EVALUATION OF FALIURE BEHAVIOUR OF SERVICE AGED ELECTROMAGNETIC PROTECTIVE RELAYS

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ABSTRACT

Protection systems in medium voltage grids consist for the largest part of protective relays of the electromechanical kind. The first series of this kind of protective relays were introduced in the late 40s. Later kinds (static and numerical) were introduced in the early 70s.
For years, these electromechanical protective relays have been serviced to an "as new" condition with a time based maintenance policy (preventive maintenance). This is no longer the case. The influence of no longer servicing to an "as new" condition and the ageing of these relays on the reliability of these relays has not been investigated.
For the investigation of failure behavior of electromechanical protective relays, a new evaluation method has been developed. This method is a qualitative method based on Failure Mode Effect and Criticality Analysis.

ANALYSIS OF CURRENT PROTECTIVE RELAYING PRACTICES IN DUTCH MEDIUM VOLTAGE GRIDS

Medium voltage networks in the Dutch grid are for the largest part represented by 10 kV level installations.
This study is mainly concentrated on 10 kV transportation/distribution networks commissioned by Dutch system operators. Protective relaying in these setups consists of several types of protection systems. The combination of a protective relay and a circuit breaker forms the protection system. Each of these systems takes their share in protecting a system component. For example such components are:

- Transformer
- Bus bar
- Feeder/line

These components need to be protected against the following fault situations:

- Over current or over voltage:
  Over currents occur during short circuit fault and over voltages occur after a lightning stroke.
- Duration (overload):
  In case of a line, cable or transformer carries a higher burden than the rated value.

In the Dutch medium voltage grids common types of protection are:

- over current protection,
- differential protection
- distance (zone) protection

The following tables [1-3] give an indication of the magnitude of the Dutch sub transmission/distribution grids and presence of protective relays in these grids.
The table 2 and figure 1 show an indication of the presence of protective relays in Dutch medium voltage grids.

TABLE I
MAGNITUDE OF THE DUTCH MEDIUM VOLTAGE

Dutch medium voltage grid	
Voltage levels [kV] :	**3, 6, 10, 12.5, 20 and 25**
Number of substations:	**103177**
Grid length [km] :	**91930**

TABLE 2
PRESENCE OF MICROPROCESSOR BASED PROTECTIVE RELAYS

Type	Total	Voltage ≤ 50 kV microprocessor based (numerical)	Percentage
Distance	3072	305	9.93%
Differential (zone)	2353	2	0.08%
Differential (transformer)	411	24	5.84%
Bus bar	35	0	0.00%
Over current	40132	981	2.44%
Total	46053	1362	2.96%

The information shows what type of protection systems are used in medium voltage grids. Table 2 also shows that the

majority of protective relays are of older kinds[1] of protective relays.
[3] Describes the reliability of the Dutch high/medium and low voltage grid. Most disturbances occur in medium voltage grids. Common causes for disturbances in the medium voltage grids are:

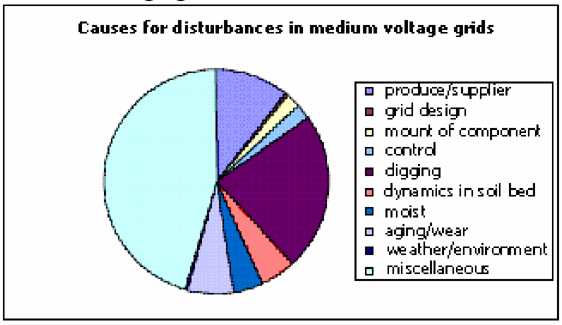

Figure 1. Causes for disturbances in the medium voltage grid in 2002.

Disturbances caused by failing protective relays are not mentioned. Studies concerning the reliability of protective relays in the Dutch grids and especially the medium voltage grids are hardly available. Information about the performance of protection systems is only published in confidential company bound reports.
The maintenance process needed to keep the protective relays operative has been a labor-intensive process for years. This is typically valid electromechanical protective relays. Electromechanical relays were checked in intervals of once per year. These checkups consisted of inspecting visually, testing, recalibration and if needed repair and refurbishing to an as new component. Since protective relays are mainly idle components in their operational life, regular checks can only give confidence that a protective relay will operate when it is supposed to. The later introduced static and numerical protective relays didn't have the need for such intensive maintenance activities. Manufacturers have recommended only visually inspecting and testing these relays since no or hardly any serviceable parts are present in these relays. Also the intervals of checkups were changed into longer intervals.
The past 10 to 15 years new insights in maintenance activities on protective relays and the recent liberalization of the Dutch energy market have forced some changes in the maintenance of protective relays. These changes affected the maintenance activities on electromechanical relays especially. One major change was the approach in the regular checkups. Electromechanical relays consist of some delicate components like moving coils, springs, contacts etc. A checkup in which these components are subjected to some invasive actions could damage these parts. Invasive actions are for example the burnishing of contacts, adjusting springs and adjustment of other mechanical parts. To carry out a more invasive inspection, a criterion has been set. Only in the case of not passing a functional test because of faulty or drifted settings, a more invasive inspection is allowed. This approach resulted in a gradual loss of skill of maintenance personnel in maintaining electromechanical relays.
Another factor of influence is that the manufacturers stopped the technical support on electromechanical protective relays in the mid 80s. Since then power companies are depending on their stored supplies of replacement parts. A common practice is the replacement by a protective relay from a spare feeder.
The stretching of inspection intervals has become a common practice. The liberalization of the Dutch energy market is a factor of influence in this. The preventive maintenance approach is more and more shifting to a condition based approach.

TECHNIQUE FOR INVESTIGATING FAILURE BEHAVIOR OF E.M. PROTECTIVE RELAYS

The way in which protective relays fail can in some cases tell a lot about what cause is accountable for this. Experienced engineers recognize the failure modes and know what effects these failure modes have on the components performance. A systematic way for documenting this knowledge is the Failure mode effect analysis (FMEA). The international standard IEC 812 describes the FMEA procedure. As a supplemental analysis

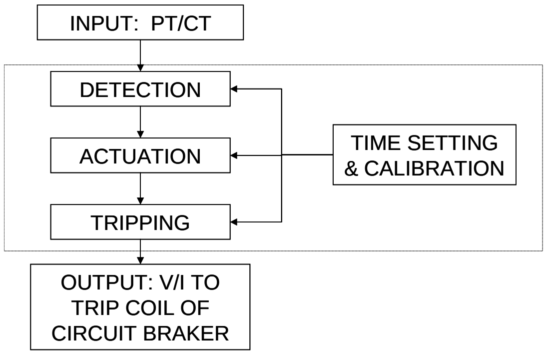

Figure 2. Functional block diagram.

to the FMEA, a criticality analysis (CA) can be carried out to focus the attention scope on to critical failure modes. FMEA or FMECA is an exhaustive procedure that results in an as complete as possible list of failure modes and causes for failures. Also part of the FMECA is composing a list of failure detection methods. The herein presented results of the FMECA procedure [4] are supplemented with an analysis of current maintenance practices.
An e.m. protective relay can be described by four processes. These processes are:

1. Detection
2. Actuation
3. Tripping
4. Time setting & Calibration

The detection and tripping processes represent the input- and output circuits. The actuation part describes the

operating principle. Two common operating principles are:
1. Armature attracted
2. Induction disk

The Time setting & Calibration process describes the way in which the operation of the three other processes is influenced. An electromechanical protective relay can be described by the following functional block diagram, see figure 2. The four process description forms also the basis for the subsystem decomposition of an electromechanical protective relay.

Normally, a FMECA is conducted only on the part level. Here, this still is done with the difference that all parts are assigned to subsystems. These subsystems are related to the functional description. The subsystem approach brings the following advantages:
1. Local effects of part failures can be described more detailed.
2. Influence of local effect on the end effect can be described.
3. The effectiveness of failure detection methods can be evaluated.

The basic input of a FMECA sheet is the textual description of the following:
- Subsystem.
- System element (component).
- Function.
- Failure mode.
- Failure cause
- Local effect of failure
- End effect of failure
- Detection provisions
- Preventive actions

EVALUATION OF FAILURE BEHAVIOR OF AN ELECTROMECHANICAL OVER CURRENT PROTECTIVE RELAY

The described FMECA procedure is conducted on an e.m. over current protective relay. The analyzed relay setup is a common induction disk relay as manufactured by ABB and GE. This unit has both operating principles. The main unit is an induction disk type. The relay setup has a backup unit which has the armature attracted operating principle.

The identification of failure modes, causes and their effects resulted in a list of 54 events in 21 components. These events are summarized into 10 failure modes with 8 general causes and 4 end effects. The failure effects explain in which way a failure mode affects the operation of a protective relay. The function of a protective relay is to energize the trip circuit of a circuit breaker. This will cause the circuit breaker to isolate the faulted line. The failure effects as described in fig 3 are defined in table 3. These four failure effects can be assigned to general categories, which are useful when defining a performance indicator for protective relays. These categories are:
- Missing operation [No trip, No seal in]
- Unwanted operation [Delayed trip, Early trip]

TABLE 3
DESCRIPTIONS OF FAILURE EFFECTS

Failure effect	Description
No trip	System does not generate a trip signal. Circuit breaker does not act in fault situation.
Delayed trip	System generates a trip signal but not within required time constraint. Circuit breaker acts on trip signal but is stressed longer.
Early trip	System generates a trip signal earlier than the required time constraint. Circuit breaker acts on trip signal.
Trip without seal in	System generates a trip signal but does not energize circuit breaker trip circuit sufficiently. Circuit breaker does not act in fault situation.

DETECTION OF COMPONENT FAILURES

Component failures can be detected with the following procedures/means:
- Non invasive visual inspection
- Invasive inspection maintenance (checking components by procedures)
- Functional testing with test sets or other testing means
- Measurement of input and output circuitry
- Inspection of terminals

The table 4 gives a description of what activities are included in the methods.

With the application of these methods and the use of the means it is possible to detect most component failures. The detection of component failures depends on the following factors:

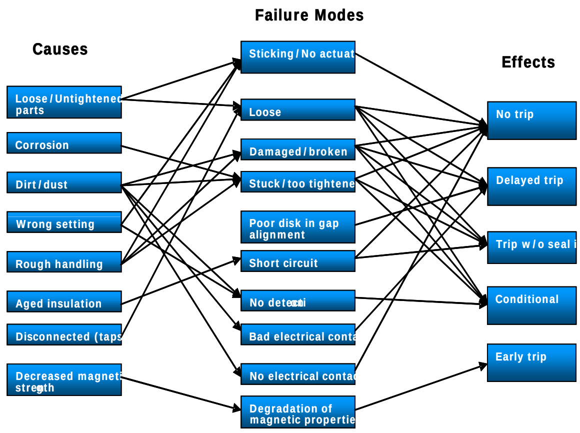

Figure 3. Causes for failures, failure modes and failure effects

- skill of maintenance engineers
- method of detection
- simplicity/complexity of relay setups

An insightful detection method, easy and obvious, results in a unique, unquestionable, interpretation. This is not always the case with detection methods applied in maintenance on e.m. protective relays.

Most failures at e.m. protective relays are detected during the maintenance process. A functional test is mostly carried out as a first step in an inspection. When it passes this test, it is often not needed to take more steps. Sometimes the test shows that relay doesn't operate as the intended setting indicates. A (re)calibration of the settings is in most cases sufficient enough. In other cases other means of detection methods should be used. A setting or (re)calibration procedure can also reveal failure phenomena. However, such a procedure is not intended as a detection method.

TABLE 4
DESCRIPTIONS OF MAINTENANCE ACTIVITIES

Maintenance activities
Inspection: *Visual (non invasive)* • Inspection on dirt, dust or other foreign materials • Inspection of the insulation of internal leads/wiring • Checking the settings on the scale • Checking the flag indication • Terminal connections *Visual (invasive)* • Checking gaps • Checking contacts • Checking pivots and bearings • Checking moving parts *Mechanical adjustments (invasive)* • Bearings/pivots • Tightening screws • Contacts *Auxilliary Measurements* • Wye point measurement input circuitry • Measurement output circuitry **Functional testing** • Settings • Pickup/drop out • Timing (characteristic) • Instantaneous • Flag indication / Seal in unit • Trip circuit test (protective relay + circuit breaker) if possible

CONCLUSIONS

Not all detection methods mentioned in the former paragraph are still applied when conducting maintenance on e.m. protective relays. Table 5 shows which methods are currently in use. Currently, e.m. protective relays are not serviced to an "as new" condition. The current approach no longer includes invasive activities. Main reason for the "case closed" policy is to avoid environmental contamination of the parts (dust, moist, dirt) and to avoid physical contact with sensitive parts. Mechanical parts are not checked anymore. The casing of the e.m. protective relay is only opened when terminals are inside the casing.

Finally the following can be concluded:

1. The failure behavior of electromechanical protective relays can be evaluated with the use the FMECA method.
2. Electromagnetic protective relays are ageing since they are no longer serviced to an "As new" condition.
3. The current set of applied failure detection methods is not sufficient for finding mechanical component failures.
4. The servicing process currently is focused on the verification of the functionality of the protective relay.

TABLE 5
CURRENT MAINTENANCE ACTIVITIES

Inspection: *Visual(non invasive)* • Checking the settings on the scale • Checking the flag indication • Terminal connections • Checking contacts *Auxilliary Measurements* • Wye point measurement input circuitry • Measurement output circuitry **Functional testing** • Settings • Instantaneous • Flag indication / Seal in unit • Trip circuit test (protective relay + circuit breaker) if possible

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