FIELD EXPERIENCE WITH A DIFFERENTIAL TRANSFORMER RELAY BASED ON NEURAL NETWORK TECHNOLOGY

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INTRODUCTION

Based on several years of research on neural network techniques and thorough mastering of conventional digital relaying, the neural network technique has been introduced in Schneider product range four years ago: the transformer differential protection has been equipped with an artificial neural network (ANN) restraint element [1].

Nearly 1500 such relays have been installed since then all over the world, giving appreciable feedback on this technology.

This paper describes field experience in Light SESA Company with this relay. An internal fault occurred in one of the protected transformers. The short tripping time reduced significantly the damages inside the transformer, making its repair cost-effective. No incorrect operation of the relay occurred since commissioning in January 2000.

THE LIGHT SESA EXPERIENCE

The Light SESA Company is responsible for the distribution of 75% of Rio de Janeiro State´s electricity consumption, including the city of Rio de Janeiro. In our days, this is related to about 9 million inhabitants spreads in an area of 10970 km².

The total energy distributed by Light SESA is around 24000 GWh/year, attending 3.4 million customers. To do its job Light_SESA has 2200 km of transmission lines, 83 substations, 5 hydro power plants (780MW) and 4000 employees. Light SESA has its overhead and underground sub transmission system in 138 kV and its distribution system in 25 and 13,8 kV.

Since march 2000, EDF has become the main shareholder of Light SESA.

Substations description

The transformer differential relays equipped with ANN restraint was installed in two substations, Taquara and Santissimo.

The Taquara substation is supplied by two 138 kV incomers, one main and one back-up. Two 40 MVA 138/13.8 kV transformers feed 16 distribution feeders and two 7.2 Mvar capacitor banks, arranged on two busbars with bus-tie.

The Santissimo substation has two 138 kV incomers, two 36 MVA 138/25 kV transformers, six 25 kV feeders and two 5.3 Mvar capacitor banks.

Each substation is connected on two parallel 138 kV overhead lines, as shown on figure 1. These lines are protected by distance relays and teleprotection.

Both substations are equipped with one automatic transfer system and one reclosing system:
- in case of loss of voltage on the main 138 kV line and normal voltage on the back-up one, the supply is transferred to the back-up ;
- in case of transformer failure, the protection opens the 138 kV line, isolates the transformer and recloses the 138 kV breaker ; the normally open MV bus tie is then closed, in order to restore the voltage on all feeders.

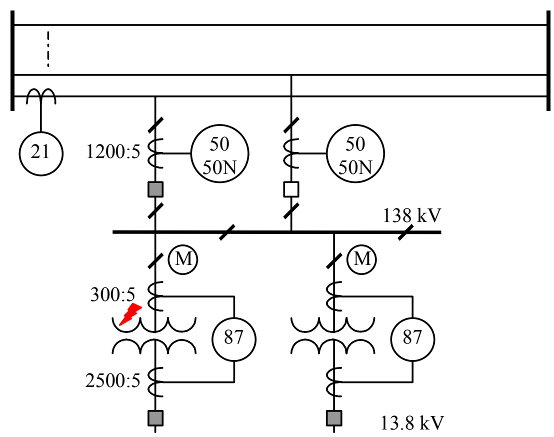

Figure 1: single-line diagram of the Taquara substation

Relay settings

The two 138 kV incomers are equipped with Sepam B07, providing overcurrent busbar protection (50-50N) and the automatisms described above. Each transformer is protected with Sepam D22, transformer differential protection (87) and Sepam S02 back-up protection (51H/51G).

	threshold	time delay
50	2400 A	50 ms
50N	1800 A	50 ms
87, Id/It	30%	

table 1: protection settings

ANN technology allows a commissioning of the relay barely simple. Actually, it should be noted that the differential protection needs only one setting: the slope of the percentage characteristic. The other parameters needed by the relay can be found on the nameplates of the equipment.

Fault description and relay fast trip

The 17th of July, 2001, a phase-to-phase fault appeared inside transformer n° 3, 40 MVA, in Taquara substation. Phase A and C were involved in the fault, and the value of the short-circuit current was 10800 A rms.

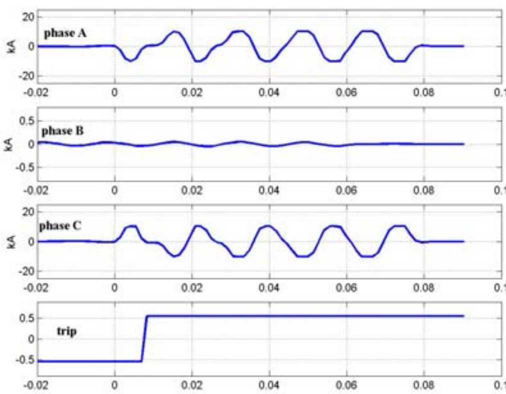

Figure 2: fault recording of Sepam D22 (transformer differential protection)

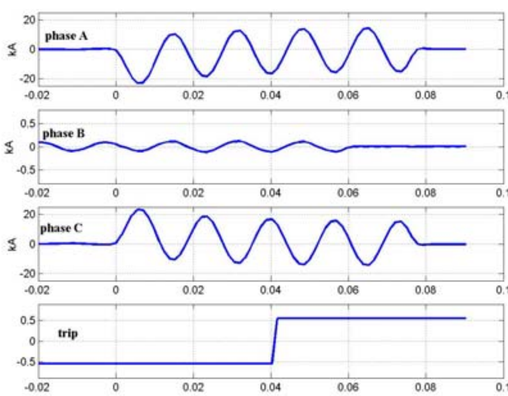

Figure 3: fault recording of Sepam B07 (overcurrent protection)

The protection functions operated properly :

- the transformer differential operated in ½ cycle, as shown on figure 2,
- the overcurrent protection operated in 2.5 cycles.

The 138 kV breaker opened, isolating the faulted transformer, and the automatic reclosing permitted to recover the complete load of the substation.

The operating times of the protection functions were measured from the data recording of the relays. The closing time of the output relays (5ms, approximately), must then be added in order to get the actual tripping time of the device.

The data recording of the relays also gives the magnitude of the fault current. This can hardly be estimated with the recording issued from the differential relay, due to CT saturation. But the recording issued from the overcurrent relay give very good accuracy, as shown on figure 3.

Damage survey and transformer repair

Thanks to the fast tripping of the transformer differential protection, it was found that the 40 MVA transformer could be repaired.

The HV side of the transformer is connected in Delta. Only the HV winding phase A was found damaged :

- The LV winding was healthy.
- On the HV winding, the pancake coils number 101 to 114 had to be re-winded, since they had melted together ; but coils number 1 to 100 were retrieved. (see figure 4).
- The tap coil was replaced.
- The isolators, both at the top and at the bottom of the winding were fully burned and had thus to be replaced.

HV windings phases B and C were simply carefully cleaned up.

Figure 4: damages in the tap coil (left) and HV winding (right). Relatively low damages were due to the fast trip of the transformer differential protection.

Conclusion

As frequently stated, the main advantages of a transformer differential protection is to remain stable on external faults and to trip fast when an internal fault occurs. During the field tests carried out by Light SESA, the transformer differential protection based on ANN revealed those two essential characteristics.

<u>Fast trip on internal fault:</u> the phase-to-phase primary fault on the 40 MVA transformer was detected in ½ cycle, despite heavy CT saturation giving a high 2nd harmonic current ratio.

<u>Stability on external fault:</u> the behaviour of the relay was recorded during three months ; 116 external faults occurred during this period and the relay never tripped. The substations were energised in January, 2000 and, since then, no incorrect operation of the relay and no relay software/hardware problem occurred.

DESCRIPTION OF THE TRANSFORMER

DIFFERENTIAL PROTECTION

Overview of the relay

Sepam 2000 D22 and D32 are protection relays for two and three winding transformers, including one transformer differential protection, one or two restricted earth fault protections [2], the processing of buchholz and thermostat data, the relevant measurement functions, disturbance recording and communication facilities.

This relay is made with the standard Sepam 2000 hardware modules, providing a high level of electromagnetic compatibility and a high level of safety due to continuous self testing [3].

A relay designed for easy commissioning

The relay has been designed in order to get cost cuts in substation design and commissioning. Among the three following features, the two first are the direct benefit of the ANN technology :

CT sizing is easy : standard IEC 5P20 CTs, with rated power in relation with the connected load, are convenient for the transformer differential protection. Additional requirements have to be fulfilled for the restricted earth fault, but for specific applications only.

The setting is straightforward : the characteristics of the CTs (rated current) and the protected transformer (rated voltage, power and vector group) are first entered in the relay. The differential protection has then one setting only, which is the slope of the characteristic. No specific setting for the restraint and no high set are needed.

Testing the relay has been made easier with a test position, under which the current matching software modules of the differential protection are by-passed. Balanced testing conditions are then obtained when the same current is injected at primary and secondary sides of the relay.

Description of the 87T protection

Each protection function can be considered divided in two parts, the signal processing stage followed by the information processing stage.

The purpose of **the signal processing stage** is to deliver the differential current, the through current, the second and the fifth harmonic ratios.

The current in each transformer winding is first measured and sampled. First, second and fifth harmonic phasors are then calculated using sine and cosine filters, as described in [4].

The magnitude of primary and secondary current are matched according to the parameters set in the relay.
For winding 1 currents, the zero-sequence current is removed using the following calculation :

$$J1 = i1 - (i1 + i2 + i3)/3$$
$$J2 = i2 - (i1 + i2 + i3)/3$$
$$J3 = i3 - (i1 + i2 + i3)/3$$

For winding 2 and 3 currents, the vector-shift of the transformer is taken into account in the following way :

vector group 0 :

$$J1' = i1' - (i1' + i2' + i3')/3$$
$$J2' = i2' - (i1' + i2' + i3')/3$$
$$J3' = i3' - (i1' + i2' + i3')/3$$

vector group 1 :

$$J1' = (i1' - i2')/\sqrt{3}$$
$$J2' = (i2' - i3')/\sqrt{3}$$
$$J3' = (i3' - i1')/\sqrt{3}$$

The calculation with the other vector groups can easily be derived from the previous.

The differential and through currents are defined as follows:

$$Id1 = abs(J1 + J1')$$
$$Id2 = abs(J2 + J2')$$
$$Id3 = abs(J3 + J3')$$

and

$$It1 = max(abs(J1), abs(J1'))$$
$$It2 = max(abs(J2), abs(J2'))$$
$$It3 = max(abs(J3), abs(J3'))$$

The second and fifth harmonic ratios are calculated from the differential currents.

The purpose of **the information processing stage** is to make the tripping decision.

As shown on figure 5, the differential protection has three elements – one per phase, each element being made of a biased differential element and a restraint element.
The inputs of these elements are the differential current, the through current, the second and fifth harmonic ratios.

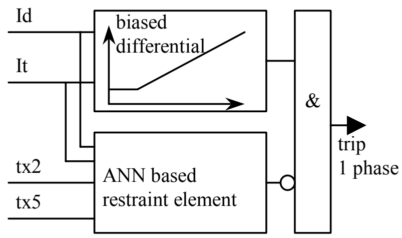

figure 5: the algorithm of the transformer differential protection

The tripping characteristic of the protection is shown on figure 6.

The slope of the biased differential element is settable between 15% and 50%.

The ANN restraint element has its own characteristic, which is shown in dotted line on figure 6, when the second and fifth harmonics are zero. When the slope is set to a low value, part of this characteristic can be tested, as a kind of second slope.

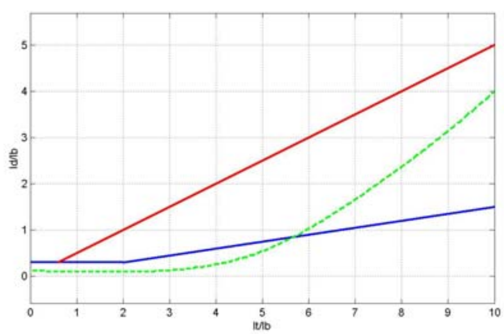

Figure 6: tripping characteristic of the relay

The reduced number of settings was made possible by the use of the ANN-based restraint element. This element has an optimised characteristic, which fits all expected needs. It is no longer necessary to adjust it

Moreover, as the ANN-based restraint element takes as inputs more information than a traditional one, it becomes possible to make a difference between second harmonic due to transformer inrush and second harmonic du to CT saturation in case of a severe internal fault. No additional high set is then necessary.

BENEFIT OF THE ANN TECHNOLOGY IN RELAYS

Manufacturer experience with ANN

The research on the application of neural techniques in the protection field started in the early 90's with a long-term partnership between Schneider Electric, relay manufacturer and Supelec, Institute based near Paris. The research on that field never stopped since then.
The transformer differential protection is the first industrial application of the technique. In this protection, the ANN used is a multi-layer perceptron (MLP), which is a well-known classification tool. The two classes – the two values taken by the output of the MLP – are "trip" or "restrain", the purpose of the perceptron being, for a given set of inputs, to determine whether they belong to one class or the other, that is whether the protection can trip or not.

This protection, part of the Sepam 2000 product range, has been introduced on the market in 1999 with full success.

Other applications of ANN in the protection relay field are under consideration. The most advanced one is an earth-fault protection, suitable for Petersen-coil earthed systems, which does not need voltage measurement [5].

In the two former examples, ANN are used for processing the information. They can also be suitable for signal processing. Based on the principle described in [6], it is possible to re-build the primary current from the secondary signal of a saturated current transformer. In that application, the MLP processes directly the samples of the signal. The output can take continuous values and will provide at each time step one sample of the re-built current

Implementation in protection relays

A MLP can be seen as a system having a large number of inner parameters : the "weights" and "bias" associated with each neuron [7].

The function of the MLP is defined from a "training base", which is a set of examples including both the inputs and the desired output. During the training step, weights and bias are adjusted in order that the MLP computes the right outputs from the inputs of the training base.

After a successful training step, the MLP has good generalization features, in a sense that it can compute the right output for a set of inputs different from the training base. Obviously, extensive testing is necessary to check that the MLP has the proper behavior in all expected cases.

The keys for the success of the development of an MLP are:
1. To get an efficient training base. As each time of each simulated fault case provides a new set of inputs, the number of examples is incredibly high, and can only be mastered with good methodology and good skills in power system transient behavior.
2. To select the proper size for the MLP : it must be small enough to allow a good generalization and large enough to get successful training.
3. To carefully select and code the inputs of the MLP, so that they are representative of the events to be identified.

After the MLP has been developed, all the weights and bias are fixed. It can be coded as is in the microprocessor of the relay. From our experience, running the MLP in real time will use an acceptable amount of processing resources.

Advantage and future of this technique

The ANN technique is a powerful tool for the relay manufacturer.

Used in the differential protection, it allows to make better decision from given inputs. The benefit for the user is a high-performance protection barely simple to set.

Used in the other applications, as directional earth-fault without voltage measurement, it allows good decision from a reduced number of inputs. The benefit for the user is that voltage transformers are no longer necessary.

In both cases, the technique will lead to cost cuts for the user.

Of course not all the problems will be solved with this technique. But if we consider that the purpose of digital relays is not to provide extensive toolboxes for experts but to be simple and robust sentinels, then the ANN technique has an open future.

CONCLUSION

The Light SESA field experience reveals that leading-edge technology based in ANN has been used in Sepam relay to:

- make the commissioning easier
- provide fast fault detection when internal fault and then cut cost on equipment repair
- provide stability on external faults

Within Sepam range, the new Sepam series 80 is intended to cover high-end applications from year 2003. Together with other advanced protection algorithms, ANN based transformer differential protection has been implemented in this new range, in order to provide this key values for demanding customers.

Schneider Electric intend to push research on ANN to find other applications, specially in directional earth-fault detection without voltage measurement.

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