# Field tests for assessing electrical protection performance regarding electromechanical protection relays

## Pruebas de campo para la evaluación del desempeño de funciones de protección eléctrica en relés de protección electromecánicos

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**ABSTRACT**

This article describes designing and using a series of field tests (such as pick-up test and operating characteristics) aimed at ascertaining the correct operation of relays' electromechanical protection. The characteristic elements involved in adjusting electromechanical protection relays are presented.

**Keywords:** Relay protection, power system, electrical protection, electromechanical relay.

RESUMEN

En este artículo se establece el diseño y la ejecución de una serie de pruebas de campo, como la prueba de *pick-up*, característica de operación entre otras que, de acuerdo con la función de protección evaluada, permiten verificar el correcto funcionamiento de los relés de protección electromecánicos. Además se presentan los diferentes elementos característicos de ajuste en los relés de protección electromecánicos.

**Palabras clave:** Relé de protección, sistemas de potencia, protecciones eléctricas, relé electromecánico.

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## Introduction

Electrical protection goes unnoticed when there are no faults in an electrical power system (EPS). EPS elements can fail and it is precisely in such circumstances that a protection system does its job by identifying the equipment related to a particular failure in the system to disconnect and isolate it in the shortest possible time. These requirements can only be satisfied with a suitable protection system philosophy and suitable adjustment and control of equipment.

A series of tests verifying that a relay is working correctly (both in normal and abnormal conditions) must be made to maintain the settings and criteria necessary for a protection relay's correct operation, because the characteristic elements of a protection relay begin to fail with the passage of time.

This paper presents the field tests used to verify relays' correct operation; such information has been orally transmitted but very little has been written about it, being reflected in the paucity of pertinent literature on this subject.

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## Settings

Each component must be identified for adjusting electromechanical relays, because the physical structure can vary according to the role of the protection used and its manufacturer. However, knowing the main elements can lead to identifying adjustment points, regardless of the type of electromechanical relay.

All the mechanical elements used to adjust an electromechanical relay's characteristics (mainly consisting of "screw adjustment" need careful handling as excessive torqueing (tightening) may occur and cause damage. Figure 1 presents the development scheme for making the necessary adjustments to electromechanical protection relays. The main adjustment elements for calibration in electromechanical protection relays are:

- Permanent magnet
- Fixed contact element
- Spring spiral
- Variable resistance

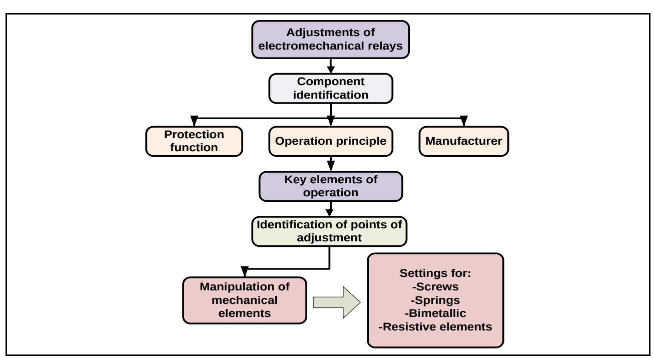


Figure 1. Synopsis for the adjustment of electromechanical relays

*Permanent magnet*

A permanent magnet is used to adjust response speed. Moving the induction drive away allows greater displacement speed; approaching the disk creates an opposing force that slows down disc movement. A permanent magnet is adjusted by using a screw to approach or retreat from an induction disc magnet.

*Fixed contact element*

A fixed contact item is fixed to the chassis of the relay, facilitating closure during mobile element circuit operation. A screw on the element is turned to adjust its setting to provide greater/lesser contact opening. This element is not usually modified (no more than necessary).

*Spiral spring*

This element consists of a thin spiral sheet affording induction disk adjustment by modifying its compression "K". Increasing spiral spring compression slows the disk starting. This element must be manipulated with caution because it is a very sensitive element. Excessive force can cause it to lose its original form.

*Resistance*

Another characteristic element is a resistor or a set of variable resistors. They are non-linear elements in some cases; resistance is used to adjust pick-up level, adjust operation times or as an operation restriction element, depending on the manufacturer. The manufacturer's catalogue must be consulted for fitting this element.

Relay operating structure varies considerably when not working with an induction drive according to relay function and type. Common elements such as tap range/setting, operating unit and operation with other contacts are operated through a set of variable resistors (non-linear elements) used for adjusting different values. For example, different resistance settings can be set in a relay; pickup value can be adjusted by resistor R1, current harmonics restricted with R2 and current operation with R3, depending on a relay mechanism's adjustment characteristics.

Table 1 summarises electromechanical relays' main adjustment and calibration elements, according to the required adjustment (injected magnitude or operating time).

Table 1. A summary of electromechanical relay setting elements

| **Injected adjustment element** | **Element for adjusting operating time** |
|---|---|
| Tap | Dial |
| Resistance | Spiral spring |
| | Permanent magnet |
| | Fixed contact |

## General considerations

A user's specific requirements vary with the type of relay in question, as well as the testing equipment. Three preparatory steps are required to ensure a proper test; their scope depends on the complexity of the test to be performed.

1. *Verifying initial relay parameters and adjusting nominal operation variables*, associated with rated voltage, current, frequency, characteristics of the area, etc. This information would already be in a test computer dialogue software programme or disclosed in test format to parameterise the equipment.

2. *Defining the test system's hardware configuration* (injection equipment) to suit the application of a specific test to be performed (voltage and current to be used, binary input and output configuration, adjusted firing/injection area, etc.).

3. *Adjusting trigger conditions or triggering binary entries* as ensure that relay contacts are connected for properly measuring relay firing times. The following aspects are important for carrying out the tests described in this document.

- The operation of any electromechanical relay set very close to nominal work value can easily be influenced by external factors. This is because the net acting force is so low that any additional friction can hamper performance, reflected by increased relay operating time.
- During the electromechanical relay protection tests described in this document, the amount of work (voltage, current, frequency) should be injected slowly, i.e. by injecting short, consistent pulses to be able to evaluate the minimum value required for low relay test operation.
- Variation or delta levels should be chosen to change according to the needs or requirements of the test to be run so that values are obtained having considerably less error. Deltas having very fine values should be used when a test is required to assess operation threshold levels, for example, during a "pick-up" or "under fire" test.
- A time element or counter ("trigger") interaction is not necessary in trials seeking to evaluate relay operation at minimum operation values. Operating units associated with a relay (indication target or banner) may not necessarily fire during these procedures.
- Every procedure uses a different test equipment source configuration to avoid possible error by the inrush of sources other than those strictly necessary. When loading test equipment's set configuration, attention must be paid to the number of tension sources and enabled current to avoid an operator performing such test inadvertently enabling a source that is not to be relayed.
- It should be pointed out that these tests are subject to human error, so concentration and attention are required. As electromechanical relays' mobile elements are very sensitive, their behaviour before minimum operating values are achieved must be observed. It is advisable to identify all the characteristic elements of a relay to be tested prior to performing a particular test.

## Types of test

The main measurable variables in testing electromechanical protection relays and settings are as follows:

- Voltage
- Current
- Power (magnitude and direction)
- Impedance
- Frequency

The following field tests are run for measurable variables to check the status of a relay in trial operation.

*Boot (pick-up) test*

Pick-up tests assess and determine the minimum value regarding the magnitude of the variable being manipulated in a relay being tested to verify that a relay operates satisfactorily for establishing tap settings.

The variable manipulated for pick-up value depends on relay protection. For example, if working on an overcurrent protection relay, proof of pickup is performed at minimum operation flow. Overvoltage relay pick-up value would be the minimum voltage producing operation.

Pick-up value can easily be observed in electromechanical induction drive relays as the disk begins to scroll to make injection operate. Such minimum transaction value is known as boot or pick-up value. Electromechanical relays' electromagnetic attraction determines an expected response; equipment behaviour is different, depending on the manufacturer and the type of protection. For example, some relays operate sudden operation contact, in most cases without physically recording a transaction, i.e. they perform a switching movement that does not necessarily lead to indication in its firing units. Other equipment, such as some voltage relays, generate a characteristic noise that manifest relay inrush, such test being known as inrush test, although the purpose or principle is the same as a pick-up test.

*Contact switch indication (CSI) test*

A CSI test verifies indicator element operation or target state operation by injecting DC current into a low relay firing circuit test terminal. Each target element has a winding (coil target) operating at default DC current level; this value can be 0.2 $A_{DC}$, 1 $A_{DC}$ or 2 $A_{DC}$. According to target operation level, it would be expected that it would become activated at a lower level than that indicated.

This test is performed to verify low relay test indicator or target operation.

Operation of the test circuit relay must be identified during this test for the manual closing of operation contacts. This is done with induction disc relays by moving the disk to the end of its run, i.e. closing the operating contacts circuit, gathering fixed mobile contact. The disc must be kept in this position ensuring that the contacts are closed, at the same time running DC current injection through the firing circuit. The disc is loosened once the indicator or target has been triggered.

It must be ensured that the element is related to the firing circuit in electromagnetic attraction type relays (instant units). Typically, there are several auxiliary coils for this purpose, as indicated in Figure 2. The close contact winding element should inject DC current.

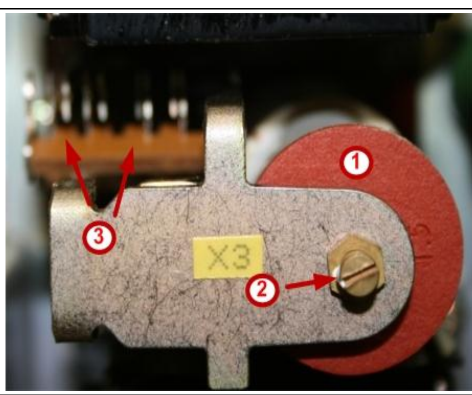


Figure 2. Auxiliary trigger circuit coil. 1) Auxiliary coil in operation. 2) To operate the coil (allows the closure of the associated contacts). 3) Contacts associated to the auxiliary coil

*Operating characteristics test*

An operating characteristics test assesses the operating time of a timed unit's relay being tested, for different multiple operation values. This test is usually performed by injecting current tension values depending on the assessed protection function. The variable to be tested is injected and awaits a response from the relay with times defined by its curve or characteristic equation. Is such information is not available, response is compared to previous test time values.

This test requires configuring a time element or counter measuring the time taken to operate the relay following the injected signal. This timer is known as a trigger configured to operate according to relay contact operating state, i.e. "open/closed" or "closed/open" depending on the configuration of a relay being tested. This detail may be seen directly in the relay by checking contact status prior to energising it (although this should be verified with the manufacturer's specifications given in the operating catalogue).

Operating characteristics are verified using several test points for equipment behaviour traceability. Wear occurring from operation increases error in a particular instrument, since electromechanical mechanisms are involved.

This factor must be considered when approving test criterion. As several operating points are evaluated, it may be that one or more points are out of adjustment; a decision must thus be made about whether the unit should be adjusted or calibrated.

*Balance Test*

A balance sheet test evaluates whether a relay operates successfully regarding an operation imbalance, characterised by the lack of voltage or current operation in one of their respective fields.

This test involves injecting a specific variable's scale values (voltage or current), simulating a system balanced from a three-phase source. Different relay fields are fed in the test to verify balance between phases; the test is measured by disconnecting one of the test terminals to verify relay operation, thereby energising the field corresponding to the rated winding point characterised by activating the target or indication element (banner).

*Axis reactance intersection test*

The axis reactance test evaluates Mho relay operating characteristics concerning voltage and current injection magnitude by evaluating maximum and minimum operating points. These values guarantee relay operation by reactance intersection points using a 90° operating angle (current delay angle regarding tension).

*Operating angle test*

The operating angle test evaluates the operating points at which a relay operates to find operation angle magnitude value. This test finds two test values representing the operating threshold for a relay being tested (such values are known as "blinders" in the pertinent literature).

This test depends on evaluating the injection of two test variables: one involves fixed value magnitude and the extent of its variable angle, and another concerns magnitude and fixed angle. For example, if the function being tested is field protection, a fixed voltage magnitude is injected at a fixed angle, for example

40∠0° V and a fixed current magnitude is injected at a variable angle, for example 4∠X° A.

*Firing test*

A firing test evaluates the operating point of a relay being tested; this test is similar to an operating characteristics test, only this involves a single point of evidence within the relay's area or adjusted operating margin. The test involves injecting magnitude and fixed angle values for the variables used, depending on the type of protection. A trigger element is configured to measure the response time of the relay being tested.

*Differential characteristics test*

A differential characteristics test assesses the minimum differential current occurring through winding operation to fire the relay being tested, while circulating a nominal current through the restriction windings. Figure 3 shows that current I2 flow through the restriction windings. This stream must have a value whose magnitude is fixed. Another current is injected through the operating winding to measure at current difference the relay operates. This is usually done with differential relays.

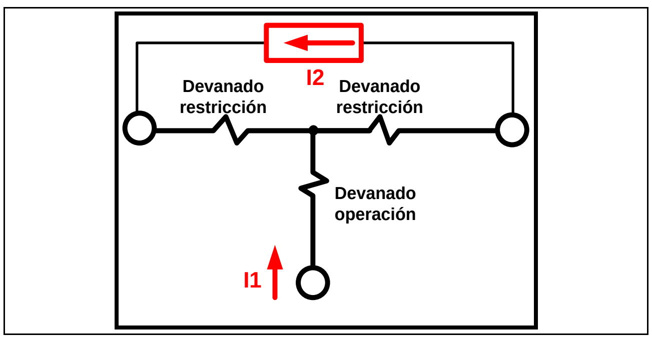


Figure 3. Scheme of differential characteristic test

*Harmonics restriction test*

The harmonics restriction test assesses the behaviour of a relay being tested regarding high harmonic content signals. Harmonic drive restriction consists of a harmonic filter preventing relay operation/response to signals having frequency values different from that set as fundamental frequency.

This function is used to filter signals which can produce a shot or the unnecessary operation of a relay being tested. Since different phenomena occur in a power system, there are special conditions in which signals have high harmonic content, whose magnitude could cause a relay to fail during operation. These signals represent a possible failure or negative event, thereby generating unnecessary operation.

A classic example would occur during power transformer inrush (i.e. the so-called "inrush" stream, manifesting itself as a transient high frequency current operating outside normal range, presenting a high magnitude current, having high harmonic content). This feature is usually adjusted by variable resistance allowing the restriction range or band to be adjusted.

These tests show that protection works within the limits established by the manufacturer or by the application, according to the quantities of measurable variables in such type of relay. There are schemes to test looking for shot protection limits, by gradually changing injected variable magnitude, whereas rapid and selective disconnection also requires that protection operating time is correct. Operation time is checked by feeding a relay test quantities exceeding its functional limits, taking the established time required for fire protection.

## Results

Various tests for assessing a relay's proper performance are carried out according to the protection function of a particular relay being tested. Table 2 illustrates the major field tests carried out regarding protection features.

Table 2. Tests applied in worked-protection features

| **Number*** | **The relay function** | **Applied evidence** |
|---|---|---|
| 21 | Distance | 2-3 |
| 27 | Low voltage | 1-2-3 |
| 32 | Directional power | 1-2-3 |
| 37 | Low power or low flow | 1-3-6-7 |
| 40 | Field | 2-3-5-6-7 |
| 46 | Balance of phases | 1-2-3 |
| 50-51 | Overcurrent | 1-2-3 |
| 55 | Power factor | 1-3 |
| 59 | About stress | 1-2-3 |
| 60 | Balance of current or voltage | 4 |
| 64 | Failure to land | 1-2-3 |
| 87 | Differential | 1-2-3-8-9 |

** Numerical symbolism according to standard IEEE C37.2 2008.*

## Conclusions

Electromechanical relays' performance characteristics vary significantly; a relay's physical design inherently produces negative features that are not present in latest technology relays. A clear example concerns the problem that may occur from local induction drive displacement as close contact is physically mounted in the induction drive. This leads to inertia which cannot be stopped immediately after interruption of a flow or variable of interest, resulting in possible excess travel on the local drive. This means that a relay can make one more course to the point of adjustment. This feature may result in a lack of selectivity, and even poor operation. By comparison with new technologies this inherent characteristic of electromechanical technology can be improved to reduce coordination, even in a 0.1s time interval. Some performance advantages which other relay technologies can provide include: wider operating temperature range, improved time coordination intervals, greater accuracy, better frequency response, and less loaded relays. However, electromechanical relays are less sensitive to overvoltage and electromagnetic interference. Each feature must thus be considered, since they play an important role in the protection of a system or selected piece of equipment.

Despite continuous advances in numerical technology, electromechanical relays will still be providing your service for some time to come. This is one of the reasons electromechanical protection relays persist, because it is easier to replace existing links with identical equipment, which prevents the adaptation of new elements and staff can still make advances with known equipment. Some electromechanical relays are still very common, and even made with modern materials. New facilities sometimes use new electromechanical relays rather than more modern designs; electromechanical relays may thus persist for at least another 10 or even 20 years. The type of relay testing described above will remain an important issue, especially regarding the performance expected from electromechanical relays compared to the protection provided by modern numerical relays.

Electromechanical relays' operating characteristics vary significantly depending on a relay's physical design (i.e. each function's inherent characteristics).

Electromechanical relay testing will continue to remain an issue, considering that many electromechanical relays already in operation should be tested despite the development and implementation of electronics in electrical protection. A structured information system has thus been provided using the technical information contained in this manual/tool, making test analysis more effective.

Establishing testing protocols and developing a structure for implementing them will lead to establishing a well-structured test management system. This is appropriate for making timely decisions, identifying cause as a result of failure and increasing security personnel during tests, as well as facilities.

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