

POWER QUALITY INDICES ASSESSMENTS ON THE TRANSMISSION NETWORK IN THE NORTHEAST OF BRAZIL

José Júlio LINS LEITÃO

CHESF – Federal Power Utility
Recife, Brazil

Iony PATRIOTA DE SIQUEIRA

CHESF – Federal Power Utility
Recife, Brazil

Milde Maria da SILVA LIRA

UFPE – Federal University of Pernambuco
Recife, Brazil

Paulo RIBEIRO

Calvin College
Grand Rapids, Michigan

Abstract - The characteristics of the voltage sags are important in determining how extensive the impact of the event extension is on various consumer operations. It is important to remember that the end user equipment will have widely varying degrees of sensitivity, depending mainly upon the magnitude and duration of the event. The propose of this paper is to provide information that can be used to establish the limit of performance indices of the Transmission System in the Northeast of Brazil, based on historical data. Example sag data are shown in several points of connection of the transmission grid. The survey results provide a knowledge base for monitoring, designing and utilizing voltage sags mitigating technologies.

1. INTRODUCTION

There is no doubt about the Brazilian position in the industrialized world, however it is lacking conditions that will ensure the competitiveness of its products, which certainly includes the availability of electricity of high quality. Power quality is increasingly becoming an issue to the final consumer. It is possible to verify the concerns expressed by the Brazilian National Energy and Electricity Regulatory Agency – ANEEL – and other actors controlled by them, i.e. the utilities.

The new Brazilian power system configuration is divided into the following sectors: generation, transmission, distribution and energy commercialization. In this new configuration, it is imperative that the performance indices (Power Quality Indices) should be assessed by all sectors

and agents in a so called "condominium" (shared responsibility) model.

The drastic economic impact caused by the short duration voltage variations (VTCD) has been evidenced in several recent works [1, 2]. The VTCD is mainly caused by short-circuits in the transmission lines, which, some times, can impact great areas of the power system, even if the faulted area is quickly isolated by the respective protection scheme.

In the sense of creating the necessary regulatory instruments, the ANEEL has issued the Resolution #24 from January 2000 that establishes some power quality indices that must be observed. This resolution also delegates to the National Power System Operator – ONS – the attribution of establishing the performance standards (limits) to the Basic Network (above 230kV) that must be monitored in some control points (point of common coupling with distribution and generation companies, special consumers and international interconnections), as established in the National Grid Code [3].

In the past few years, particularly CIGRÉ, IEC and IEEE have proposed a great number of patterns for describing and measuring the power quality indices.

CHESF, Federal Power Utility, has a transmission system with more than 17 thousand kilometers of transmission lines at 500, 230, 138 and 69 kV located in the northeast of Brazil; transmitting energy from generation to the utility power distribution of each state and to the industrial consumers connected to the Basic Grid. The transmissions system of CHESF is monitored by a

net constituted recently for approximately 100 Digital Fault Recorder (DFR) interconnected to a server, through TCP/IP protocol.

This paper presents the following main contributions: methodology to analyze the data collected by monitoring systems installed in points of connection of the transmission system in the Northeast of Brazil (using historical data); the use of the historical data to establish the performance of the system bus.

The paper's organization is as follows. The propagation through the entire CHESF Power System of voltage sags collected in a specific power quality monitor in 2004 is shown in section 2. Section 3 presents two cases studies involving two faults that occurred in the transmission and distribution system. The performance indices in Mussuré substation are given in section 4, and the conclusions of this approach are included in section 5.

2. PROPAGATION OF THE EVENTS BETWEEN MRD-230 kV AND MRD-69 kV

In order to evaluate the severity of the VTCD, the Electric Studies Division of CHESF defined the degrees of severity on a scale of 0 to 4 (Fig.1), characterized by magnitude and duration of the voltage sag, and sensibility required by the loads connected to the respective bus. The time aggregation for the presentation of summary results, and a one-minute "sliding window" was used to aggregate events. For events less than 10% retained voltage, the abbreviations IMT and ITT mean Momentary and Temporary Voltage Interruptions, respectively [3].

0,9		Severity 0	Severity 0	Severity 1	Severity 2
0,8			Severity 1		
0,7		Severity 1	Severity 2	Severity 3	Severity 4
0,6			Severity 2		
0,5		Severity 2	Severity 3	Severity 4	Severity 4
0,4			Severity 3		
0,3		Severity 3	Severity 4	Severity 4	Severity 4
0,2			Severity 4		
0,1		Severity 5	IMT	Severity 6	ITT
0	1cycle	300ms	500ms	3s	1min

FIGURE 1. Degrees of severity

To analyse the propagation of the events that occurred in the transmission system from 230 kV to 69 kV and vice versa, we will use the records collected from January to December 2004 in

Mussuré II, in the state of Paraíba, whose data have been collected from MRD-04T3 (230kV) and MRD-04T2 (69kV) sites, located in the primary and secondary side of a transformer, respectively. MRD-04T2 registered 90 voltage sags in 2004, which were divided into 63 voltage sags of severity 0 (zero); 16 of severity 1; 4 of severity 2 and 7 of severity 3. The pie chart of Fig. 2 shows the origin of these voltage sags in percentage.

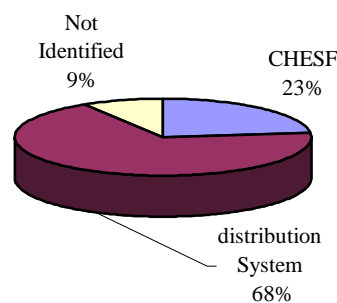


FIGURE 2. Origin of the voltage sags registered at MRD-69kV in 2004

Table 1 shows the voltage sags (percentage of the nominal) and their duration monitored on MRD-69kV and MRD-230kV sites, whose severities were above 2. An examination of this table clearly reveals that if the fault occurs at the distribution system the magnitude of the voltage sag at the 69kV level is smaller than the one at the 230kV. However, if the fault occurs at CHESF (transmission system) the magnitude of the voltage sag is smaller at the 230kV level than the one at the 69kV. With the purpose of seeing how these events extend geographically on the transmission system of CHESF, we analysed the 14 Industrial Consumers and the eight main cities of the Northeast of Brazil.

TABLE 1. Events with severity above 2 in 2004

Date and time	MRD_04T3 (230kV)		MRD_04T2 (69kV)		Severity	Origin
	Duration (s)	V_MIN (%)	Duration (s)	V_MIN (%)		
2004-set-27 10:37:47	2.00000	51.7	1.90000	55.2	3	Chesf
2004-nov-19 10:52:37	0.80000	57.6	0.70000	62.2	2	Chesf
2004-nov-24 14:28:24	0.43333	68.7	0.40000	59.0	2	Dist.
2004-jan-04 10:54:36	0.66667	55.6	0.66667	32.9	3	Dist.
2004-mai-19 14:31:05	1.50000	64.7	1.83333	42.8	3	Dist.
2004-jun-21 16:38:53	0.60000	59.2	0.63333	35.2	3	Dist.
2004-jun-30 06:48:34	1.13333	57.9	1.13333	35.1	3	Dist.
2004-dez-10 00:34:15	0.30000	68.5	0.90000	36.5	3	Dist.
2004-dez-25 03:47:27	2.03333	68.4	2.06667	37.1	3	Dist.

The results have shown that the faults occurred at the distribution system, in spite of presenting a

voltage sag of severity 3, the sags were seen at the most by four monitor nodes. On the other hand, the faults originating at CHESF with a voltage sag of severity 2 were felt over all the Industrial Consumers (I.C.) and main cities, such as: Aracaju, Fortaleza, João Pessoa, Maceió, Salvador, Natal, Recife and Teresina (this one more than 1000 Km far from MRD substation). We can see from what has been shown, that if the fault occurs at the distribution system the number of circuits affected is limited. However, if the fault occurs at the transmission system, the number of circuits seeing the voltage sag could be very large and could geographically extend anywhere from a few square kilometers to hundreds of square kilometers. This area is called the zone of influence.

3. CASE STUDIES

In this section, we are going to study two cases of faults, one localized at transmission system and another at distribution system. Our aim is to analyse the severity of the voltage sag overall the electric power system of CHESF (Fig. 3) and the zone of influence. The arrows 1 and 2 in the Fig. 3 show the local of the event in case II, and I respectively.

CASE I:

This event happened on 19/11/04 at 10:52 in the centre-subsystem of CHESF stemming from an automatic breaker opening of busbar (500kV) in the substation LGZ (Luiz Gonzaga). Cause: explosion of the 75B2-B/LGZ-surge arrester.

Tab. 2 shows the magnitude and duration of the voltage sag, voltage level of the measured point and its geographical location at the transmission system of CHESF.

The monitoring locations were selected in order to reach all the voltage level and a vast geographical area of the transmission system of CHESF. It is worth to mention that the lowest voltage sag was measured in MLG_04T5, which presented a magnitude equal to 39.5% of the nominal voltage. The substation of Milagre is localized in the North subsystem of CHESF and is fed by a power line - 05V1_LGZ-MLG of 500kV- coming from Luiz Gonzaga's substation where the event occurred. This is the main reason of such critical voltage sag. From the eight DFRs at the 500kV system, two of them didn't feel the effect of this event: e.g. PAQ_05C1 and CMD_05T3. The hydroelectric power station of Paulo Afonso turned its busbar into a very strong one, and in spite of the line 05C1_PAQ-LGZ connecting both substations, the

DFR monitoring the line PAQ_05C1 didn't feel the event that occurred in Luiz Gonzaga. The DFR in CMD_05T3 measuring the voltage sags in the autotransformer (600MVA) didn't see this event, probably due to one line of this substation being interconnected with the substation of PAQ (a power generation station).

TABLE 2 . Measurement of the selected site that were sensitized to the event of Case I

Duration (s)	Sag (%)	Site Name	Voltage level (kV)	Subsystem	Cities or I.C.
2.86667	52.4	FTZ_04T2	69	NORTH	Fortaleza
1.46667	54.3	NTD_02J4	69	EAST	Natal
0.76667	54.4	MTT_04T3	69	SOUTH	Salvador
0.70000	62.2	MRD_04T2	69	EAST	João Pessoa
2.83333	63.0	BGI-04T4	69	EAST	Recife
0.60000	65.5	JDM-04T2	69	SOUTH	Aracaju
0.56667	69.3	RLD_04T3	69	EAST	Maceió
3.03333	70.9	TSA_04T4	69	WEST	Terezina
0.03333	89.1	ENP_04T1	138	SOUTH	-
2.23333	44.4	BNO_03C2	138	CENTER	-
2.73333	52.0	FTZ_04Z4	230	NORTH	I.C.
0.66667	56.5	JCR_04N3	230	SOUTH	I.C.
0.56667	59.5	RLD_04S2	230	EAST	I.C.
2.86667	39.5	MLG_04T5	230	NORTH	-
0.50000	55.5	USB_05T4	500	SOUTHWEST	-
2.03333	77.7	TSD_05C8	500	WEST	-
0.53333	60.9	MSI_05V4	500	EAST	-
0.50000	65.7	UXG_05V6	500	CENTER	-

From the three sites in the 138kV system, the critical voltage sag happened in the DFR located in BNO_03C2 (centre-subsystem of CHESF), which is close to the event, as shown in Tab. 2. In spite of the DFR in FNL-04T2 being closer to the occurrence of the event than the DFR in ENP-04T1, it registered a soft voltage sag of 89%, while the other didn't present any voltage sag on that day and hour. The probable cause of this scenario is the attenuated voltage sag in South area of the system and the hydroelectric generator of 30MW in this substation.

All the Industrial Consumers (I.C.) and all main cities of the Northeast felt a voltage sag stemmed from this event, the magnitude depending on its proximity to the place of occurrence and on the short-circuit level of the substation busbar where such DFRs are located, as shown in Tab. 2.

Fig. 4 shows the rms of the worst voltage sag waveform in 69, 138, 230 and 500 kV related to the Case I.

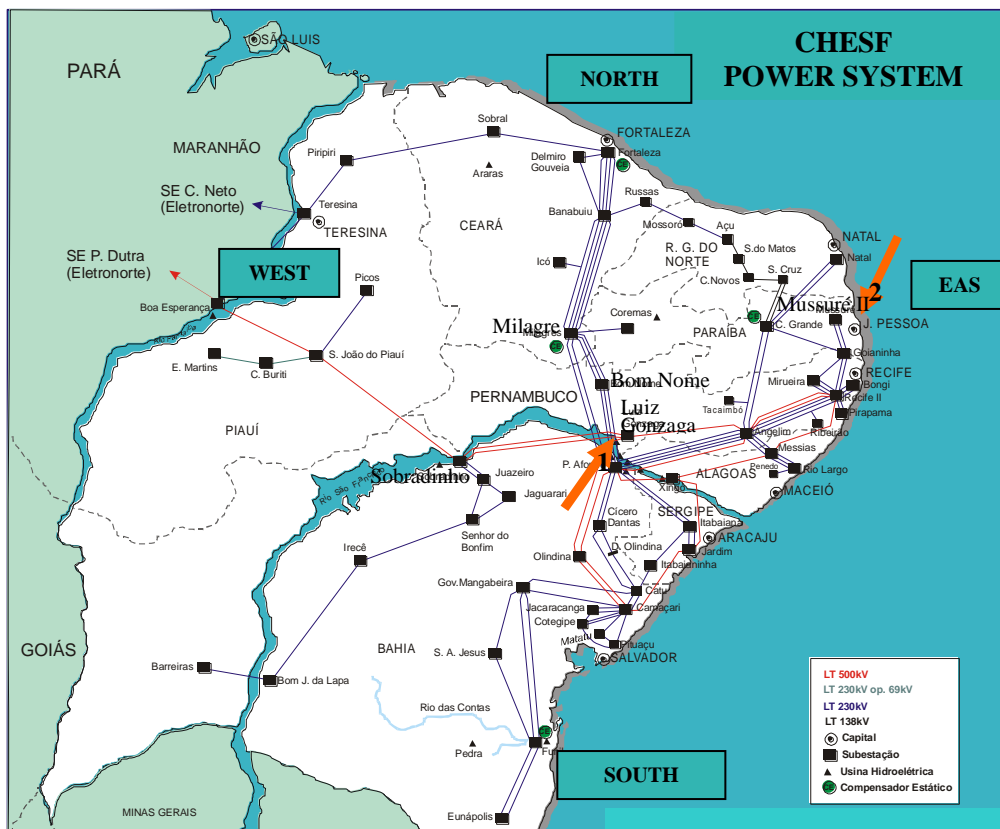


FIGURE 3. CHESF Power System

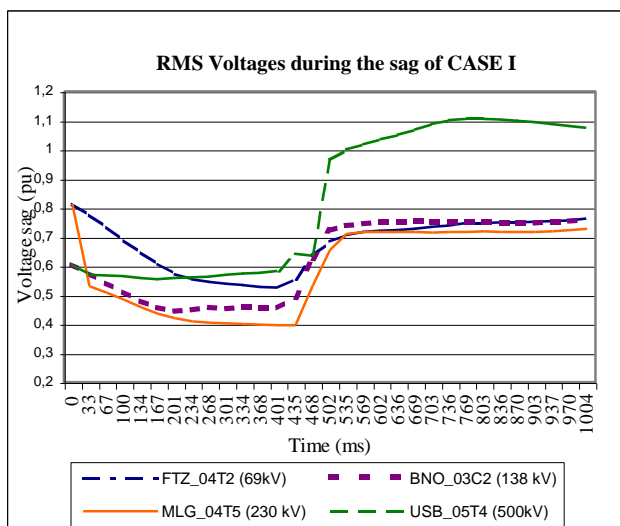


FIGURE 4. RMS Voltages during the sag

CASE II:

This event happened on 04/01/04 at 10:54 in the distribution utility stemming from an automatic breaker opened of the transmission lines 02J1 and 02J2 in MRD/ João Pessoa. Cause: vandalism.

The DFR were chosen in order to reach all the voltage levels and a vast geographical area of the

electric system of CHESF. The measurements of all DFR in all Industrial Consumers, in the main cities and in the areas close to the event were analysed. Tab. 3 presents the magnitude of the voltage sag in the sites that saw this occurrence.

TABLE 3. Measurement of the selected site that were sensitized to the event of Case II

Duratio n (s)	Sag (%)	Site Name	Voltage level (kV)	Subsystem	Cities or I.C.
0,03333	90,0	MRR_04T2	69	EAST	-
0,66667	77,2	GNN_02M2	69	EAST	-
0,66667	32,9	MRD_04T2	69	EAST	João Pessoa
0,66667	55,6	MRD_04T3	230	EAST	-
0,26667	87,8	PRD_04S1	230	EAST	I.C.
0,23333	88,0	BGL_04C1	230	EAST	I.C.
0,66667	71,9	GNN_04F1	230	EAST	-
0,23333	87,5	RCD_04T5	230	EAST	-

We observed in Tab. 3 that the lowest magnitude was registered in MRD_04T2, whose measurement was collected in the 69kV side of a transformer (100MVA). This is the site of the CHESF monitoring system closer to the event that in the distribution utility. The second lowest magnitude of the voltage sag was registered in

MRD_04T3, measured on the 230kV side of the same power transformer. We can also verify that all the other sensitised measurement sites are located in the East of the CHESF power system, which is the same area of the occurrence. Another interesting observation, is that the monitor in BGI_04T4 located in the 69kV side of the 100MVA power transformer didn't see any voltage sag related to case II, although the monitor located in the transmission line BGI_04C1 of 230kV has registered a voltage sag of 88.0%. According to Bollen [4] for measured voltage sags, the three rms voltages through a transformer will often be different due to the characteristic phase angle jump and other phenomena.

From the 14 Industrial Consumers, only two located East of the system were sensitised. And from the eight main cities, only in João Pessoa the voltage decreased below 90%.

Fig. 5 shows the rms of the worst voltage sag waveform in 69 and 230 kV related to the Case II.

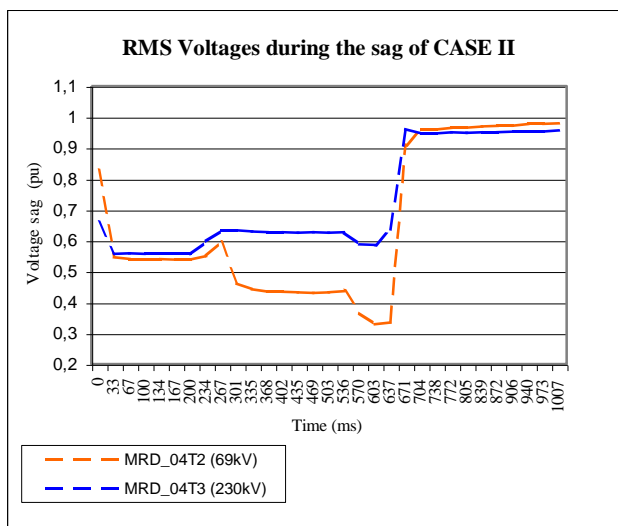


FIGURE 5. RMS Voltages during the sag

We observed from the two studied cases, that event 1 stemmed from CHESF was more harmful to the CHESF transmission system than the event 2, whose origin was in the distribution utility. According to the degree of severity, it is worth to mention that the voltage sag in MRD-04T2 caused by the event 1 was classified as severity 2, while the voltage sag caused by the event 2 was classified as severity 3.

4. PERFORMANCE INDICES

Short duration voltage variations include variations in the fundamental frequency voltage that last less than one minute. These variations

are best characterized by plots of the RMS voltage vs. time but it is often sufficient to describe them by a voltage magnitude and a duration that the voltage is outside of specified thresholds. It is usually not necessary to have detailed waveform plots since the RMS voltage magnitude is of primary interest.

The “System Average RMS (Variations) Frequency Index” or “SARFI” was developed by EPRI to describe voltage sag performance. It has been adopted by several U.S. utilities, and also utilities in the U.K. and Singapore. It is recommended for the basic grid in Brazil [5].

The SARFI Index is usually expressed as a function of equipment sensitivity (or minimum phase magnitude). The SARFI_x indicates the annual number of voltage sags where the retained voltage (on the minimum phase) is less than x %. This is equivalent to an event when the voltage is (1- x) % below the nominal (prefault voltage). The SARFI_{CBEMA} indicates the annual number of voltage sags where magnitude and duration of the event is outside the CBEMA equipment sensitivity tolerance curve.

The index is general enough so that it can be applied to any sensitivity level. It can also be applied for a given site, or across an entire system.

Tables 4 and 5 show the SARFI₉₀, SARFI₈₀, SARFI₇₀, SARFI₅₀ and SARFI₁₀ as function of the event duration; and SARFI_{CBEMA} in MRD_04T2 and MRD_04T3 sites, respectively. Analysing and comparing the performance indices in MRD-04T2 (Tab.4) and MRD-04T3 (Tab.5), we can see that the frequency of events is higher and more severe in MRD-04T2. This result was expected, because the system at high voltage level is stronger, in the sense of being closer to the generation and being less sensitive to short-circuits originated in the equipments connected to low voltage level.

TABLE 4. Performance indices in MRD-04T2 in 2004

SARFI_Index	0 - 0,2 s	0,2 - 0,5 s	0,5 - 3,0 s	3,0 - 60 s	TOTAL
SARFI_90	57	10	23	0	90
SARFI_80	10	3	14	0	27
SARFI_70	3	2	10	0	15
SARFI_50	1	0	8	0	9
SARFI_10	0	0	0	0	0

$$\text{SARFI}_{\text{CBEMA}} = 19$$

TABLE 5. Performance indices in MRD-04T3 in 2004

SARFI_Index	0 - 0,2 s	0,2 - 0,5 s	0,5 - 3,0 s	3,0 - 60 s	TOTAL
SARFI_90	42	11	23	0	76
SARFI_80	8	4	10	0	22
SARFI_70	3	4	9	0	16
SARFI_50	0	0	0	0	0
SARFI_10	0	0	0	0	0

SARFI_CBEMA = 17

5. CONCLUSIONS

This paper has shown the voltage sag propagation through the CHESF Power System. We saw that if the fault occurs at the lowest level of distribution voltage, the number of circuits affected in CHESF power system is limited. However, if the fault occurs at CHESF transmission system, the number of circuits seeing the voltage is large and geographically extends from a few square kilometres to hundreds of square kilometres.

Other power quality indices will be reported in subsequent papers.

6. REFERENCES

1. Leitão J. J., Reis L. B.: *Economic Evaluation of the Power Quality Losses in the Basic Grid*. Proc. of Seminário Brasileiro sobre Qualidade, da Energia Elétrica, Sergipe, Brazil, 2003.
2. Mcgranaghan, M., Roettger, B.: *Economic Evaluation of Power Quality*. IEEE power Engineering Review, February, p. 8-12, 2002.
3. ONS (National Power System Operator). *National Grid Code*. 2004.
4. Bollen M. H., Styvaktakis E.: *Characterization of Three-Phase Unbalanced Dips (as easy as one-two-three?)* IX ICHQP, Oct.2000.
5. Electrotek Concepts: *Review and Recommendations for the ONS Power Quality Management System (PQMS)*. Jun, 2002.

José Julio A Lins Leitão

was born in 1955 in Caruaru, Brazil. He received the M.Sc. degree in electrical engineering from University of Itajubá-UNIFEI, MG-Brasil, in 1987. He received his D.Sc. degree from University of São Paulo-USP,

SP-Brasil, in 2002. Since 1979, he has been working for San Francisco River Hydroelectric Company-CHESF, at present in Protection and Automation areas. His areas of interest include electric power quality, protection performance and disturbance analysis.

Mailing address:

J Julio Leitão
CHESF/DPA - Edifício COS, sala B316
Rua 15 de março, 50, CEP 50761-901
RECIFE-PE, BRAZIL
phone: (+55)(81)3229.4160
e-mail: julio@chesf.gov.br

Iony Patriota de Siqueira

was born in 1951 in São José do Egito, Brazil. He received the M.Sc. degree in operations research from Federal University of Pernambuco in 1999 and the MBA on Information Systems from Catholic University of Pernambuco, in 1982. His areas of interest include reliability, maintenance, artificial intelligence and system performance. He is a member of Cigré and IEEE.

Mailing address:

Iony Patriota de Siqueira
Companhia Hidro Elétrica do São Francisco
Department of Protection and Automation
Rua 15 de Março., 50, Bongi, Recife
PE, Brazil
Phone:(+55)(0-81) 32294145
E-mail: ionys@chesf.gov.br

Milde Maria da Silva Lira

was born in 1961 in Recife, Brazil. She received the M.Sc. degree in electrical engineering from Federal University of Pernambuco in 1999. She received her D.Sc. degrees from Federal University of Pernambuco in 2004. His areas of interest include wavelets, artificial neural networks, fuzzy intelligent system and electric power quality.

Mailing address:

Milde Lira
Federal University of Pernambuco
Department of Electric Power Engineering
Acadêmico Hélio Ramos Str., s/n Cidade Universitária,
50.740-530 Recife-PE
BRAZIL
phone:(+55)(0-81) 2126 8155
e-mail: milde@ufpe.br

Paulo F. Ribeiro

was born in 1952 in Recife, Brazil. He received the Ph.D. degree in electrical engineering from the University of Manchester, England, in 1985. He worked for the San Francisco River Hydroelectric Company-CHESF, in Brazil, and since 1987 he has worked in the USA as an engineer, researcher, consultant and university professor. His areas of interest include electric power quality, power

electronics, energy storage, and power systems
modelling and simulation.

Mailing address:

Paulo F. Ribeiro

Calvin College

Department of Engineering

3201 Burton Street, SE

Grand Rapids, Michigan

phone:(+1)(616) 526.6407

e-mail: pribeiro@calvin.edu