RESEARCHERID
THOMSON REUTERS

[Voufo* *et al.*, 6(11): November, 2017]
IC™ Value: 3.00

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ROBUSTNESS 'ANALYSIS OF FAULT DIAGNOSIS WITH FAULT PASSAGE INDICATORS ON MEDIUM VOLTAGE DISTRIBUTION NETWORKS IN PRESENCE OF THE DISPERSED GENERATION: CASE OF CENTRAL-AFRICAN COUNTRIES

Joseph Voufo*[1], Joseph Kenfack[2],O Videme Bossou[3], John Ngundam Mucho[4], T. Tamo Tatiétsé[5]

[2,3,4&5*] National Advanced School of Engineering Yaoundé-Cameroun

[1*] National Advanced school of engineering Yaoundé-Cameroun, CETIC

DOI: 10.5281/zenodo.1066224

ABSTRACT

The article analyses the robustness of the fault diagnosis in the MV distribution network with the fault passage indicators (FPI). A probabilistic method using the probabilities of functioning and the signature response of FPI is proposed. The efficiency of the method is proven experimentally.

KEYWORDS: Distribution network, Fault passage indicator(FPI), fault diagnosis, decentralized energy generation(GED), Conditional probability

I. INTRODUCTION

The development of the production combined to electricity and heat, the valorization of the energies a long time neglected and the deregulation of the market of the energy contributed to increase the introduction of the sources call decentralized or dispersed generation sources (GED) in the low voltage (LV) and medium voltage(MV) distribution networks [1]. The present evolution of the network complicates the working conditions of the fault diagnosis devices and can make the present methods of diagnosis inefficient [2]. Indeed, the development of DGS modifies the transits of the powers and the amplitude of the signals related to the faults. The modification of these signals causes inadvertent tripping of the protection devices thus increasing the fault zone, the diagnostic time and the time of the network unavailability.

For the Central-African countries, potential importance of the renewable energies [4] [3], the diagnosis of the fault is almost manual [5] and the time of the network unavailability after a fault is very big [6]. The introduction of the DGS in their distribution network is going to increase this time more and more.
Studies showed that the use of the fault passage indicators (FPI) can be an efficient solution for reduction of the time of the network unavailability [7] [8]. The FPI are part of the protection scheme of a distribution network. It detects the presence of fault while providing the indications locally or to the remote control system. With these indications, the operators can determine the faulty section of the network in order to quickly replenish the healthy zones of this network.

The FPI are installed in huge number on the MV networks, in the streets or on supports in the wild. They are often victim of vandalism. They are not meant to be used frequently. Most models are battery powered and do not detect faults for years [9]. However, it is important that the FPI works properly when a fault occurs, and it is generally once a fault occurs that malfunctioning of the FPI is detects. This aspect can be critical for the localization of the faulty zone. The fact that the FPI are defective during the fault weakens the diagnosis device. Indeed, it is possible that a defective FPI misleads the technicians in looking for the faulty zone. Thus degrading the network operation at a very critical moment and furthermore increasing the fault localisation time.

For the Central-African countries, in addition to these constrained, is added the one related to the installation because to properly function, the FPI must be installed according to rules and be maintained [10]. Because it is difficult to judge the company that will be in charges to install and to assume the maintenance of the FPI in those countries. Our work therefore focuses on the analysis of the probability diagnosis of the faulty section with one or few incorrect indications of the FPI for their efficiency use in Central-Africa.

The structure of this article is as follow: the section 2 presents the description of the different models of FPI and their functioning principle. The section 3 describes in details the theory of the proposed fault localization method. It details the different stages of the method. The section 4 shows a practical example for determining the faulty zone to verify the robustness of the method proposed. Conclusion is given in section 5.

II. FAULT PASSAGE INDICATORS

The fault passage indicators (FPI) is part of the protection plan of a distribution network and are used during the localization of fault process. It is installed along the feeder of the MV distribution networks [11]. By the local signal analysis of current and voltage (for some models), it's capable to indicate in local or at distance to the operator of the network the presence of the fault. These have been designed to detect the flow of a fault current on the line or the cable where they are installed. They work with a basic current threshold logic which considers that the current flow is not normal but due to a fault situation when its value passes the threshold value [12]. The directional FPI can detect in addition to the threshold current, the direction of the fault current flow. It requires the voltage knowledge (simple or residual). For the non-directional FPI, it is necessary to observe the FPI consecutively in order to deduct the sense of the flow of fault current.

Considering the communication of the signature of the FPI to the operators, two types of FPI exist: the communicating FPI and the non - communicating FPI, the both two can be presents on a same network [13]. The state of the communicating FPI can be retrieved remotely and is used by the operation scheme in order to quickly isolate the faulty section from the rest of the network. The non-communicating FPI use a light signal on site, therefore a maintenance crew has to physically move to the field to retrieve the FPI state. The communicating FPI are often associated to a remote switch, meanwhile non-communicating FPI can be associated to a manual switch. The FPI state information is therefore used in two steps: communicating FPI are used for an automatic faulty zone isolation, and non-communicating FPI are used for a finer fault isolation [10].

III. PROBABILISTIC METHOD

In a MV distributor network, several FPI are installed and numbered. The network is divided in several sections. Each section is delimited by one upstream FPI and one downstream FPI (Figure N° 1). This means for each section there is a default number of FPI that detected a fault current and the rest that did not detected anything. In case of fault detection by opening the circuit-breaker of the departure, we can say for each section there is a sort of "signature response" made of all the FPI states. And thinking the other way around, that for a given FPI "signature response" there is a corresponding faulty section.

The current threshold of FPI is fix according to the fault position in relation with the GED, the value of the fault current can be less than the chosen current threshold. Then, we define a zone of detection of the fault current for every GED; it corresponds to the zone in which the fault current is greater than the the current threshold of FPI.

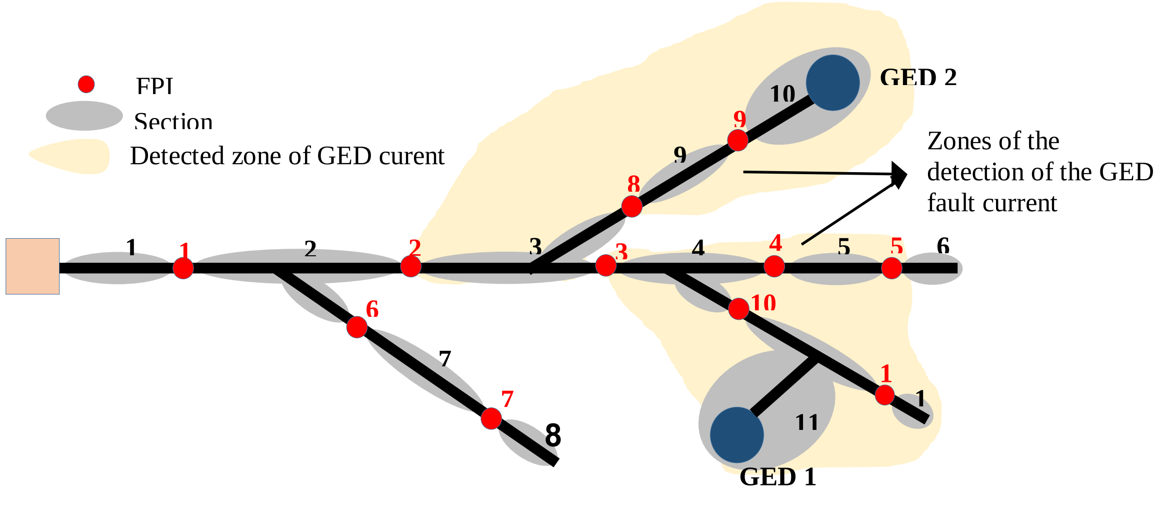

Figure N° 1 Sections limited by the FPI and the zones of detection of fault currents in a MV network

3.1- Signature response matrix

We are going to describe in this paragraph how the signature response matrix of FPI is built.

Considering non-directional FPI, it possesses two states

- 0: no fault detected (FPI no light)
- 1: fault detected (FPI light)

Considering directional FPI, it possesses three states

- 0: no fault detected (FPI no light)
- -1: an upstream fault detected (FPI light)
- 1: a downstream fault detected (FPI light)

To build the signature response matrix, we will consider each section and look which FPI are on the fault current path. These FPI will be in state 1 (or -1 when the fault current is flowing upstream) and the others in state 0. The cases with upstream fault current detected can occur only if there is a GED on the network, that it contributes to the fault current and that the FPI in this zone are directional.

For example, let us consider the figure N° 1, for a fault in the section 5 with the presence of the GED 1, the FPI 1, 6, 7 and 4 see the fault current descended of the source. The FPI 10 sees the current descended of the GED 1 and its state will be -1 because the fault current comes from the GED that is in its downstream. The other FPI don't see this current. The signature of the FPI for a fault in the section 5 with the presence of the GED 1 is then R5 = [111100000-10]

We can construct the signature response of the FPI for every section while taking into account the non-presence or the presence of the GED.

The signature response matrix regroups all the signature response of each section which gives for each possible faulty section, the corresponding FPI signature. We present in the next tables the signatures response matrixes of the FPI for a network with or without GED in the network.

Table N° 1 Ideal signature response matrix of the non-directional FPI without GED

		Fault FPI number										
		1	2	3	4	5	6	7	8	9	10	11
Number of the faulty section	1	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	0	0
	3	1	1	0	0	0	0	0	0	0	0	0
	4	1	1	1	0	0	0	0	0	0	0	0
	5	1	1	1	1	0	0	0	0	0	0	0
	6	1	1	1	1	1	0	0	0	0	0	0
	7	1	0	0	0	0	1	0	0	0	0	0
	8	1	0	0	0	0	1	1	0	0	0	0
	9	1	1	1	0	0	0	0	1	0	0	0
	10	1	1	1	0	0	0	0	1	1	0	0
	11	1	1	1	1	0	0	0	0	0	1	0
	12	1	1	1	1	0	0	0	0	0	1	1

Table N° 2 Ideal signature response matrix of the directional FPI with GED

		Fault FPI number										
		1	2	3	4	5	6	7	8	9	10	11
Number of the faulty section	1	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	0	0
	3	1	1	0	0	0	0	0	-1	-1	0	0
	4	1	1	1	0	0	0	0	0	0	-1	0
	5	1	1	1	1	0	0	0	0	0	-1	0
	6	1	1	1	1	1	0	0	0	0	0	0
	7	1	0	0	0	0	1	0	0	0	0	0
	8	1	0	0	0	0	1	1	0	0	0	0
	9	1	1	1	0	0	0	0	1	-1	0	0
	10	1	1	1	0	0	0	0	1	1	0	0
	11	1	1	1	1	0	0	0	0	0	1	0

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

	12	1	1	1	1	0	0	0	0	0	1	1

The FPI between the GED and the fault don't give a direction of the fault when fault current is greater than the current threshold of FPI (grey case in the matrix above).

3.2- Conditional probability matrix

3.2.1- Probabilities of the FPI states

Let us define the following functioning rates:

- functioning rate of FPI: α, it is the probability that when its state is read the FPI is functioning. Therefore **1- α** is the probability that when its state is read the FPI does not function

correct functioning rate of FPI: **β ,** it is the probability that the FPI is working correctly (meaning in its correct state for a given situation). Therefore **1- β** is the probability that the FPI is in a wrong state (either for the sense of the fault or for the presence of fault).

We can now determine the functioning probability of the FPI for every situation. We have two essential cases: the FPI is functioning or is not functions. In the case where the FPI is functioning, we can have two or three possibilities depending on the type of FPI: no fault detected, the upstream fault detected or the downstream fault defected.

3.2.1.1- Non-directional FPI

As we saw previously, we have two state for the FPI (0 or 1). By using the definite function rates previously, we can determine the functioning probabilities of the FPI. We summarize these probabilities in the table below.

Table N° 3 Different functioning situations of the non-directional FPI and the corresponding probability

		FPI's state	
State probabilities		**0**	**1**
FPI does not function		1- α	0
FPI function	fault	$\alpha(1-\beta)$	$\alpha.\beta$
	No fault	$\alpha.\beta$	$\alpha(1-\beta)$

For example,

FPI doesn't function, the correct state is 0

- P(0) = 1- α as defined, it is the probability that the FPI doesn't function
- P(1) = 0 since FPI doesn't function, the probability to be in state 1 is zero

3.2.1.2- Directional FPI

For this type of FPI, three states are possible: 0 -1 and 1. Proceeding like the non-directional FPI, we determine the different probabilities according to the situations.

The following table gives the different functioning situations of the FPI and the corresponding probability

Table N° 4 Different functioning situations of the directional FPI and the corresponding probability

		FPI's state		
State probabilities		0	1	-1
FPI does not function		1- α	0	0
FPI fonction	Downstream fault	$\alpha(1-\beta)/2$	$\alpha.\beta$	$\alpha(1-\beta)/2$
	Upstream fault	$\alpha(1-\beta)/2$	$\alpha(1-\beta)/2$	$\alpha.\beta$
	No fault	$\alpha.\beta$	$\alpha(1-\beta)/2$	$\alpha(1-\beta)/2$

3.2.2- Conditional probabilities of the FPI

In this section, we define the conditional probability based on the real state and ideal state of the FPI. The ideal state is the state in which should be the FPI for a given situation whereas the real state is the state of FPI in the given time.

The conditional probability is the probability of one event if another event occurred [14] [15]. The conditional probabilities will give us the probabilities for a FPI to be in a given real state knowing its ideal state: P(real state/ideal state). To compute this conditional probabilities, we will use the state probabilities of table N°3 and N° 4. The method is as follow: since the two situation are disjointed, the probability of a given real state, is the sum of the state probability of the two main situations (FPI functions and FPI doesn't function). In the case where the FPI functions, we use the probability corresponding to the ideal state.

Let us compute the conditional probabilities for the non-directional FPI using the table N° 3. For each combination real state/ideal state, we compute the matrix of the conditional probability below

Table N° 5 Conditional Probabilities of non-directional FPI

FPI's Signature		Ideal state	
		0	**1**
real state	**0**	$1-\alpha+\alpha.\beta$	$1-\alpha+\alpha.(1-_j)$
	1	$\alpha.(1-\beta)$	$\alpha.\beta$

For each combination real state/ideal state, we compute the matrix of the conditional probability for the directional FPI using the table N° 4.

Table N° 6 Conditional Probabilities of directional FPI

FPI's Signature		Ideal state		
		0	1	-1
real state	**0**	$1-\alpha+\alpha.\beta$	$1-\alpha+\alpha.(1-\beta)/2$	$1-\alpha+\alpha.(1-\beta)/2$
	1	$\alpha.(1-\beta)/2$	$\alpha_j.\beta$	$\alpha.(1-\beta)/2$
	-1	$\alpha.(1-\beta)/2$	$\alpha.(1-\beta)/2$	$\alpha\beta$

3.2.3- Generalization

Observing the conditional probabilities matrix above, we can define a coefficient k function of the type of FPI permitting us to establish one conditional probabilities for the two types of FPI: k will take the value 1 for the non-directional FPI and the value 2 for the directional FPI.

The general matrix of the conditional probabilities P(real state / ideal state) is as follow

Table N° 7 General matrix conditional Probabilities of the FPI

FPI's Signature		Ideal state		
		0	1	-1
real state	**0**	$1-\alpha+\alpha.\beta$	$1-\alpha+\alpha.(1-\beta)/k$	$1-\alpha+\alpha(1-_j)/2$
	1	$\alpha.(1-\beta)/k$	$\alpha_j.\beta_j$	$\alpha.(1-\beta)/2$
	-1	$\alpha.(1-\beta)/2$	$\alpha.(1-\beta)/2$	$\alpha.\beta$

3.3- Conditional probabilities of the network

The conditional probabilities that we have compute until now are only the conditional probabilities for only one FPI. We need the conditional probability of the response signature of all the FPI of the network. We are going to define

$P(R_j/S_i)$: the probability that the signature response of the FPI is R_j knowing that section i is faulty

$P(S_i/R_j)$: the probability that section i faulty knowing that the response signature of the FPI is R_j. This probability is the probability we want to compute.

$P(S_i,R_j)$: the conjoint probability that section i is faulty and the signature response of the FPI is R_j

$P(S_i)$: the probability that the section i is faulty. We will consider that $P(S_i)$ is equal for each section i. $P(S_i)=1/N_s$.

The conditional probability $P(R_j/S_i)$ will be the sum of all conditional probability P(real state/ideal state) for each of the FPI composing the signature of R_j.

The operators of the networks need to know the faulty section knowing the signature response of the FPI. They need the conditional probability $P(S_i/R_j)$.

We have the relations between these different probabilities. From the definition of the conditional probability we have

$$P(S_i/R_j)=P(S_i,R_j)/P(S_i) \quad \textit{(1)}$$

therefore

$$P(S_i,R_j)=P(R_j/S_i).P(S_i)=P(S_i/R_j).P(R_j) \quad \textit{(2)}$$

The law of total probability give[16] $P(R_j)=\sum_{Si}P(S_i,R_j)=\sum_{Si}P(R_j/S_i).P(S_i)$ (3)

The Bayes' formula give[17] [18], $P(S_i/R_j)=\dfrac{P(R_j/S_i).P(S_i)}{\sum_{Si}P(R_j/S_i).P(S_i)}$ (4)

Every section having the same probability to be faulty $P(Si)={}^{1}\!/_{N_s}$, therefore, all $P(Si)$ is equal and the probability then becomes $P(S_i/R_j)=\dfrac{P(R_j/S_i)}{\sum_{Si}P(R_j/S_i)}$ (5)

IV. STUDY OF CASE

In this part, we will use the previously described probabilistic fault localization method on the network of the Figure N° 1. The goal is to see on a practical case how the method works. We will have implemented the method to analyze the capacity of determination of the faulty section when the FPI function correctly or don't function correctly. We will consider different cases, with the non-directional FPI, with de directional FPI, with GED and without GED.

We will use the identical functioning rates for all FPI of the network: α = 0,95 and β = 0,95

4.1- Network without GED

The network includes only non-directional FPI. The matrix of the ideal signature response of the FPI according to the section is given by the table N° 1

4.1.1- All FPI function correctly

Fault in the section 3

For a fault detection in the section 3 and the correctly functioning of the all FPI, the signature response of the FPI is R_3 = [1 1 0 0 0 0 0 0 0 0 0 0].

For i from 1 to 12, the conditional probabilities $P(R_3/S_i)$ are given below in the table

Table N° 8 Matrix of the conditional probabilities $P(R_3/S_i)$

P(R3/S1)	**P(R3/S2)**	**P(R3/S3)**	**P(R3/S4)**
0,001456	0,0276647	0,525629	0,0538045
P(R3/S5)	**P(R3/S6)**	**P(R3/S7)**	**P(R3/S8)**
0,005508	0,0005638	0,002832	0,0002899
P(R3/S9)	**P(R3/S10)**	**P(R3/S11)**	**P(R3/S12)**
0,053805	0,0055076	0,005508	0,0005638

The probability of the occurrence of the signature response is P(R3) = 0,683131. We compute the localization probabilities P(Si/R3) of the fault in section i knowing that the signature response of the FPI is R3. Classifying these probabilities from the highest to the lowest, we sort sections from the most possibly faulty to the least possibly faulty.

Table N° 9 Matrix of the conditional probabilities P(Si/R3)

Section	**3**	**9**	**4**	**2**
probability	0,76944	0,07876	0,078762	0,0405
Section	**5**	**10**	**11**	**7**
Probability	0,00806	0,00806	0,008062	0,00415
Section	**1**	**6**	**12**	**8**
probability	0,00213	0,00083	0,000825	0,00042

We can see that the algorithm gives section 3 as the most probably faulty section with a probability of 0.77. The second most probably section is section 9 with a much lower probability of 0.079.

4.1.2 - Some FPI functioning incorrectly

4.1.2.1- Fault in the section 5 and incorrect functioning of the FPI 1

The signature response of the FPI is R = [0 1 1 1 0 0 0 0 0 0 0]. This signature response doesn't correspond to any possible ideal combination. The probability to obtain this signature response is very weak (P = 0,059423), compared to the one of the signature response of P(R5).

The computed conditional probabilities P(Si/R = [0 1 1 1 0 0 0 0 0 0 0]) are summarized in the table below

Table N° 10 Matrix of the conditional probabilities P(Si/ R = [0 1 1 1 0 0 0 0 0 0 0])

Section	**5**	**6**	**4**	**11**
probability	0,85793	0,08782	0,045154	0,00462
Section	**3**	**1**	**12**	**9**
Probability	0,00238	0,00122	0,000473	0,00024
Section	**2**	**10**	**7**	**8**
probability	0,00013	2,5E-05	1,28E-05	1,3E-06

The analysis of the results on the table shows that the probability that the section 5 been the faulty section in this condition is 85,79%.

4.1.2.2- Fault in the section 5 and incorrect functioning of the FPI 2

The signature response of the FPI is R = [1 0 1 1 0 0 0 0 0 0 0]. This signature response doesn't correspond to any possible ideal combination. The probability to obtain this signature response is very weak (P= 0,062333), compared to the one of the signature response of P(R5) but is superior to the one of the section 5 faulty and incorrect functioning of FPI 1.

The computed conditional probabilities P(Si/ R = [1 0 1 1 0 0 0 0 0 0 0]) are summarized in the table below

Table N° 11 Matrix of the conditional probabilities P(Si/ R = [1 0 1 1 0 0 0 0 0 0 0])

Section	**5**	**6**	**4**	**1**
probability	0,81787	0,08372	0,043046	0,02336
Section	**2**	**11**	**3**	**7**
Probability	0,02213	0,00441	0,002266	0,00227
Section	**12**	**8**	**9**	**10**
probability	0,00013	2,5E-05	1,28E-05	1,3E-06

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

The analysis of the results on the table shows that the probability that the section 5 been the faulty section in this condition is 81,79%. It is lower to the one of the section 5 faulty and incorrect functioning of FPI 1. The first three sections are identical that those previously.

4.2.- Network with GED

4.2.1- Non-directional FPI

Fault in the section 3, correct functioning of non-directional FPI and GED 2 connected

The signature response of the FPI is R = [1 0 0 0 0 0 0 1 1 0 0] because the FPI 8 and 9 detect the downstream fault current provided by the GED 2 but cannot detect its direction.

The results of the analysis give the following conditional probabilities P(Si / R = [1 0 0 0 0 0 0 1 1 0 0])

Table N° 12 Matrix of the conditional probabilities P(Si / R = [1 0 0 0 0 0 0 1 1 0 0])

Section	**3**	**9**	**10**	**11**
probability	0,33324	0,33324	0,33324	9,4E-05
Section	**4**	**2**	**5**	**12**
Probability	9,4E-05	4,9E-05	9,67E-06	9,7E-06
Section	**7**	**1**	**6**	**8**
probability	5E-06	2,6E-06	9,9E-07	5,1E-07

The probabilities that the sections 3, 9 and 10 being the faulty section when the signature response were R = [1 0 0 0 0 0 0 1 1 0 0] are the same (33,33%). We can note that the algorithm does not determine which section between sections 3, 9 and 10 is the most probably faulty section. In conclusion, we will say that the reliable localization of the faulty section with the signature response of non-directional FPI in the network with GED with the big power becomes impossible.

4.2.2- Directional FPI

Considering the insertion of the two GED 1 and 2 in the network, the matrix of the ideal signature response of the FPI for the fault of every section is given by the table N° 2.

4.2.2.1- Insertion of one GED

We are going to take the previous case using the directional FPI

Fault in the section 3, correct functioning of directional FPI and GED 2 connected

The signature response of the FPI is R = [1 0 0 0 0 0 0 -1 -1 0 0] because the FPI 8 and 9 detect the downstream fault current provided by the GED 2 and detect its direction.

We found the conditional probabilities P(Si / R = [1 0 0 0 0 0 0 -1 -1 0 0]) as follow

Table N° 13 Matrix of the conditional probabilities P(Si / R = [1 0 0 0 0 0 0 -1 -1 0 0])

Section	**3**	**9**	**10**	**2**
probability	0,97366	0,02562	0,000674	1,8E-05
Section	**4**	**11**	**7**	**1**
Probability	1,7E-05	4E-06	1,37E-06	4,7E-07
Section	**5**	**12**	**8**	**6**
probability	4,2E-07	3,1E-07	1,06E-07	1E-08

The probabilities that the sections 3 being the faulty section when the signature response were (R = [1 0 0 0 0 0 0 -1 -1 0 0]) is 97,36%. The section 3 is the section having the faultiest probability. The other probabilities being very low.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

4.2.2.2- Insertion of the two GED

4.2.2.2.1- Fault in the section 3 and directional FPI

The signature response of the FPI with the correctly functioning is R = [1 1 0 0 0 0 0 -1 -1 0 0]. Its occurrence probability is P(R3) = 0,472892.

The probability of the existence of the fault in every section is given by the matrix below

Table N° 14 Matrix of the conditional probabilities P(Si / R = [1 1 0 0 0 0 0 -1 -1 0 0])

Section	**3**	**9**	**10**	**2**
probability	0,99789	0,0020333	5,35E-05	1,8E-05
Section	**4**	**7**	**1**	**5**
Probability	4,1E-06	1,408E-06	4,79E-07	3,2E-07
Section	**11**	**6**	**8**	**12**
probability	3,2E-07	3,208E-07	1,09E-07	2,5E-08

We can see that the algorithm gives section N° 3 as the most probably faulty section with a probability of 99,70%.

4.2.2.2.2- Fault in the section 3 and FPI 1 or 2 does not function

When the section 3 is faulty and the FPI 1 does not function or function incorrectly, the signature response of the FPI is R = [0 1 0 0 0 0 0 -1 -1 0 0]. Its occurrence probability is p=0,03961.

The probability of the existence of the fault in every section is given by the matrix below

Table N° 15 Matrix of the conditional probabilities P(Si / R = [0 1 0 0 0 0 0 -1 -1 0 0])

Section	**3**	**9**	**10**	**1**
probability	0,97345	0,02562	0,000674	0,00023
Section	**2**	**4**	**11**	**7**
Probability	1,8E-05	4E-06	4,04E-06	1,4E-06
Section	**5**	**6**	**12**	**8**
probability	3,1E-07	3,1E-07	3,13E-07	1,1E-07

We can see that the section 3 remain the most probably faulty section with a probability of 97,34%.

When the section 3 is faulty and the FPI 2 does not function or function incorrectly, the signature response of the FPI is R = [1 0 0 0 0 0 0 -1 -1 0 0].

The probability of the existence of the fault in every section is given by the matrix below

Table N° 16 Matrix of the conditional probabilities P(Si / R = [1 0 0 0 0 0 0 -1 -1 0 0])

Section	**3**	**9**	**2**	**7**
probability	0,96437	0,02538	0,008625	0,00067
Section	**10**	**1**	**8**	**4**
Probability	0,00067	0,00023	5,17E-05	4E-06
Section	**11**	**5**	**6**	**12**
probability	4E-06	3,1E-07	3,1E-07	3,1E-07

We can see that the section 3 remain the most probably faulty section with a probability of 96,43%.

4.2.2.2.3- Fault in section and FPI nearby the GED solicited

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

The section 4 is not in the zone of detection of the current flow from the GED 1. Yet we can have an abnormal variation of the current of zone that provokes the solicitation of the FPI 9 nearby the GED 2(signature response 1 or -1). In these cases, the signature response of the FPI are R = [1 1 1 0 0 0 0 0 1 -1 0] and R = [1 1 1 0 0 0 0 0 -1 -1 0]

For FPI R = [1 1 1 0 0 0 0 0 1 -1 0], the occurrence probabilities of the fault in every section are shown below:

Table N° 17 Matrix of the conditional probabilities P(Si / FPI R = [1 1 1 0 0 0 0 0 1 -1 0])

Section	**4**	**5**	**11**	**10**
probability	0,90244	0,06987	0,023748	0,00184
Section	**12**	**6**	**3**	**9**
Probability	0,00184	0,00014	4,84E-05	4,8E-05
Section	**2**	**7**	**1**	**8**
probability	1,6E-05	1,3E-06	4,33E-07	9,9E-08

For R = [1 1 1 0 0 0 0 0 -1 -1 0], the occurrence probabilities of the fault in every section are shown below:

Table N° 18 Matrix of the conditional probabilities P(Si / R = [1 1 1 0 0 0 0 0 -1 -1 0])

Section	**4**	**5**	**11**	**3**
probability	0,90083	0,06975	0,023706	0,00184
Section	**9**	**12**	**6**	**10**
Probability	0,00184	0,00184	0,000142	4,8E-05
Section	**2**	**7**	**1**	**8**
probability	1,6E-05	1,3E-06	4,32E-07	9,8E-08

We can see that the algorithm gives always the section 4 as the most probably faulty section with probabilities of 90,24% and 90,08% respectively.

4.2.2.3- Directional and non-directional FPI in a same network

We can replace the directional FPI out of the zone of the contribution of the GED to the fault currents by the non-directional FPI. In this case, we use non-directional FPI for the positions 1, 2, 6 and 7 and the directional FPI for the positions 3,4,5,8,9,10 and 11. The matrix of the ideal signature response of the FPI is identical to the case of the network with directional FPI only (table N° 2).

We are considering the identical cases to the previous section (insertion of the two GED).

4.2.2.3.1- Fault in the section 3 and FPI 1 or 2 does not function

If the section 3 is faulty and the FPI 1(or 2) does not function or function incorrectly, the signature response of the FPI is R = [0 1 0 0 0 0 0 -1 -1 0 0] (or R = [1 0 0 0 0 0 0 -1 -1 0 0]).

The probability of the existence of the fault in every section is given by the matrix below

Table N° 19 Matrix of the conditional probabilities P(Si / [0 1 0 0 0 0 0 -1 -1 0 0])

Section	**3**	**9**	**10**	**1**
probability	0,97332	0,0256136	0,000674	0,00035
Section	**2**	**4**	**11**	**7**
Probability	3,5E-05	4,041E-06	4,04E-06	3,6E-06
Section	**8**	**5**	**6**	**12**
probability	3,7E-07	3,129E-07	3,13E-07	3,1E-07

or

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

Table N° 20 Matrix of the conditional probabilities P(Si / R = [1 0 0 0 0 0 0 -1 -1 0 0])

Section	**3**	**9**	**2**	**7**
probability	0,96627	0,0254283	0,006537	0,00067
Section	**10**	**1**	**8**	**4**
Probability	0,00067	0,0003441	6,85E-05	4E-06
Section	**11**	**5**	**6**	**12**
probability	4E-06	3,106E-07	3,11E-07	3,1E-07

We can see that the section 3 remain the most probably faulty section with probabilities of 97,33% (or 96,63%).

4.2.2.3.2- Fault in section and FPI nearby the GED solicited

The section 4 is not in the zone of detection of the current flow from the GED 1. Yet we can have an abnormal variation of the current of zone that provokes the solicitation of the FPI 9 nearby the GED 2(signature response 1 or -1). In these cases, the signature response of the FPI are R = [1 1 1 0 0 0 0 0 -1 -1 0]
(or R = [1 1 1 0 0 0 0 0 1 -1 0]).

The occurrence probabilities of the fault in every section are be follow:
Table N° 21 Matrix of the conditional probabilities P(Si / R = [1 1 1 0 0 0 0 0 -1 -1 0])

Section	**4**	**5**	**11**	**3**
probability	0,90081	0,0697479	0,023706	0,00184
Section	**9**	**12**	**6**	**10**
Probability	0,00184	0,0018355	0,000142	4,8E-05
Section	**2**	**7**	**1**	**8**
probability	3,3E-05	3,361E-06	1,73E-06	3,4E-07

or

Table N° 22 Matrix of the conditional probabilities P(Si / R = [1 1 1 0 0 0 0 0 1 -1 0])

Section	**4**	**5**	**11**	**10**
probability	0,90242	0,0698727	0,023748	0,00184
Section	**12**	**6**	**3**	**9**
Probability	0,00184	0,0001424	4,84E-05	4,8E-05
Section	**2**	**7**	**1**	**8**
probability	3,3E-05	3,367E-06	1,73E-06	3,4E-07

We can see that the algorithm gives always the section N° 4 as the most probably faulty section with probabilities of 90,08% and 90,24% respectively.

V. CONCLUSION

The use of the fault passage indicators (FPI) can be an efficient solution for the reduction of the time of the network unavailability. The principle of the FPI is to measure currents.

and voltages at different locations on the network. The FPI can inform if they have detected a fault current, and some of them (the directional FPI) can even inform on the fault current direction (downstream or upstream). However, reliability problems appear when using this type of equipment. Since by definition FPI do not operate often, the failures are discovered when a fault occurs, thus degrading the network operation at a very critical moment and furthermore increasing the fault localization time. In order to counter this effect, we developed a probabilistic method which is robust to the possible FPI failures. The proposed method processes a probabilistic analysis of the FPI states, therefore sorting the different sections or zones from the most probably faulty to the least probably faulty.

ISSN: 2277-9655
Impact Factor: 4.116
CODEN: IJESS7

The present results show an average percentage of success of identification of the faulty section of more than 85% on the studied network. It shows a good performance and robustness to the failing FPI. The cases of " bad " localization don't identify effectively the good faulty section but give a section always in the same " zone ", giving an important information to the operator on the coarse localization of the faulty zone.

This method brings numerous improvements to the techniques of localization of the faulty section, without requiring big investments. Besides, it can be associated to an algorithm of calculation of fault distance in order to have a complete and precise algorithm of fault localization.
The method is therefore robust, to a certain level, to FPI failures which are expressed by wrong FPI states during the fault occurrence, consequently reducing the misleading analysis made by the operator in order to locate and isolate the fault from the rest of the network.

VI. REFERENCES

[1] T. Ackermann, G. Andersson, and L. Soder. *Distributed generation: a definition*. Electric Power Systems Research, 57(3):195-204, 2001
[2] Trung Dung LE, *Contribution des moyens de production dispersés aux courants de défaut. Modélisation des moyens de production et algorithmes de détection de défaut.* Thèse de doctorat, SUPELEC école doctorale STITS, 2014
[3] J.Kenfack , O. Videme Bossou , J. Voufo , S. Djom, *addressing the current remote area electrification problems with solar and microhydro systems in Central Africa*, Renewable Energy N° 67 (2014) pages 10-19
[4] ONUDI, *Rapport mondial sur le développement de la pettie hydraulique 2016*, 40 pages, www.smallhydroworld.org
[5] T. Tamo Tatietse, J. Voufo; *Fault Diagnosis on Medium Voltage (MV) Electric Power Distribution Networks: The Case of the Downstream Network of the AES-SONEL Ngousso Sub-Station***;** *Energies* 2009, volume *2*, pp 243-257
[6] J. Voufo, J. Kenfack, T. Tamo Tatietse ; *Diagnosis of defects on medium voltage electric energy distribution networks:The case of rural zone's supply* **;** Electrical Power and Energy Systems 45 (2013) 229–234
[7] Malik Megdiche, *Sûreté de fonctionnement des réseaux de distribution en présence de production décentralisée*, Institut National Polytechnique de Grenoble, Thèse de doctorat, 2004
[8] Bjerkan, E., Myhre, R., "Efficient Outage Management using Fault Passage Indicators", *International Conference On T&D Assetment Management*, 2008, Kuala Lumpur, Malaysia
[9] Cong Duc PHAM, Détection et localisation de défauts dans les réseaux de distribution HTA en présence de génération d'énergie dispersée, Institut National Polytechnique de Grenoble, thèse de doctorat,19 Septembre 2005, France
[10] Raphaël MARGUET**,** *Améliorations de Méthodes de Localisation de Défauts pour les Réseaux de Distribution Electrique,* université de Grenoble, Thèse de Doctorat, 2015
[11] Manuel J. Domínguez, news *in fault passage indicators in overhead and underground MV lines,* Schneider Electric, 17th International Conference on Electricity Distribution, Barcelona,2003
[12] Manuel J. Domínguez, José Chaves, *News in fault passage indicators in overhead and underground mv lines*, CIRED, 17th International Conference on Electricity Distribution, Barcelona, 2003
[13] Eilert BJERKAN, *efficient fault management using remote fault indicators*; Nortroll AS – Norway CIRED 20th International Conference on Electricity Distribution Prague, June 2009
[14] Allen B. Downey; Think Bayes Bayesian Statistics Made Simple, Version 1.0.9 Green Tea Press, Needham, Massachusetts
[15] Bret Hanlon and Bret Larget, *Probability and Conditional Probability* Department of Statistics University of Wisconsin| Madison, 2011
[16] Nils Berglund ; *Probabilités et Statistiques, cours,* Université d'Orléans, Mars 2010
[17] Ke Li, Qiuju Zhang 1, Kun Wang, Peng Chen, Huaqing Wang, *Intelligent Condition Diagnosis Method Based on Adaptive Statistic Test Filter and Diagnostic Bayesian Network;* Sensors **2016**, 16, pp 1-16;
[18] Prof. A.H. Techet **13.42 Design Principles for Ocean Vehicles,** Spring 2005