



Test Summaries of the IFD™ Sensor in Oil Filled Electrical Distribution Equipment

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Executive Summary

Utility line crews frequently perform manual re-energizing of distribution transformers. Industry studies indicate on average between 3% and 5% of the in-service population of pole top transformers are re-energized annually.^[1] Because of the potential hazards caused by the possibility of reclosing on a faulty transformer, all reclosing should follow strict safety procedures. These procedures are prone to human error and crews are often under pressure to restore power rapidly, putting themselves at risk. These risks can be eliminated when transformers are equipped with a reliable indicator that will signal the presence of an internal fault. The Internal Fault Detector (IFD) described in this report is such an indicator.

The IFD is designed for installation in the air space of oil filled electrical distribution equipment and is activated by the unique, rapid pressure rise that accompanies an internal arcing fault. Once activated it displays a highly visible signal, identifiable day or night to a ground based observer.

The feasibility of the concept was proved and patented in 1993/4. Design criteria satisfying side mounting, inclusion of the PRV and other requirements arising from discussions with Utilities and Transformer Manufacturers are detailed and information provided as to how these requirements were met. The operating conditions reflected in the section on design criteria include:

- A required minimum operating life of thirty years
- Be maintenance free over the life of the transformer
- Be able to reliably detect internal faults at current levels as low as 500 A.

To satisfy these requirements a detailed set of design criteria was established and explanations given of how these criteria were met. As an example, to meet the design criteria of responding reliably to a wide range of pressure transients that might occur in the transformer air space, starting from peak pressure values as low as 0.5 psig (3.5 kPa) within five to seven milliseconds. To meet this requirement a pressure sensing membrane was developed.

On-going development projects are led by IFD Corporation with utility and manufacturer technical reviews held formally and informally through each stage of the process. This includes each iteration of design, prototyping, testing, IFD production and installation into transformers in manufacturing plants.

Certification tests are performed on completed units to ensure they meet the specified requirements. Powertech Labs performs a wide range of high power equipment testing including internal arcing fault testing on randomly selected units installed in various designs of transformers and with various input currents ranging from 500 A through 8000 A. These internal fault tests are performed using the withstand test protocol outlined in the IEEE C57.12.20 transformer standard as a guideline.



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1. Introduction

This report describes the tests and results from 2000 to 2011 of the internal fault detector (IFD); designed for installation in oil filled electrical distribution equipment.

The IFD is a safety device that can clearly be seen from the ground in daylight, and during the night with a hand held flashlight. When activated by an internal arcing fault, it signals to the line crews the presence of potentially hazardous conditions so preventing any attempt to re-energize the faulted unit.

When an IFD is installed inside a distribution transformer, the diagnostic procedures that are prone to human error and currently must be conducted on every disconnected transformer are no longer required. Therefore power restoration to the customers can proceed more safely and faster.

The IFD incorporates the conventional pressure relief valve (PRV), to allow the relief of overpressures caused by fluctuations in operating temperatures and includes features specific to performance in ester based fluid environments.

The IFD has been installed in pole type distribution transformers in Canada, the US and various other countries since 2002. From the beginning of field installations for utilities the IFD has proven to be a robust and reliable sensor. After approximately 10 years experience with the IFD sensor, a senior lineman commented...“Now when we get an outage call we hope the transformer is one with an IFD on it.”



2. Design

The first designs evolved from prototypes built in 1993 / 94, which proved the feasibility of the concept. The design has since continued to evolve and change through time to meet the expanding set of requirements defined by both utility and transformer manufacturers.

This section details the design criteria required to satisfy utility and manufacturing requirements.

2.1. Product requirements

The operating conditions reflected in the selection of the product requirements include the following.

Utility outage statistics indicate that between 3% and 5% of the total installed population of pole mounted transformers will experience an internal fault every year.^[1] It follows that in the normal case the IFD may have to operate reliably for the first time after some thirty, or more, years of service.

- IFD's must be maintenance free over the expected service life of the transformer,

And

- IFD's must be able to reliably trigger and signal the presence of an internal fault in a pole mounted distribution transformer even if the fault current magnitude is as low as $500 A_{rms}$.

To satisfy this and other operating conditions the following set of design criteria was defined.

1. Reliably activate an external signal for pressure transients of at least 0.5 psi / 5-7 ms (3.5 kPa / 5-7 ms) resulting from an internal arcing fault.
2. Not trigger during slower pressure variations expected to occur in the air space of the transformer due to the fluctuations in ambient temperature or load variations, also due to any bolted faults at the secondary terminals of the transformer.
3. Provide a reliable service life of 30 years installed in typical transformer.
4. The device should be a mechanical device and not electrically connected to the transformer.
5. The installation shall not interfere either mechanically or electrically with any manufacturing procedures including testing, field installation and normal operation of the transformer.
6. Not provide a conductive path through the wall of the transformer tank.
7. Provide a positive indication by means of an external signal flag, highly visible to a trained person located on the ground. This person should be able to distinguish between the normal and activated positions. The flag should not detach from the body of the IFD upon operation.
8. Be designed to prevent accidental triggering under a variety of operating conditions, including mechanical vibrations or seismic shocks.



9. After activation be non re-settable from outside the enclosure.
10. Have an easy to remove shipping lock that will prevent accidental triggering during storage, shipment and installation
11. Incorporate a pressure relief valve (PRV) with optional settings that meet either the CSA C2.2 or IEEE C57.12.20 transformer standards.
12. Incorporate the ability to allow manual operation of the PRV, without causing the IFD to activate.
13. Be sealed to prevent the entrance of any foreign materials or moisture into the tank, or any internal materials to exit into the environment at pressures below the relief pressure setting of the PRV.
14. Provide access to the interior of the transformer tank to allow for pressure and vacuum processes during equipment manufacturing.
15. Be suitable for installation in a typical transformer tank.
16. Be cost effective to manufacture, easy to assemble and install in a standard transformer tank.
17. Be unaffected by contact with the insulating oils used in the transformer, and also be compatible with oil vapors and hydrocarbon gases generated through any oil decomposition.
18. Ensure all parts that are exposed to weathering be resistant to UV radiation.
19. Be designed to minimize ice build up on the external parts exposed to weathering.



2.2. Materials

Sensor components:

Polybutylene terephthalate (PBT) has been selected for the main components of the IFD for its:

- F1 rating (best available) for outdoor suitability as described by the UL 746C standard^[7] which describes tests for UV light durability as well as water exposure and immersion.
- Stable performance over a wide range of temperatures
- Chemical resistance

A glass fiber reinforced grade of PBT is used for the rigid components.

Sealing components:

Nitrile rubber has been selected for the tank gasket and pressure relief valve (PRV) o-ring for its:

- Common use as a gasket material in oil filled electric distribution equipment
- Stable performance over a wide range of temperatures
- Chemical resistance

Alcryn melt processable rubber has been selected for the main barrel seal for its:

- Ability to be injection molded onto PBT components to provide a direct mechanical bond
- Stable performance over a wide range of temperatures
- Chemical resistance

2.3. Physical dimensions

Physical dimensions of the unit were selected to ensure the device would fit easily into the airspace of distribution transformers, and, external parts were sized to minimize the surface exposed to weathering, including ice build up.

The images below are approximately actual size, and a detailed overview drawing is available in the appendix.



Figure 1: IFD sensor (approximate scale: 1:1)



2.4. Functional components

The functions of some of the key components in the IFD system are described below.

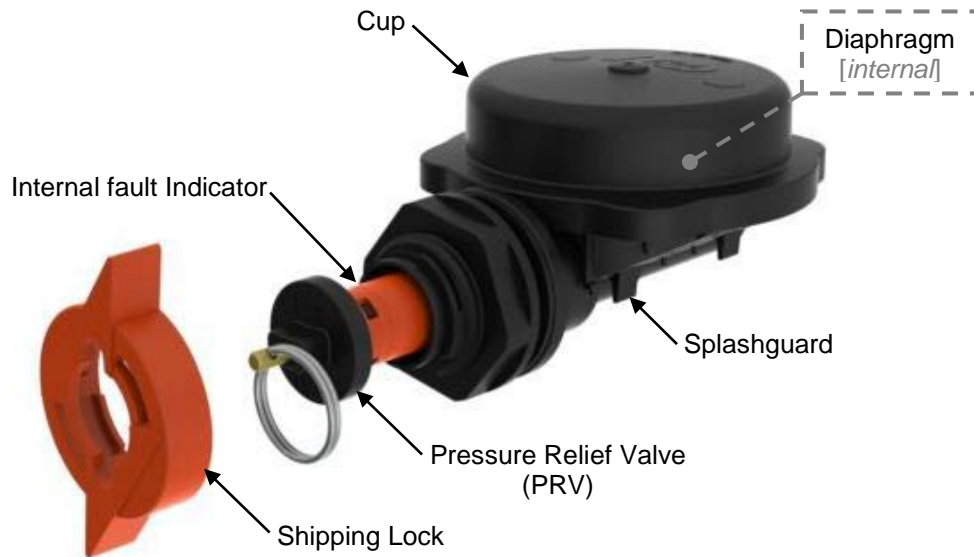


Figure 2: IFD sensor labeled

Diaphragm

A critical component of the IFD's activating mechanism is the pressure-sensing diaphragm. IFD Corporation considered the initial design to be too difficult to allow for consistent maintenance of appropriate tolerances for mass production. Therefore the current diaphragm design, which is more suited to quantity production and long service life, was chosen.

Cup and splashguard

The cup provides a controlled volume to allow for the correct operation of the diaphragm. It includes a compensating vent (orifice) sized to minimize pressure differentials across the membrane at slower pressure fluctuations, thus preventing any movement of the membrane, which might be caused by load and temperature changes.

The diaphragm is protected against oil splashing by being enclosed by the cup and splashguard.

Internal fault indicator

When a fault is detected by the IFD a highly visible indicator is extended through the wall of the transformer. This indicator is bright orange in color and can be clearly seen from the ground. To prevent tampering it cannot be reset after it has operated.

Regardless of whether the indicator is in the set, or activated position it provides a positive seal, preventing ingress of air and moisture.



Shipping lock

To prevent the IFD triggering while the transformer is being moved or transported, a shipping lock is installed. The line crew must remove this lock after installation. The line crew must also re-install a shipping lock when removing a transformer from service that has not experienced an internal fault.

Pressure relief valve (PRV)

An important requirement identified by utilities was to include the PRV function into the design of the IFD.

The PRV is available in two versions and can be specified to meet the requirements outlined in either the CSA C2.2 standard, or the IEEE C57.12.20 standard. The PRV remains operable whether or not a shipping lock is installed, or if the indicator is in the set or activated position.

For inspection purposes line crews can manually operate the PRV in the same manner as the conventional PRV by pulling on the provided pull ring.



3. Electrical testing

The following section describes the testing that was performed on the IFD™ sensor to ensure it meets application and electrical requirements for use in oil filled electrical distribution equipment.

3.1. Internal arcing faults

To certify the performance of the IFD's a series of tests were performed on various size and style distribution transformers following the test protocol outlined in C57.12.20 section 9.1 using an input voltage of 14.4 kV and variable parameters for arc depth and input current to simulate various possible internal arcing faults.

These tests were observed by utility engineers and technical experts to provide guidance during testing and ensure validity of the results.

[Complete table and discussion follows on next page]



Results:

ID	Tx (kVA)	Type	Oil	Air Vol. in ³ (cm ³)	Input (A _{rms})	Current (sym. / offset)	Arc (V)	Arc time (ms)	Arc energy (KJ)	P _{peak} psig (kPa)
1.	25	Pole	Min.	137 (2245)	509	Sym.	996	32.4	7.10	0.78 (5.4)
2.	25	Pole	Min.	137 (2245)	509	Offset	313	18.1	3.31	2.43 (16.8)
3.	75	Pole	Min.	1992 (32643)	509	Offset	456	12.9	3.93	1.95 (13.4)
4.	100	Pole	Min.	1992 (32643)	509	Sym.	863	33.1	6.47	1.08 (7.4)
5.	100	Pole	Min.	2714 (44475)	509	Sym.	180	40.4	11.79	1.21 (8.3)
6.	75	Pole	Min.	1992 (32643)	504	Offset	311	17.0	1.53	1.55 (10.7)
7.	25	Pole	Min.	137 (2245)	504	Offset	228	11.9	0.91	0.74 (5.1)
8.	75	Pole	Min.	1992 (32643)	504	Offset	494	10.7	3.29	2.65 (18.3)
9.	100	Pole	Min.	2714 (44475)	504	Offset	594	17.2	2.97	2.10 (14.5)
10.	10	Pole	Min.	452 (7407)	504	Sym.	278	14.0	1.37	3.31 (22.8)
11.	100	Pole	Min.	2714 (44475)	504	Offset	785	17.1	2.09	0.58 (4.0)
12.	25	Pole	Min.	1374 (22516)	504	Sym.	1270	31.6	6.33	6.31 (43.5)
13.	50	Pole	Min.	1700 (27858)	504	Sym.	309	13.7	1.20	0.90 (6.2)
14.	100	Pole	Min.	2714 (44475)	7990	Sym.	1240	32.7	209.00	20.90 (144.1)
15.	100	Pole	Min.	2714 (44475)	7990	Offset	283	13.2	36.60	7.40 (51.0)
16.	25	Pole	Min.	1374 (22516)	5000	Offset	440	13.1	37.60	7.20 (49.6)
17.	25	Pole	FR3	1206 (19763)	497	Sym.	819	24.7	4.96	1.24 (8.5)
18.	25	Pole	FR3	1206 (19763)	497	Sym.	569	7.6	1.26	1.77 (12.2)
19.	75	Pad	Min.	4083 (66908)	750	Sym.	382	7.4	1.39	0.32 (2.2)
20.	75	Pad	Min.	4083 (66908)	1000	Sym.	381	7.1	1.60	0.32 (2.2)
21.	75	Pad	Min.	4083 (66908)	1500	Sym.	450	6.7	3.30	0.30 (2.1)
22.	75	Pad	Min.	4083 (66908)	1500	Sym.	494	7.0	3.84	0.33 (2.3)
23.	75	Pad	Min.	4083 (66908)	8060	Sym.	1480	6.8	13.30	recorder failure
24.	75	Pad	Min.	4083 (66908)	8060	Sym.	635	7.0	24.40	5.1 (35.2)

The above data shows no clear relation between the air-space volume and the peak pressure reached during the internal arcing faults. In addition, the duration of the arcing tends to be longer in tests with symmetrical current, clearly indicating that the interruption of the symmetrical current is more difficult for the fuse cutout.



The lack of influence of the air-space volume on the transient pressure rise as well as the scatter of the peak pressure were previously observed and reported by Ontario Hydro researchers who performed a significant number of tests to obtain data for a statistical evaluation.^[2]

In general, the results show a large scatter in all of the recorded and derived parameters, and there is no clear correlation between arc energy, $\int I * dt$, and $\int I^2 * dt$, or arc duration and the peak pressure.

Further inspection of the pressure curves traced during testing shows a common rate of rise of pressure across all tests of 0.5 psi / 5-7 ms (3.5 kPa / 5-7 ms), regardless of the input current or resulting peak pressure. It is this rate of rise that allows the IFD to mechanically differentiate between the pressure changes inside a transformer experienced during normal operation from the pressure rise created during an internal arcing fault.

As the IFD is a mechanical device utilizing a diaphragm to capture the mechanical energy created by the event it is detecting, the device requires a minimum applied force on the diaphragm for activation to ensure the reliable operation of the indicating components and to maintain the ability of the diaphragm to differentiate between the rate of rise experienced during an internal arcing fault and all other pressure events experienced by a transformer. Considering the following three factors:

- The wide range of pressures recorded during 500 amp internal fault tests
- The minimum threshold for activation, or mechanical lifting force, is related to the peak pressure generated during the fault
- Utility engineers requested a minimum activation threshold relating to an input current of 500 amps for pole mounted transformers.

The minimum activation threshold for peak pressure of 0.5 psig (3.5 kPa) was selected as it was the lowest of the data points from testing completed in 1999 through 2001 with a 500 amp input current, test ID's 1 to 16.

The combination of the minimum rate of rise of 0.5 psi / 5-7 ms (3.5 kPa / 5-7 ms), and the minimum peak pressure of 0.5 psig (3.5 kPa) provides sufficient force for a mechanical differentiation factor large enough to ensure reliable detection of internal faults without risk of false activations due to normal pressure changes inside a transformer.

Test ID's 17-24 show the design validation tests performed on the IFD in 2007 and 2011, and these tests confirmed the IFD's operated as designed by activating the indicator flag at a minimum threshold of 0.5 psi / 5-7 ms (3.5 kPa / 5-7 ms), and in some cases showed higher performance levels of as low as 0.3 psi / 5 ms (2.1 kPa / 5-7 ms).

Samples of the oscillograms recorded during internal arcing fault tests are in the appendix.



3.2. Transformer Impulse

To validate that the IFD has no impact on the electrical function of the transformer, impulse tests as specified in IEEE C57.12.90 were performed by a customer transformer manufacturer with the detailed results provided in the appendix.

Results:

For this test a pass is considered to be a transformer that passes the following two criteria:

- The transformer passes the impulse test outlined in IEEE C57.12.90 with an IFD installed.
- The IFD is not damaged / does not activate during the test.

ID	Tx size	Tx type	kV _{peak}	Wave type	Result
25.	25 kVA	Pole mount	145	Full wave	Pass
26.	25 kVA	Pole mount	167	Chopped wave	Pass

These test results confirm that the IFD does not impact or otherwise affect the electrical integrity of the transformer. In addition, this test is completed with the IFD included on an ongoing basis during the transformer manufacturing process by all manufacturers, and the IFD continues to pass this test.

3.3. External short circuits

To confirm the IFD will not operate due to an external fault, a type test of the long duration short circuit test defined in IEEE C57.12.90 was performed at Powertech's High Power Lab.

Results:

For this testing a pass is considered to be an IFD that does not activate during the test cycle.

ID	Tx size	Tx type	Result
27.	25 kVA	Pole mount	Pass
28.	25 kVA	Pole mount	Pass

These test results confirm that an external short circuit will not activate the IFD.

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.



3.4. Bay-o-net under oil expulsion fuse

To confirm the IFD will not operate due to the normal operation of a bay-o-net under oil expulsion fuse type tests were performed at Powertech's High Power Lab.

The test was designed with the intention of creating a plausible worst case scenario for the interruption of current by the bay-o-net fuse.

A distribution Standards Engineer from one of IFD Corporations utility customers was present to observe the testing and verify the validity of the results.

A diagram of the test circuit used for testing the bay-o-net fuses is in the appendix.

Results:

For this testing a pass is considered to be an IFD that does not activate during the test cycle.

ID	Type	Description	Equip	Input current (A _{rms})	Input volts (kV)	Result
29.	Bay-o-net fuse	Under oil expulsion fuse operation @ 9.5 times Tx rated current	Pad mount 100 kVA	67	14.4	Pass
30.		Under oil expulsion fuse operation @ 22 times Tx rated current		153	14.4	Pass
31.		Under oil expulsion fuse operation @ 22 times Tx rated current		153	14.4	Pass

These results confirm the IFD is compatible for use with equipment protected by a bay-o-net under oil expulsion fuse.

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.



3.5. Load break switch

To confirm the IFD will not operate due to the normal opening and closing operations of a load break switch type tests were performed at Powertech's High Power Lab.

The test was designed with the intention of creating a real world condition for the interruption of current by the load break switch.

A distribution Standards Engineer from one of IFD Corporations utility customers was present to observe the testing and verify the validity of the results.

A diagram of the test circuit used for testing the load break switch is in the appendix.

Results:

For this testing a pass is considered to be an IFD that does not activate during the test cycle.

ID	Type	Description	Equip	Input current (A _{rms})	Input volts (kV)	Result
32.	Load break switch	Manual switching operation (1 test = close / open)	Pad mount 100 kVA	9.5	14.4	Pass
33.				9.5	14.4	Pass
34.				9.5	14.4	Pass

These results confirm the IFD is compatible for use with equipment that includes a load break switch.

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.



3.6. Secondary breaker

To confirm the IFD will not operate due to the normal operation of a secondary breaker a type test was performed at Powertech's High Power Lab.

The test was designed with the intention of creating a real world condition for the interruption of current by the secondary breaker.

A distribution Standards Engineer from one of IFD Corporations utility customers was present to observe the testing and verify the validity of the results.

A diagram of the test circuit used for testing the secondary breaker is in the appendix.

Results:

For this testing a pass is considered to be an IFD that does not activate during the test cycle.

ID	Type	Description	Equip	Input current (A _{rms})	Input volts (kV)	Result
35.	Secondary Breaker	Overload interruption	Pole mount 25 kVA CSP	753	14.4 / 0.240	Pass

These results confirm the IFD is compatible for use with transformers protected by a secondary breaker.

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.



3.7. Tap changer for voltage regulators

To confirm the IFD will not operate when the tap switch in a voltage regulator switches positions to regulate voltage a type test was performed at Powertech's High Power Lab.

Although the exact service conditions of the equipment tested is not known, the test was performed on a voltage regulator that was originally built in 1977 to ensure the tap changer being tested had seen substantial service. The test was performed by energizing the voltage regulator under full rated load and remotely operating the tap changer from positions 0 through positive 16, and 0 through negative 16.

A distribution Standards Engineer from one of IFD Corporations utility customers was present to observe the testing and verify the validity of the results.

A diagram of the test circuit used for testing the load break switch is in the appendix.

Results:

For this testing a pass is considered to be an IFD that does not activate during the test cycle.

ID	Type	Description	Equip	Input current (A _{rms})	Input volts (kV)	Result
36.	Tap changer	Tap changer operation under full load (± 16 tap positions)	Voltage Regulator 76.2 kVA	101 (load amps)	7.2	Pass

These results confirm the IFD will not operate as a result of the normal functioning of a tap changer used in voltage regulators.

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.



4. Mechanical testing

The following section describes the testing that was performed on the IFD™ sensor to ensure it meets the physical and material requirements for use in oil filled electrical distribution equipment.

4.1. Thermal cycling

To explore the thermal stability of the IFD, thermal cycling between -40°C and 105°C (-40°F to 221°F) was conducted on 10 IFD's. Thermal cycling was conducted at the Polymer Engineering Company Ltd. materials laboratory using the Instron environmental chamber.

Thermal cycling consisted of ten, one-hour cycles during which the temperature was varied from -40°C to 105°C (-40°F to 221°F) and back once per cycle. Parts were visibly examined for evidence of physical failure and diaphragm function after 1, 5 and 10 full cycles. Five of the 10 parts were tested with shipping locks in place.

Results:

For this testing a pass is considered to be an IFD that activates in the IFD activation chamber at 0.5 psi / 5-7 ms (3.5 kPa / 5-7 ms) after the completion of 10 thermal cycles.

ID	Shipping lock	Result
37.	No	Pass
38.	No	Pass
39.	No	Pass
40.	No	Pass
41.	No	Pass
42.	Yes	Pass
43.	Yes	Pass
44.	Yes	Pass
45.	Yes	Pass
46.	Yes	Pass

These results show that all of the IFD's subjected to thermal cycling maintained full sensor functionality after the end of the test cycle.



4.2. Diaphragm

A robust diaphragm is required not only during its service life, but also during initial manufacturing of the electrical equipment it is being installed in.

Using a pressure transducer and data logger, research was performed at various manufacturing sites and it was determined the maximum rate of pressure change the IFD is likely to encounter during processing is approximately 100 psi / s (690 kPa / s)

Results:

For this testing a pass is considered to be a diaphragm with no visible permanent deformation of the diaphragm after exposure to the tested rate of pressure change.

ID	Rate of change psi / s (kPa / s)	# tested	# passed
47.	45 (310)	5	5
48.	150 (1034)	5	5
49.	300 (2068)	3	3

These results show the IFD diaphragm is sufficiently robust to withstand normal manufacturing processing.

4.3. Nut and barrel strength

To validate the nut and barrel meet strength requirements the nut and barrel were placed through a tank wall and the nut was tightened to 200 in-lb (23 N-m) and held for a duration of 15 minutes.

This test represents an extreme scenario as the IFD nut is specified to be tightened to 90 ± 10 in-lb (10 ± 1 N-m) for transformer manufacturing.

Results:

A pass for this testing is considered to be a nut and barrel with no visible signs of deformation or cracking.

ID	Torque level in-lb (N-m)	Hold time (min.)	# tested	# passed
50.	200 (23)	15	20	20

These results show that the IFD nut and barrel threads meet requirements.



4.4. Slow pressure rise

To verify the IFD sensor will not activate due to pressure fluctuations caused by normal operating conditions IFD's were subjected to various rates of pressure rise without a shipping lock installed.

When investigating pressure variation inside a transformer there are 3 key factors to consider. The effects of thermal and compressive forces created as the oil heats and expands and the effect of gas absorption into the oil.

As it relates to the case of a rapid rise in temperature, the effects of gas absorption can be considered negligible as the dissolution of gas inside a transformer does not occur rapidly and will typically occur over at least several hours.^[3]

Now, according to the Simple Gas Law, an increase of a 10°C (18°F) inside a transformer will result in:

1. A rise in pressure of the airspace of approximately 0.5 psi (3.5 kPa) assuming a constant volume thermal rise.
2. In a typical 25 kVA pole mounted transformer an approximate oil rise of 0.2 inches (2.5 mm) will occur using the mean value 0.00075 / °C or for a typical coefficient of oil expansion as outlined in section X1.1 of ASTM D3487^[4]. This reduction of volume of airspace with an original height of 4.5 inches (114 mm) will result in a pressure increase of approximately 0.65 psi (4.5 kPa).

When these 2 factors are combined the result shows that for every 10°C (18°F) increase in temperature, a transformer will experience a pressure rise of approximately 1.2 psi (8.3 kPa).

It is not expected that a distribution transformer under normal operating conditions will achieve a rate of thermal rise of the airspace and oil of 8.3°C / s (15°F / s) which would relate to a rate of pressure rise of 1 psi / s (6.9 kPa / s), and this test scenario is considered to be a worst case, if not extreme condition.

Results:

For this testing a pass is considered to be an IFD that does not activate during the test cycle.

ID	Rate of change psi / s (kPa / s)	# tested	# passed
51.	0.5 (3.5)	5	5
52.	1 (6.9)	5	5

These results show that expected temperature fluctuations that occur due to normal transformer operation will not cause the IFD to activate.

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.



4.5. PRV function

To validate the pressure relief valve (PRV) portion of the IFD meets the minimum venting and sealing requirements of the specified standards the following data was collected.

ID	Standard	Minimum Requirements		# tested	# passed (actual)
53.	IEEE C57.12.20	Activate:	10 ± 2 psig (69 ± 13 kPa gage)	20	20 (10 ± 1 psig)
54.		Reseal:	≥ 6 psig (≥ 42 kPa)	20	20 (≥ 6 psig)
55.		Flow:	≥ 35 scfm @ 15 psig (≥ 16.5 L/s @ 103 kPa gage)	20	20 (≥ 50 scfm)
56.		Zero leakage to	-8 psig (-56 kPa gage)	20	20 (≤ -8 psig)
57.	CSA 2.2	Activate:	30 – 50 kPa (4.35 – 7.25 psig)	20	20 (45 ± 5 kPa)
58.		Reseal:	must reseal	20	20 (≥ 5 kPa)
59.		Flow:	≥ 16 L/s @ 100 kPa (≥ 34 scfm @ 14.5 psig)	20	20 (≥ 23.5 L/s)
60.		Zero leakage to	No spec Same as IEEE C57.12.20	20	20 (≤ -8 psig)

4.6. PRV mechanical strength

To validate the IFD meets the physical requirements as specified by the IEEE C57.12.20 - 2005 standard the following data was collected.

ID	Standard	Specification	# tested	# Passed
61.	IEEE C57.12.20	“The valve shall have a pull ring for manually reducing pressure to atmospheric level using a standard hookstick, and shall be capable of withstanding a static pull force of 112 N (25 lbf) for 1 min without permanent deformation.”	20	20
62.		“The valve shall withstand for 1 min a static force of 445 N (100 lbf) applied normal to its longitudinal axis at the outermost extremity of the body.”	5	5



4.7. Pressure and vacuum testing using dry air

To validate seal performance requirements are met, IFD's were tested at various pressure and vacuum levels.

Results:

For this testing, a pass is considered to be a pressure variation of 0 psi over a test duration of 15 minutes.

ID	Sample size	Pressure psig (kPa)	Result
63.	50	12 (82.7)	Pass
64.	50	1.5 (10.3)	Pass
65.	50	-1.5 (-10.3)	Pass
66.	50	-8 (-55.2)	Pass

These results show that the IFD seals perform as required at various levels of pressure and vacuum.

This testing is ongoing as a part of IFD Corporations QC program.



4.8. Static fluid submersion testing

To validate seal performance, IFD's were submerged in water and transformer mineral oil under static conditions and inspected periodically.

It is not expected that an IFD will remain submerged under oil for any extended period of time; however, it is possible an IFD may become submerged in oil at some point in the life of the transformer.

Results:

For this type test, a pass was considered to be no visible oil on the swab inside the catch basin.

ID	fluid	Fluid Height Inches (mm)	Head Pressure Psig (kPa)	1 day	7 days	30 days	300 days
67.	Water	28 (711)	1.01 (7.0)	Pass	Pass	Pass	Pass
68.	Oil	28 (711)	0.92 (6.3)	Pass	Pass	Pass	Pass

These results show that the IFD seal performs as required when submerged under fluid in a static condition.

4.9. Dynamic fluid submersion testing

To simulate an IFD submerged under mineral oil travelling along a conveyor system in a typical manufacturing environment, or being transported on a truck, an IFD was submerged in transformer mineral oil under dynamic conditions and inspected periodically.

Results:

For this type test, a pass was considered to be no visible oil on the swab inside the catch basin of the test setup.

ID	Test fluid	Fluid Height Inches (mm)	Pressure head Psig (kPa)	Test Parameters	Result
69.	Oil	28 (711)	0.92 (6.3)	Max shock: ± 5 g Max Tilt: $\pm 10^\circ$ Duration: 15 min	Pass

These results show that the IFD seal meets requirements when submerged under fluid in dynamic conditions.

4.10. Indicator visibility study

A study to determine the visual ergonomics of the IFD fault indicating flag was performed by the Ergonomics and Human Factors Group of BC Research Inc. The purpose of this testing was to determine the visibility of orange, yellow and light grey as well as to determine how well viewers could distinguish between the activated and non-activated states of the IFD sensor.

To collect the data 5 people were asked to view each color of the IFD at 0° and 90° orientation to the transformer, in both the activated and non-activated states as well as under both day and night light conditions. In order to best represent a 'drive-by visibility' condition the viewing target was arranged as in figure 1.

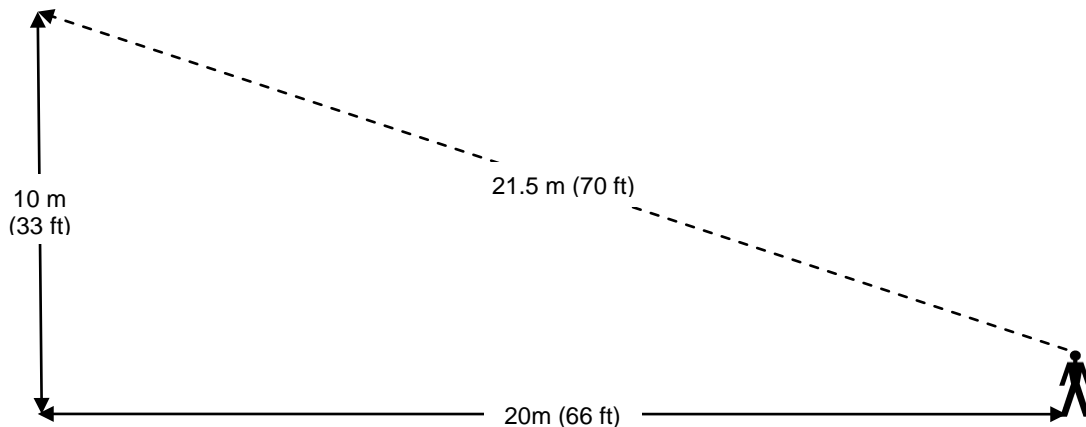


Figure 3: Visibility test setup

"When the signal was presented at 90°, all participants were able to detect and correctly identify the activation state and orientation both in daylight and in the dark with a flashlight. Thus, for simple detection of the active signal, all colors would likely work equally well. However, in actual use, the grey signal would not likely provide adequate contrast, particularly in snow or frost. A colored signal would provide the most contrast under a variety of environmental conditions. In this study, the active fluorescent orange signal was easier for participants to identify under a variety of conditions, and would be preferred over the yellow color used.

Generally, there was some difficulty determining whether the signal was active or inactive, particularly in the fluorescent orange color. The determination of activation might be improved using a 2 color system. One color for the inactive state (i.e., the end plug) and another color for the active (core rod)." ^[5]

Based on these results an indicator color of bright orange was selected.



4.11. Mechanical vibration

After consultation with a team of distribution engineers, a deliberate random test was designed. In the test a 25 kVA transformer was suspended from the forks of a forklift ten feet about the ground, and then lowered in several sudden sharp drops until the transformer was one foot above the ground. This caused the transformer to jump and swing violently in all directions, up to 90° from the normal vertical position.

4.12. Transportation testing

In addition to the real world experience of shipping IFD's installed in transformers to utilities throughout North America, deliberate transportation simulation tests have been performed by IFD Corporation as well as its customers.

IFD transportation test

A 25 kVA pole mounted transformer with 5 IFD's installed around the airspace was shipped from the west coast to the east coast of Canada, and back, as follows:

1. Ship from Vancouver to Edmonton: 680 mi. (1100 km)
2. Unload and reload in Edmonton (Forklift handling)
3. Ship from Edmonton to Toronto: 2200 mi. (3500 km)
4. Unload and reload in Toronto (Forklift handling)
5. Ship from Toronto to Sackville: 1000 mi. (1600 km)
6. Unload and reload in Sackville (Forklift handling)
7. Return trip repeats steps 1 through 6 in reverse order
8. Unload in Vancouver and inspect

After the tests were complete the IFD's were inspected to confirm they were in good condition and still functioning as designed.

Transformer manufacturer transportation simulation

Using a three phase pole mounted transformer equipped with an IFD sensor a test consisted of running a programmed transport tester for 8 hours, which is representative of a return trip on a typical transport truck from the east to the west coast of the continental United States of America. During the test it was observed that even though the transformer was secured to a palette in the typical fashion used for transportation the transformer was still able to shift slightly on the palette during the test. Upon completion of the test the IFD was inspected and it was found to be in proper working condition.

4.13. Field service inspections

Detailed information about the service conditions IFD's that are returned from field is not available. Engineering inspections of IFD's that have been in service for up to 8 years have shown that the IFD materials exhibit no signs of degradation and the IFD sensors are continuing to perform as designed.



5. Natural ester based dielectric fluid certification

To validate the IFD is compatible for use in transformers filled with natural ester based dielectric fluids and the following testing was performed.^[6]

The IFD Orca product that began shipping in January 2011 was designed with complete consideration of the requirements for use in natural ester based dielectric fluid applications. The design was further optimized for use in Envirotemp[®] FR3[™] (FR3) as this is the most common natural ester fluid in the current marketplace.

Biotemp[®] natural ester dielectric fluid developed by ABB was not available at the time of this testing, however, after reviewing these test results ABB engineering determined that the IFD is compatible with Biotemp natural ester based dielectric fluid and no further testing would be required.

The following table summarizes the results detailed in the following sections and shows that the IFD[™] sensor is certified for use in sealed design transformers filled with natural ester based dielectric fluids.

Section	Description	Result
5.1	Impact FR3 polymerization on IFD activation	Pass
5.2	Impact FR3 polymerization on PRV function	Pass
5.3	Impact of IFD storage in a FR3 filled transformer	Pass
5.4	Impact of IFD submersion in FR3	Pass
5.5	Internal arcing fault testing in FR3	Pass

There are no standard test protocols, so we used previous FR3 testing documentation in addition to our internal specific test procedures to build a valid test program. Prior to, during and after all testing was reviewed with Cooper Power Systems FR3 Fluids Group, and the FR3 Fluids Group has now added the IFD sensor to the list of FR3 approved products.

IFD Corporation is solely responsible for the testing procedures and results described in this report.



5.1. Impact of FR3 polymerization on IFD activation

Although sealed transformers are designed to protect internal components from continuous exposure to the ambient environment, and FR3 has demonstrated stable operation in sealed design transformers for the past 14 years, should a transformer develop an opening in the airspace and become free-breathing there is some potential for FR3 to undergo oxidative polymerization. (See Cooper Power Systems certified test report # CP0414.)

To determine if the IFD will activate as designed with a coating of polymerized FR3, IFD's were immersed in FR3 and the oxidative polymerization process was accelerated using each of the following methods.

1. Exposed to ambient* for:
 - a. 90 days
 - b. The same units were then left for an additional 90 days to generate a total of 180 days of exposure
2. Heated in a dry, non-sealed oven for 8 hrs at 120°C (248°F)
3. Exposed to ambient* for 168 hours, heated in a dry, non-sealed oven for 6 hrs at 100°C (212°F) and then exposed to ambient* for an additional 168 hours.

*** Ambient = An air conditioned room at approximately 20°C (68°F)**

In all cases the polymerized FR3 was a hard, non-tacky layer on the external components of the IFD prior to activation testing.

Results:

These are worst case test scenarios and represent severe conditions only.

ID	Polymerization method	# tested	# passed @ 0.5 psi / 5-7 ms
70.	1a	5	5
71.	1b	5	5
72.	2	2	2
73.	3	4	4

These results show that if a sealed design transformer experiences an enclosure failure that causes it to become free breathing, the IFD will activate as designed with a coating of polymerized FR3 on the device.



5.2. Impact of FR3 polymerization on PRV operation

The PRV components for the IFD Orca were designed to meet the guidelines outlined in Cooper Power Systems document # MS-43201. In addition, following the test protocol outlined in Cooper Power Systems document # MS-43201 requires the internal components to be protected from oxidative polymerization to represent a PRV installed in a normally functioning transformer without any enclosure failure.

Therefore these following tests represent the absolute worst case scenario of an enclosure failure and the results still confirm the PRV will function as required should oxidative polymerization occur on both the internal and external portions of the PRV.

1. PRV components had Krytox applied to the o-ring only, were dipped in FR3 fluid and installed in an IFD body. These IFD's were then heated in a dry, non-sealed oven for 8 hrs at 120°C (248°F).
2. PRV components had Krytox applied to the o-ring, shaft, spring and spring retainer, were dipped in FR3 fluid and installed in an IFD body. These IFD's were then heated in a dry, non-sealed oven for 8 hrs at 120°C (248°F).
3. PRV components had Krytox applied to the o-ring only, were installed in an IFD body and then the internal face only of the PRV shaft was coated with FR3 fluid. These IFD's were then heated in a dry, non-sealed oven for 8 hrs at 120°C (248°F).
4. PRV components had Krytox applied to the o-ring, shaft, spring and spring retainer, were installed in an IFD body and then the internal face only of the PRV shaft was coated with FR3 fluid. These IFD's were then heated in a dry, non-sealed oven for 8 hrs at 120°C (248°F).

*** Ambient = An air conditioned room at approximately 20°C (68°F)**

In all cases the polymerized FR3 was a hard, non-tacky layer on the external components of the IFD prior to PRV testing.

Results:

These are worst case test scenarios and represent severe conditions only. A pass is considered to be a PRV that meets the requirements outlined in Cooper Power Systems document # MS-43201 of activation at or below 15 psig (103 kPa) and resealing at or above 1 psig (6.9 kPa).

ID	# tested	# passed
74.	10	10
75.	8	8
76.	5	5
77.	5	5

These results show that if a sealed design transformer experiences an enclosure failure the PRV will still operate with a coating of polymerized FR3 on both the internal and external components.

In an effort to maximize the environmental benefit, additional testing is being performed to determine if Krytox can be eliminated from the IFD PRV design for FR3 dielectric fluid.



5.3. Impact of IFD storage in an FR3 filled transformer

An IFD was installed in a 25 kVA sealed design pole-type distribution transformer filled with FR3 and placed in an indoor storage warehouse with an average temperature range of 18°C – 25°C (64°F - 77°F), and inspected periodically.

Results:

ID	Inspection Date	Duration (months)	Comments
78.	Jan 7/07	1	Thin film of fluid covering entire airspace, no oxidation or tackiness. Oil appears as new.
79.	May 14/08	17	Thin film of fluid covering entire airspace, no oxidation or tackiness. Oil appears as new. ▪ IFD activated at 0.5 psi / 7ms
80.	Mar 27/09	27	Thin film of fluid covering entire airspace, no oxidation or tackiness. Oil appears as new. ▪ IFD activated at 0.5 psi / 7ms
81.	Jan 20/10	36	Thin film of fluid covering entire airspace, no oxidation or tackiness. Oil appears as new. ▪ IFD activated at 0.5 psi / 7ms

These results show there is no negative impact on the IFD after 36 months of storage in a distribution transformer filled with FR3 dielectric fluid.

5.4. Impact of IFD submersion in FR3

To simulate the event that a transformer is tilted enough to cause the IFD to be completely covered by oil, IFD's were submerged in for 3 days at 20°C (68°F), then removed and placed in their service orientation for 12 hours. Finally, the IFD's were inspected and tested at the minimum threshold for activation of 0.5 psi / 7 ms.

Results:

ID	# Tested	Drainage test	Activation test
		# fully drained after 12 hrs	# activated @ 0.5 psi / 7 ms
82.	20	20	20

These results show there is no negative impact on IFD operation should the IFD become completely submerged in FR3 dielectric fluid.



5.5. Internal arcing fault testing in FR3

Two IFD's were installed in a 25 kVA distribution transformer filled with FR3 and tested as outlined in IEEE C57.12.20 – section 9.4 with the input amperage modified to 500A to generate a pressure wave at the minimum threshold for IFD activation. (See CEATI report No. T994700-5003)

Testing was performed by Powertech Labs.

Results:

ID	Fluid	Fault current (A _{rms})	# Passed @ 0.5 psi / 7 ms
83.	FR3	497	Yes
84.	FR3	497	Yes

These results show the IFD will activate when exposed to a 500A internal arcing fault in FR3. These results were expected and are consistent with previous testing in mineral oil.

These results of internal arcing characteristics in FR3 are consistent with the findings of the Cooper Power Systems FR3 Fluids Group.



References

Specific References:

1. Piercy, R., Filter, R., Barret, S.; *CEATI Report No. 149D941A Distribution Transformer Internal Withstand Test*, CEATI, 1997
2. Cuk, N., Hicks, S.H. and Chisholm, P.; *CEATI Report No. T994700-5003, Development of an Internal Fault Detector for Pole-Top Distribution Transformers*, CEATI, 2002
3. Ooman, T.V.; *Gas Pressure Calculations for Sealed Transformers Under Varying Load Conditions*, IEEE, 1983
4. ASTM D3487-00, *Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus*
5. Ergonomics and human factors group; *Visual Detection of the IFD Transformer Signal*, BC Research Inc., 1999
6. Pezzin, J.; *Certification of the IFD™ Sensor for use in Sealed Designed Electrical Distribution Equipment Filled with Natural Ester Based Dielectric Fluids*, IFD Corporation, 2010
7. UL 746C, *Standard for Polymeric Materials*

General References:

IEEE C57.12.20, *IEEE Standard for Overhead-Type Distribution Transformers*

IEEE C57.12.00, *IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*

IEEE C57.12.90, *IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers*

Koutsandreas, A.; *Evaluation of the IFD Part Over Selected Temperature Range*, Polymer Engineering Company Ltd., 2001

Cuk, N. and Hicks, S.H.; *The Performance Tests Performed on Internal Fault Detectors at -40°C, During Long Duration Short Circuits (ANSI), Internal Pressure Relief, Sealing, Mechanical Vibrations and Transformer Transport*, IFD Corporation, 2001

Cuk, N., Hicks, S.H.; *The Results of Performance Verification Tests on Randomly Selected Internal Fault Detectors*, IFD Corporation, 2001

Cuk, N.; *CEATI Report No. 149D491, Oil tank explosion resistance*, CEATI, 1990

Clark, W.; *Detecting Distribution Transformer Faults*, IFD Corporation, 2005

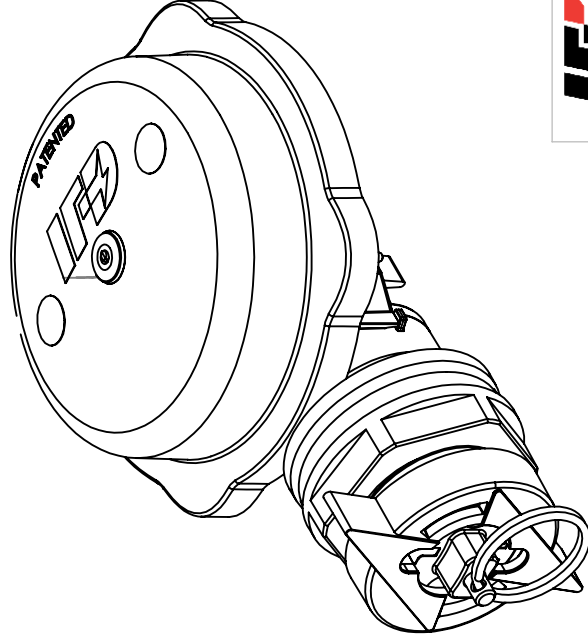
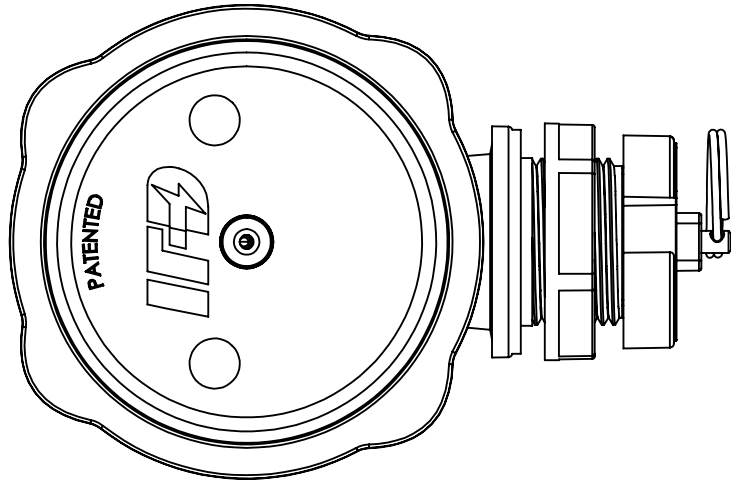
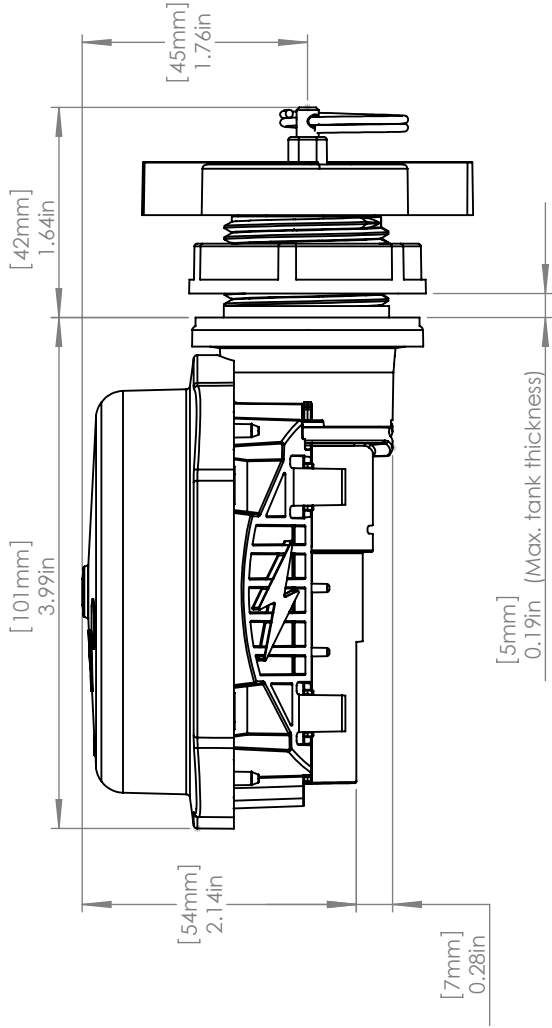
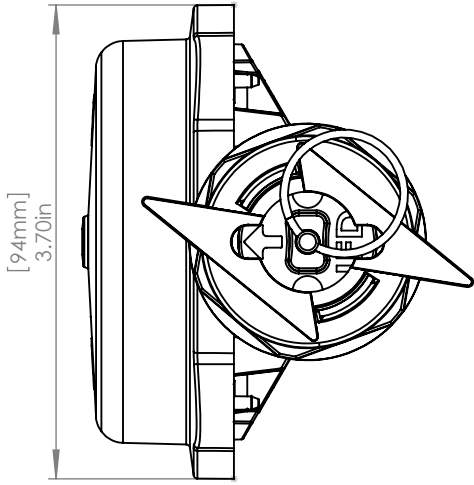
Hamel, A., et al.; *Estimating Overpressures in Pole-Type Distribution Transformers Part I: Tank Withstand Evaluation*, IEEE, 2003

JB. Dastous et al., *Estimating Overpressures in Pole-Type Distribution Transformers Part II: Prediction Tools*, IEEE, 2003

Barkan, P., et al.; *Overpressure Phenomena in Distribution Transformers with Low Impedance Faults: Experiments and Theory*, IEEE Trans. Power App. Syst., vol. PAS-95 Jan/Feb 1976



Appendix A: IFD overview drawing



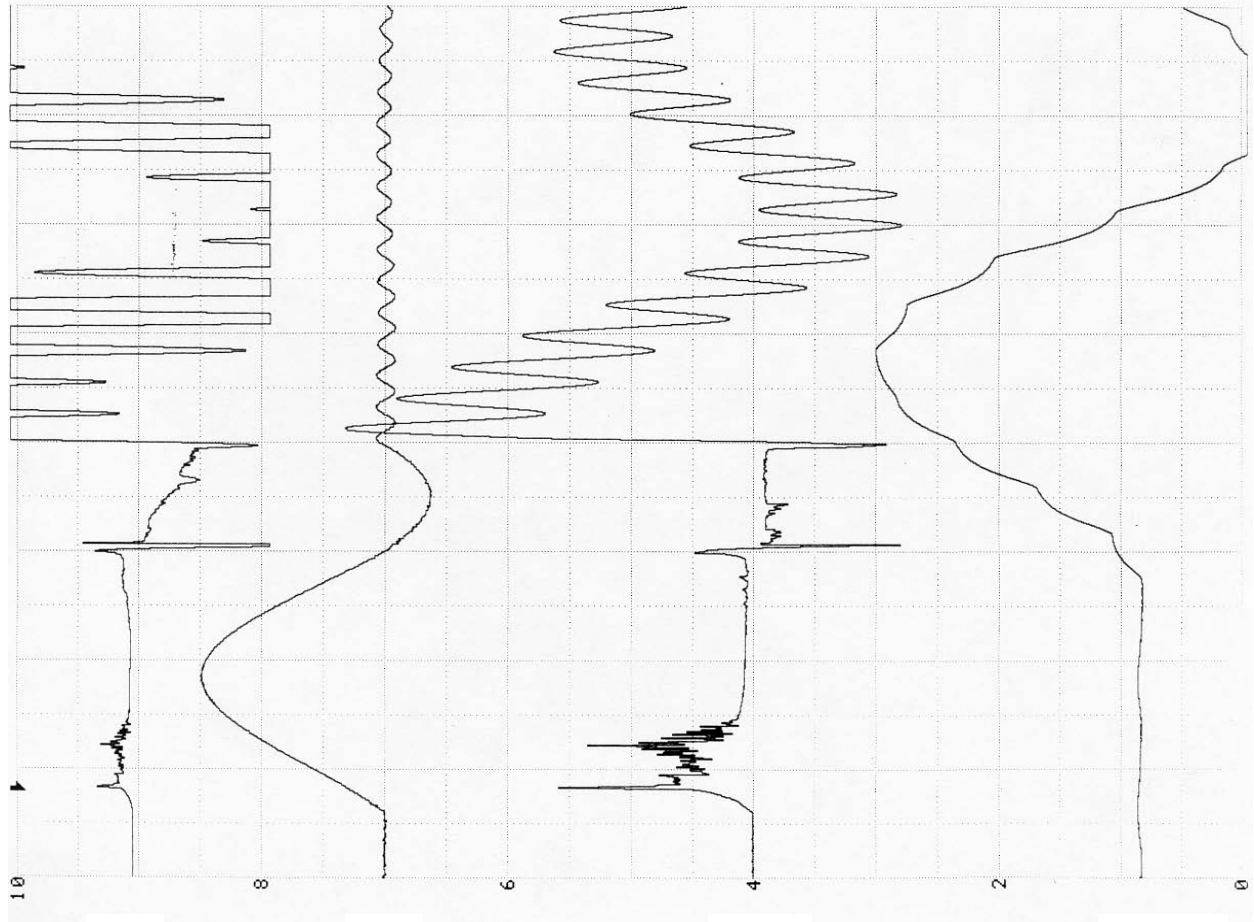
TITLE: IFD Orca

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF IFD CORP. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF IFD CORP. IS PROHIBITED.	SIZE PART NO.	REV
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DRAWN BY: A. Hunsberger SHEET 1 OF 1



Appendix B: Sample oscillograms



HIOKI 8820
MEMORY HI CORDER

●FUNCTION : MEM
●TIME/DIV : 5ms
●SHOT(DIV) : 80
●FORMAT : x1
●CHART : 24~ 34%
●DOTorLINE : LINE
●PEN TYPE
[CH1] SLIM
[CH2] SLIM
[CH3] SLIM
●TRIG
SOURCE : INT
PRE-TRIG : 25%
CHANNEL : 123
SLOPE : ↑↑↑
ANDorOR : OR
FILTER : OFF
●AMPLIFIER
[CH1] 0.1V/DIV
OFFSET 70%
COUPLING DC
[CH2] 0.20/DIV
OFFSET 40%
COUPLING DC
[CH3] 0.20/DIV
OFFSET 10%
COUPLING DC
[CH4~8] SETTING

●DATE '01-06-08
●TIME 10:04:37
●CHART NO.54

Voltage across cutout (VD#6)

Test Current

Voltage across transformer

Pressure transient in the air space

HIOKI 8820
MEMORY H1 CORDER

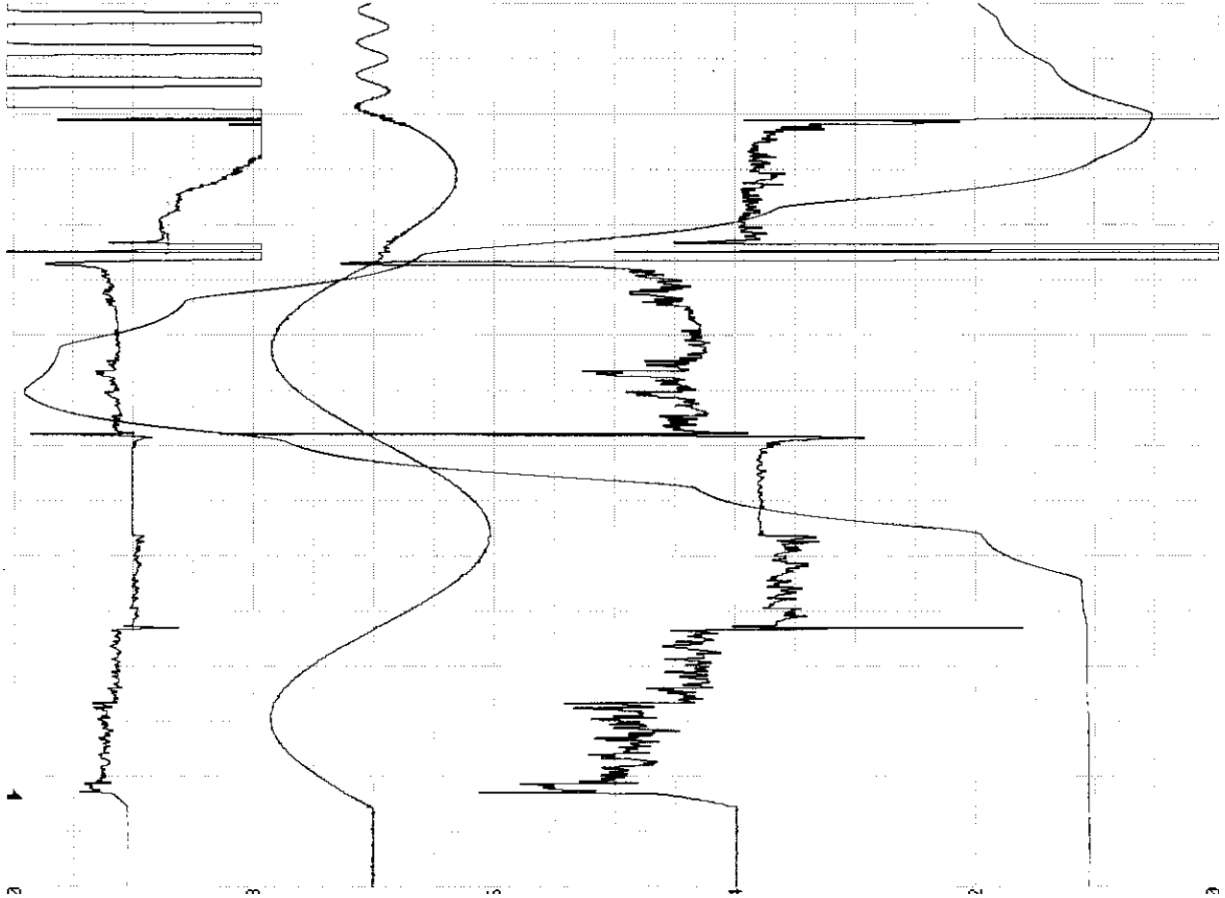
●FUNCTION : MEM
●TIME/DIV : 5ms
●SHOT(DIU) : 80
●FORMAT : x1
●CHART : 24~ 34%

●DOTorLINE : LINE
●PEN TYPE
[CH1] SLIM
[CH2] SLIM
[CH3] SLIM

●TRIG
SOURCE : INT
PRE-TRIG : 25%
CHANNEL : 123
SLOPE : ↑↑
ANDorOR : OR
FILTER : OFF

●AMPLIFIER
[CH1] 0.10/DIV
OFFSET 70%
COUPLING DC
[CH2] 0.20/DIV
OFFSET 40%
COUPLING DC
[CH3] 0.20/DIV
OFFSET 10%
COUPLING DC
[CH4~8] SETTING

●DATE '01-06-08
●TIME 11:34:08
●CHART NO.66



Voltage across cutout

Test Current

Voltage across

Pressure transient in the air space



Appendix C: Lightning impulse test results

The lightning impulse tests were performed at the Moloney Electric test facility, and the results are produced on the following pages.



**MOLONEY ELECTRIC INC.
STANDARD IMPULSE LOG**

Customer:	MOLONEY ELECTRIC INC.	Voltage Divider Ratio	HV = 75.09	LV = N/A
Order#	VO15634-E	Phase 1	HZ 60	HV-KV/mm: 1.0727
Design #	TPTO025A76	HV 17320	DELTA	LV-KV/mm: N/A
KVA	25	LV 242.0		

SER	IMPL.	TYPE OF	Ctg.	CURRENT		VOLTAGE					REMARKS	
				F.SWP	ATTEN	F.SWP	Atten..	DC	KV/mm	Def.		Appl.
#	APPL TO	WAVE	Volts	µs		µs		Corr.	Div.	KV		
#1	H 2	RFW	36.25	100	1.00	100	2.00	14.0	1.0727	40.0	85.82	FRONT TIME 1.19 µs
		RFW	30.62	100	1.00	100	2.00	14.0	1.0727	34.0	72.94	TAIL TIME 44.29 µs
		1stCW	70.54	100	2.00	10	4.00	14.0	1.0727	39.0	167.34	Chopping Time 1st. 2.42 µs
		2ndCW	70.54	100	2.00	10	4.00	14.0	1.0727	39.0	167.34	Chopping Time 2nd.. 2.42 µs
		FW	61.25	100	2.00	100	4.00	14.0	1.0727	34.0	145.89	
											DATE 9-Aug-01	
											TESTED BY ARTHUR	



MOLONEY ELECTRIC INC

STANDARD IMPULSE TEST- [Tests performed in accordance with IEEE C57.12.00 - Latest edition - section 5.10]

UNIT IDENTIFICATION				TYPE: POLE															
CUSTOMER: MOLONEY ELECTRIC INC.																			
ORDER#: WO15634-E	Phase: 1	HZ 60	Voltage Divider Ratio: HV: 75.09	LV: N/A															
DESIGN#: TPT0025A76	HV 17320 DELTA		HV-KV/mm = 1.0727	HV BIL 145	KV														
KVA: 25	LV 242		LV-KV/mm = N/A	LV BIL N/A	KV														
SERIAL#: 1			POLARITY: NEGATIVE																
SUMMARY OF WAVE SHAPE CALIBRATION																			
HV Calibration:		LVL: 145 KV		LV Calibration:		LVL: KV													
Front Time: 1.19 μ s		Tail Time: 44.3 μ s		Front Time: μ s		Tail Time: μ s													
Chop Time (min): 2.25 μ s				Chop Time (min): μ s															
IMPULSE GENERATOR SETTINGS:				Legend:															
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><th colspan="2">GENERATOR STAGES</th></tr> <tr><td>1</td><td>2</td></tr> <tr><td>2</td><td>N/A</td></tr> </table>				GENERATOR STAGES		1	2	2	N/A	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><td>1</td><td>SETUP FOR HV</td></tr> <tr><td>2</td><td>SETUP FOR LV</td></tr> <tr><td>N/A</td><td>NOT APPLICABLE</td></tr> </table>				1	SETUP FOR HV	2	SETUP FOR LV	N/A	NOT APPLICABLE
GENERATOR STAGES																			
1	2																		
2	N/A																		
1	SETUP FOR HV																		
2	SETUP FOR LV																		
N/A	NOT APPLICABLE																		
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><th colspan="2">Re- Tail Resistor (Ω)</th></tr> <tr><td>1</td><td>1450/200</td></tr> <tr><td>2</td><td></td></tr> </table>				Re- Tail Resistor (Ω)		1	1450/200	2		<p>Results :</p> <p>Examination of the oscillograms indicate no obvious variations between Reduced & Full Waves and between Chop Waves. The unit passed BIL Test as specified in IEEE C52.12.00</p>									
Re- Tail Resistor (Ω)																			
1	1450/200																		
2																			
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><th colspan="2">Rd- Front Resistor (Ω)</th></tr> <tr><td>1</td><td>50/50</td></tr> <tr><td>2</td><td></td></tr> </table>				Rd- Front Resistor (Ω)		1	50/50	2											
Rd- Front Resistor (Ω)																			
1	50/50																		
2																			
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><th colspan="2">Cd - Tail Capacitor (nF)</th></tr> <tr><td>1</td><td>4.0</td></tr> <tr><td>2</td><td>N/A</td></tr> </table>				Cd - Tail Capacitor (nF)		1	4.0	2	N/A										
Cd - Tail Capacitor (nF)																			
1	4.0																		
2	N/A																		
Scope - Rea		Vol.Div - Capacitor (pF)																	
1	75.09	1	1015																
2	N/A	2	N/A																
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><th colspan="2">Rod Gap</th></tr> <tr><td>1</td><td>4.25"</td></tr> <tr><td>2</td><td></td></tr> </table>				Rod Gap		1	4.25"	2											
Rod Gap																			
1	4.25"																		
2																			
<table border="1" style="width: 100%; border-collapse: collapse;"> <tr><th colspan="2">Rs - Shunt Resistor (Ω)</th></tr> <tr><td>1</td><td>1.00</td></tr> <tr><td>2</td><td></td></tr> </table>				Rs - Shunt Resistor (Ω)		1	1.00	2											
Rs - Shunt Resistor (Ω)																			
1	1.00																		
2																			
TEST SEQUENCE:				CURRENT				VOLTAGE				Remarks:							
Terminal ID	Impl.	Appl.	Type of wave	Chg. Volts	F.swp	Atten.	F.swp	Atten.	DC corr.	KV/ mm	Def. Div	Appl. KV	Oscillograms available upon request						
HV	H	2.	RFW	30.62	100	1.00	100	2.00	14.0	1.0727	34.00	72.94							
			1stCW	70.54	100	2.00	10	4.00	14.0	1.0727	39.00	167.34	1st chopping Time	2.42 μ s					
			2ndCW	70.54	100	2.00	10	4.00	14.0	1.0727	39.00	167.34	2nd Chopping Time	2.42 μ s					
			FW	61.25	100	2.00	100	4.00	14.0	1.0727	34.00	145.89							
Tested By: Arthur				Date: 9-Aug-01				Approved By:											



Appendix D: High power test circuit diagrams



Test circuit for internal arcing fault testing:

Test circuit for load break switch and bay-o-net fuse testing:





Test circuit for secondary breaker testing:

Test circuit for voltage regulator tap switch testing: