Fault Identification Using Multiple Information Sources in Smart Distribution Grids

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ABSTRACT

This paper outlines research and development work to use multiple information sources for improves the traditional outage management system. The architecture was designed considering a smart grid environment. The methodology presented allows the automatic solution of the fault identification and fault location problem in distribution systems using a methodology based on a fuzzy inference system. A pilot system using the proposed methodology has been implemented in an electrical utility in South of Brazil. To illustrate the paper are presented results and preliminary analysis from real situations based on historical data.

INTRODUCTION

The modern distribution systems are becoming more complex, since a revolution in technological aspects and regulatory issues are increasing operation challenges. The need to meet higher levels of quality and reliability requires improvements in on-line monitoring, protection and control of distribution network. Fundamental tasks to reach these requirements are the identification and location of faults and service restoration of distribution network after outages.

Several new technologies using automation and intelligent devices have become available and are now being installed on the distribution network, allowing an implementation of smart grid concepts in distribution systems. In this sense, the electrical utilities have invested time and funds to developed and install Modern Distribution Control Center integrating Distribution Management System – DMS, Outage Management Systems - OMS, SCADA, Intelligent Electronic Devices – IEDs and Advanced Metering Management – AMM in order to create conditions for future self-healing functions [1]. Reference [2] presents an overview about new technologies for future distribution networks, which include massive use of information technology, communication infrastructure, sensors and intelligent systems.

SYSTEM ARCHITECTURE

A fault management system using data from five different sources (DMS, reclosers, smart meters, IEDs in substation and trouble call) has been developed. The figure 1 shows a structure of the implemented system.

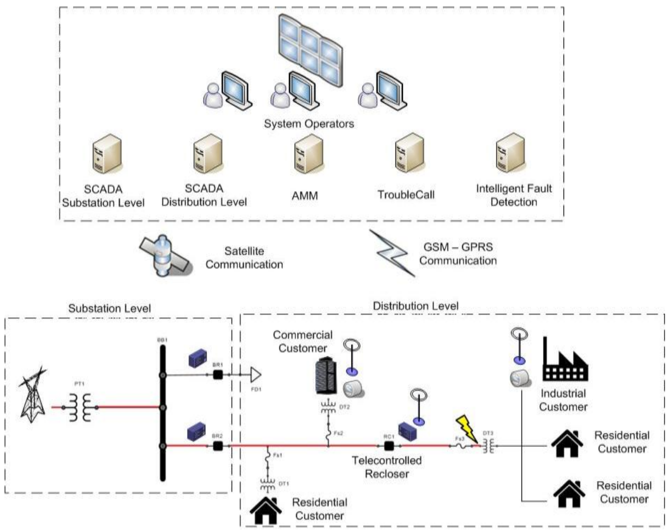

Figure 1 –System architecture.

The system can be divided in four sub-systems: data acquisition, data validation, fault identification and fault location, as follow: 1) data acquisition from substation IEDs is done by the sub-transmission SCADA via satellite communication link, data from smart meters and reclosers are obtained by the AMM and distribution SCADA via GSM-GPRS communication link; 2) The validation process is used to ensure that collected data are confident, cutting bad measurement, unnecessary data and noises; 3) Fault detection is executed to fault anticipation and fault identification; 4) Finally, a fault location analysis is executed, combining data and make an information fusion in order to estimate a fault section in the distribution system.

Next session presents the proposed methodology whose focus is sub-systems 3 and 4.

PROPOSED METHODOLOGY

In a distribution system with medium automation level, the faults can be cleared by monitored (recloser, IED) or non-monitored (fuses) protection devices. Information of faults removed by monitored protection devices are sent to SCADA and treated using an analysis routine providing a complete fault report, assisting Distribution Control Center to support the field crews activities.
The fault report contains the following information:

- Type of fault (line-to-earth; line-to-line; double line-to-earth and three-phase);
- Indication of temporary or permanent fault;
- Time stamp (initial and final instant of fault);
- Interrupted customers;
- Estimated interrupted load;
- Fault critical index.

In case of monitored transient protection action (autoreclose trip), there is a chance of a permanent fault has been cleared by a downstream non-monitored device. In this case, a fuzzy inference routine identify which non-monitored protection device has operated based on the pre and post electrical measurements, the estimated state network, the call center and AMR information.
The system uses non-synchronous multiple information sources with different time scales, as shown in Figure 2. Therefore it is necessary an inference routine to handle the information and dynamically update the solution as soon as the information becomes available.
After the occurrence of a transient fault, the first information available in the control center is the fault report and pre/post electrical measurements.
The first step of the inference routine is to identify the possibility of downstream protection operation. This is executed by comparing the difference between the values monitored before and after a failure occurrence with expected range of variation of this variable. The concept used is similar to "Bollingers Bands" technical analysis tool [3] common used in financial market analysis.
The variation between two samples of a specific measure obtained from SCADA can be defined by equation 1.

$$\Delta meas(t) = (meas(t) - meas(t-1)/\Delta t \quad (1)$$

Analyzing $\Delta meas(t)$, using equation 2, in the post-fault time, it is possible to identify whether there was a significant loss of load or not.

$$\Delta meas(t) > MA_{\Delta meas(t-1)} + K.\sigma_{\Delta meas(t-1)} \quad (2)$$

where:
- $MA_{\Delta meas(t-1)}$ is the N arithmetic moving average of the $\Delta meas(t-1)$;
- $\sigma_{\Delta meas(t-1)}$ is the N moving standard deviation of the $\Delta meas(t-1)$;
- K is the number of standard deviation.

A significant loss of load after a transient fault can indicate a downstream permanent protection action. After loss of load detection, the proposed solution utilizes a three stage fuzzy engine to identify which non-monitored device operated, as shown in Figure 2.

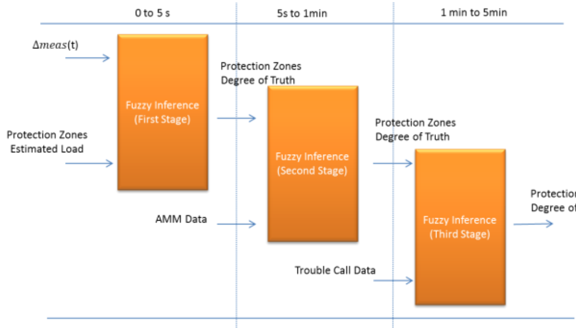

Figure 2 - Non-Monitored Fault Identification Fuzzy Block

The aim of the fuzzy system is to determine a fuzzy number indicating the degree of truth related to a non-monitored protection device operation. The inputs of the inference engine are: estimated active power of each protection zone, power variation $\Delta meas(t)$, AMM voltage status from consumers with AMR and trouble call information.

PILOT SYSTEM RESULTS

The proposed methodology is being integrated in a self-healing solution under development at CELESC S.A., a distribution utility localized in south of Brazil. Complete solution architecture comprise a fault identification and location, fault isolation and network reconfiguration modules with full integration among technical databases, GIS, SCADA, AMM and Trouble Call system.
To validate the proposed methodology was selected a pilot system of CELESC, as presented in Figure 3. This system contains a substation and three feeders. Currently, these feeders have the information of substation IED, three monitored reclosers, some AMR costumers. There are several non-monitored protection zones protected by fuse devices.
To illustrate the application performance was selected a transient protection action on the feeder breaker where the fault was cleared by a non-monitored protection device.

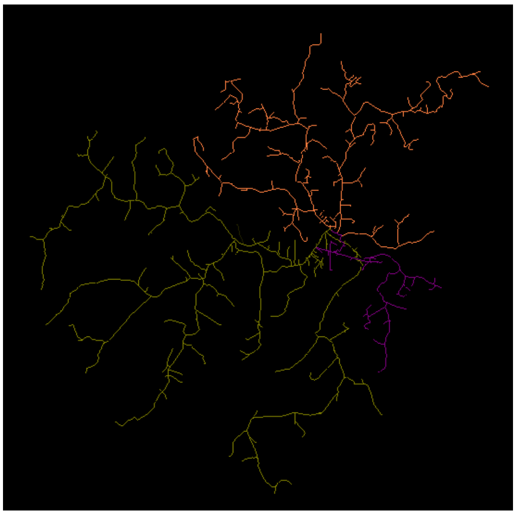

Figure 3 – Electrical Distribution Pilot System

The SCADA sequence of measurements for this trip is shown in table 1.

Table 1 – Transient protection action SCADA measurements set

TimeStamp	***Meassure***	***Value***	***Phase***
12:09:44:944	FaultCurrent	1211	A
12:09:44:944	FaultCurrent	100	B
12:09:44:944	FaultCurrent	524	N
12:09:44:944	FaultCurrent	976	C
12:09:48:948	State	0	ABC
12:09:48:948	51Trip	1	A
12:09:48:948	51Trip	0	B
12:09:48:948	51Trip	1	C
12:09:54:954	State	1	ABC
12:09:54:954	51Trip	0	C
12:09:54:954	51Trip	0	N
12:09:54:954	51Trip	0	A

The result of fault analysis routine is shown in table 2.

Table 2 – Fault analysis routine result

Variable	***Value***
Device	CPA01
Type	Double Line-Earth
Classification	Temporary
N AutoReclose Trips	1
Phases	ACN
Start	28/10/2012 12:09:44:94
End	28/10/2012 12:09:54:95
Duration	10,01 s
Estimated Interrupted Load	180 kW
Critical Index	0

Table 3 shows pre and post fault electrical measurements.

Table 3 – Pre and post fault electrical measurements

Var	***Phase***	***Pre Fault Value***	***Post Fault Value***
I	A	54,1 A	45,2 A
I	B	66,7 A	54,3 A
I	C	55,8 A	43,9 A
I	N	13,2 A	9 A
V	AB	13,80 kV	13.82 kV
V	BC	13.81 kV	13.95 kV
V	CA	13.94 kV	14.07 kV
P	ABC	1359 kW	1179 kW
Q	ABC	381 kVar	182 kVar

During the fault occurrence, the active power presented a variation of 180kW in a time interval of 5 seconds. Applying equation 2 and using N =20 and K = 2, the algorithm detected a loss of load.
Table 4 shows the output results from first stage fuzzy block indicating a confidence value of 0,66 for protection zone 4272 and 0,67 for protection zone 606.

Table 4 – First stage fuzzy inference machine result

Protection Zone Id	***Estimated P (kW)***	***Degree of Truth***
4704	126,7148	0
4110	45,41751	0
3591	23,49945	0
4272	200,1626	0,664230181
4273	13,02058	0
606	149,5348	0,679110203
3594	76,42228	0
3595	34,40613	0
9177	28,84961	0
4591	42,34531	0
4231	70,27085	0
76033	130,0759	0
73287	19,53137	0
4701	56,68657	0
4950	30,43101	0
3174	20,8138	0
4700	39,19561	0
3598	70,41581	0
4661	16,63332	0
604	80,61987	0

In the example, the current outage management system, whose is based on the traditional method of grouping trouble calls per distribution transformers and protection devices [1], took 29 minutes to identify the failure in the correct protection zone (606). Considering that the first trouble call occurred 5 minutes after the transient protection action, the second stage fuzzy engine could identify the block 606 in only 5 min, representing a time reduction of 82.7% in the process of fault identification.

CONCLUSIONS

This paper introduces a fault management system architecture in a smart grid environment. The methodology presented allows the automatic solution of the fault identification and fault location problem in distribution systems using multiple information sources. The case example shows the feasibility of using transient protection as a trigger to detect a permanent fault in downstream non-monitored protection devices.

The architecture of the fault diagnostic proposed allows the reduction of the fault identification time.

Additional researches must be done to investigate the observability of the protection zones and to avoid misoperation during avalanche of events.

Moreover, this architecture was designed to support future applications of self healing functions.

Acknowledgments

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REFERENCES

[1] J. Northcote-Green, R. Wilson, 2007, *Control and Automation of Electrical Power Distribution Systems*, CRC Press, Boca Raton, FL, USA.

[2] C.W. Gellings, 2011, "Power to the People – New Distribution Technologies on the Horizon", *Power and Energy*. vol. 9, N05, 52-63.

[3] C. D. Kirkpatrick, J. R. Dahlquist, 2010, *Technical Analysis: The Complete Resource for Financial Market Technicians*, FT Press, USA.