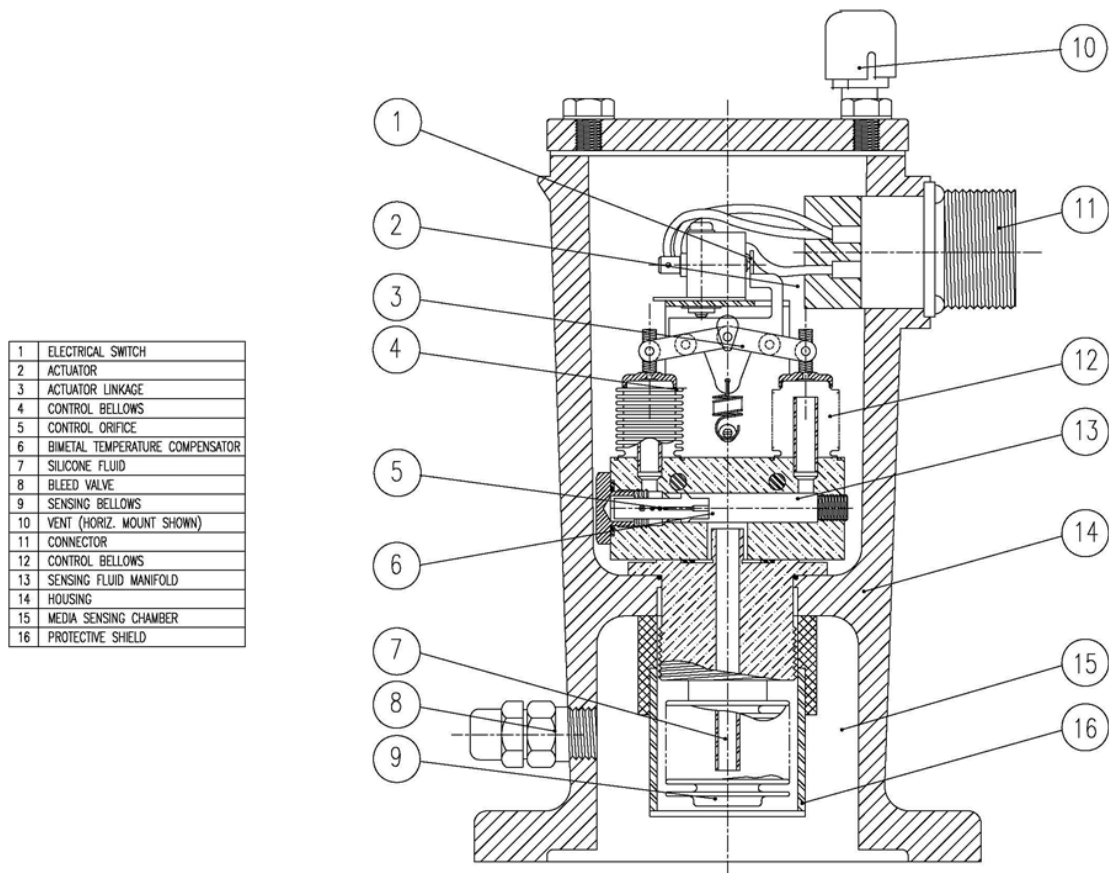


Figure 3-1. Sectional View of a Modern Mechanical Pressure Sensing Sudden Pressure Relay

A second method is where the sudden pressure sensing relay is located on the side of the transformer below the minimum level of the oil in the tank. The relay senses conditions in the oil within the main transformer tank. This is known as an “Under Oil” sudden pressure relay. This relay type may be applied on any oil immersed transformer. The sensing chamber contains a bellows, a micro-switch, and an orifice that connects the sensing chamber to the reference chamber, functionally similar to the “In Gas” relay, though specifically designed to operate using the transformer fluid. This version of the pressure sensing relay is also illustrated in Figure 3-1. Under both normal and internal fault conditions, the relay operates very similarly to the “In Gas” relay.

The most recent version of the pressure sensing relay entered the market in the mid 1990s. One manufacturer has available a micro processor based relay which monitors separately for rapid pressure rise, slow (static) pressure rise, provides a built in seal-in relay, and an analog current loop to provide SCADA or remote pressure sensing. It may be used for either “in gas” or “under oil” applications by settings adjustments. This device is shown in Figure 3-2.

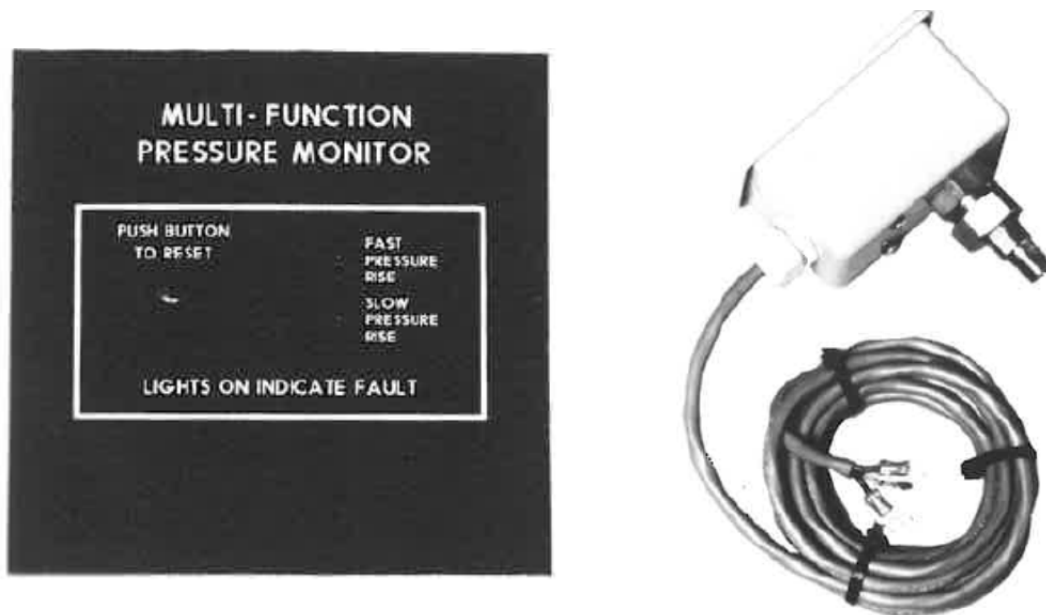


Figure 3-2. Multi-Function Sudden Pressure Relay Control Panel (left) and Relay Housing with Connecting Control Wires (right).

3.2 Flow Sensing

The flow sensing sudden pressure relay is located between the transformer tank and an oil conservator and is commonly referred to as the Buchholz relay. This relay normally utilizes two different detection principles to detect transformer faults. One method is the accumulation of gasses within a detection chamber. Once the gas volume is sufficient, normally $100 - 200 \text{ cm}^3$, an output contact is closed. The second method detects oil flow from the transformer tank to the conservator. If the speed of the oil flow reaches $0.85 - 1.15 \text{ m/s}$ an output contact is closed. This device is shown in Figure 3-3.

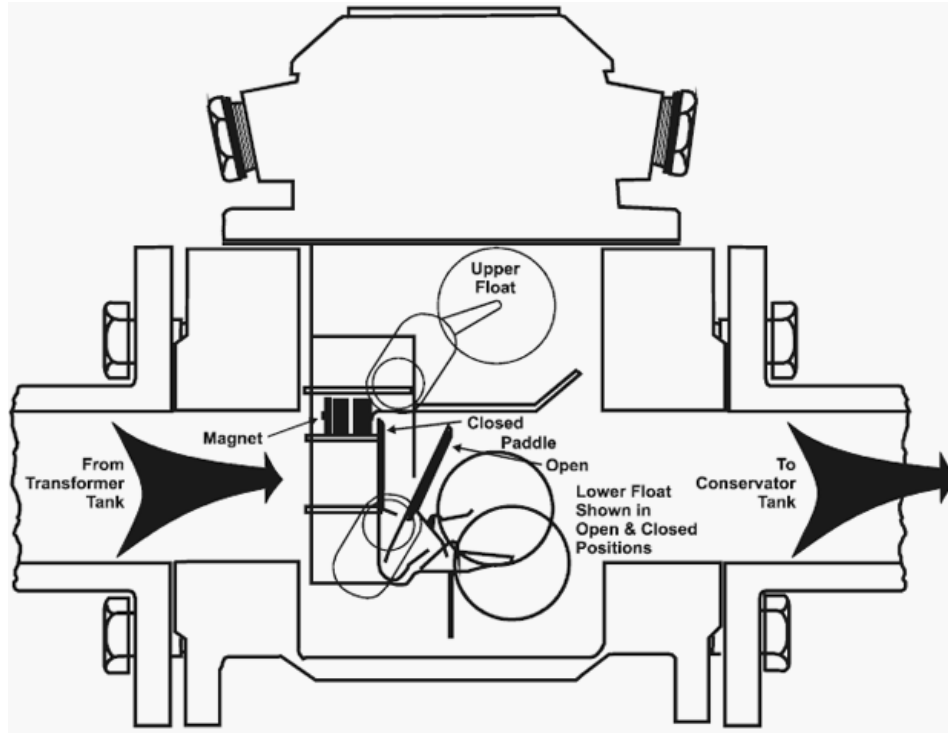


Figure 3-3. Sectional View of a Buchholz Relay

4.0 Sudden Pressure Relay Applications

Sudden pressure relays are employed to detect faults that are not normally seen by current based (overcurrent or differential) relays. They are applicable to just about any size and type of liquid filled transformer. The decision to use the sudden pressure relay is often based on the transformer size, location within the power system, cost, and past operating experience. The decision to trip and/or alarm has been an ongoing concern since the early development of this type of relay.

4.1 Factors for Considering SPR Use

Faults that are low in current magnitude that may not be detected by conventional current based relays and other unusual events include:

1. Turn to turn [12]
2. High resistance joints [11]
3. High eddy current between laminations [11]
4. High resistance faults
5. Hot spots on the core due to a short circuit of the lamination insulation [4]
6. Core bolt insulation failure [4, 13]
7. Faulty joints [4, 13]
8. Loss of oil due to leakage [4]

Sudden pressure protection could also aid in the protection of grounding transformers and transformers with complicated circuits like phase shifting and phase regulating [11]. The sudden pressure type of relay is insensitive to the exact location of the winding fault [6]. Sudden pressure relays may also be used in the tap changer mechanism compartment [11].

The types of faults listed above may result in current magnitudes that are well below the sensitivity of the overcurrent or differential relay. Given enough time, these conditions will eventually evolve into a more significant fault, but perhaps at the expense of considerable damage. Thus the ability to detect the condition sooner and to initiate tripping could prevent extensive transformer damage.

The decision to use a sudden pressure relay may be based on the following factors:

1. Cost. The more expensive the transformer, the more protection that can be justified. The decision to use the protection on less expensive transformers is another matter. The true cost may not be just that of the transformer directly, but that of the labor, the downtime for replacement, and the loss of revenue from the customers fed by the transformer.
2. Transformer MVA size. The larger the transformer, the more protection that can be justified as the larger size implies a more expensive transformer, higher levels of load and often more customers.
3. Location within the power system. If the transformer is in a location where it is critical to maintaining service to customers, i.e. a radial system; then perhaps the expense of incorporating a sudden pressure relay is justified. Small transformers that are in a substation with several others may not have the sudden pressure relay since the loads can be switched to alternative sources. Transformers feeding high impact customers, i.e. hospitals, may warrant the installation of sudden pressure relays at any cost.
4. Past operating experience. Many utilities have incorporated sudden pressure relaying for tripping, but later removed or converted the relay to alarm only due to misoperations of the scheme. Such changes more commonly occurred on older, less secure schemes. Newer relays and designs have reduced misoperations and may warrant reconsideration for those utilities that changed their designs to alarm only or removed the trip.

Once the decision has been made to incorporate a sudden pressure relay, several other issues need to be addressed, namely the type of sudden pressure relay and whether to trip or alarm.

Proper circuit design is essential for reducing the likelihood of a false operation due to electrical transients. Appendix A provides a history of the development of the control circuitry associated with sudden pressure relays. Sudden pressure relays that have vibration reduction designs are helpful in high seismic areas and some industrial applications. Relay designs that have two or more sensitivity settings can be considered. The use of Form C auxiliary contacts reduce the chance of false tripping for contact bounce. However, SPR inhibiting schemes, where overcurrent relays supervise the trip logic of the sudden pressure relay can be considered to reduce the risk of operation for external high current faults [5, 6, 9, 11, 12] and potentially in seismic areas.

To avoid possible operation during cooling pump starts and stops, a brief intentional time delay might be included in the relay scheme [4].

During maintenance, the sudden pressure relay can have the trip disabled or put into alarm only. The surges in pressure during these operations may be enough to operate the relay [4].

4.2 Limits to Sudden Pressure Relay Application

Some utilities have elected to alarm only for fear of a possible false operation. Older circuit designs seemed to have more issues and more modern designs appear to have reduced problems.

Objections to using sudden pressure relays include [13]:

1. Additional transformer construction may be required.
2. The cost to inspect a transformer following a SPR operation in conjunction with a through fault or a seismic event to verify that the transformer was not damaged by the event that caused the SPR operation.
3. Difficult to maintain the relay.

Most utilities have adopted reliable circuitry and installed or are moving toward newer, more secure types of SPR relays. However, the utility industry still experiences a level of misoperations at least sometimes perceived to be higher than for most electrically operated protection systems.

One large North American utility defeated most of their sudden pressure relays from tripping when an analysis of their operational history showed that the sudden pressure relays often experienced false trips and transformer modeling analysis indicated that differential or overcurrent relays could reliably detect turn-to-turn faults. [1] Though the sample size was relatively small, this utility's records indicated that their sudden pressure relays experienced a misoperation rate of over 80%. There were very few faults inside the main transformer tank for which the differential or overcurrent relays did not trip. Transformer modeling indicated that even turn-to-turn faults would generally result in changes in current at the

transformer bushings detectable by differential or overcurrent relays, and that these relays are generally faster than sudden pressure relays.

4.3 Through Fault Issues

Sudden pressure relays on power transformers have been reported to operate during through fault conditions, although the data is not very specific as to age or fault history of the transformer. [3]

Transformers are designed and tested to industry standards. The windings are clamped in some manner to prevent movement during shipment and operation. During a through fault, the windings move. While the distances may be small due to the clamping, the movement is very fast, and with much force. This movement of the windings produces shock waves in the transformer oil. The more winding movement the larger the shock wave and the more likely it is for a sudden pressure relay to operate.

Possible reasons for through fault SPR operations could be higher magnitudes of fault current or cumulative effects of aging. As the transformer ages, the clamping forces relax, thus allowing a greater susceptibility to increased pressure waves. The more faults and the greater severity of a fault has an adverse cumulative effect on the clamping. Many other factors influence the degradation of the blocking or clamping within a transformer. The insulation can change in both thickness and elasticity over time due to the effect of moisture, temperature, and chemical aging. This degradation is supported by the probabilistic based damage curves that are published in IEEE literature for frequent and infrequent faults.

When the SPR operates a transformer is usually taken out of service, is inspected, and tested. The process takes time, can be costly, and impacts system operation. Catastrophic failures are easily seen. However, degraded clamping may be difficult to identify and actually may have been the cause of the operation. Thus, a condition exists to easily believe that the SPR false operated or is a nuisance alarm. Some utilities do not use the SPR in trip circuits and some users apply overcurrent blocking of the SPR to specifically prevent tripping for through fault conditions. While these actions allow the transformer to remain in service, accumulating problems can go undetected until a more severe event occurs.

The SPR can be used as a diagnostic tool in assessing the overall health of a transformer, especially if a transformer's operational history, including fault data, is known. Proactive analysis of through faults and SPR operations can be used in conjunction with the typical age, temperature, and oil analysis to determine inspection frequency and the testing required to verify transformer health. Thus, the reoccurring operation of the SPR could be indicative of a near future failure and not using the data as such, could be a missed opportunity and costly mistake.

Also, the clamping pressure in a transformer can be restored. This process may require the transporting of the transformer to a repair facility but in some cases it can be done in the substation. Regardless, it is likely more economical to fix the blocking than to replace a failed transformer.

4.4 Seismic Activity

Seismic activity poses a significant concern for applying sudden pressure protection. Misoperations during an earthquake could result in many transformers tripping simultaneously, potentially initiating a large scale system collapse.

One utility experienced four seismic events within a period of less than 20 years. Although none of the events were a major earthquake, each resulted in the false tripping of several transformers by way of the sudden pressure protection. One event resulted in a system separation, while another could have initiated a major system collapse had the system loads been greater. To mitigate the extent of simultaneous trips for future events, this utility decided to defeat the sudden pressure tripping for all transformers having, at least, one set of high speed differential relays [1].

Another major North American utility recently experienced a 5.8 magnitude seismic event which was centered slightly over ten miles from one of its nuclear power plants. Both units were safely shut down, while overall damage was minimal; there was no damage to any of the safety systems. A complete assessment found the greatest physical damage was to eight 500 kV bushings; each had compromised seals and were leaking oil. These bushings were on the six in service transformers forming the main transformer banks (GSUs) for the two units, and the two spares for these banks. The most significant ramification of the event was the actuation of several sudden pressure relays, which resulted in the tripping of sixteen plant transformers. The smaller transformers that tripped had a single sudden pressure relay applied, while the larger transformers all had three relays mounted at different locations in the tank wall, with the relays in a two-out-of-three voting scheme. Among the transformers taken out of service by these trips were: the main transformers (GSUs) for Units 1 and 2, the station service transformer (SST) for Unit 1, and four transformers of the reserve station service system providing off site power for the plant. The loss of the reserve station service transformers prevented the transmission network from providing power to the plant for approximately three hours; during this time, the on site diesel generators were the only sources available for supplying the critical unit functions. This loss of off site power was, by far, the most serious consequence of the event.

Initial investigations revealed that none of the sudden pressure trips were due to short circuit faults, internal or external to any of the transformers. After quickly verifying this for each of the reserve station service transformers (RSSTs) that tripped, they were put back in service, so as to restore the off site power. In

reference to the perceived “safety” value of the sudden pressure relaying in preventing low magnitude fault events internal to the transformer tank from escalating into more dangerous situations, the decision was made to keep the sudden pressure tripping enabled on all plant transformers, except for a select few. For three of the transformers in the reserve station service system (one 500-34.5 kV and its associated ground bank, and one 34.5-4.16 kV) the sudden pressure relaying was set to alarm only. These particular transformers were selected to ensure that the “preferred” source of off site power was secure from being lost under future earth movements.

A task team was formed to study the event and consider possible scheme solutions that would provide an acceptable degree of protection for electrical faults, yet have a low probability of misoperation under seismic activity. Any recommended solutions were to be considered only for the transformers of the plant’s reserve station service system. Initially, the team had seismic tests performed on similar sudden pressure relays and - associated auxiliary seal-in package assemblies-. Testing indicated that the operations were due to pressure waves in the transformer tank, during the earthquake, and not contact vibration within the sudden pressure relay, itself, or within the auxiliary package. The team’s ultimate recommendation was divided into two alternatives:

- A transformer protection scheme with the sudden pressure coverage provided in a non tripping alarm mode. Under this alternative, the tripping of the sudden pressure relaying would normally be disabled, while its alarm and event capture features would always be in service. Gas monitoring with an associated alarm would also be included. The transformer protection would be provided by dual differential protection packages, each supplied from separate, dedicated CT circuits. In addition to the normal percentage differential protection, each package will also have negative sequence differential and restricted earth fault features enabled. In the absence of sudden pressure protection, this is an attempt to provide as much coverage as possible for internal faults that are below the sensitivity of the normal differential protection. Even with these protective enhancements, the lowest magnitude tank events will have to be detected by the sudden pressure alarming, with the transformer not automatically removed from service. In addition, a switching arrangement would allow the sudden pressure relaying to be put into a tripping mode in situations where the protection is deemed necessary. For example, differential relay protection may not be available during commissioning operations when relay current circuits are not yet proven. In such situations, sudden pressure may be providing the only backup, or in some cases, the only transformer protection.
- A transformer protection scheme with the sudden pressure coverage provided in a tripping mode with a seismic detection device supervising its operation. This alternative has the sudden pressure protection set in the

traditional tripping and alarming mode, but also introduces a seismic detection device (SDD) for blocking the sudden pressure relay tripping. A separate SDD will provide an alarm function. The SDD functionality is based on an observed relationship between the strong motion seismology of earthquakes and the response curves of sudden pressure relays. Research and operational experience has shown that earthquakes can be detected seconds before the ground motion reaches the level that can potentially cause unintended sudden pressure relay operations, which provides a sufficient time for blocking. With an SDD having picked up, upon the ceasing of actuating seismic activity, there is a relatively lengthy dropout time ranging from 30 to 60 seconds. There will, of course, be no sudden pressure coverage for internal transformer faults during this period. Since the sudden pressure protective coverage will be in service for this alternative plan, the additional protective features of negative sequence differential and restricted earth fault are not a requirement. Change out of the existing electromechanical or solid state electronic transformer protection for digital packages providing these functions is, therefore, not required. Ultimately, installing dual transformer packages, with the extra functions prescribed in the first alternative, would be preferred, in addition to the supervised sudden pressure protection.

5.0 Maintenance and Testing Practices

5.1 Misoperations due to Maintenance Practices

Misoperation of a SPR on a generator step-up unit (GSU) led to the detection of a unique failure mode [2]. Investigation revealed that the bellows that are integral to the pressure sensing were permanently distorted and that, depending on the exact damage, could result in either permanently closing the trip contacts or blocking the contacts from operating entirely. The root cause of the failure was that the valve on which the relay was mounted had been closed during maintenance. Heat from the sun caused oil pressure to increase to a damaging level because the oil in the relay could not flow back to the transformer tank. At least one working group member's company has experienced a similar case of relay damage, discovered during maintenance, which would have prevented the relay from tripping.

Single tank transformers with a nitrogen blanket supplied from a gas bottle may also experience SPR misoperations. Changing an empty nitrogen bottle for a full one can result in pressure transients that trip the relay unless it is defeated during the maintenance procedure. Both "in gas" and "under oil" SPR relays are potentially susceptible to this cause of misoperation.

5.2 SPR Testing

An appropriate SPR test program, analogous to testing electrically operated relays, should be used to ensure that sudden pressure relays will work correctly

when subject to internal transformer faults. Sudden pressure relay tests can be performed using a simple pressure (GO - NO GO) test within specific pressure ranges. Testing should be performed at installation and at least during the transformer's normal maintenance cycle.

The necessary test instrument is a pressure tester (available from the SPR manufacturer or easily made from a manual blood pressure kit). With the kit including the gauge, hand squeeze bulb, and tubing. If the blood pressure kit is used, the conversion from mm Hg to psi is accomplished by dividing the mm Hg by 51.5, 760 mm / 14.7 psi. Pipe fittings to connect to the SPR are also needed. Refer to the manufacturer's instructions for the procedure and operating pressures expected, but the test procedure will generally include the following steps:

1. Remove the SPR from the control circuit by removing the cable.
2. Connect an ohm meter across the relay contacts.
3. Pump up the pressure to the upper end of the range and hold constant for 30 seconds.
4. Suddenly release the pressure. The relay should operate (GO test).
5. Pump the pressure to just below the lower end of the operate range and hold constant for 30 seconds.
6. Suddenly release the pressure. The relay should not operate (NO GO test).

The test procedure steps 3 – 6 may be repeated to gain confidence in the consistency of the relay operation and identify the specific GO - NO GO pressure. If the SPR does not test within the manufacturer's specifications the SPR must be either re-calibrated or replaced.

6.0 Turn-to-Turn Fault Detection with Negative Sequence

Protection for turn-to-turn faults is normally provided by sudden pressure relays because conventional differential protection cannot be relied upon to detect these faults. SPRs operate from the sudden change in gas pressure generated by arcing in insulation oil produced by the turn-to-turn fault. This is a relatively slow mechanism of operation when compared to normal phase differential protection.

Turn-to-turn faults usually occur as a result of winding insulation breakdown during overvoltage stress conditions. Very high currents occur in the shorted windings that are not measurable with conventional differential protection particularly during heavy load conditions. The single phase transformer of Figure 6-1 illustrates the effect of a turn-to-turn fault. The primary winding turns, n_p , has a shorted winding section, n_{tt} . The secondary winding turns is n_s . With the polarity as indicated, the amp-turns equation is as shown in Equation 6-1. The turn-to-turn fault current, I_{tt} , is determined with Equation 6-2. It is readily observed that with only a few shorted turns where n_{tt} is small that I_{tt} can be very large. This is particularly true where there are hundreds of turns on the primary winding.

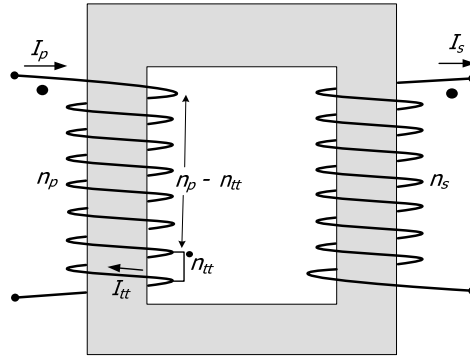


Figure 6-1. Single Phase Transformer with Turn-to-Turn Fault.

$$(n_p - n_{tt})I_p = n_{tt}I_{tt} + n_s I_s \quad \text{For } n_{tt} \neq 0: \quad (6-1)$$

$$I_{tt} = \left(n_p/n_{tt} - 1 \right) I_p + n_s/n_{tt} I_s \quad (6-2)$$

6.1 Negative Sequence Differential Protection

As described above when a turn-to-turn fault occurs, the phase currents of the transformer windings do not change significantly and may not dependably detect the fault condition. However, the transformer winding symmetry is disturbed and results in negative sequence current in all transformer windings. The negative sequence currents are balanced and appear in terminal currents regardless of delta or wye winding connections. They can easily be expressed (represented) on one winding's base accounting for phase shift and turns ratio. This suggests the use of negative sequence to detect turn-to-turn faults.

As with any fault on the power system, the source of negative sequence voltage is at the point of the fault or other system unbalance. This negative sequence voltage produces negative sequence current that flows from the negative sequence source voltage into the system. This is illustrated in Figure 6-2 where E_{2f} is the negative sequence voltage at the fault location and I_{2s1} and I_{2s2} are the negative sequence currents flowing to the system 1 and system 2 source impedances Z_{2s1} and Z_{2s2} , respectively.

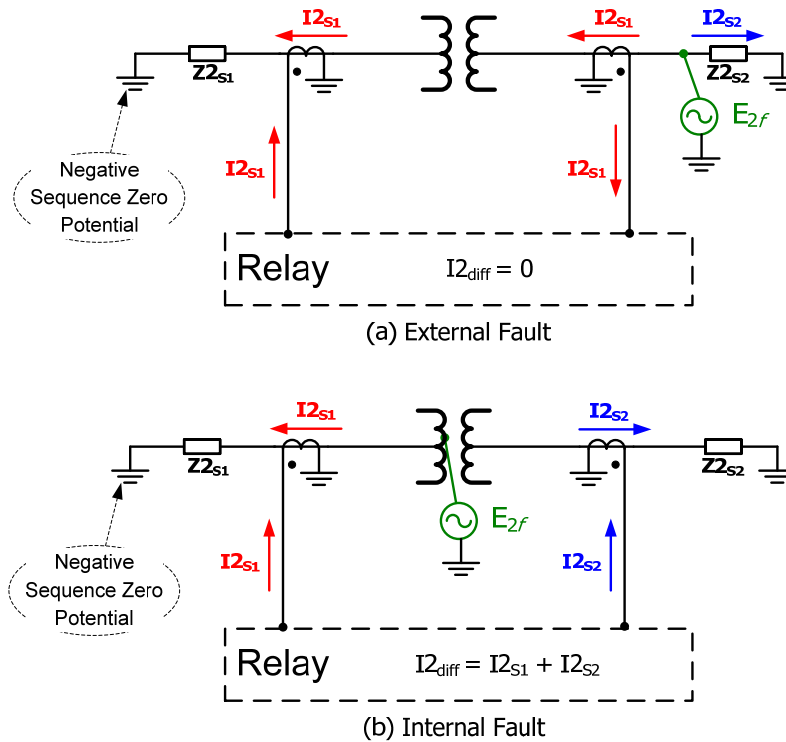


Figure 6-2. Negative Sequence Currents During External (a) and Internal (b) Transformer Faults.

6.2 Negative Sequence Sensitivity

Figure 6-2 shows that a negative sequence current differential may detect turn-to-turn faults, provided sufficient negative sequence currents are produced in the turn-to-turn unbalance for detection. But how sensitive is the negative sequence differential relative to the SPR for detecting turn-to-turn faults in transformers, and can this function reliably replace the SPR application?

References 15 and 16 add to the validation for the use of negative sequence differential. Reference 15 evaluates a transformer fault record playback into a transformer relay of a fault record initiated with a SPR trip. The transformer was a 300 MVA, 400/110 kV autotransformer that experienced a turn-to-turn fault in the neutral end of the Phase C common winding. The play back test results show that negative sequence differential resulted in very fast detection of the turn-to-turn fault in 12 milliseconds with tripping in 27 milliseconds.

Reference 16 discusses tests performed at the University of Idaho on a 50 kVA, 240/240/24 V, three phase transformer designed specifically for testing the sensitivity of a negative sequence differential function for turn-to-turn faults. The shorted turns ranged from 10% down to 2% (1 turn). The test results showed the reduced capability to detect turn-to-turn faults with conventional phase current

differential, especially when masked by load current, and the effectiveness of negative sequence differential for detecting turn-to-turn faults down to 2% of the winding shorted.

Additional references regarding the use of negative sequence differential protection on power transformers can be found in References 17, 18, and 19.

7.0 Summary of North American Utility Industry SPR Practices

The IEEE Power System Relaying Committee Sudden Pressure Relay survey compiled as part of this PSRC Working Group assignment offers some insight into the present practices of North American utilities with respect to using sudden pressure relays.

The detailed survey is included as Appendix B to this paper. The survey is based on numbers of utilities that responded, rather than numbers of transformers or sudden pressure relays owned and operated by the utilities.

In general, sudden pressure relays are widely, though not universally used to trip, depending on the particular equipment being protected and the portion of the system at which the equipment is applied (generation/transmission/distribution). More than 90% of respondents use sudden pressure relays to trip for some purpose, and over half (60%) also use them to alarm. Alarms are often used when tripping is not, although some utilities use both the trip and alarm functions. For distribution applications, roughly 60% use the sudden pressure relay to trip while 40% alarm. For transmission applications, roughly 75% of utilities trip and 45% alarm. For generation facilities nearly 70% will trip and 40% will alarm for generator step up transformer applications.

7.1 SPR Applications

All utilities responding to this survey use sudden pressure relays for at least some applications.

A large percentage of utilities use sudden pressure relays for power transformers, phase shifters, or shunt reactors, however only about three of five companies trip distribution transformers using a sudden pressure relay.

A greater percentage of respondents use sudden pressure relays for transmission and generator step up transformers, compared to distribution transformers. This is most likely due to the larger percentage of distribution transformers being protected with transformer fuses as compared to the transmission and generation transformers which limits the opportunities for tripping a fault interruptive device. Additionally, sudden pressure relays used on generator auxiliary transformers are used at a somewhat lower level than that for distribution transformers.

Respondents apply sudden pressure relays in transformer LTC compartments about 40% of the time. Most utilities apply sudden pressure relays on transformer

main tanks and on LTCs using similar application philosophies. However, a few utilities specify the LTC sudden pressure relays to be either more sensitive or less secure than what would be used for the main tank.

The utility respondents apply sudden pressure relays in shunt reactor installations approximately 60% of the time.

Sudden pressure relays are used by utilities at a lower rate on phase shifting transformers than for all the rest of the equipment identified, however the number of respondents indicating they have phase shifting transformers was also lower than for any other category of equipment. This may be the reason for the lower usage rate.

For those respondents that indicated they use transformer size as a factor of when to apply sudden pressure relays, few use sudden pressure relays below 10 MVA but the usage of fuses for transformers of this size may have been a factor. . Approximately half of the respondents apply sudden pressure relays for transformers that are above 10 MVA.

Respondents indicated that a single sudden pressure relay is installed slightly more often than multiple sudden pressure relays. Multiple sudden pressure relay applications include main tank and LTC applications. When a single sudden pressure relay is used, the manufacturer typically specifies its location about twice as often as the utility. When more than one sudden pressure relay is used, the relays are generally located on the main tank and LTC compartment, or on opposite sides of the main tank.

Only about a quarter of sudden pressure relay users also use voting schemes. Nearly half of “voting” scheme users implement a “1 of 2” scheme, which is really redundancy rather than for voting.

About 40% of utilities that apply sudden pressure relays use Form “c” logic, which requires that the 63a contact closes and the 63b contact opens to allow tripping. In addition, approximately three fourths of the users employ a separate seal-in auxiliary relay, and the vast majority (>80%) locally annunciate sudden pressure relay operation.

A small number of sudden pressure relay users (<10%) include some type of current supervision for sudden pressure relay operation to minimize misoperation for through faults. For those few users that apply current supervision, most use overcurrent supervision. A few of the sudden pressure relay users that apply current supervision use undercurrent supervision, and a few apply directional current supervision. Three users indicated that current supervision is applied to prevent sudden pressure relay misoperation during seismic events.

7.2 Trip Verses Alarm

A majority of utility respondents use a sudden pressure relay as a protective trip relay and most use a sudden pressure relay to alarm in addition to the tripping. Most respondents that do not trip with a sudden pressure relay do provide an alarm from the sudden pressure relay.

If the utility respondent uses transformer overcurrent protection, just over half trip the differential lockout with overcurrent protection. The remainder of the respondents indicated that overcurrent protection either trips a dedicated lockout or a shared overcurrent/sudden pressure lockout.

Approximately half of the respondents indicated that a single lockout relay is used for all transformer trips (differential, sudden pressure, overcurrent). Other respondents indicated that three separate lockouts are applied, one for each protective function (differential, sudden pressure, overcurrent), or two lockouts are used, one of which is tripped by the differential protection and the second that is tripped by both the sudden pressure relay and overcurrent protection.

7.3 SPR Type

Respondents indicated that both “in gas” and “under oil” sudden pressure relays are applied on all types of equipment, though a greater percentage apply “under oil” sudden pressure relays.

Multifunction sudden pressure relays are currently available from a single manufacturer, and have been available only recently. Due to these factors, multifunction sudden pressure relays are rarely applied and have only a small market penetration to date.

Buchholz relays are used less frequently than “under oil” and “in gas” sudden pressure relays.

For single sudden pressure relay installations, most utility owners use an “under oil” or “in gas” application, with only a few using a Buchholz relay.

Very few respondents have noticed any difference in performance between “in gas” and “under oil” sudden pressure relays.

7.4 SPR Maintenance

A significant majority of utility respondents indicated that they expect the sudden pressure relay to last until the transformer is replaced or the sudden pressure relay fails (no routine replacement).

The survey results indicate that most utility respondents apply a test switch to provide sudden pressure trip isolation for maintenance and testing. Some utilities also use sliding link terminal blocks to provide testing isolation, and

approximately 20% of the respondents indicated that no form of trip isolation is installed for sudden pressure relay maintenance.

Most utilities either perform sudden pressure relay maintenance during transformer maintenance activities or use an interval between two and five years. For those that perform some form of regular relay testing, approximately two thirds indicated that the sudden pressure relay is pressurized to verify operation, whereas about one third simply test the trip output contact.

7.5 Diagnostics Following SPR Operation

A high percentage of utility respondents indicated that multiple diagnostic tests are performed following a transformer event in which a sudden pressure relay operates to trip the transformer. The most common tests include dissolved gas in oil (DGA), power factor (Doble), insulation (Megger) and transformer turns ratio (TTR). However, significantly fewer utilities performed the same tests if the sudden pressure relay is used for alarming only.

About half of respondents have experienced accidental sudden pressure relay trips during routine maintenance.

Approximately half of the utility respondents indicated that they have experienced sudden pressure relay operations due to high current external faults. Most of these operations were attributed to “under oil” sudden pressure relays; however, the responses seem to be consistent with the larger population of “under oil” sudden pressure relay users.

Most sudden pressure relay misoperations not attributed to an external fault were associated with “under oil” sudden pressure relays. However, the population of “under oil” sudden pressure relay users was large.

Other causes of sudden pressure relay misoperations reported by the respondents included moisture related corrosion, maintenance activity and damaged relays.

Utility users indicated that there is no clear difference in sudden pressure relay misoperations for transformer designs (core or shell), nor is there a clear difference in the quantity of misoperations for various transformer winding configurations.

7.6 SPR Operation

About 40% of respondents have experienced at least one transformer event that was detected by a sudden pressure relay and not by another protective relay. The types of events that the sudden pressure relay detected that another protective relay did not include bushing to tank fault, LTC fault, winding movement, and closing out of synchronism.

The utility respondents offered divided opinions on whether differential protection is sensitive enough to detect turn-to-turn faults. The sensitivity issue has historically been one of the common reasons for application of sudden pressure relay tripping.

Most utilities have experienced transformer failures due to turn-to-turn faults. The respondents indicated that sudden pressure relays provided detection of this type of fault in a majority of the cases. However, even when the sudden pressure relay detected the fault and operated correctly, most utilities don't claim that the sudden pressure relay operation reduced transformer damage or operated faster than other protective relays.

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Appendix A - A History of Transformer Pressure Relay Applications

The application of transformer pressure relays prior to 1960 was generally limited to the General Electric Type E static pressure relay. This relay was quite unreliable and for this reason was only allowed to alarm.

The sudden pressure relay has proven to be a relatively dependable relay for rapid detection of electrical faults in oil filled containers; however early installations were not appropriately secure from false tripping. The DC circuitry involving sudden pressure relaying has evolved to provide better security against transients that occur during faults and other voltage abnormalities that occur on the substation DC system.

Early Sudden Pressure Relay Development

In the 1950's, sudden pressure relays based on the "rate of rise" of pressure principle were developed which included the Westinghouse Type SPR and the General Electric Type J relay. Both types of relays are still in service, with the majority being the type SPR relays.

However, by the early 1990s many of these older relays, especially the Type J, were being phased out. The Type J was particularly prone to misoperation on vibration and also was reported as misoperating due to plugged orifices.[12]

Sudden Pressure Relay Control Circuit Development

About 1960 sudden pressure relays then in service began to be used to trip in addition to alarming. In fact at this time, SPR relays were added to autotransformers and generator transformers not so equipped. The circuit used was taken from the Westinghouse SPR instruction booklet I.L. 46-750-IJ and is shown in Figure A-1.

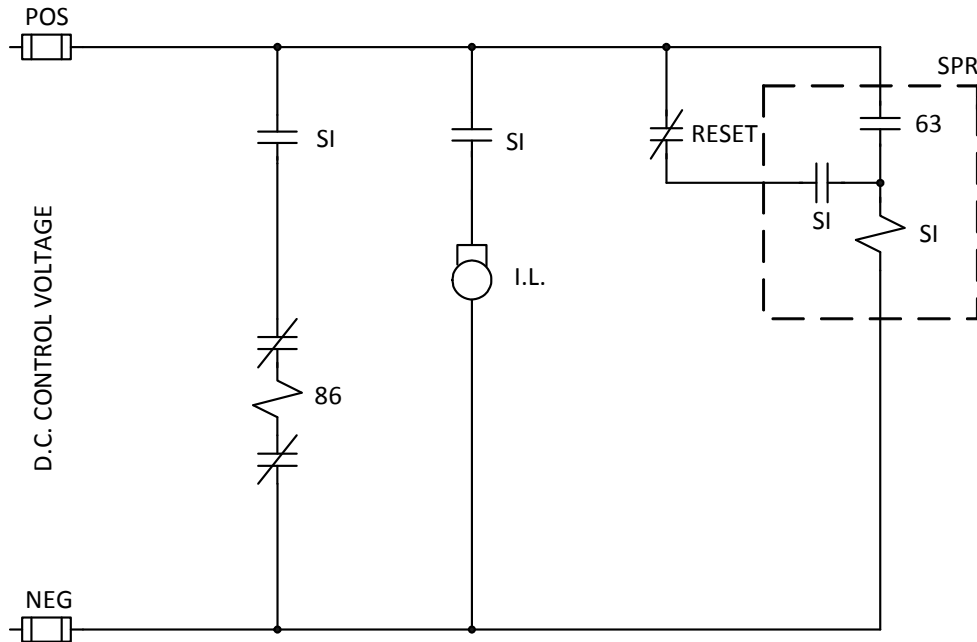


Figure A-1. Vintage 1960 SPR Relay Application.

In order to use the SPR for tripping, micro-switches with 6 millimeter gaps in some of the older relays manufactured before 1958 had to be changed out with micro-switches having 20 millimeter gaps. This required cutting open and re-welding the cases.

In this circuit, an operation of the pressure switch would energize the internal auxiliary relay which would seal itself in, trip, and alarm. Since no relay target was provided, the “alarm” was an indicating light used to indicate an operation. A manual reset switch was provided to break the auxiliary relay seal-in circuit after an operation.

This early design proved to be susceptible to misoperation due to surges on the DC supply arcing over the 63 normally open micro-switch contact.

The design of the SPR relay was modified by Westinghouse in 1962 by removing the internal auxiliary relay and providing an external auxiliary relay mounted in the transformer control cabinet near the reset switch. Still, no target was provided on the auxiliary relay.

These two applications of the SPR relay were in service until about 1967, when the scheme was changed to include a General Electric current operated HAA (12HAA15A5) auxiliary relay instead of the auxiliary relay provided by Westinghouse. The new circuit is shown in Figure A-2.

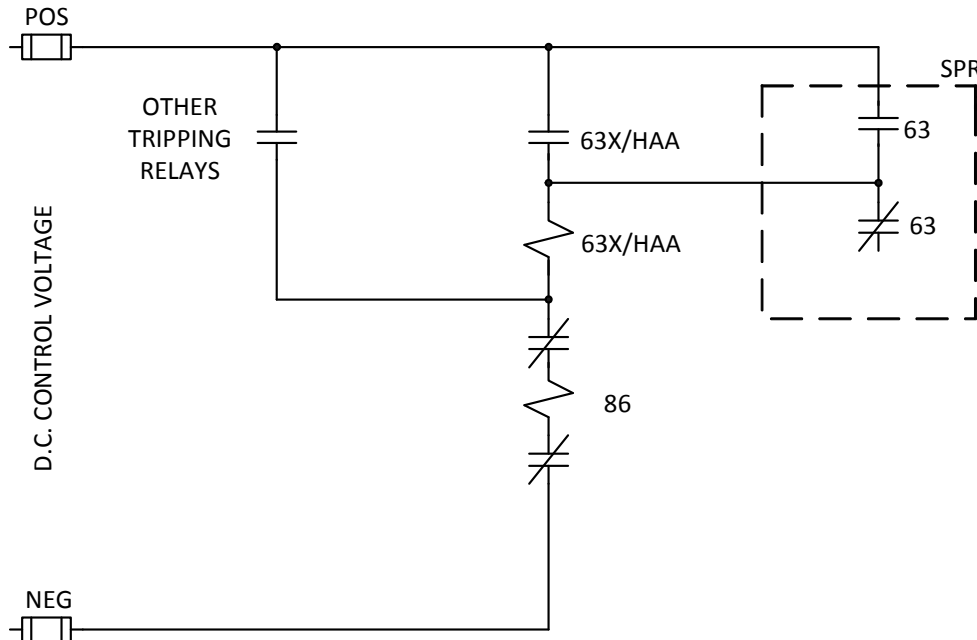


Figure A-2. Vintage 1967 SPR Relay Application.

The reason for using the HAA relay was to gain the target provided on this relay. Other changes made at this time removed the indicating light and the reset switch, which was considered a liability in the case where someone would forget to reset the circuit after an operation.

The circuit was similar to the Type J relay circuit then in use. However, each circuit was subject to undesirable tripping due to surges on the DC supply arcing the 63 normally open micro-switch contact. The evolution of both the SPR and the Type J circuits is similar from this point.

In 1968, General Electric developed a voltage operated HAA (12HAA16B) relay supplied with a 350 ohm internal resistor and an external resistor whose value depends upon the supply voltage (650 ohms for 125 VDC). This relay was developed specifically for use with transformer pressure relays. At this time the scheme suggested by GE, was modified to include a trip seal-in contact and 63X/HAA coil shorting as shown in Figure A-3.

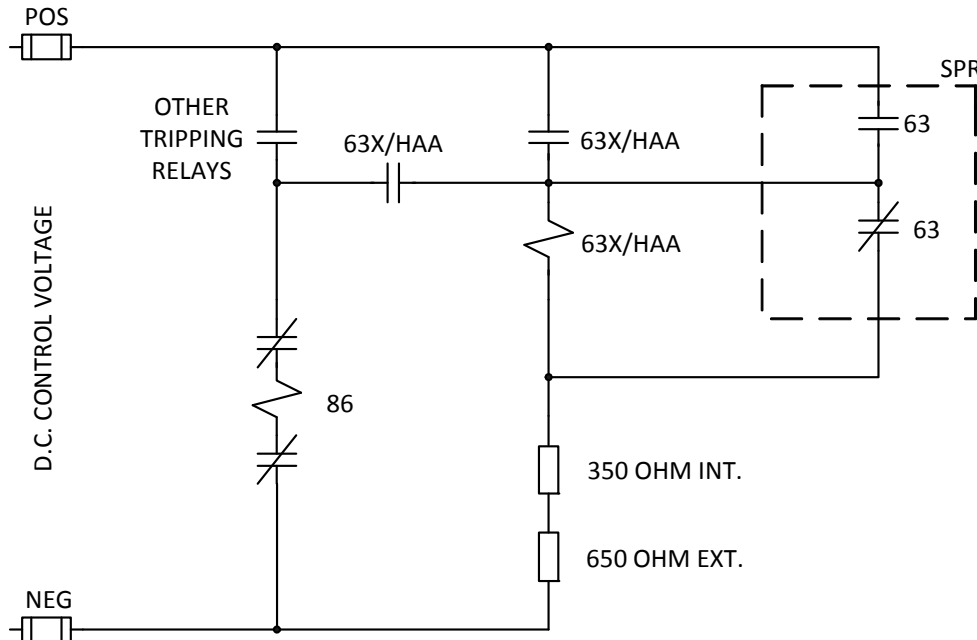


Figure A-3. Vintage 1968 SPR Relay Application.

This scheme offered increased security over the previous schemes. The 63 normally closed contact prevented operation of 63X relay (and tripping) for arcing of the 63 normally open contact due to DC surges. The 350 ohm resistor prevented shorting the DC supply should the 63 normally open contact arc over. Also, the HAA introduced a short time delay (1 cycle) to prevent misoperation should the 63 normally open contact close momentarily (less than 1 cycle) from a shock or pressure wave.

Theoretically, the 63 normally closed contact prevented operation of the 63X relay on a surge, as mentioned above. However, field experience and subsequent tests showed that the voltage across the 63X coil during flashover of the 63 normally open contact could be of sufficient magnitude to pick up the 63X relay and operate the tripping relay. When the 63 normally open contact arcs over, the current flow in the circuit causes a voltage drop between the 63 normally closed contact and positive side of the resistors. Often the resistance of the lead between these terminals was enough that the voltage drop across it operated the 63X coil. This discovery led to the modification as shown in Figure A-4.

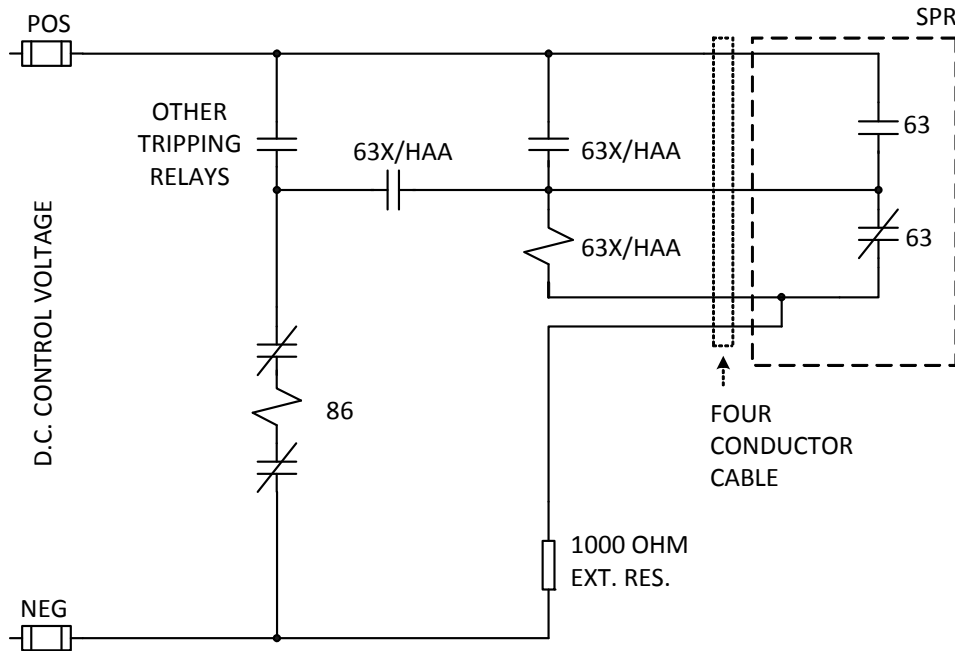


Figure A-4. Vintage 1971 SPR Relay Application.

The Figure A-4 shows that the 350 Ω internal resistor and the 650 Ω external resistor have been replaced by a 1000 Ω external resistor and that the SPR leads have been rewired. A 12HAA16B with no resistor, but furnished with a 1000 Ω external resistor is available from G.E.

This circuit prevents operation of the HAA due to a DC surge arcing the 63 normally open contact. The voltage drop across the HAA coil during the arcing of the 63 normally open contact is limited to the voltage drop across the 63/N.C. contact and the short length of conductor to the transformer terminal block. This voltage is considerably less than the surge voltage developed across the HAA coil in Figure A-3, and probably will not operate the HAA.

Westinghouse recommended the use of shielded trip leads and the use of a “Voltrap” surge suppression device in shunt with the trip contact to prevent false operations due to surges. However, since the trip leads are not lengthy when the HAA is located in the relay house, this has often not been necessary. However, it is recommended that a four conductor cable be used for the four leads between the transformer and the auxiliary relay circuit. Any surge induced in one conductor will be induced in all four conductors; since all conductors will be at equal potential, and no circulating currents will flow.

The root cause of the security issues surrounding the DC circuitry of sudden pressure relay schemes involves the arcing over of the normally opened the 63 contact during voltage transients. Figures A-5 and Figure A-6 depict SPR trip circuit arrangement that have provided the most reliable SPR trip circuits in service to date. Both of these circuits contain four wires between the transformer and the substation control house.

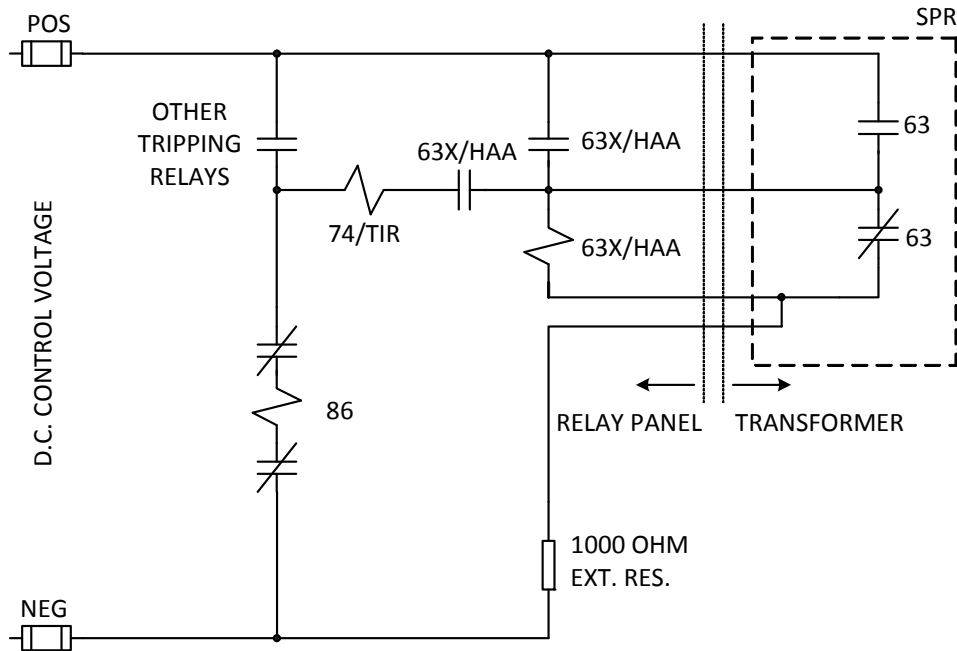


Figure A-5. Transformer SPR Circuit with Auxiliary Trip Indication Relay.

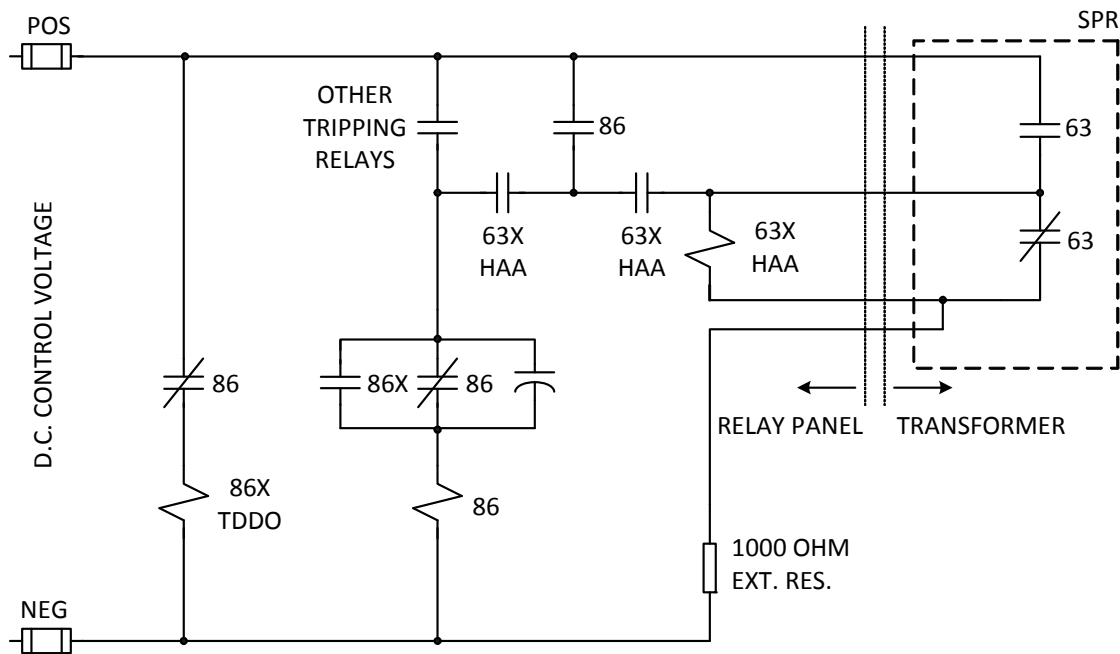


Figure A-6. Transformer SPR Circuit without Auxiliary Trip Indication Relay.

The scheme shown in Figure A-7 is a reasonably secure scheme that uses a surge arrester to control the DC surge. This scheme can be used at locations where only three control wires are available between the control house and the transformer and other factors prohibit the addition of another control cable. The surge arrester's integrity becomes a very important part of this scheme and is therefore the weak point in the scheme, which

[illegible]

Blocking Sudden Pressure Relay Trip Operation for High Through Fault Currents

Figure A-8 shows a typical scheme for current supervision of SPR relays. This figure shows the use of separate auxiliary relays which could be implemented using internal logic found in modern digital relays. If this supervision scheme is used, it should be noted that the reset time of the SPR after a contact closure can vary from a few seconds to around a minute and a half.

30

seconds. This allows adequate time for the SPR to reset. Since this scheme disables the SPR for all high current faults, it is important that the transformer be adequately protected (with the appropriate redundancy) by other relays that will detect and operate for the high current fault conditions.

One obvious deficiency with this scheme occurs when a through fault causes a transformer to fail between the time the 62-2 relay picks up and drops out; however, this scheme does offer relatively secure protection for all other contingencies.

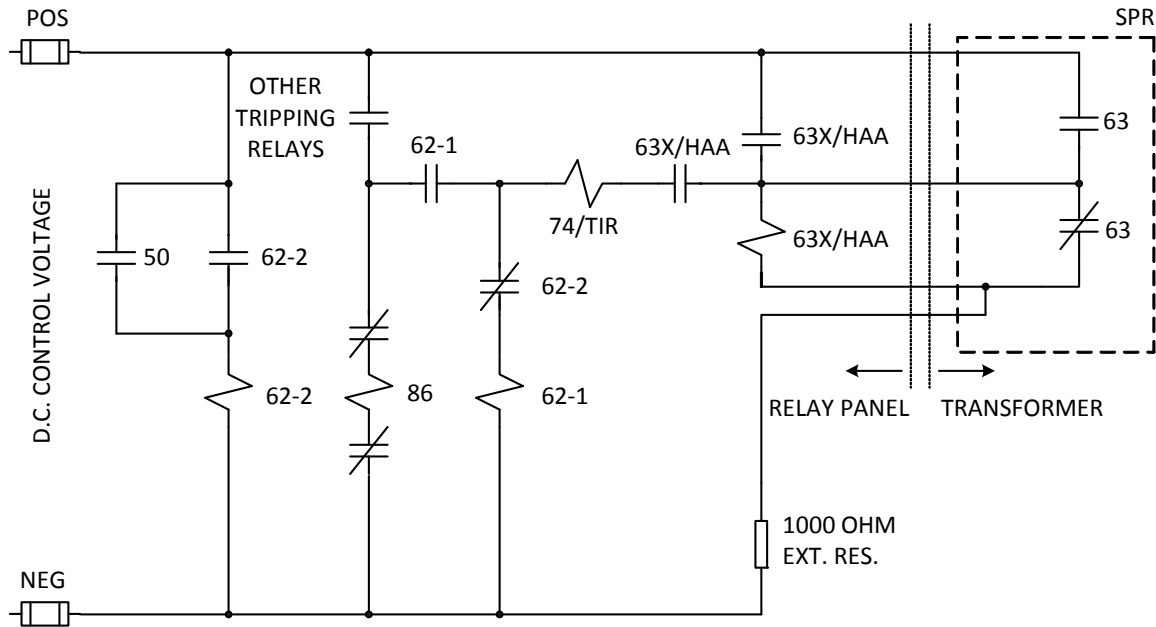


Figure A-8. High Current Blocking Supervision Scheme for the SPR Relay.

Recent Control Circuitry for Sudden Pressure Relays

General Electric sold their transformer auxiliary line of business to Qualitrol, including sudden pressure relays (GE's then latest model was the "under oil" 900-1). At the time, GE was still using the HAA relay for targeting, as shown in Figure A-9

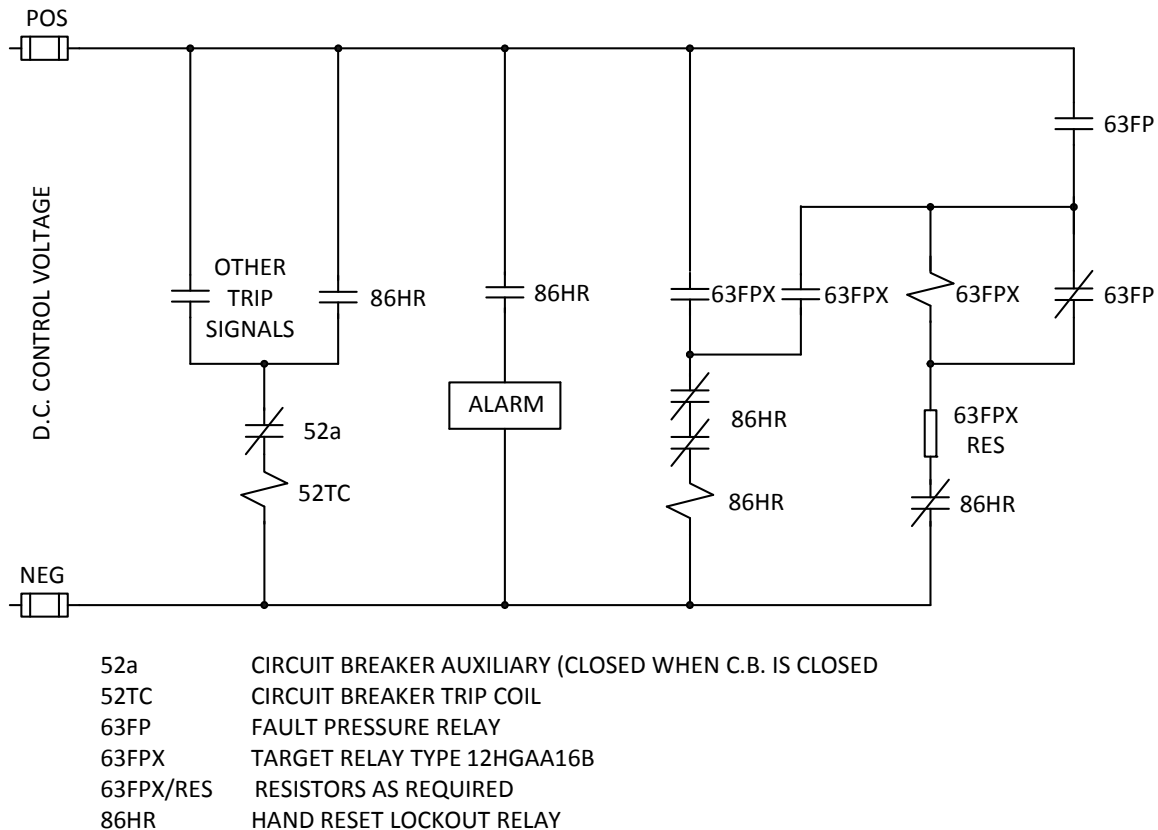


Figure A-9. Recommended Tripping and Alarm Seal-in Circuit for the GE 900-1.

Qualitrol subsequently developed a separate seal-in auxiliary relay that combines the functions of the HAA relay, a manual reset, and protection against switching surges. This seal-in relay is typically mounted in the transformer control cabinet. The circuitry for this seal-in relay is shown in Figure A-10. It may be set up to operate over a wide range of control voltages. The SPR relay Form C contact sensing is wired externally to the seal-in relay (dotted lines). The lockout relay operate coil is typically wired to the surge protected terminals 9-10 and terminals 6-7-8 may be used for an electrically isolated alarm circuit. Other circuit breaker trips are typically wired in parallel with the lockout relay tripping contacts. A red LED turns on when the seal-in is latched and turns off when the seal-in is manually reset.

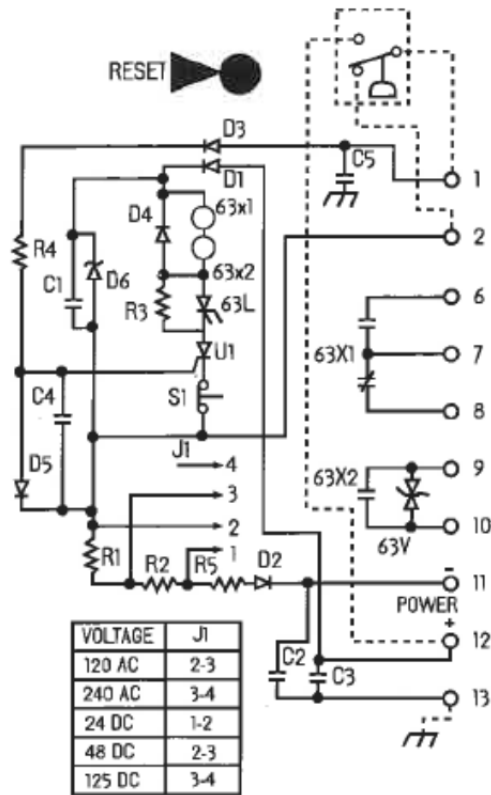


Figure A-10. Seal-in Auxiliary Relay Typically Used with the Qualitrol 900 and 910 Relays.

Securing Sudden Pressure Operation through Contact Logic

On some transformers, multiple sudden pressure relays are used and arranged at different locations on the transformer in different geometric planes to reduce the likelihood of a non-internal fault event from operating multiple relays. When this is done, two or more contacts are arranged in an “and circuit” configuration. A two relay scheme using this philosophy could be described as a 2 of 2 voting scheme.

Condensation in Rapid Pressure Rise Relays such as Qualitrol 900 and 910

A number of misoperations of rapid pressure rise relays have been due to moisture or condensation on the micro-switch within the relays. Condensation develops when moisture is sucked into the sealed secondary chamber of the relay during a rapid change in temperature. This is most often noticed in climates such as the southeastern US, where a rain storm causes moisture to collect on the relay coincident with a rapid decrease in the air temperature. Over time, more moisture collects and condensation forms on the contacts of the micro-switch, creating a conductive path across the contacts and resulting in a relay misoperation. In the mid 1980s, the manufacturer recommended a modification to make the secondary chamber “free breathing” by adding a vent to the test plug to equalize the pressure.

Appendix B - Survey of North American Utility Industry SPR Practices

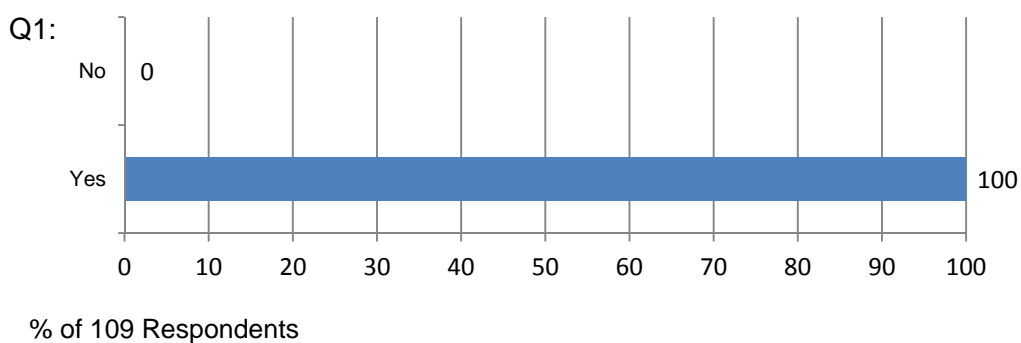
This survey was undertaken by the K6 Working Group of the Power System Relaying Committee to document current utility industry practices in North America with respect to sudden pressure relays (SPR).

This survey included responses by 109 individuals from 75 companies. When more than one person responded from a company, the individuals typically represented different operating divisions (which may apply different philosophies), of a single, larger company. These individual responses from separate operating companies were included in this analysis. Respondents who indicated a desire to receive the results are provided with a copy of these survey results directly.

Each question includes specific numbers or percentages of use when the respondent indicated that their company uses the specific category of equipment, function or configuration. Therefore each question and chart typically is based on a different number of responses. The usual format used here is to list the question, include a chart of responses and provide a brief analysis.

Separate bar charts are provided for questions for which this type of data presentation seemed appropriate. The numbers to the right of each “bar” are the percentage or number of affirmative responses for that category. In the lower left of the chart is indicated the actual number or percentage of respondents to that question.

Q1: Does your company use sudden pressure relays on power transformers, phase shifters, or shunt reactors?



A1: All utilities responding to this survey use sudden pressure relays for at least some applications.

Questions 2 – 11

This group of questions identified specific SPR applications for different categories of equipment. Eight equipment categories included; Distribution, Two Winding Transmission, Autotransformer Transmission, Generator Stepup Units (GSU), Generation Auxiliaries, LTC Compartments, Phase Shifting Transformers (PST), and Shunt Reactors. Eight applications included; Trip, Alarm, In Gas, In Oil, Multi-function, Buchholz, Unknown, and Not Applicable.

A respondent who provided a “Not Applicable” response to specific equipment types (Shunt Reactor, etc) allowed the analysis to subtract out those responses for each type of equipment, indicating that specific equipment was not used on the respondent’s system. For example, out of 109 survey respondents, 40 indicated that Shunt Reactors were “Not Applicable” on their system, leaving 69 indicating some application of this equipment.

This analysis of the response data seems to make sense. However, the survey authors are not certain that all respondents actually interpreted the “Not Applicable” response in this way. The results would seem to result in a higher than expected indication of use of certain equipment. For example, almost exactly half of respondents indicated that phase shifters were “Not Applicable” within their company. That’s OK, but the survey authors are not necessarily convinced that the other half actually have and use phase shifting transformers. Nevertheless, these results should still provide useful comparisons for SPR use among equipment types and applications.

The responses to Questions 2 – 9 are analyzed in two different ways. The first analysis varies the equipment type for each SPR function or configuration (presented as Q2E, etc) and the second analysis varies the function or configuration for each equipment type (presented as Q2C, etc).

The first analysis of the responses to Questions 2 – 9 provides separate charts for each SPR function or configuration (Trip, etc) using the equipment type as the variable within each chart. These charts show the total number of “Responses Received” and compares that to the number of respondents who indicated that their equipment is “Tripped by SPR (#)”, “Alarmed by SPR (#)”, etc. These charts are scaled in terms of the number of respondents, rather than percentages.

Since the “Not Applicable” data is shown on each of the charts Q2E – Q8E, there is no separate Q9E chart representing that data.

Question 11 provided an opportunity for respondents to provide comments on their applications. Sixty-nine respondents commented. These comments are grouped corresponding to the Questions 2 – 9 and are edited to reflect the specific questions where the comments apply.

Q2E: Does your company use sudden pressure relays to Trip the following equipment?

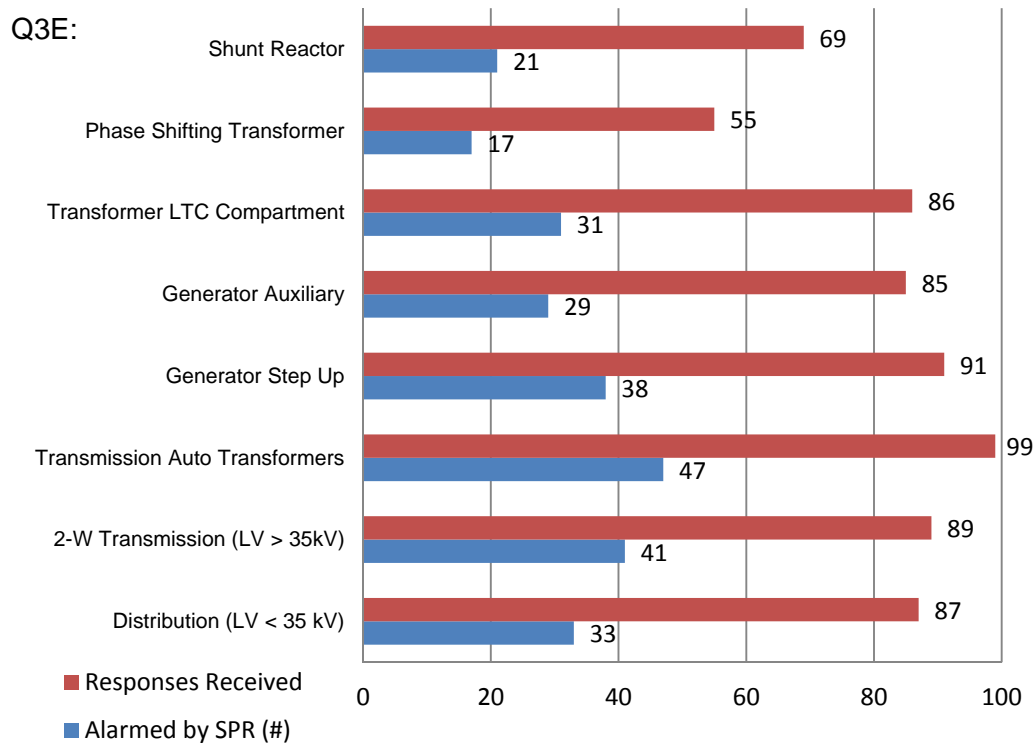


A2E: Sudden pressure relays are widely used to Trip, though by no means universally. None of the usage categories exceeded 80% of the companies that have each type of equipment.

Q11: Summary of applicable comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- 2 of 3 voting – 3 (1 for GSU)
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- Not used – 1 (2 differential)

Q3E: Does your company use sudden pressure relays to Alarm for the following equipment?



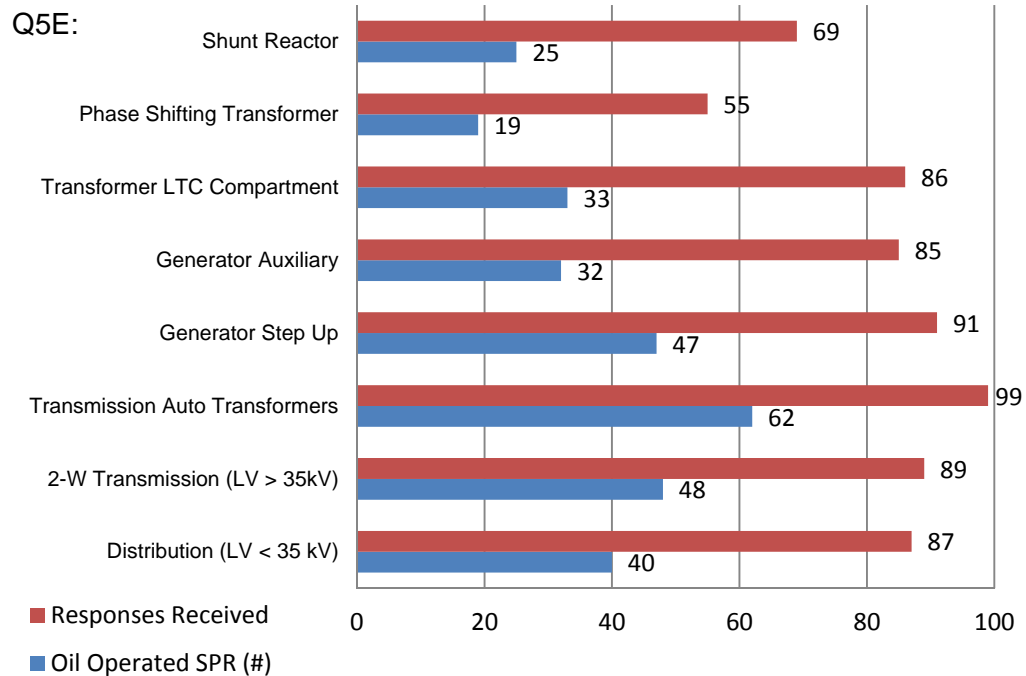
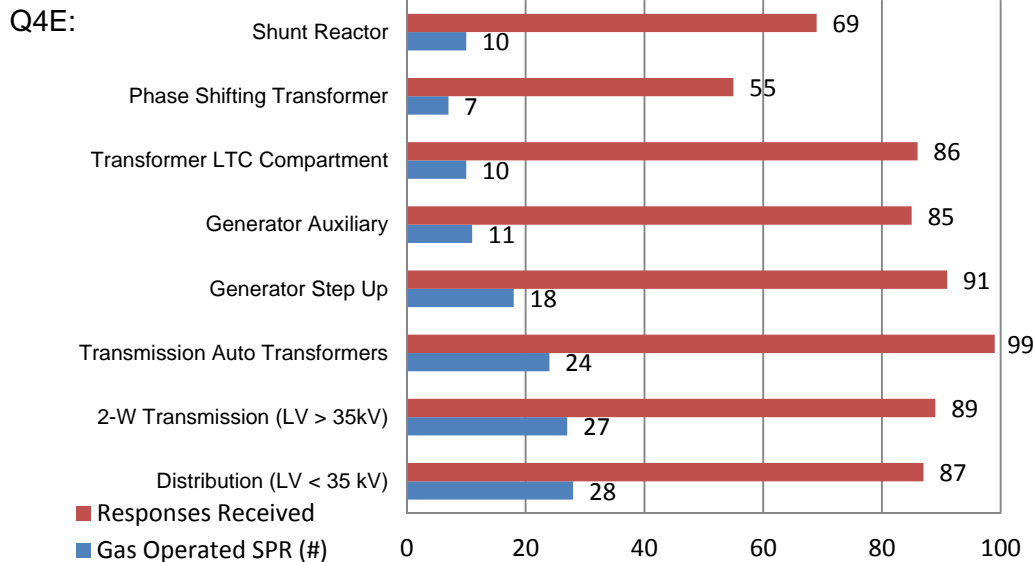
A3E: The Alarm application is often used when tripping is not, though some utilities both Trip and Alarm (see Question 14).

Q11: Summary of comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- Trip and alarm for main tank - 2
- LTC alarm only
- Not used – 1 (2 differential)

Q4E: Does your company use sudden pressure relays “In Gas” on the following equipment?

Q5E: Does your company use sudden pressure relays “In Oil” on the following equipment?



A4E, A5E: Both “In Gas” and “In Oil” applications are used, though somewhat higher numbers within each equipment category use “In Oil”. In addition, at least 70% higher

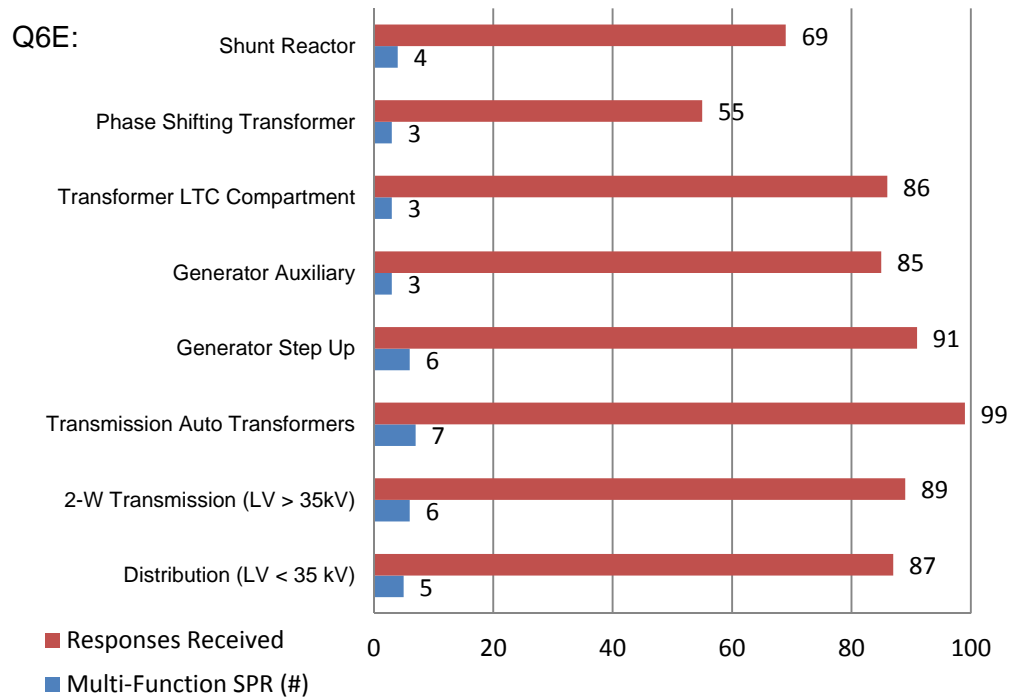
number of respondents actually use “In Oil” within each equipment category except distribution (only ~40% higher).

Q11: This question provided an opportunity for comments and qualifications to Q2-Q10. (69 respondents)

Summary of comments:

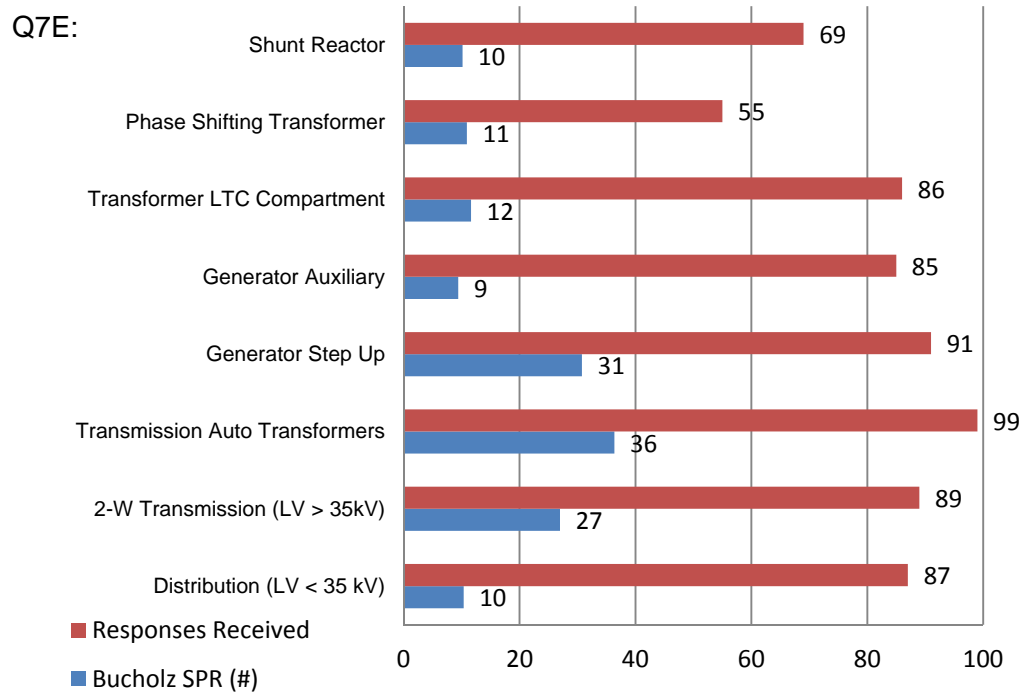
- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- 2 of 3 voting – 3 (1 for GSU)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- LTC alarm only
- Not used – 1 (2 differential)

Q6E: Does your company use multi-function sudden pressure relays on the following equipment?



A6E: The multi-function sudden pressure is available from only a single manufacturer and only relatively recently. It has only a small market penetration to date.

Q7E: Does your company use Bucholz sudden pressure relays on the following equipment?

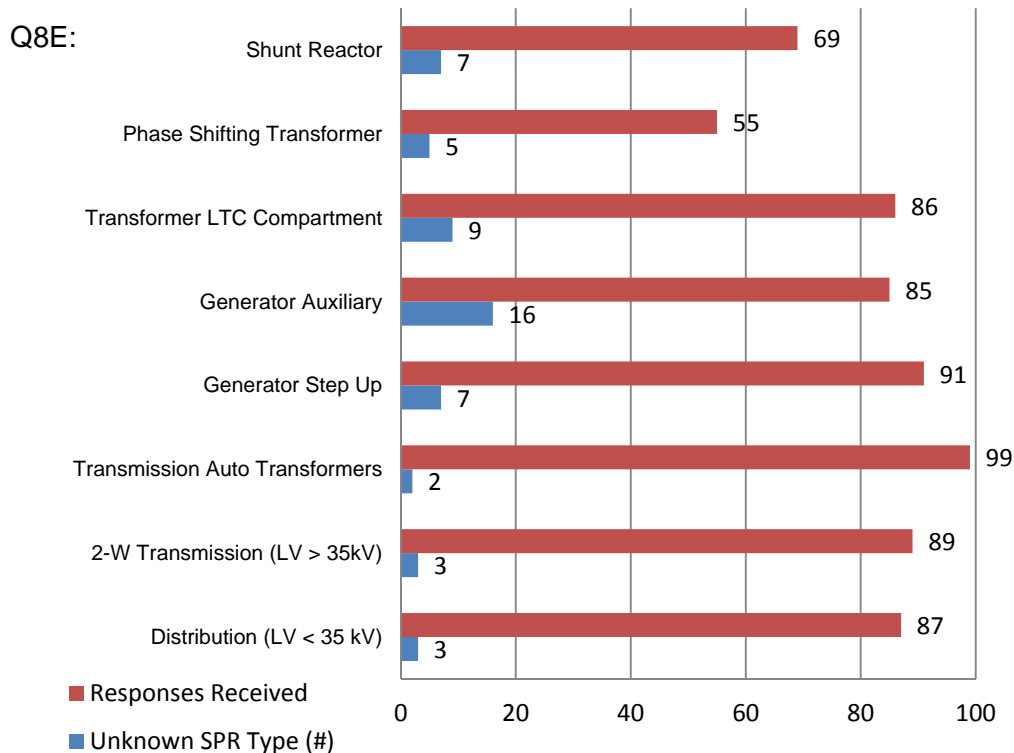


A7E: Bucholz relays are used at a somewhat lower rate than gas and oil applications. Many Bucholz users commented that these are common (i.e. are only applied) on conservator type transformers.

Q11: Summary of comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2

Q8E: Does your company use sudden pressure relays of “Unknown” type on the following equipment?



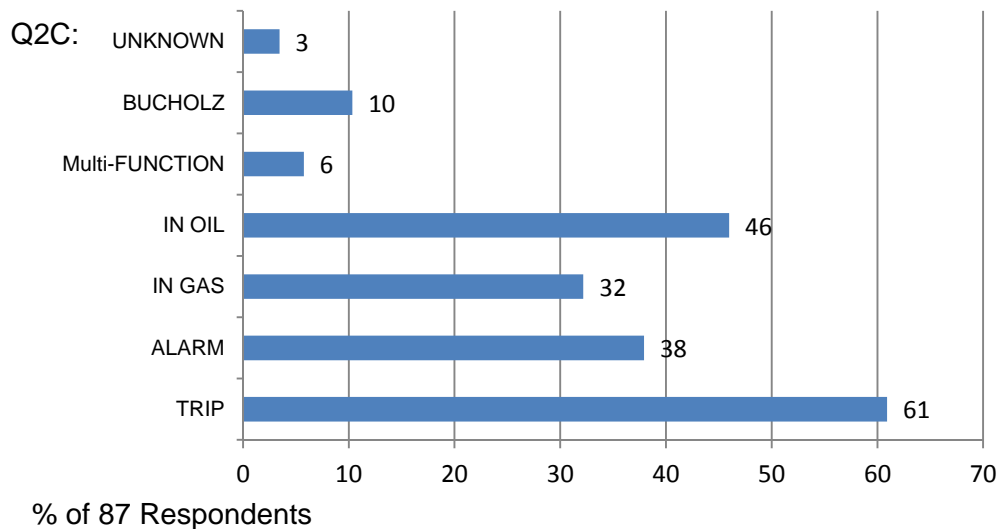
A8E: A few respondents didn't know what types of sudden pressure relays their companies use, though the numbers were relatively small.

Q11: Summary of comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- Not used – 1 (2 differential)

The second analysis of the responses to Questions 2 – 9 provided separate charts (Q2C, etc) for each equipment type (Distribution, etc) using the sudden pressure relay function or configuration as the variable. The results presented here have subtracted out the respondents who indicated that the particular equipment for each chart was “Not Applicable” by their company and presents only results for the various sudden pressure relay configurations. These charts are scaled in terms of the percentage, rather than numbers of respondents.

Q2C: Does your company use sudden pressure relays for Distribution (LV < 35 kV) applications?



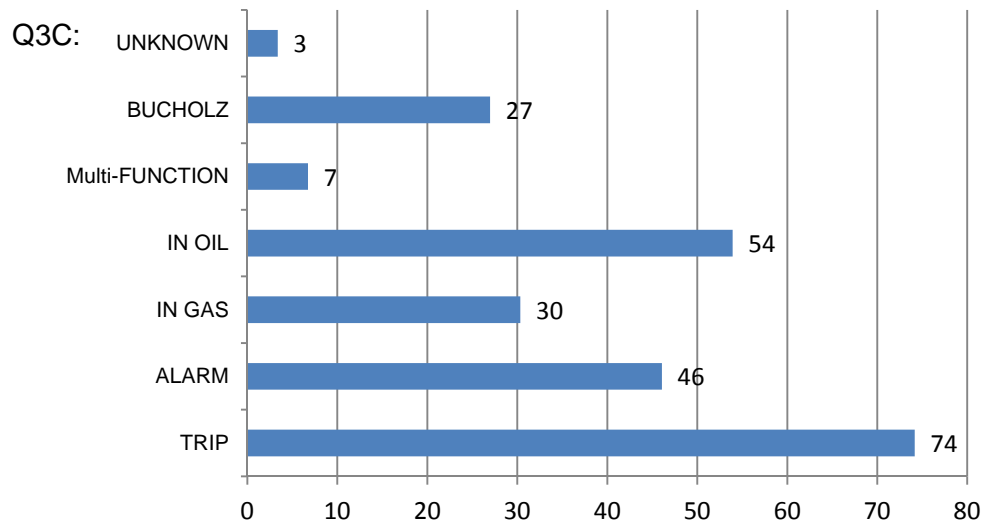
A2C: A large fraction of utilities use sudden pressure relays in some form and for some function on distribution transformers. Only about 3 of 5 companies trip distribution transformers using the SPR.

Q11: Summary of comments:

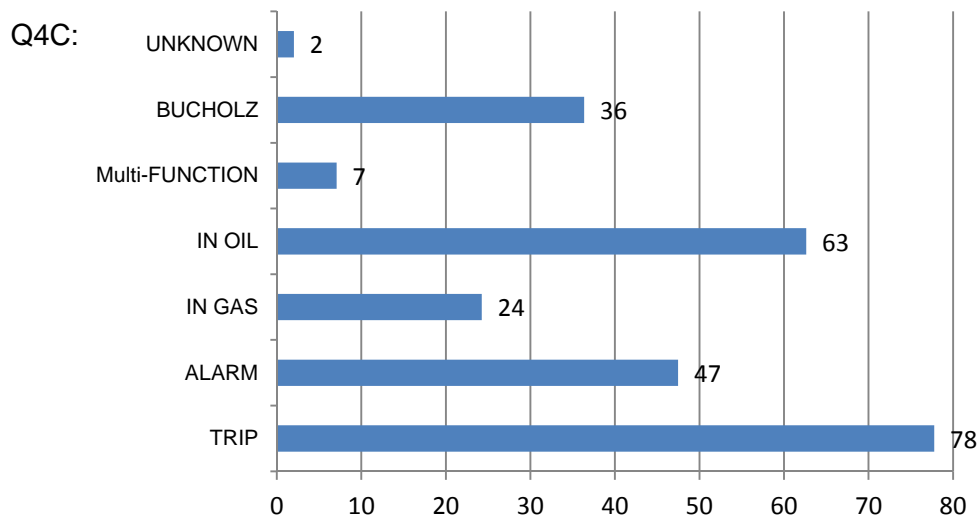
- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- LTC trip – 6 (1 when installed by manufacturer)
- 2 of 3 voting – 3 (1 for GSU)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- LTC alarm only
- Not used – 1 (2 differential)

Q3C: Does your company use sudden pressure relays for Two Winding Transmission (LV > 35kV) applications?

Q4C: Does your company use sudden pressure relays for Auto-transformer Transmission applications?



% of 89 Respondents



% of 99 Respondents

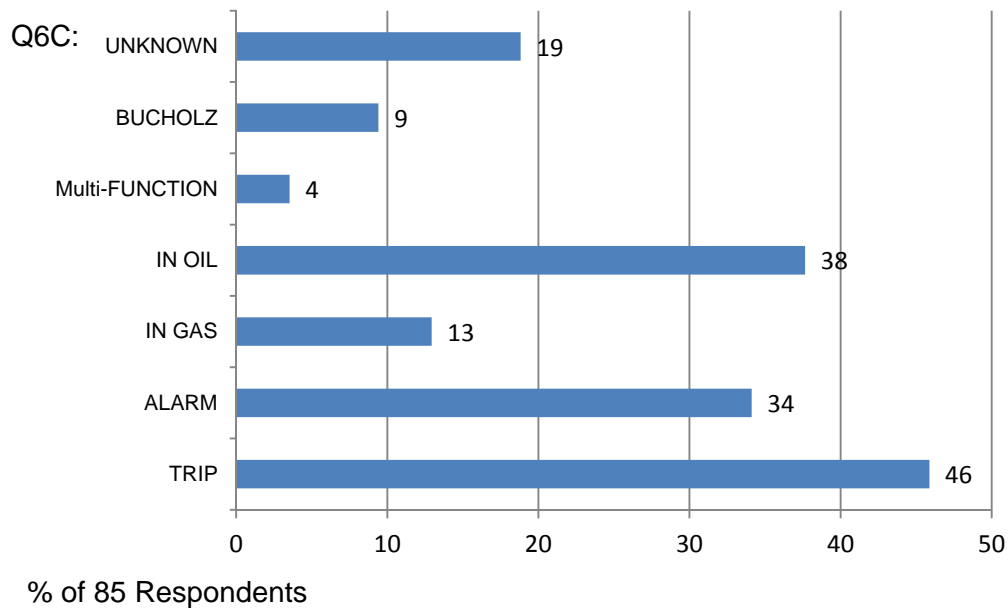
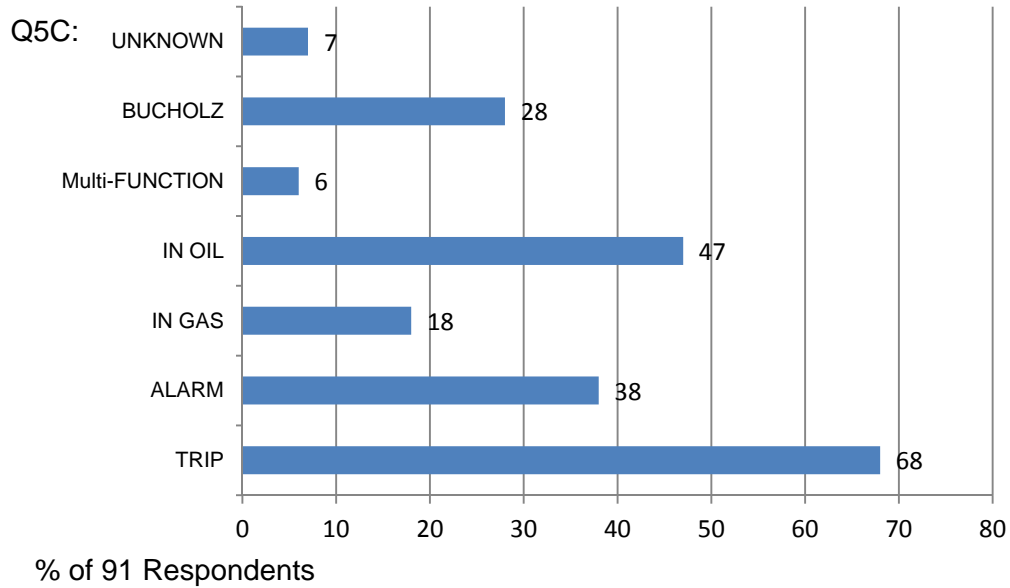
A3C, A4C: Most functional and configuration categories of SPRs increased for two winding transmission transformers and again (somewhat) for auto-transformers, compared to distribution transformers, except for “In Gas” applications.

Q11: Summary of comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- LTC trip – 6 (1 when installed by manufacturer)
- 2 of 3 voting – 3 (1 for GSU)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- LTC alarm only
- Not used – 1 (2 differential)

Q5C: Does your company use sudden pressure relays for Generator Step Up applications?

Q6C: Does your company use sudden pressure relays for Generator Auxiliary applications?



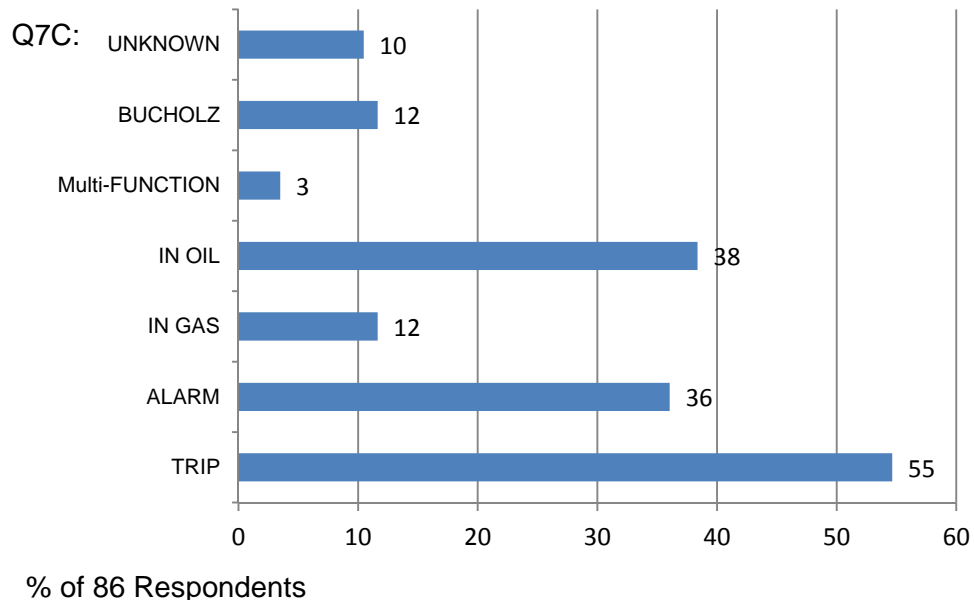
A5C, A6C: Sudden pressure relay use for generator step up transformers is about the same as for transmission transformers. However, SPR relays on the generator auxiliary transformers are used at a somewhat lower level than for distribution transformers.

Q11: This question provided an opportunity for comments and qualifications to Q2-Q10. (69 respondents)

Summary of comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- LTC trip – 6 (1 when installed by manufacturer)
- 2 of 3 voting – 3 (1 for GSU)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- LTC alarm only
- Not used – 1 (2 differential)

Q7C: Does your company use sudden pressure relays for Transformer LTC Compartment applications?

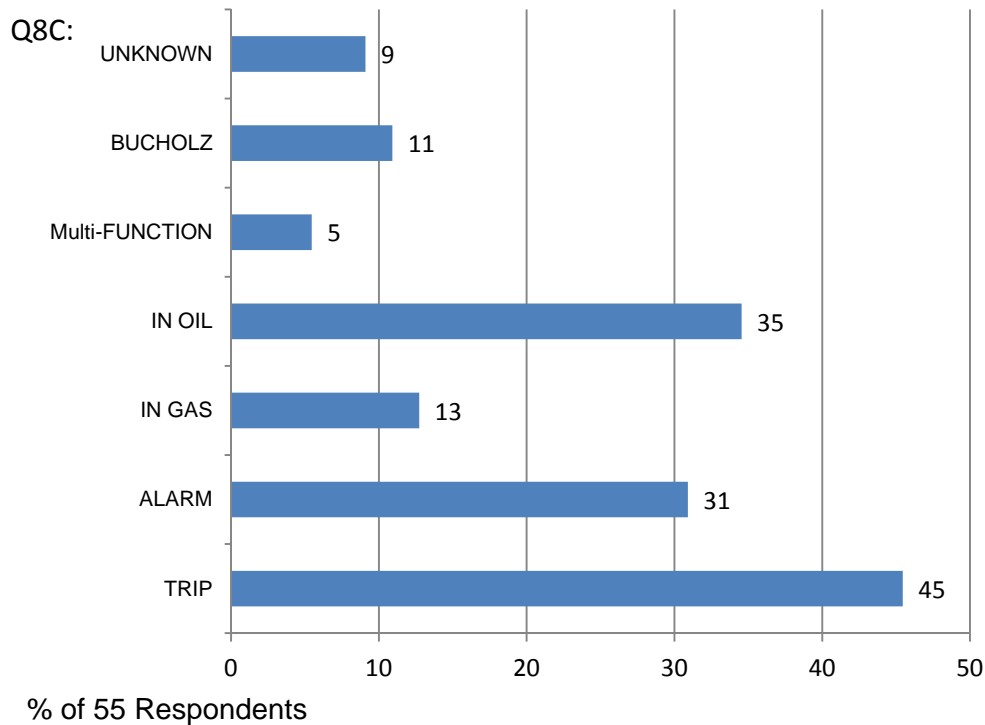


A7C: Utilities use a SPR in the transformer LTC compartment in numbers comparable to distribution transformers, except that “In Gas” applications are substantially lower.

Q11: Summary of comments:

- LTC trip – 6 (1 when installed by manufacturer)
- LTC alarm only

Q8C: Does your company use sudden pressure relays for Phase Shifting Transformer applications?

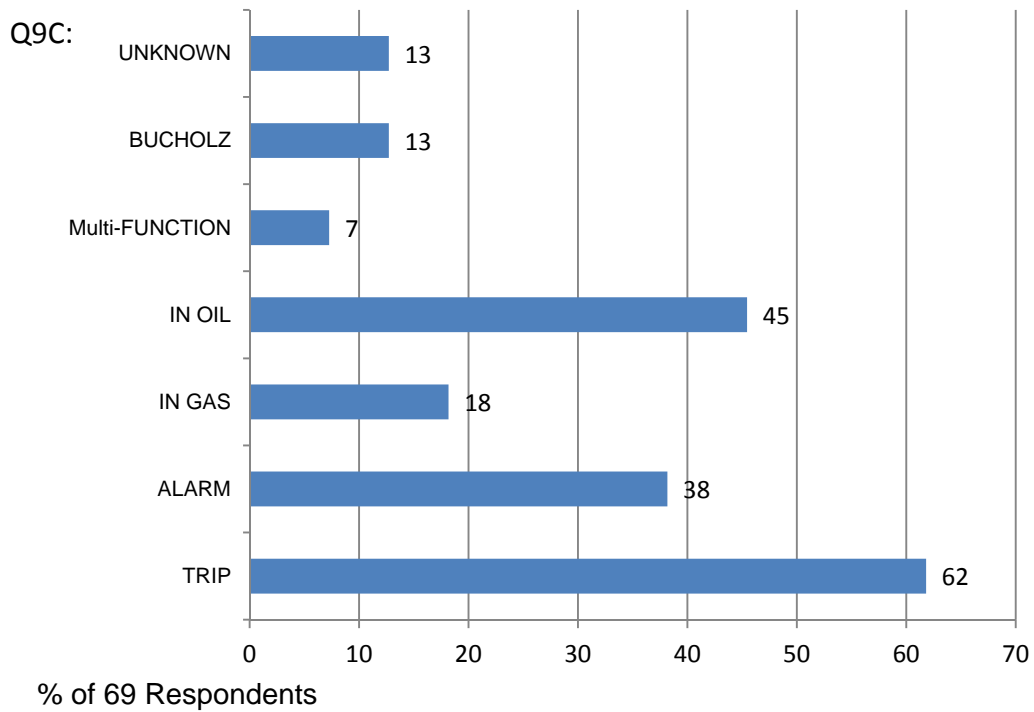


A8C: Sudden pressure relays are used by utilities at a lower rate on phase shifting transformers than for all the rest of the equipment identified. The number of respondents indicating they had phase shifting transformers was also lower than for any other category of equipment.

Q11: Summary of comments:

- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- LTC trip – 6 (1 when installed by manufacturer)
- 2 of 3 voting – 3 (1 for GSU)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- LTC alarm only
- Not used – 1 (2 differential)

Q9C: Does your company use sudden pressure relays for Shunt Reactor applications?

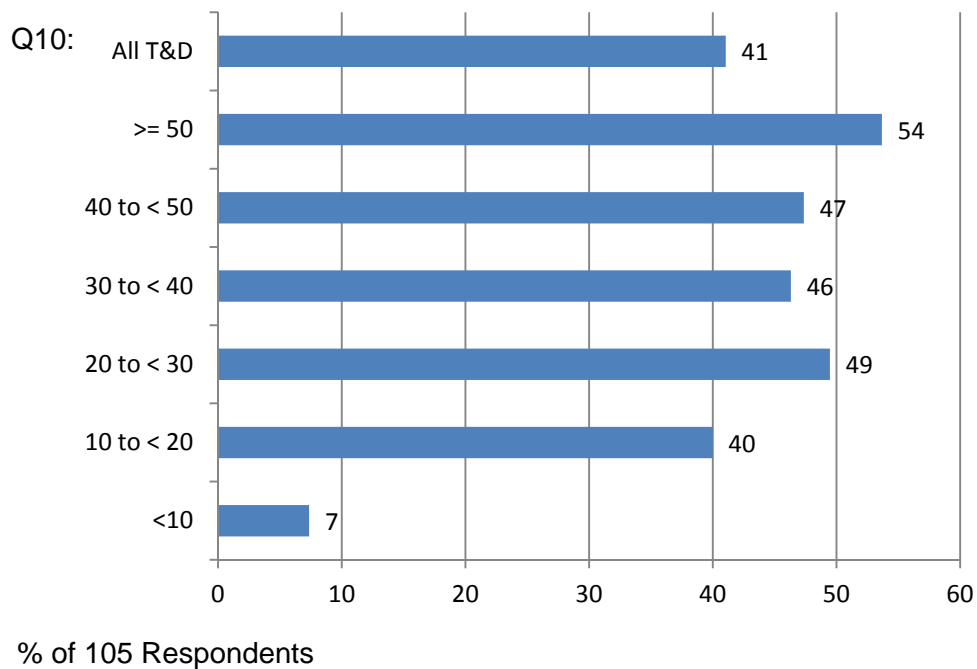


A9C: Protection of shunt reactors with SPRs is done at rates closer to distribution equipment than other transmission equipment.

Q11: Summary of comments:

- Trip only for shunt reactors

Q10: At what self-cooled MVA rating are sudden pressure relays required for your utility?



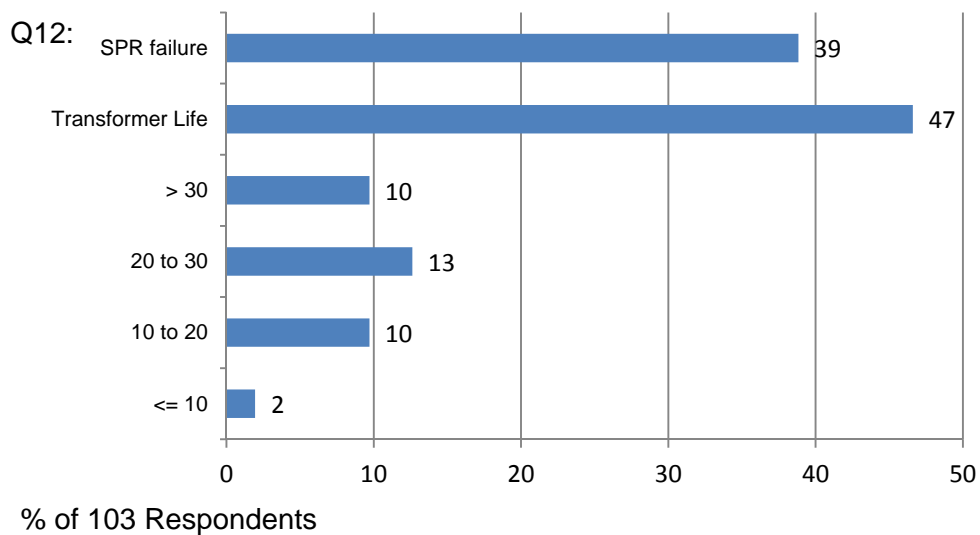
A10: For those respondents who use transformer size as an indicator to apply SPRs, few use SPRs below 10 MVA, but about half apply SPR relays above 10 MVA.

Q11: This question provided an opportunity for comments and qualifications to Q2-Q10 (69 respondents). The comments all related to specific SPR applications, rather than to the transformer or reactor MVA rating.

Summary of comments:

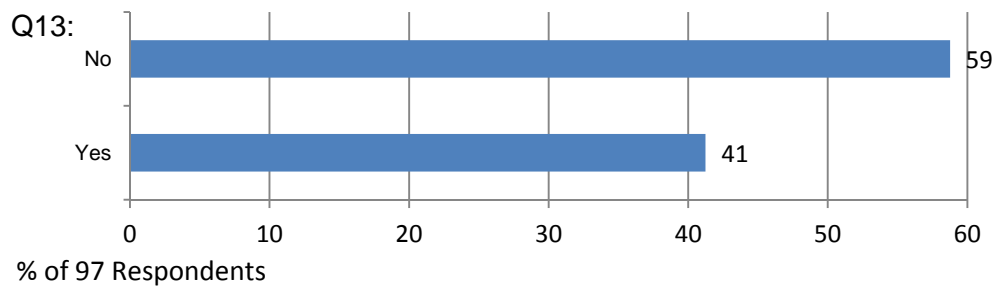
- SPR for all units – 34 (some qualifications: depends on HV winding & manufacturer, 1 for power plants)
- Bucholz for conservators – 28 (1 older only, 2 alarm only, 1 at 345 kV)
- Alarm only – 7 (1 with 2 differentials, 1 trip GSU, 1 if differential available)
- LTC trip – 6 (1 when installed by manufacturer)
- 2 of 3 voting – 3 (1 for GSU)
- SPR for non-conservator – 3
- Trip and alarm for main tank - 2
- SPR when diff not available - 2
- Manufacturer warranty – 2 (1 block after warranty expires)
- Trip only for shunt reactors
- LTC alarm only
- Not used – 1 (2 differential)

Q12: How long does your utility expect a sudden pressure relay to last before replacement?



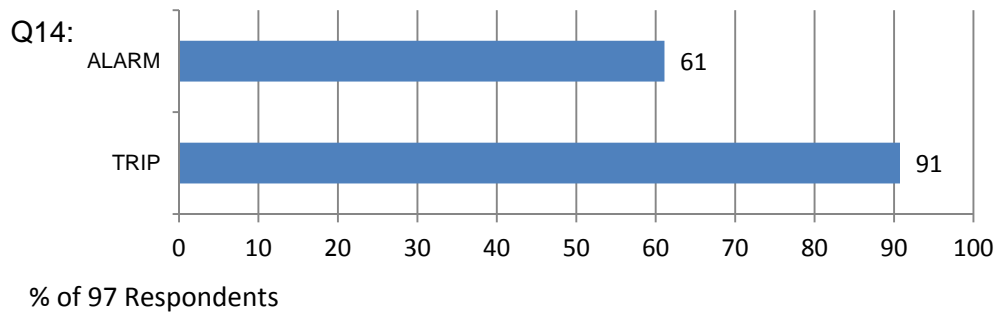
A12: Only a small fraction of utilities seem to have a specific idea of the expected life for a sudden pressure relay. The largest numbers of utilities either wait for an SPR failure or transformer replacement/failure.

Q13: Does your company use more than one sudden pressure relay per transformer?



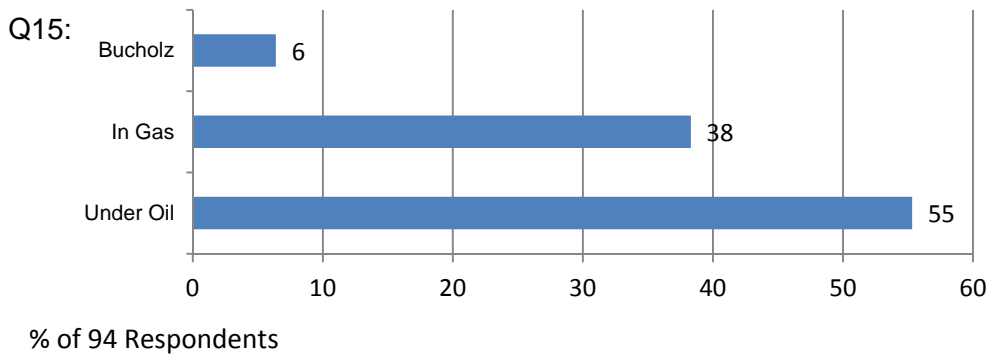
A13: Single SPR installations per transformer out number multiple SPRs by about 3 to 2.

Q14: Does your utility use a sudden pressure relay for tripping and/or alarming purposes?



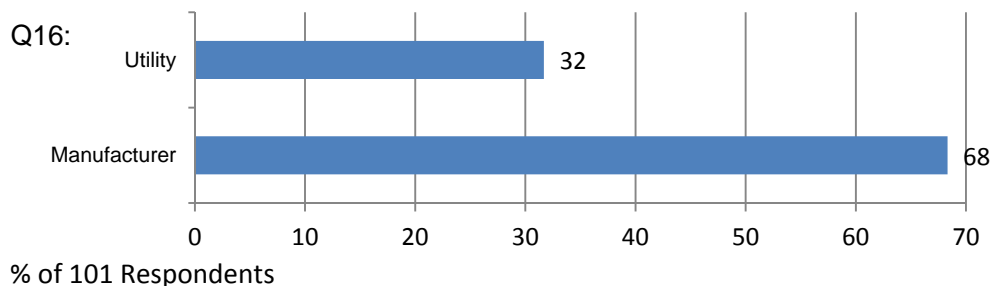
A14: More than 9 of 10 owners use SPRs for tripping and over half also alarm.

Q15: If only one sudden pressure relay is used, where is it most commonly located?



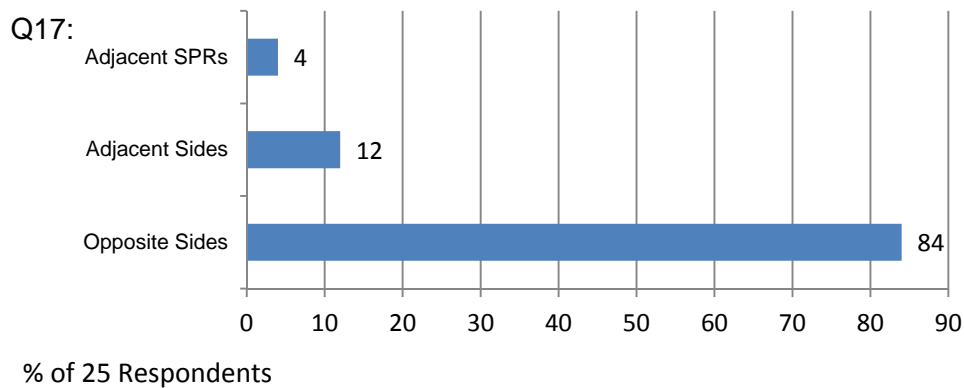
A15: For single SPR installations, most owners use an “under oil” or “in gas” application, with a few Bucholz. These results are at least qualitatively consistent with Questions 5E – 7E.

Q16: Who determines the relay location?



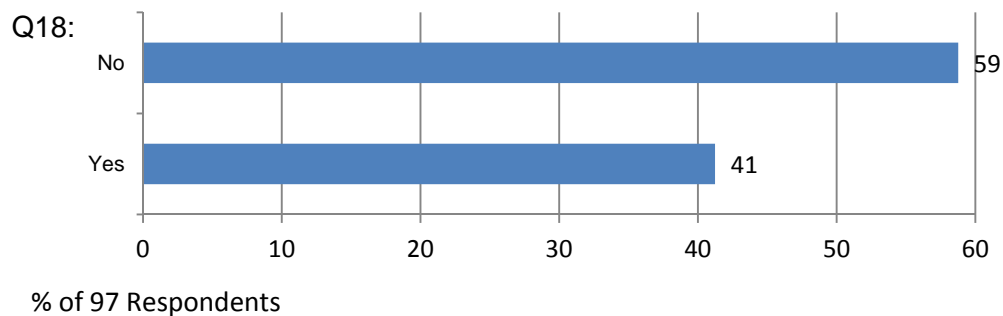
A16: When a single SPR is used, the manufacturer specifies its location about twice as often as the utility.

Q17: If two or more sudden pressure relays are used in the transformer main tank, where are the relays located?



A17: When more than one SPR is used, the relays are generally located on opposite sides of the main tank.

Q18: Are one or more sudden pressure relays used in the load tap changer compartment?



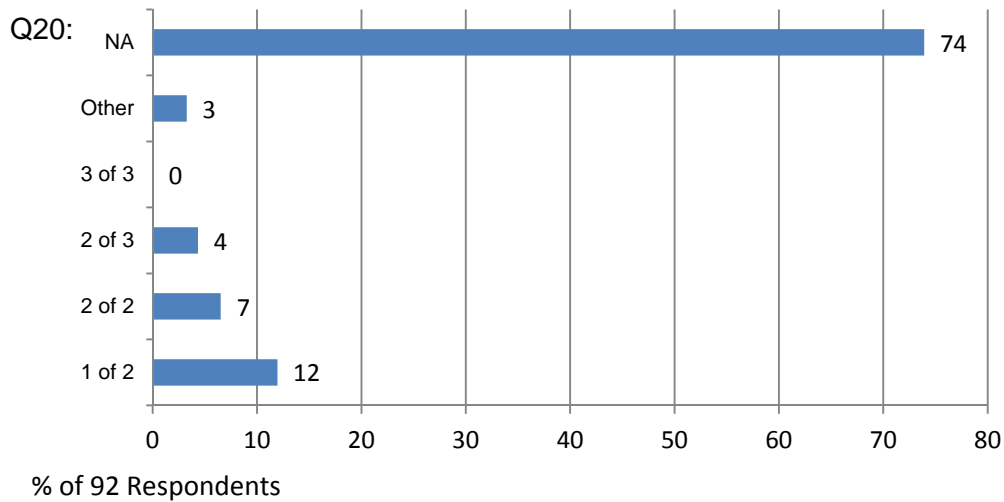
A18: Owners of LTC equipped transformers install a SPR in the LTC compartment about 40% of the time.

Q19: Provided opportunity to comment on use of SPRs in the LTC compartment (38 respondents).

Comment summary for SPRs in the LTC compartment:

- No significant difference between main tank and LTC applications – 25
- Don't use LTCs or SPRs in the LTC compartment -- 4
- LTC must be less sensitive than main tank application – 3
- LTC application is less secure, alarm only – 3
- Only a few applications (typically newer transformers or specific LTC types) -- 2

Q20: Does your company use SPRs in voting schemes? For applications using two or more sudden pressure relays in the same compartment, does your company use “voting” logic, such as 2 of 2 or 2 of 3?



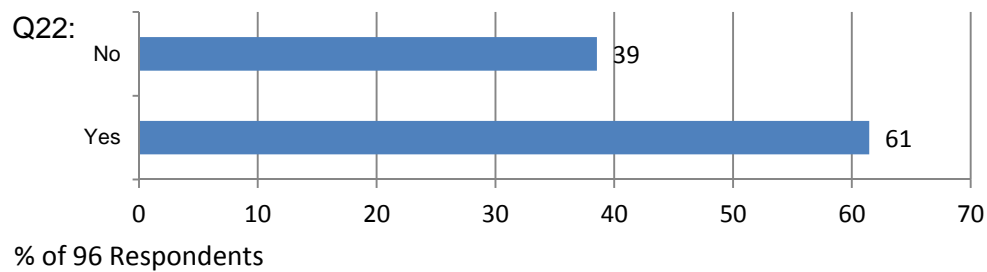
A20: Only about a quarter of SPR users also use voting schemes. Nearly half of voting scheme users use a “1 of 2” scheme, which is really more redundancy than voting.

Q21: Provided opportunity to comment on use of SPRs in voting schemes (18 respondents).

Comment summary on voting schemes:

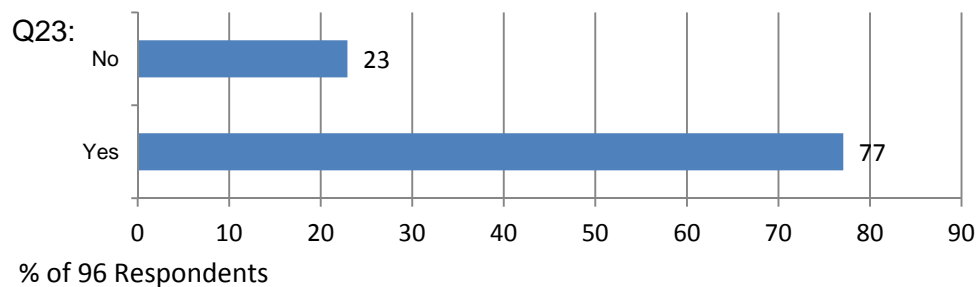
- Opposite sides (corners) of transformer – 3 (4)
- Top and side - 2
- ≥ 2 relays trip independently
- Per manufacturer – 2 (1 of 2)
- Only on new nuclear units- 2
- So few, no SOP
- Location approved by Engineering
- 2 of 3, 3 transducers at one valve (multi-function SPR)

Q22: Does your company use Form “c” logic? (The 63a closes and the 63b opens to remove a short around the auxiliary seal-in coil to allow scheme tripping.)



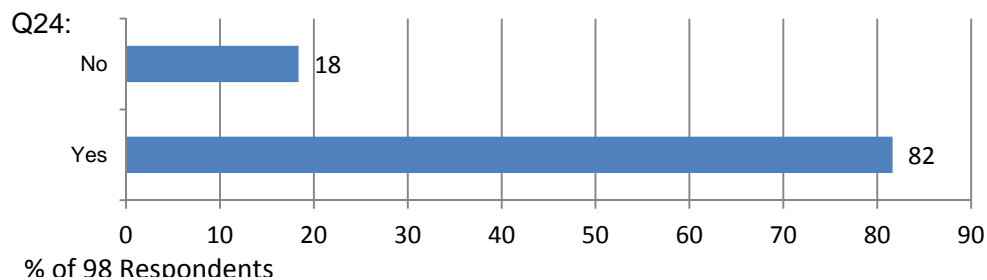
A22: About 3 of 5 utilities use Form “c” logic.

Q23: Is operation of the sudden pressure relay sealed in by a separate auxiliary?



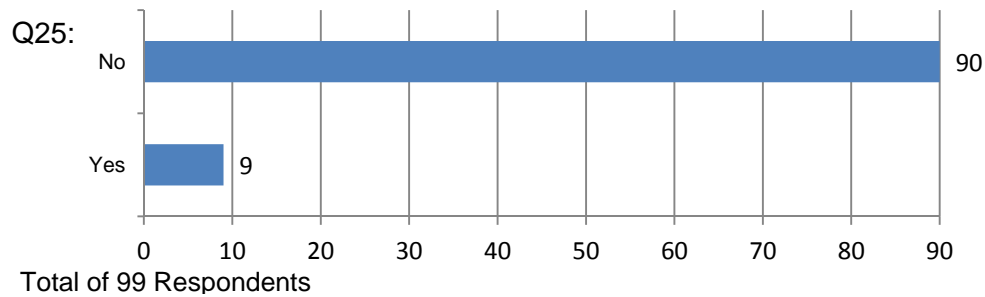
A23: About three fourths of users use a separate seal-in auxiliary relay.

Q24: Is the sudden pressure trip function annunciated locally?



A24: More than 4 of 5 SPR users include a local annunciator indication.

Q25: Does your company use current supervision for sudden pressure relay operation?



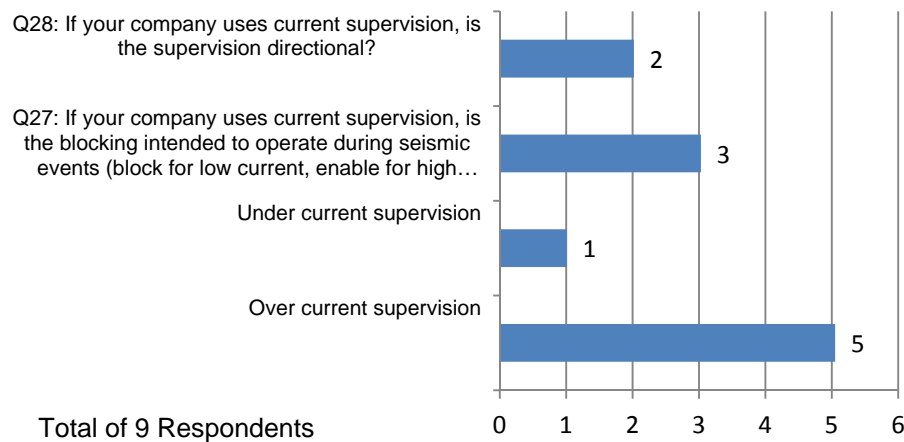
A25: Only a handful of SPR users (9 of 99, <10%) include some type of current supervision for SPR operation.

Q26: Is the blocking provided by overcurrent or under current?

Q27: Is the blocking intended to operate during seismic events (block for low current, enable for high current)?

Q28: Is the supervision directional?

Q26, 27, 28:

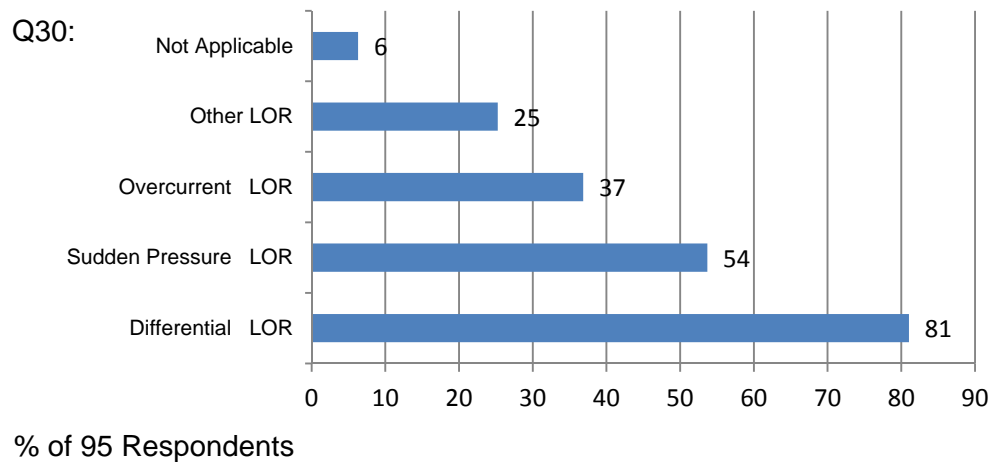


A26, 27, 28: For those few users of current supervision, most use overcurrent, followed by seismic, directional and undercurrent. This graph presents the responses for all three questions together.

Q29: Are these current supervision schemes secure and dependable?

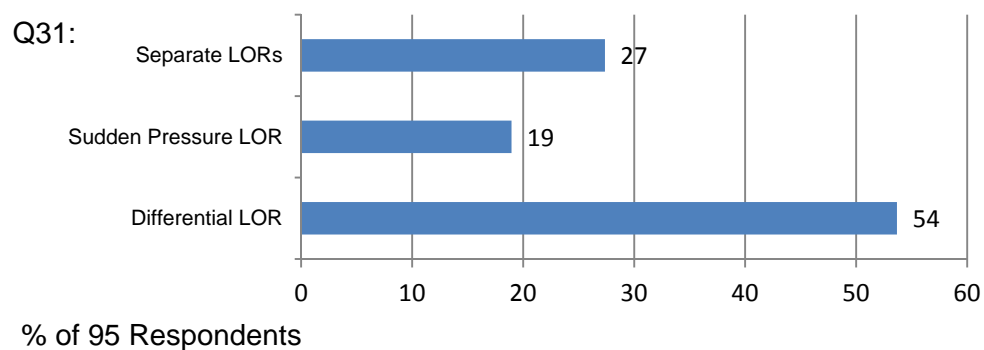
A29: Of 8 responses, all said yes.

Q30: Identify the separate lockouts that your company uses for transformer protection.



A30: “Other LOR” for various owners includes a single lockout relay for all trips (9), breaker failure (2), thermal relays (4)

Q31: If your company uses transformer over current protection, what lockout does the over current relay trip?



A31: Just over half of respondents trip the differential lockout with overcurrent protection.

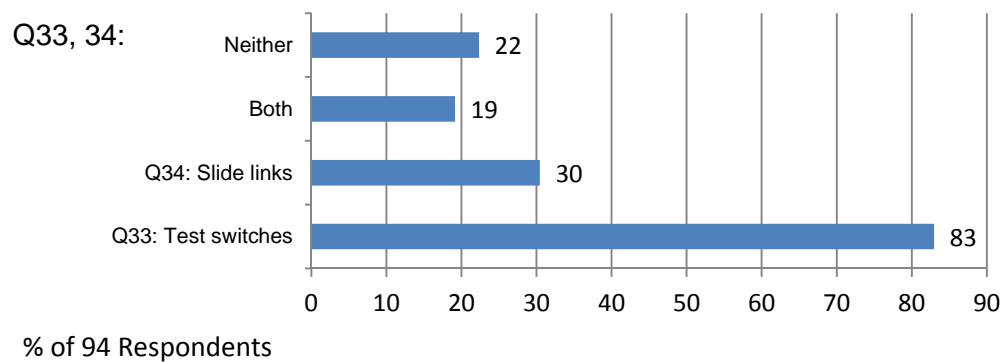
Q32: Solicited comments on use of lockout relay (LOR) arrangements in Questions 30 and 31 (76 respondents).

Comments summarize LOR arrangements:

- Single LOR (multiple functions) – 41
- Differential, SPR, OC separate – 17
- Differential separate, SPR+OC together - 9
- Differential + OC, SPR separate - 3
- Differential + SPR together, OC separate - 3
- Separate annunciator for source of trip
- Only LOR for SPR

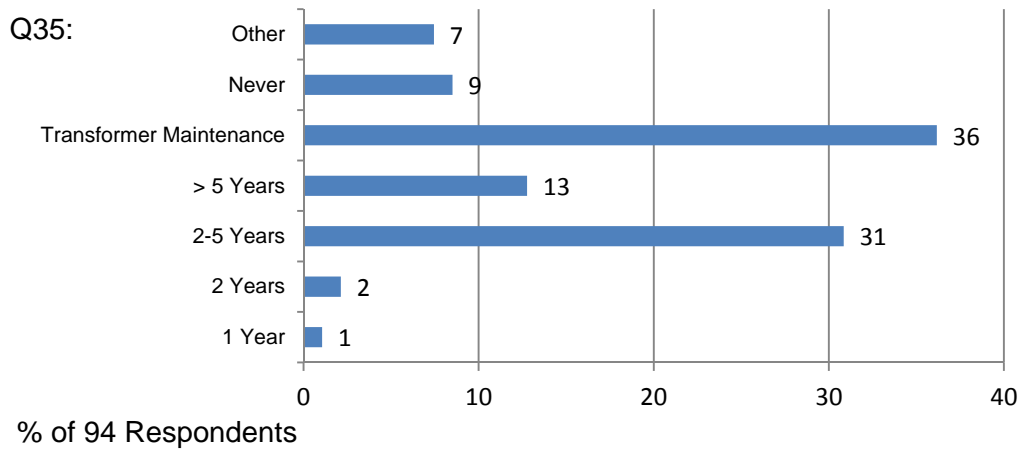
Q33: Does your utility use test switches for lockout relay isolation?

Q34: Does your utility use slide link terminal blocks for sudden pressure relay test isolation?



A33, 34: This graph presents the responses to both questions together. Since the questions were asked separately, the survey also identifies utilities that use both test switches and slide links, or neither.

Q35: How often does your utility perform maintenance checks of the sudden pressure relays?

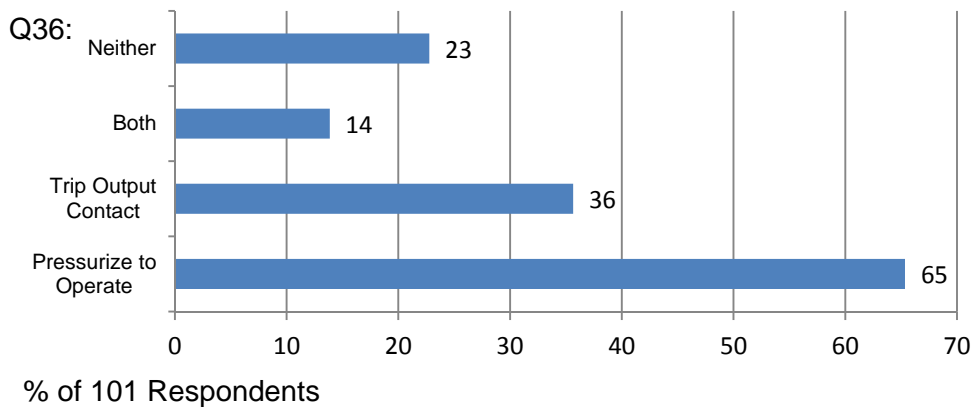


A35: Most utilities either coordinate SPR maintenance with transformer maintenance or use an interval between 2 and 5 years.

Summary of comments on maintenance intervals (7 respondents):

- 3 years or with transformer maintenance
- Commissioning tests
- At operational test
- Company schedules as reported to NERC
- Unknown
- Every outage or 5 years maximum
- Transmission 2 years, distribution 4 years

Q36: Does your utility actually pressurize to operate the relay or does your utility test the trip output contact?



A36: The spread sheet data provided separate responses to the “pressurize” and “trip output” questions, also allowing determination of “both” and “neither” responses.

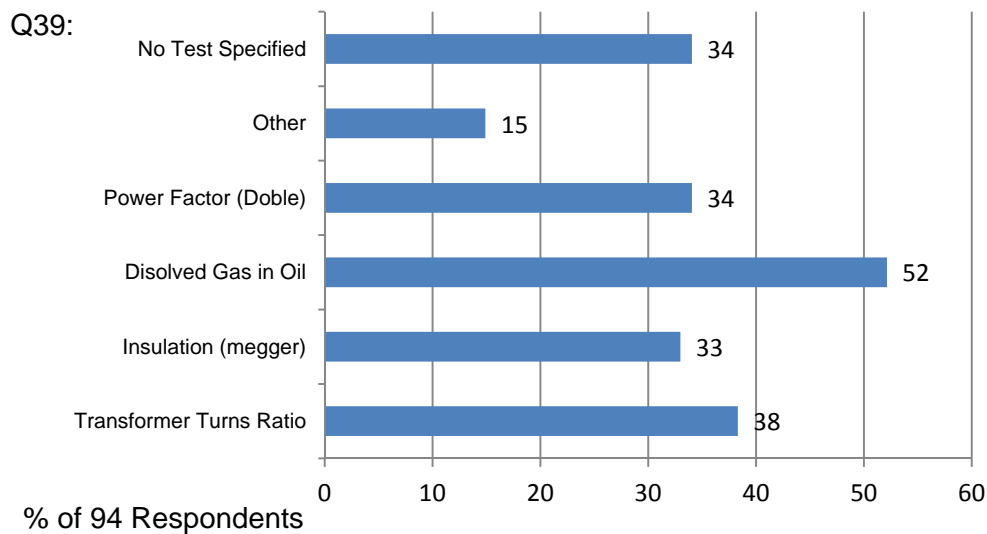
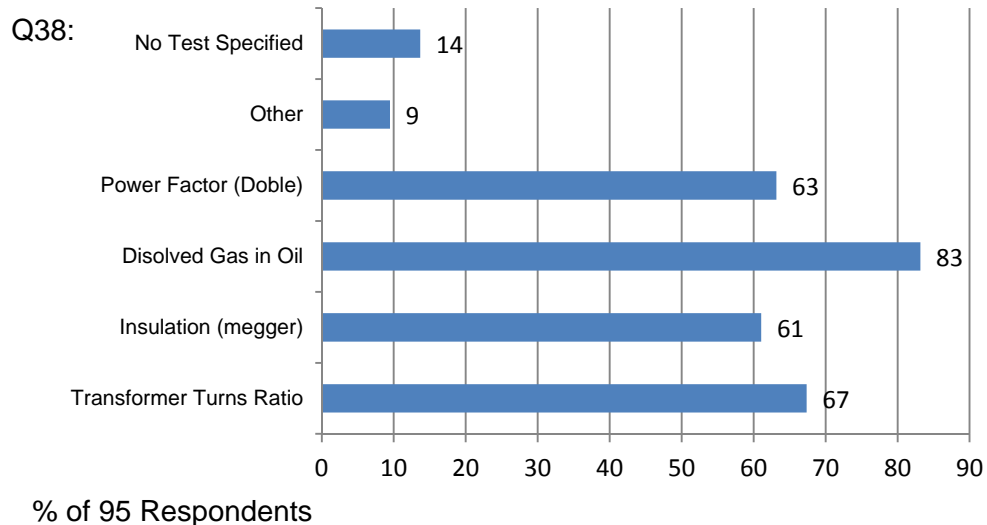
Q37: Provided opportunity to comment on testing of SPRs described in Q36 (45 respondents).

Summary of responses:

- Manufacturer’s test kit - 15
- Unspecified origin of test kit - 12
- Describe pressure test procedure - 10
- Utility designed test kit – 5
- Unknown - 4

Q38: If sudden pressure “trip” is employed, what diagnostics/procedures are used after a sudden pressure “trip” event (for example, turns ratio, insulation resistance, gas-in oil)?

Q39: If sudden pressure “alarm” is employed, what diagnostics/procedures are used after a sudden pressure “alarm” event (for example, turns ratio, insulation resistance, gas-in oil)?

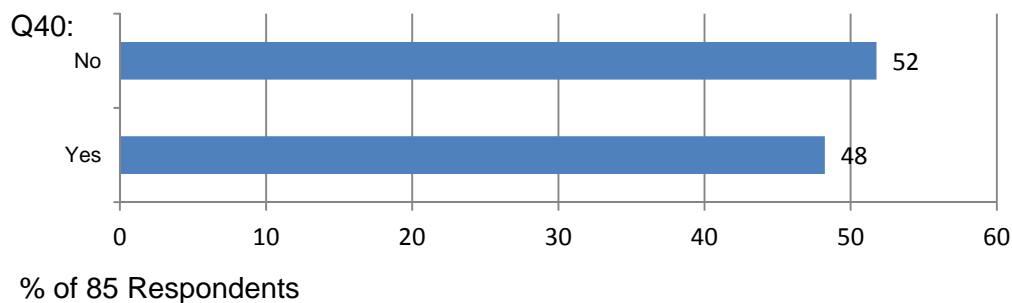


A38, A39: Most utilities perform multiple diagnostic tests following a transformer trip on a SPR operation (DGA leads the way). However, significantly fewer utilities performed the same tests if the SPR is used only for alarming.

Summary of comments describing “Other” diagnostic tests in Questions 38 and 39 (24 total responses):

- Inspection
- Fault study
- Impedance
- Doble excitation
- Gas accumulation relay inspection
- Physical damage
- Fault, DFR records
- Winding resistance
- Sweep Frequency Response Study (SFRS)
- Leakage reactance test
- Combustible gas

Q40: Has your company experienced a sudden pressure device operation/misoperation during routine transformer maintenance?

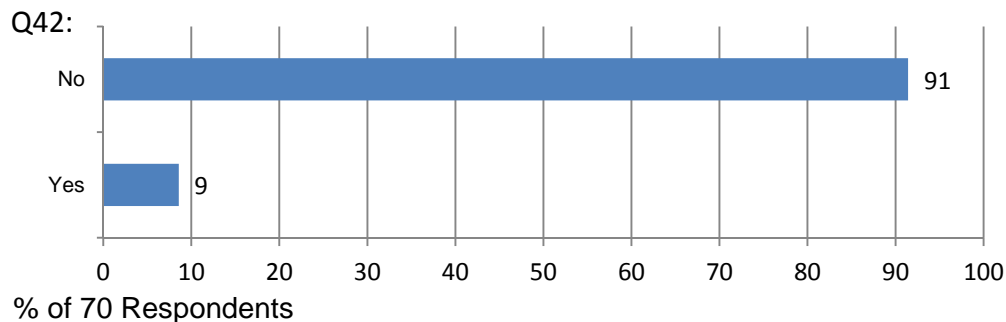


A40: About half of respondents have experienced accidental SPR trips during routine maintenance.

Q41 What were the causes of accidental trips (35 respondents):

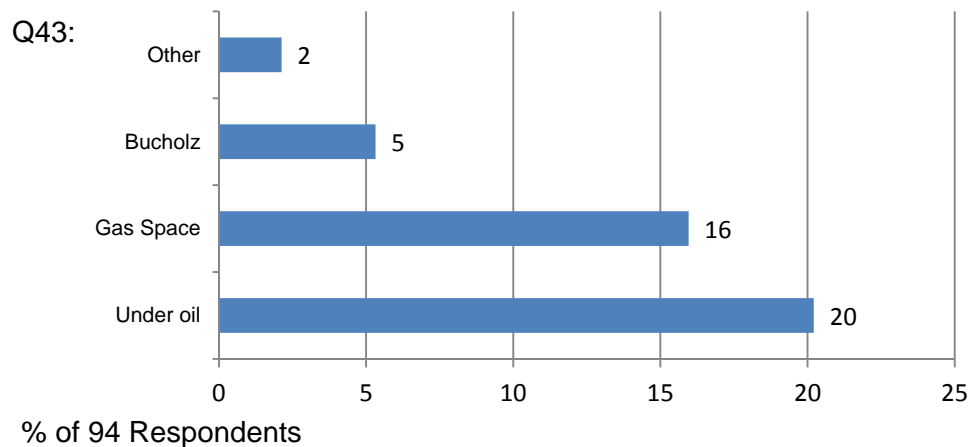
- Test procedure - 12
- Over-pressurized tank / adding nitrogen – 3
- Seismic / external vibration - 3
- Oil sampling – 3
- Failed to disable trip during maintenance - 2
- Opening valve to relay - 2
- Pumps re-started after an outage
- Over-pressure valve left shut / mislabeled as SPR
- Adding/removing oil from main tank
- Sampling from gas accumulation device
- Oil in device (in-gas SPR)
- Improper use of test switches
- Moisture in connector
- Bad relay
- Relay calibration
- Inadequate check-out during construction

Q42: Has your company experienced differences in sudden pressure relay operation and/or performance for the “in gas” verses “in oil” applications?



A42: Very few respondents have noticed any difference in performance between “in gas” and “under oil” SPRs.

Q43: Has your company experienced a sudden pressure relay operation for an internal transformer fault that no other protective relays operated for, or that operated after the sudden pressure relay? If so, indicate what relay type.

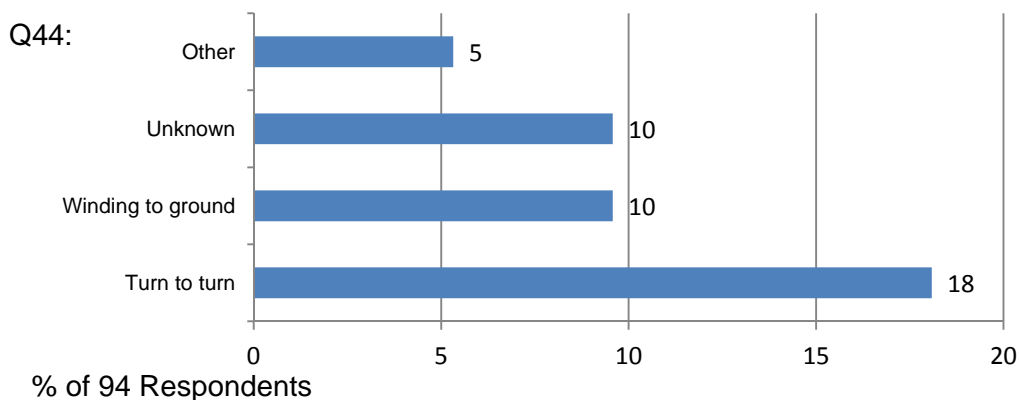


A43: About 40% of respondents have experienced at least one internal transformer fault that was detected by the SPR, but not some other relay.

“Other” causes (2 respondents):

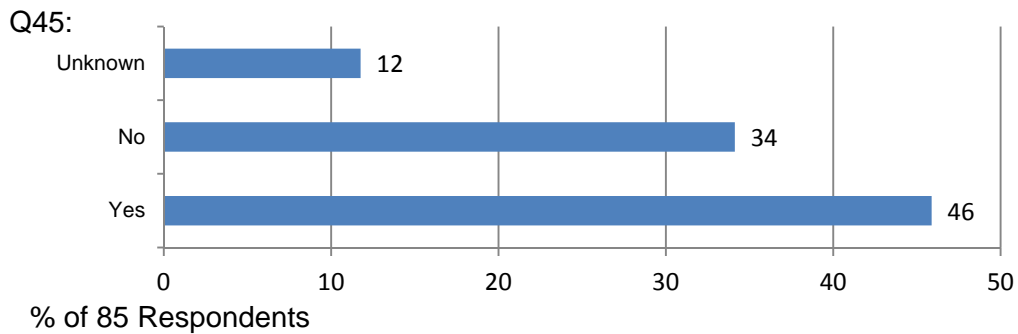
- Differential
- Nothing identified

Q44: What was the fault type identified in the above Question 43?



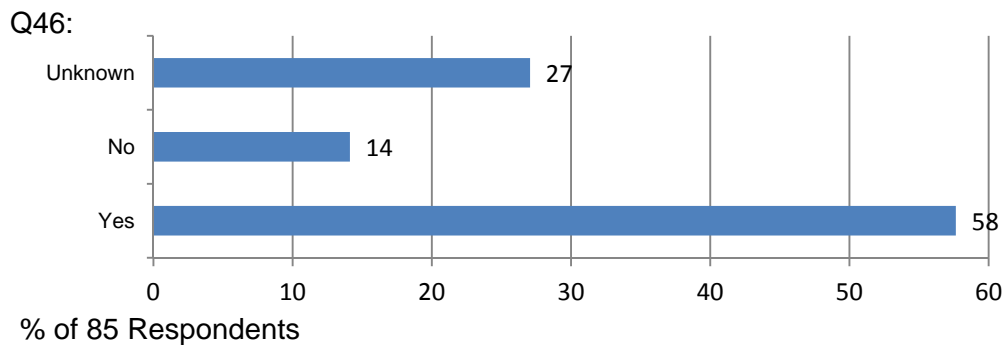
A44: “Other” fault types (6 respondents) were attributed to bushing to tank (2), nearby lightning strike (SPR misoperation), LTC, winding movement, and closing out of synchronism.

Q45: Does your company feel that transformer differential protection provides adequate sensitivity for transformer turn-to-turn faults?



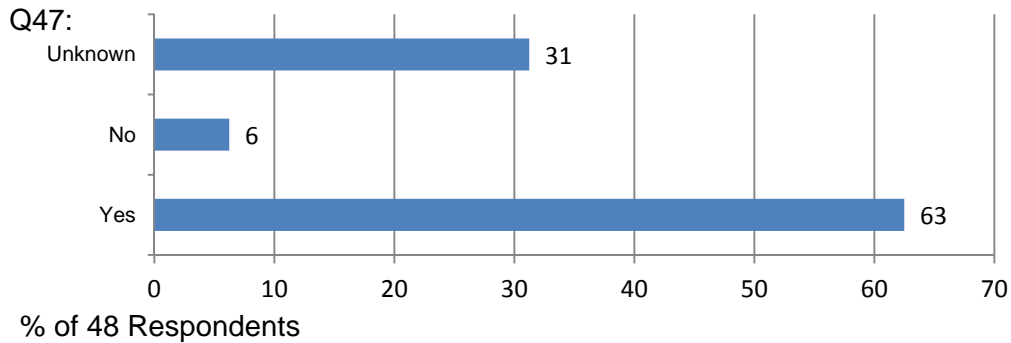
A45: There are divided opinions on whether differential protection is sensitive enough to detect turn-to-turn faults, with a small plurality saying that differential relays are sensitive enough.

Q46: Has your company experienced a transformer failure attributed to a turn-turn fault?



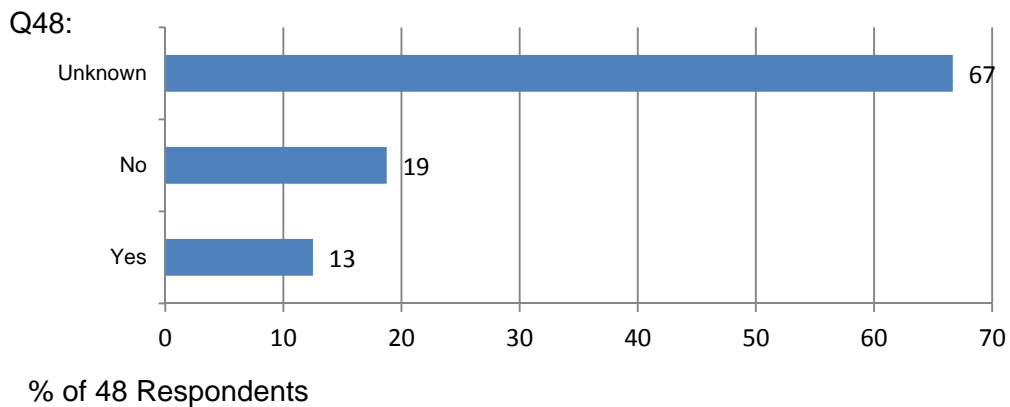
A46: Most utilities have experienced failures due to turn-to-turn faults.

Q47: If you answered Yes to Question 46, did the sudden pressure relay detect the turn-to-turn fault?



A47: Very few turn-to-turn faults went undetected by SPRs for most utilities that have experienced such faults, though nearly a third of cases are unknown.

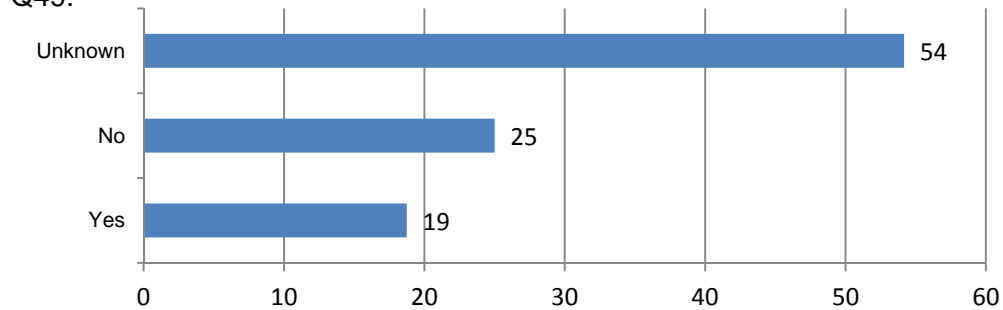
Q48: Did the analysis show that the sudden pressure relay scheme reduced damage due to the turn-to-turn fault?



A48: Even when the SPR detected the fault and operated correctly, most utilities don't claim that the SPR operation reduced transformer damage.

Q49: Did the differential protection provide faster or more sensitive protection for the turn-to-turn fault?

Q49:

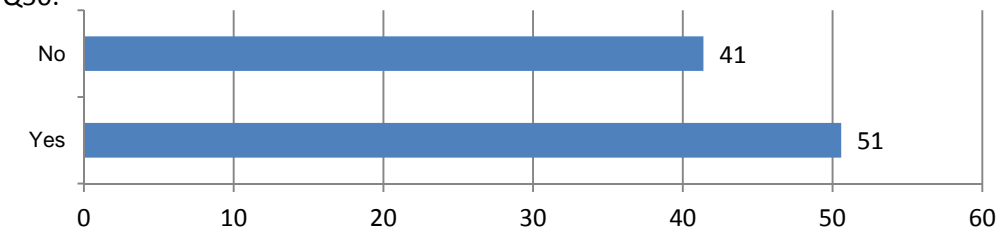


% of 94 Respondents

A49: Most utilities also don't know whether the differential or SPR relay operated faster.

Q50: Has your company experienced a sudden pressure relay misoperation that was attributed to high fault currents through the transformer for external faults?

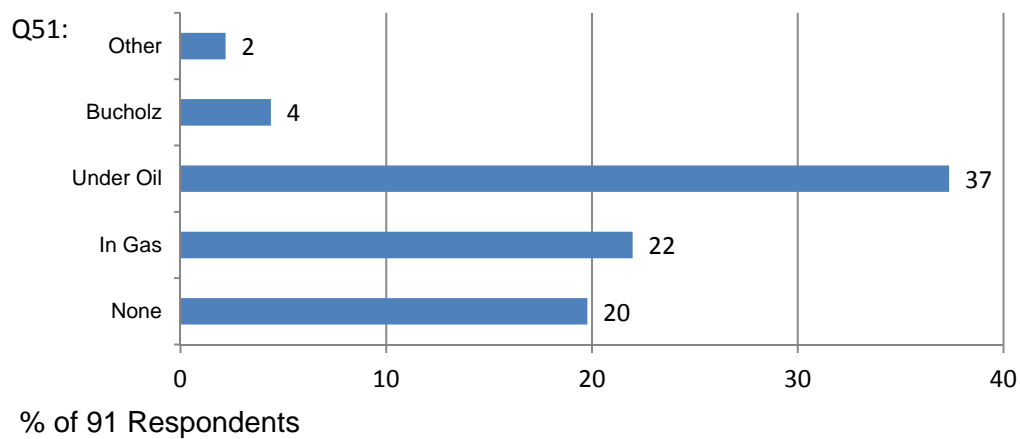
Q50:



% of 85 Respondents

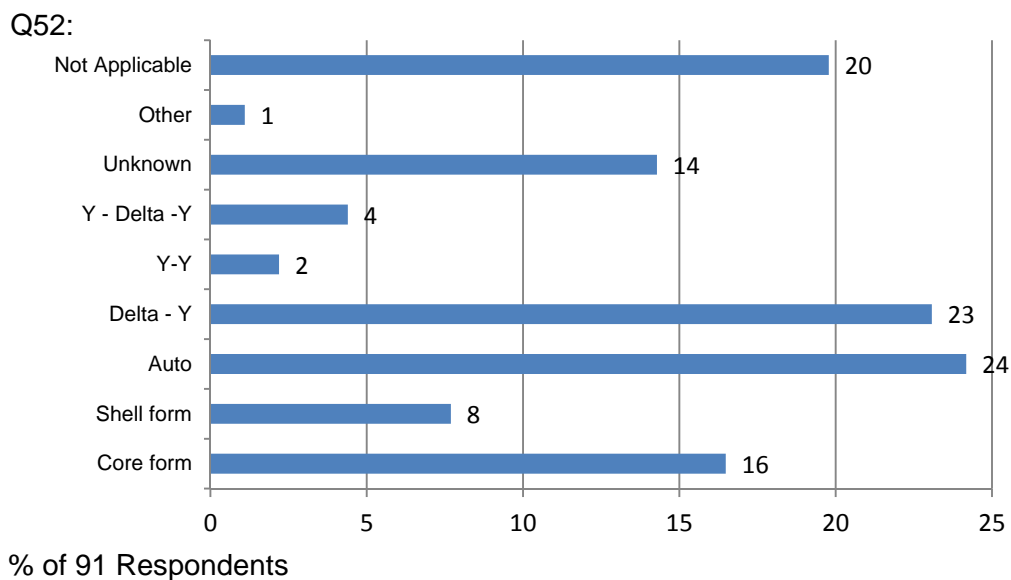
A50: About half of utilities have experienced SPR misoperations on external faults due to high through fault current.

Q51: If your company has experienced an improper operation of a transformer sudden pressure relay attributed to an external fault, what relay types were involved?



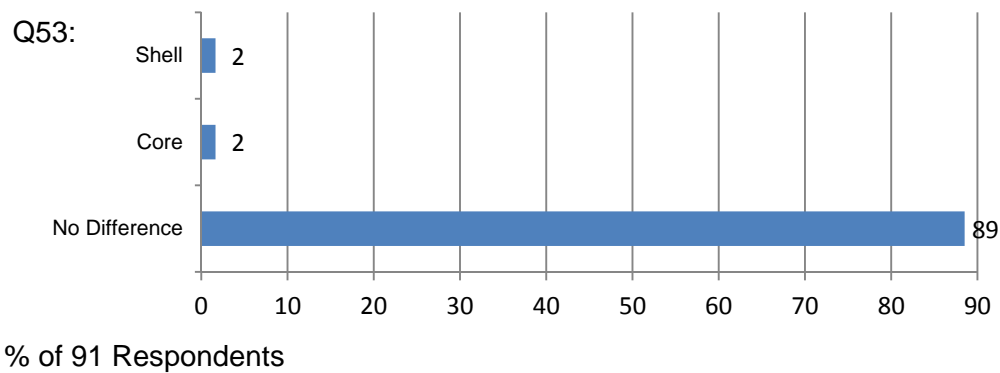
A51: Most misoperations on high fault current were attributed to “under oil” SPRs. However, the numbers seem to be approximately in line with the existing population of users (see Questions 4E-7E). The only known “other” misoperation (2 respondents) in this category was due to “any of the above due to lack of using form Form “c” contact.”

Q52: If your company has experienced an improper operation of a transformer sudden pressure relay attributed to an external fault, what types of transformers were involved?



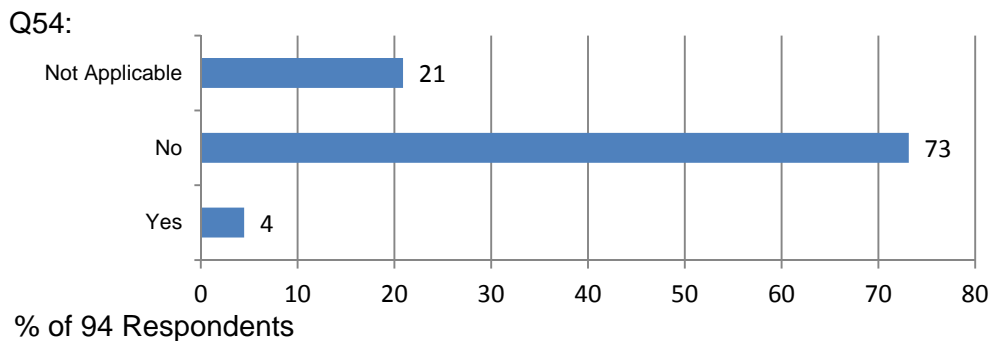
A52: There is no clear pattern between transformer type and SPR misoperations on external faults.

Q53: Has your company noticed any differences in sudden pressure relay misoperations for core form verses shell form transformer designs?



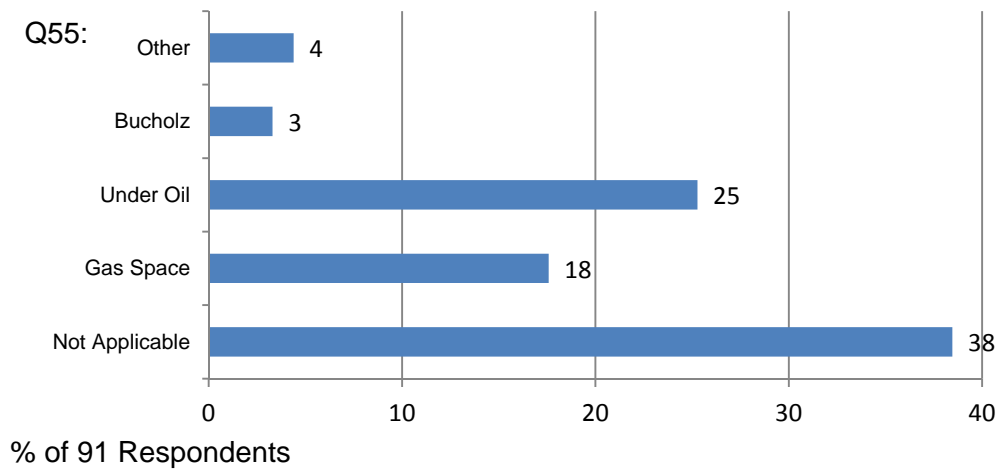
A53: There is no clear advantage on SPR performance between core or shell form transformer types.

Q54: Has your company noticed differences in sudden pressure relay misoperations correlated with transformer winding configurations?



A54: There is no advantage on SPR performance for transformer winding configuration.

Q55: If your company has experienced an improper operation of a transformer sudden pressure relay attributed to causes other than an external fault, what relay types were involved?

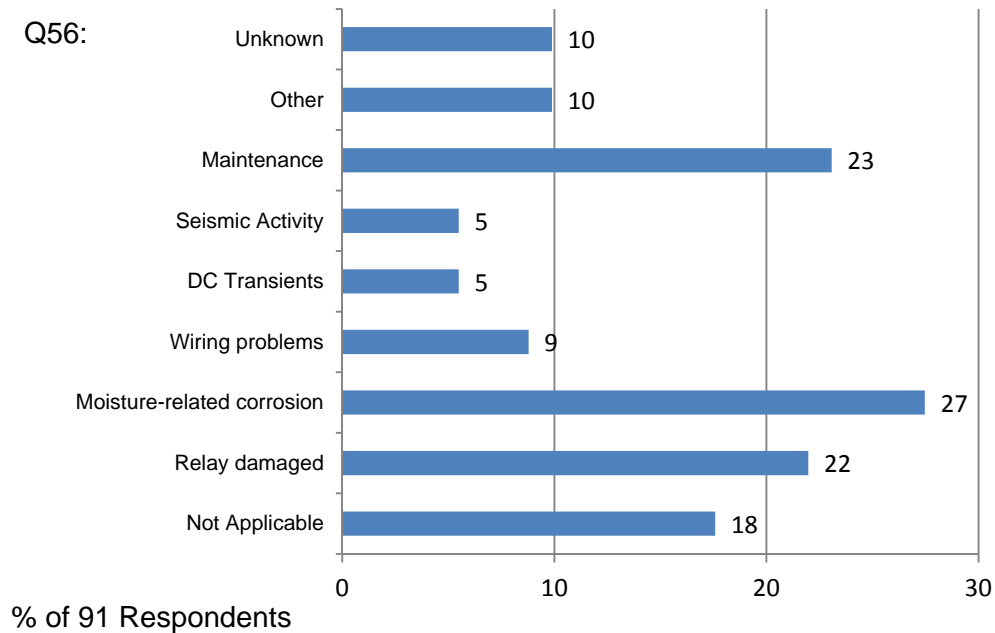


A55: Most SPR misoperations not related to external faults were attributed to “under oil” SPRs. However, the numbers seem to represent a lower numbers of users of “under oil” relays than other SPR relay types (see Questions 4E-7E).

“Other” misoperations (4 respondents) were attributed to

- auxiliary relay – 2
- LTC over pressure
- Water in the device

Q56: If your company has experienced an improper operation of a transformer sudden pressure relay attributed to causes other than an external fault, what were the causes of the misoperations?



A56: Moisture-related corrosion, maintenance activity and damaged relays are the largest causes of SPR misoperations not related to external faults.

Other causes (10 respondents) included:

- Vibration related - 3
- Cold weather mystery
- Moisture and freezing
- Auxiliary package
- Oil level – Bucholz
- Manufacturer problem
- Calibration
- Failed SPR