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# Contribution of Corporate Systems for Fault Location in Power Distribution Networks

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Abstract: In power distribution systems, short-circuit events imply long service response time, affecting the quality of service. Although many research works propose fault location methodologies, which are based on meta-heuristics, artificial intelligence and travelling waves, most power utilities do not have the data requested by such approaches. Consequently, maintenance crews locate faults through field searches, considering the operation of protection devices and affected customers' phone calls, characterizing a procedure that may last some hours. This work proposes a practical fault location methodology, considering the current scenario of few metering data concerning the short-circuit events. Based on case studies results, the proposed methodology is considered effective. It may be executed in few seconds and leads to satisfactory results.

Resumo: Em sistemas de distribuição, eventos de curto-circuito demandam longos tempos de atendimento, afetando a qualidade do serviço. Embora diversas pesquisas proponham metodologias de localização de faltas baseadas em meta-heurísticas, inteligência artificial e ondas viajantes, grande parte das concessionárias não dispõem dos dados demandados. Consequentemente, as equipes de manutenção localizam faltas através de buscas em campo, considerando a operação dos dispositivos de proteção e as ligações telefônicas dos clientes afetados, caracterizando um procedimento que pode durar horas. Este trabalho propõe uma metodologia prática para localização de faltas, considerando o atual cenário de poucos dados relativos ao instante do curto-circuito. A partir dos resultados de estudos de casos, verifica-se que a metodologia é eficaz, pode ser executada em poucos segundos e produz resultados satisfatórios.

*Keywords*: Fault location; Advanced distribution automation; Outage management; Quality of service; Electric power distribution.

*Palavras-chaves*: Localização de faltas; Automação avançada da distribuição; Gerenciamento de ocorrências; Qualidade de energia; Distribuição de energia elétrica.

## 1. INTRODUCTION

Short-circuit events in power distribution networks are cleared by protection system operation, causing the affected area to be isolated and interrupting power supply to most customers. In most Brazilian power distribution networks, power supply is reestablished based on customers' phone calls and field searches by maintenance crews. Consequently, this process may last hours and severely impact utility's quality of service.

Some researches propose the use of multiple device measurements, such as smart meters (Trindade et al., 2014). However, such approaches are still unfeasible due to incipient monitoring of power distribution systems. Other approaches consider artificial intelligence, as Dashtdar et al. (2018). As these approaches require many historical data for training and testing, they are unsuitable to most current power distribution networks.

Travelling waves-based methodologies, despite their great accuracy when applied to transmission systems, present impaired results in distribution networks due to branches and terminal sections (Pourahmadi-Nakhli e Safavi, 2010). Besides, their applicability is impacted by high costs of the related devices, despite efforts in attempting to reduce the costs involved (Liang et al., 2015).

This paper presents a fault location methodology, developed under the scope of an R&D project sponsored by Neoenergia power distribution utility. Short-circuit events are located in real-time through the data and measurements available in the utility's corporate systems. The R&D project enabled the development and deployment of metering devices aimed to assist fault location, yielding to fairly accurate fault location results. Based on such devices, the methodology also locates broken cables, which would not be possible considering traditional protection devices.

Through the case studies presented in this paper, one can notice that the methodology was applied to locate short-circuit events concerning real distribution networks served by Neoenergia.

The present paper is structured as follows: the developed methodology is introduced in Section 2. Its applications through case studies are presented in Section 3. Finally, conclusions and final comments are drawn in Section 4.

## 2. METHODOLOGY

### *2.1 Corporate system environment*

The Fault Location (FL) functionality is executed under the scope of a Distribution Operations Center (DOC), which gathers systems such as SCADA (supervisory system), GIS (geographic information system), OMS (outage management system) and FLAD (fault location assistance devices, designed under the R&D scope such as: short-circuit sensors, power quality meters and intelligent transformers). Such devices are integrated through an IT tool, namely Interoperability Bus (IB), which was implemented according to patterns established by CIM (IEC61968), aimed to enable data integration among distinct corporate systems. The integration of these systems is illustrated in Figure 1.

### *2.2 Data flow*

By integrating utility's corporate systems, data transfers among FL and the remaining DOC systems are achieved through Solicited Interactions (SI) and Unsolicited Interactions (UI). Asynchronously, networks' topological updates are forwarded to FL by GIS (US1). Similarly, updates of unsupervised switches states are forwarded to FL by OMS (US2).

As a fault location process is initiated, six steps are executed. Ultimately, utility's operator decision on the ongoing problem is supported by the possible fault location results provided by the FL module. These are the six steps comprising a fault location process:

1. SCADA and FLAD forward alarms concerning the short-circuit or cable breaking event (UI3);
2. Additional data on the event are requested by FL to SCADA and FLAD (SI1);
3. SCADA and FLAD respond to SI1 request (SI2);
4. FL executes fault location preparation;
5. FL executes fault location algorithm;
6. FL forwards fault location results to SCADA and OMS (SI3);

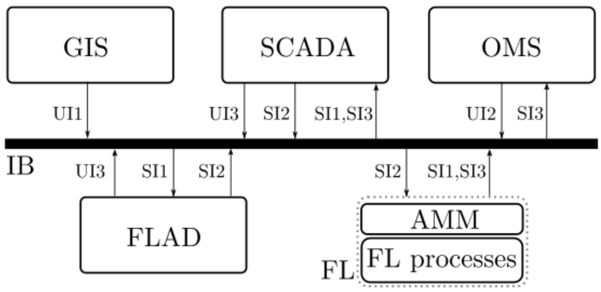


Figure 1 – Data flow in DOC environment

### *2.3 AMM – Alarms and Measurements Manager*

The FL methodology initial steps are executed by a management module named Alarms and Measurements Manager (AMM). Through such module, incoming alarms are processed (they can be related to distinct simultaneous events) and properly aggregated. Then, specific fault location process is generated for each event identified by AMM.

A given alarm is composed by a set of parameters: 1) *Timestamp*, 2) *Feeder* – identification of the feeder involved and 3) *Device* – identification of the field device responsible for emitting the alarm. As alarms are aggregated, they support the same location process in case they meet the following requirements:

1. Field *Feeder* – alarms are related to a same feeder;
2. Field *Timestamp* – time difference of few minutes between the newest and the oldest alarms (cases illustrated in this paper consider up to 3 minutes);

Considering a given alarm with parameters (*Timestamp*, *Feeder* and *Device*), a process involving *Feeder* is searched among all initiated processes. Three situations are possible:

- There is no process involving Feeder. Then, a specific fault location process is created, to which the alarm is attached. A time counting interval, named *Alarm Window*, is initiated, during which new incoming alarms can be attached to the process (cases illustrated by this paper consider *Alarm Windows* of approximately 3 minutes).
- There is a process involving *Feeder*, with *Alarm Window* open. In this case, the incoming alarm is attached to this process.
- There is a process involving *Feeder*, but its *Alarm Window* is closed. In this case, a new fault location process is created along with a new *Alarm Window*. The incoming alarm is attached to the process created.

The FL process management, conducted by AMM is summarized by a flow chart in Figure 2.

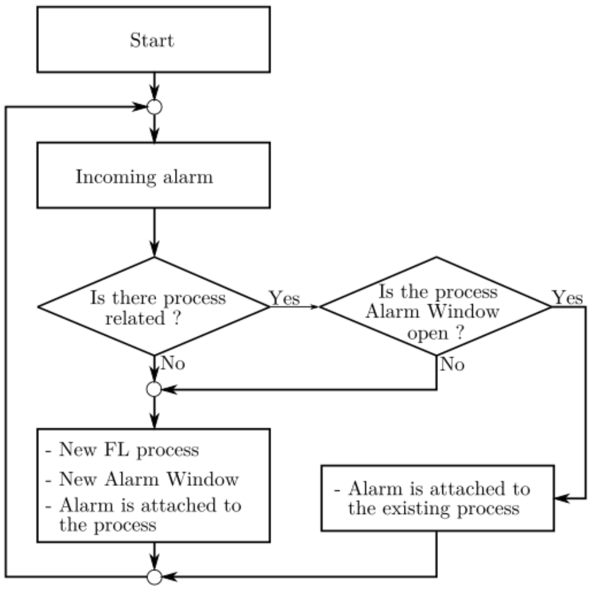


Figure 2 – FL process management by AMM

*2.4 FLP – Fault Location Preparation (FLP)*

In FLP step, data related to the FL process are pre-processed for searching area determination and fault classification. Based on alarms comprising a given FL process and based on the affected network topological model, the methodology identifies the tripped protection device closest to the fault, namely *Fault Reference Device* (FRD). The searching area includes network elements (such as sections, nodes, loads etc.) after the FRD and before the remaining downstream protection devices. By doing so, the searching area consists of a smaller network bounded by protection devices, which contains the fault point. After receiving and aggregating alarms, AMM requests SCADA measurements recorded during the event. Based on fault currents' magnitudes, the fault is classified according to the following types: 3ph (three-phase fault), 2ph-g (phase-phase-to-earth fault), 2ph (phase-phase fault) and 1ph (single-phase fault).

*2.5 Selecting the fault location algorithm*

The information regarding the events affecting power distribution systems are acquired and recorded by protection and measuring devices installed in the network investigated. Based on such information, the events can be grouped in three groups:

1. Faults involving only phases (3ph and 2ph) – which is the simplest fault location case;
2. Faults involving the ground (2ph-g and 1ph) – which requires determining the fault resistance value;
3. High impedance events with cable breaking – which is not detected by protection system tripping;

In order to locate those three groups of events, three distinct algorithms were developed: *FL1*, *FL2* and *FL3*. During the FLP step, additional information on the event is requested to SCADA through the IB, including which overcurrent protection function tripped (if applicable). From this information and based on alarms received, a Fault Location algorithm (out of *FL1*, *FL2* and *FL3*) is selected by proceeding the verifications presented in Table 1. Incoming alarms related to the tripping of overcurrent phase functions (such as 50 or 51) indicate if the fault involved only phases (such as 3ph or 2ph). On the other hand, alarms related to the tripping of overcurrent neutral functions (such as 50N or 51N) indicate faults involving the ground (such as 2ph-g or 1ph). Finally, no protection tripping along with voltage sag records indicate probable cable breaking event.

Table 1 – Determining the FL algorithm

| **Incoming alarm conditions** | **Selected algorithm** |
|---|---|
| Phase overcurrent protection functions (50 or 51) | FL1 |
| Neutral overcurrent protection functions (50N or 51N) | FL2 |
| Voltage sag alarms and no alarms from protection function tripping | FL3 |

*2.6 Description of fault location algorithms*

*2.6.1 FL1 Algorithm*

FL1 Algorithm is aimed to locate faults involving only phases (such as 3ph and 2ph). It is based a single measurement, which is the maximum fault current magnitude, normally recorded by protection relays or by short-circuit sensors. Such measurement is compared against simulated fault currents magnitudes on all networks' nodes, assisted by a short-circuit simulator based on *FaultStudy* function, available on OpenDSS simulator (Dugan, 2013). It is integrated to the FL module and provides considerable performance for calculating fault currents.

The algorithm for determining a possible fault location solution is described as follows. Considering node *k* as a node pertaining to the searching area, $I_k^{comp}$ is defined as the fault current magnitude computed on node *k*. If the absolute value of the difference between measured fault current $I^{fault}$ and $I_k^{comp}$ is smaller than a preset tolerance $Tol_{FL1}$, node k is considered a possible solution to the fault location problem, according to Equation (1).

$$\left|I^{fault} - I_k^{comp}\right| < Tol_{FL1} \rightarrow \text{node } k \text{ is a solution} \quad (1)$$

In order to exemplify FL1 Algorithm, consider the hypothetical power distribution network depicted in Figure 3. Its three-phase sections are 5 km long and present the following features: $\bar{z}_0$ = 0.01+j0.35 $\Omega/km$ and $\bar{z}_1$ = 0.01+j0.25 $\Omega/km$. Each node has attached a 300 kVA three-phase load. For a given fault location process, the relay associated to circuit breaker CB records 1159 A affecting two phases (thus, it probably refers to a 2ph fault). By executing OpenDSS-based *FaultStudy* function, three-phase (3ph) and phase-phase (2ph) short-circuits currents are listed, as illustrated in Table 2. Fault current deviations in respect to the phase-phase fault currents computed on each node of the network ($\Delta I_{2ph}^{fault}$) are also presented in Table 2. By considering 1% tolerance ($Tol_{FL1} = 1\%$), nodes 8 and 9 are considered the possible fault location solutions, because they are under the tolerance margin (0.78%).

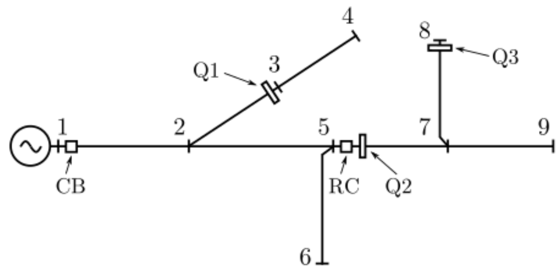


Figure 3 – Hypothetical distribution network

Table 2 – Fault location results from FL1 example

| **#Node** | ***FaultStudy* - results** | | **$\Delta I_{2ph}^{fault}$ (%)** |
|---|---|---|---|
| | **3ph (A)** | **2ph (A)** | |
| 1 | 15935 | 3800 | 227,87 |
| 2 | 4378 | 3791 | 227,09 |
| 3 | 2507 | 2171 | 87,32 |
| 4 | 1753 | 1518 | 30,97 |
| 5 | 2513 | 2176 | 87,75 |
| 6 | 1754 | 1519 | 31,06 |
| 7 | 1758 | 1522 | 31,32 |
| 8 | 1348 | 1168 | 0,78 |
| 9 | 1348 | 1168 | 0,78 |

*2.6.2 FL2 Algorithm*

FL2 Algorithm is aimed to locate faults involving the ground (such as 2ph-g and 1ph faults) and is deeply based on voltage and current phasorial measurements recorded by a power quality meter installed on the feeder, called *Fault Reference Qualimeter* (FRQ). Through the Equations System (2), total resistance $R_{tot}$ and total reactance $X_{tot}$ are seen from the FRQ position.

Given the network's electrical topology, accumulated total resistance and reactance are computed. Through Equations System (3), zero and positive parameters ($R_i^{(0)}$, $X_i^{(0)}$, $R_i^{(1)}$ and $X_i^{(1)}$) are computed. In this equations system, subscript index $i = 1$ represents the first section in the search area downstream the FRQ, $N_{nodes}$ is the total amount of nodes in the search area and $k \epsilon \{ 1, \ldots, N_{\text{nodes}} \}$.

$$\left. \begin{aligned} R_{tot} &= Re\left(\frac{\dot{V}_{tot}}{\dot{I}_{tot}}\right) \\ X_{tot} &= Im\left(\frac{\dot{V}_{tot}}{\dot{I}_{tot}}\right) \end{aligned} \right\} \tag{2}$$

$$\left. \begin{aligned} R_{tot,k}^{(0)} = \sum_{i=1}^{k} R_i^{(0)}\, ;\ X_{tot,k}^{(0)} = \sum_{i=1}^{k} X_i^{(0)} \\ R_{tot,k}^{(1)} = \sum_{i=1}^{k} R_i^{(1)}\, ;\ X_{tot,k}^{(1)} = \sum_{i=1}^{k} X_i^{(1)} \end{aligned} \right\} \tag{3}$$

The accumulated reactances on a given node $k$ are computed according the Equations System (4), where $X_{section,k}^{1ph}$ and $X_{sections,k}^{2ph-g}$ represent total reactances accumulated on node $k$ for single-phase and phase-phase-ground, respectively.

$$\left. \begin{aligned} R_{sections,k}^{1ph} &= X_{tot,k}^{(0)} + 2X_{tot,k}^{(1)}, && \text{1ph faults} \\ R_{sections,k}^{2ph-g} &= X_{tot,k}^{(1)}, && \text{2phg faults} \end{aligned} \right\} \tag{4}$$

For each node $k$ belonging to the search area, total reactance $X_{tot}$ is compared against the total reactance accumulated on node $k$, yielding to reactance deviation $\epsilon_k^{react}$, which is computed through Equation (5). Nodes presenting $\epsilon_k^{reat}$ within a given tolerance $Tol_{FL2}$ are considered the candidates as solutions to the fault location problem.

$$\epsilon_k^{react} = \left| X_{tot} - X_{sections,k} \right| / X_{sections,k} \tag{5}$$

A test consisting of short-circuit simulations on candidate nodes is executed. For testing candidate node $j$, a fault resistance $R_{f,j}^{test}$ is considered, which is computed through Equation (6).

$$R_{f,j}^{test} = \frac{1}{3} \cdot (R_{tot} - R_{sections,j}) \tag{6}$$

Based on the short-circuit test on node $j$, a measuring deviation $\epsilon_j^{teste}$ related to test $j$ is computed, through Equation (7). In this equation, $V_i^{fault}$ is the absolute value of the affected voltage, recorded by a power quality meter. $V_{i,j}^{test}$ is the phase voltage affected by the fault, recorded during the short-circuit test of solution $j$. $M$ represents the amount of power quality meters considered.

$$\epsilon_j^{test} = \sqrt{\sum_{i=1}^{M} \left[ (V_i^{fault} - V_{i,j}^{test}) / V_{i,j}^{test} \right]^2} \tag{7}$$

It should be noted that the absolute values of voltages recorded along the feeder can be also recorded by *Intelligent Transformers*, which also comprise FLAD set of devices.

In order to exemplify FL2 Algorithm, consider the same medium-voltage power feeder depicted by Figure 3. Suppose a single-phase fault occurring in the vicinities of node 9, being cleared by recloser *RC*. In this event, qualimeter indicated by *Q2* in Figure 3 detects overcurrent (376 A in phase A) and qualimeter *Q3* detects voltage sag (single-phase voltage of 6969.3 A in phase A).

Proceeding with calculations, $\dot{V}_{tot}$=7228.9∠-9º V and $\dot{I}_{tot}$ =112.92∠-18º A and, therefore, $\bar{Z}_{tot}$ =64.02∠9º Ω. Taking the imaginary part of $\bar{Z}_{tot}$ yields to $X_{tot}$=10.01 Ω. Given that $X'_{sections}$ =$X_0 + 2X_1$ =0.85 Ω, the distance between the fault and the measuring points is computed: 11.78 km, suggesting nodes 8 and 9 as possible solutions.

Testing the candidate solutions yields to $R_{f,j}^{test}$, with $j \epsilon \{8, 9\}$. For both candidate solutions, $R_{f,j}^{test}$=20.08 Ω. Testing solution on node 8, the affected phase voltage at *Q3* position is 6787.3 V, yielding to $\epsilon_8^{test}$=0.0268. Testing solution on node 9, the affected phase voltage at *Q3* is 6972.8 V, yielding to $\epsilon_9^{test}$=0.0005. Based on the tests, given that $\epsilon_9^{test} < \epsilon_8^{test}$, one may conclude that fault occurred on node 9.

*2.6.3 FL3 Algorithm*

FL3 Algorithm is aimed to locate cable breaks on medium-voltage feeders and is based on voltage sag alarms emitted by qualimeters and their respective installation points on the investigated network. The following steps are verified:

1. Among the power quality meters emitting voltage sag alarms, the most upstream is identified and named as *Q2*.
2. Following the way from *Q2* up to the substation, a qualimeter (at the trunk or at a branch of the selected feeder) not emitting voltage sag alarm is identified, which is named as *Q1*.
3. A possible cable breaking area is identified, consisting of a set of sections and nodes between power quality meters *Q1* and *Q2*.

In order to exemplify FL3 Algorithm, consider the same medium-voltage power feeder depicted in Figure 3. Suppose a cable breaking between nodes 2 and 5. Given that all sections downstream node 5 are three-phase, power quality meters *Q2* and *Q3* detect voltage sag and emit voltage sag alarms. Analyzing sections from *Q2* towards the substation, one may note that node 2 has a branch with a power quality meter *Q1* that did not detect voltage sag occurrence. Then, the section between nodes 2 and 5 is the solution of the cable breaking.

*2.7 Forwarding the location solutions*

After one of the fault location algorithms is executed, the FL methodology generates a results file structured in four blocks. Block #1 contains trigger information (identification of the alarm starting the process). Block #2 contains general data (identification of the affected network). Block #3 identifies the algorithm selected to locate the fault. Finally, Block #4 contains all possible solutions of the fault location. By its turn, each solution contains the node, the geographic coordinates, the closest switch identification, among other information. The methodology results are forwarded to SCADA and OMS through the IB and the fault location process is terminated.

## 3. APPLICATION AND RESULTS

*3.1 Power distribution analyzed*

The proposed methodology was carried out in a Brazilian rural power distribution network, with rated voltage of 13.8 kV and total section length of 222 km. The power feeder comprises 156 distribution transformers and presents low loading level. Its geographical distribution is depicted in Figure 4. The case studies presented in this paper consider simulated data and measurements recorded by the following field devices:

- CB: protection relay attached to the feeder circuit breaker;
- RC: protection relay attached to a feeder's recloser;
- SR1 and SR2: sensors for short-circuit detection;
- Q1, Q2 and Q3: power quality meters, devices aimed to record phasorial voltages and currents on the network during the event, such as a short-circuit;

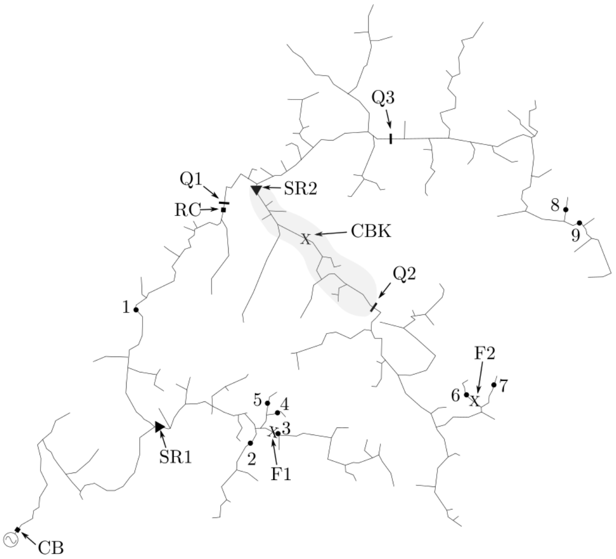


Figure 4 – Power feeder involved in the study case

*3.2 Case study 1*

A given phase-phase fault event affects the analyzed feeder, being cleared by the protection system. Then, maintenance crews indicate point F1, depicted in Figure 4, as the fault site. The fault current recorded by the circuit breaker CB relay is considered the only available measurement (371 A). An alarm related to overcurrent protection function is emitted by this relay, which is considered the *FRD*. Given that relay's additional information indicates phase-phase fault, FL1 Algorithm is executed, yielding possible solutions #1 to #5 in Figure 4.

*3.3 Case study 2*

This case refers to the same phase-phase short-circuit event considered in case study 1, depicted in Figure 4 by *F1*. However, fault currents of sensor *SR1* are also considered (372 A in phase A and 368 A in phase B). An alarm of overcurrent protection function (51) by *CB* relay and an alarm of overcurrent by sensor *SR1* are emitted. *SR1* is considered the *FRD*. Given that sensor's information indicates phase-phase short-circuit, FL1 algorithm is executed, yielding to solutions #2 to #5 in Figure 4.

*3.4 Case study 3*

A second single-phase fault is considered on point *F2*, depicted in Figure 4. The measurements considered include fault current (52 A) registered by *RC* relay and those recorded by power quality meter *Q1* (voltages: $\dot{V}_{AG} = 6035{,}5\angle-40{,}1^o$ V, $\dot{V}_{BG} = 8669\angle-149{,}8^o$ V, $\dot{V}_{CG} = 7519{,}9\angle 94{,}5^o$ V and currents: $\dot{I}_A = 52{,}95\angle-49{,}1^o$ A, $\dot{I}_B = 0{,}84\angle-161{,}9^o$ A and $\dot{I}_C = 1{,}11\angle 110{,}4^o$ A). In this case, an overcurrent protection function alarm is emitted by *RC* relay, which is considered the *FRD*. Given that the fault detected involves the ground, *FL2* algorithm is selected and *Q1* is considered the *Fault Reference Qualimeter* (*FRQ*). The algorithm execution determines solutions #6 to #9 illustrated in Figure 4 as the possible ones.

*3.5 Case study 4*

Case study 4 refers to the same single-phase fault event considered in case study 3, depicted in Figure 4 by *F2*. However, the fault current recorded by sensor *SR2* is also considered (52 A in phase A). In this case, along with overcurrent protection alarm emitted by *RC* relay, an overcurrent alarm is emitted by sensor *SR2*. This sensor is considered the *FRD* and its network elements form the search area. Given that information from *RC* relay indicate neutral overcurrent protection function tripping, algorithm *FL2* is selected, considering qualimeter *Q1* as the *FRQ*. As the algorithm is executed, possible solutions 6 and 7 in Figure 4 are obtained.

*3.6 Case study 5*

Considering a cable breaking at the point indicated by CBK in Figure 4, Q2 emits a voltage sag alarm. Absolute values fo phase-to-ground voltages recorded at this moment are: $V_{AG}$ = 7826.4 V (0.982 pu), $V_{BG}$ = 3685.2 V (0.463 pu) e $V_{CG}$ = 7892.6 V (0.991 pu). Voltages at the remaining qualimeters are not affected. Q1 records voltages $V_{AG}$ = 7829.8 V (0.983 pu), $V_{BG}$ = 7929.9 V (0.995 pu) and $V_{CG}$ = 7895.1 V (0.991 pu) and Q3 records $V_{AG}$ = 7810.7 V (0.980 pu), $V_{BG}$ = 7929.1

V (0.995 pu) e $V_{CG}$ = 7891.2 V (0.990 pu). Then, *Q1* and *Q3* do not emit voltage sag alarms. Algorithm *FL3* is executed and, as response, indicates that the gray region highlighted in Figure 4 contains the cable breaking point.

### *3.7 Results analysis*

In case study 1, a set of possible solutions is obtained based on only one fault current measurement, recorded by CB relay. Such set includes solution 1, because it presents the same distance to CB point, in respect to the remaining solutions, as they probably present similar impedance values. Considering sensor SR1 is highly beneficial, as it excludes solution 1 from the set of solutions. Solutions 2 to 5 exhibit a 500 meters long radius and solution 3 coincides with the actual fault location.

Study cases 3 and 4 comprise the location of a fault involving the ground. This situation is more complex in respect to the faults involving only phases, because it is necessary to address an additional variable, the fault resistance. By using power quality meter Q1, it is possible to determine fault total reactance and, then, list several possible location solutions, dismissing the need of determining the fault resistance. Similarly, to case studies 1 and 2, by considering sensor SR2, it is possible to eliminate solutions 8 and 9, restricting to solutions 6 and 7. Solution 6 coincides with the actual fault point.

Ultimately, for case study 5, FL3 algorithm detects a cable breaking event and, as response, provide a 8.7 km long region, which represents only 3.9% of the power feeder's total extension. Considering FL3 algorithm features, one may verify that the delimited area could be reduced in case more power quality meters or intelligent transformers were considered nearby. In order to locate events, such as that investigated in this case study, utilizing devices such as power quality meters and intelligent transformers is paramount. Such devices, which were also devised under an R&D project, allows the detection of events unable to sensitize traditional protection.

## 4. CONCLUSIONS

Several fault location methodologies proposed by the literature are still unfeasible to be applied to Brazilian power distribution systems, due to low monitoring and difficulties in interacting with field devices. The present work, developed under the scope of an ANEEL R&D project, represents important contribution to address those problems through two aspects.

Firstly, the R&D project enabled the increase of monitoring through devices such as sensor, power quality meter and intelligent transformer. The implementation of an IT tool, such as the IB, provides the integration among the utility's corporate systems and the measuring devices devised under the project. Finally, this tool allows the fault location methodology to utilize information available in power utility's corporate systems, recorded by typical protection equipment and by the devices devised under the R&D scope.

Although the power quality meter is not widespread yet, it constitutes the basis for FL2 and FL3 algorithms. In the first case, voltage and current phasors at the short-circuit instant represent valuable measurements, as they enable the computation of a fault reactance. Associated with topological data, such reactance indicates possible fault location solutions. In the case of FL3 algorithm, power quality meters detect voltage sag and emit corresponding alarms. This simple and innovative functionality is likely to be performed by smart meters, which soon will replace electromechanical meters. If only customers' phone calls would be considered to locate faults, a long time would be necessary to conclude the process comprising of detection, location and restauration.

As future steps concerning the problem of fault location, optimized allocation of monitoring equipment may be considered. Such analysis would provide the power utility with more fault location benefits while considering a given set of monitoring devices available.

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