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Statistical Investigation of the Disturbances Affecting the Power Distribution Networks (HTB/HTA) of a Few Source Substations in South-Benin

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Abstract: Power quality is a significant issue that has become increasingly important to both electric power utilities and their customers because of financial losses caused by insufficient. In this work, the Fourier transform (FT) has been exploited for the statistical investigation of the disturbances affecting the electrical distribution networks (HTA) in South-Benin. The data coming from the overhead line disturbances and underground cables, especially from the source substations of MARIA-GLETA, VEDOKO, AKPAKPA, GBEGAMEY and SEME have been treated. These data have been collected and made in our disposal by the Beninese Electricity Energy Company (SBEE) over the period from 2010 to 2017. Harmonic Distortion Rate (TDH) and the Disturbance Rate (D_R) have been used to evaluate the variation coefficient of the different disturbances registered at the each source substation, in order to characterize the harmonic pollution and the reactive power consumption. According to the EN 50160 N standard, the results obtained show that VEDOKO registered 500 to 2000 interruptions of duration between $0.4x10^5$ and $1.8x10^5$ minutes, between 2013 and 2016 especially due to a very critical load shedding. The dominance of the disturbances observed has been due exclusively to the incidents setting off and the load shedding incidents in 2017. 2013 and 2015 have been characterized by the frequent blackouts of long living, and occasion considerable damages, and consequently slow down the economic activities, social and cultural life of consumers.

Keywords: Power Quality, Fourier Transform, Harmonic Distortion Rate, Disturbance Rate, Load Shedding, Incidents Setting off

1. Introduction

The power grid quality constitutes a big interest these last decades for all governments and all actors of the electrical system: Administrative of networks, suppliers, producers or consumers of electricity. In Benin, the sector of the electric power cyclically recorded from 2003 to 2013 the major crises. They are essentially due to the chronic shortages of electrical energy, resulting in the regular power cuts commonly called: load shedding (unballasting). A low rate of access to the electricity by the populations, particularly in the rural zones becomes a knotty problem for the sustainable development in Benin. In 2014, the national electrification rate was 31% with 58% in urban middle and 6.7% in rural middle. The electricity consumption per capita is very low, about 110 kWh/occupant/year [1]. The national electricity production is essentially offered from the thermal power plants and represents 8.45% of the total demand in 2015 [2]. The electricity demand is constantly increasing, around 7% per year owing to the household's consumption.

Many feeds problems are caused by the electrical distribution networks. These networks implement thousands kilometers of the transmission lines, thousands transformer stations, and numerous cutting devices and automatic regulators, sized to ensure the efficient working of the electrical energy supply, in order to guarantee the continuity of the services offered to households [3]. However, these networks are exposed to the meteorological phenomena (floods, thunderstorms, hurricanes, snow, etc.), at the equipment failures, traffic accidents and major toppling over (rocking) operations [4, 5]. In Benin, this sector is characterized by the frequent blackouts, throughout the distribution networks, and occasion considerable damages, and consequently slow down the economic activities, social and cultural life of consumers. These blackouts are owing to technical failures, the lack of systematic control of the installations, the voltage poor quality at the delivery points, the early ageing of electrical devices and equipment at the users, the relatively high costs of managing the urban network.

These disturbances and operational failures of the distribution network to stand for themselves in the several other forms:

1. *The power cuts proceed from energy distributors:* the distribution networks are themselves subject to failures or disturbances (material failure, atmospheric disturbance, etc.). They result in voltage sags, long voltage break (two or four days of power cut) at the arrival posts (substations). According to the network topology and the means implement, these disturbances can propagate to the receivers;
2. *Isolation defects*: short-circuits cause at the receptors level voltage sags or voltage cuts which depend on:
   a. the protections set up and of their selectivity,
   b. the electrical distance of the receiver in relation to the defects,
   c. the network topology offering or not the means reconfiguration in active or passive redundancy,
3. *Network untimely opening*: they cause a supplying cut of the receivers placed in the downstream.
4. Undetected failures cause a network malfunction due to the phenomenon:
   a. Loss of the protection and / or selectivity;
   b. Loss of the means of reconfiguration, emergency relief [4, 6].

In addition, Benin depends strongly on the combustibles imports and electricity. In 2017, more than half of the country's total supply still proceeded from NIGERIA, GHANA or IVORY COST. The infrastructures are very ageing and still undersized to respond to the growing demand of the population in the electrical energy. The distribution network is always characterized by technical and commercial losses as those of 2013 estimated at 22.4%, as well as the frequent overloads and excessive voltage fluctuations [7]. Due to its dependence opposite to the imports and its inadequate electrical infrastructure, Benin always suffers a widespread electricity shortage. This situation changed somewhat in 2016 and 2017, when the government installed power generation capacity in the form of generator diesels rent out at a substantial cost [8]. Moreover, the poor quality of the electrical power can be attributed to power disturbances such as overvoltages, capacitor switching transients, interruptions, harmonic distortions and impulse transients [9]. In electric power system, short-circuit or ground defects may cause voltage sags or momentary interruptions whereas switching off large load or energizing of a large capacitor bank may lead to voltage swell. The using of solid-state switching devices and nonlinear loads such as rectifiers or inverters may cause harmonic distortion and notching in the voltage and current waveforms. Ferroresonance, transformer energization, or capacitor switching may cause transients. Ferroresonance, transformer energization, or capacitor switching may cause transients [8-11]. The term of power quality covers several types of problems of electricity supply and power system disturbances.

Our objective is to study quantitatively the disturbances affecting the electrical distribution networks in South-Benin. Data analyzed come from the overhead line disturbances and underground cables in south-Benin, specifically from the source substations of MARIA-GLETA, VEDOKO, AKPAKPA, GBEGAMEY and SEME. Statistical models have been exploited to identify and characterize the disturbance types from the data collected and made available for this study, by the Beninese Electricity Energy Company (SBEE) over the period from 2010 to 2017.

The rest of this paper is organized as follows: in Section 2, the different electrical disturbances of the distribution networks have been enumerated. Subsequently, we characterized the source posts HTB/HTA, the voltage HTA, and the associated mathematical models for the numerical simulations. The results and discussions are presented in Section 3. Finally, the conclusion and outlook are listed in Section 4.

2. Methodology

2.1. Types of Disturbances

Different electrical disturbances of the distribution networks are listed [12].

Table 1. *Types of disturbances.*

Types of disturbances	Disturbance subtypes	Times	Range	
			Min value	Max value
Frequency	Slight deviation	10 s	49.5 Hz	50.5 Hz
	Severe deviation		47 Hz	52 Hz

Types of disturbances	Disturbance subtypes		Times	Range	
				Min value	Max value
Voltage	Average voltage		10 min	0.85 Un	1.1 Un
	Flicker		-	-	7%
	Sag	Short	10 ms -1s	0.1 U	0.9 U
		Long	1s -1min		
		Long-time Disturbance	> 1min		
	Under-voltage	Short	< 3min	0.99 U	
		Long	> 3min		
	Swell	Temporary short	10 ms -1s	1.1 U	1.5 KV
		Temporary Long	1s -1min		
		Temporary Long-time	> 1min		
		Over-voltage	< 10 ns		6 KV
Harmonics and other information signals	Harmonics		-	THD > 8%	
	Information signals		-	Included in other disturbances	

Moreover, in the power distribution system, most of voltage sags are caused by increase in current. They are caused by short-circuits or ground defects, motor starting, transformer energizing or an abrupt increase in loads or source impedance. Just like under-voltage, overvoltage events are given different names according to their duration and magnitude. Overvoltage events of very short duration and high magnitude are called as transient overvoltages, voltage spikes or sometimes voltage surges. Voltage swells are almost caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator. They can also be caused by a damaged or loose neutral connection [11-13]. Voltage interruption is a condition in which the voltage at supply terminals is close to zero. Voltage interruptions are caused by faults. Other causes of voltage interruption are protection operations when there is no fault present, broken conductor and operator intervention. A transient event is a short-lived oscillation in a system caused by a sudden change of voltage, current or load. These sudden changes are mostly found as the result of the operation of switching devices. Voltage events with a very short duration, typically one cycle of the power system frequency or less, are referred to as transients, transient overvoltages, voltage transients, or wave shape faults [13, 14]. In addition, harmonic distortion is the change in the waveform of the supply voltage from the ideal sinusoidal waveform. The voltage wave-form is never exactly a single frequency sine wave. This phenomenon is called harmonic distortion or simply voltage distortion. Harmonic distortion is caused by the interaction of distorting customer loads with the impedance of the supply network. Its major adverse effects are the heating of the induction motors, transformers and capacitors and overloading of neutrals. Power factor correction capacitors can increase harmonics to unacceptable values in the presence of harmonic distortion [13-17].

Consequently, the quality of the distribution networks is closely linked to the quality of the voltage and the nature of the loads. For this reason, the quality of the electrical power is often reduced to the quality of the voltage [18]. voltage sags, voltage swell, voltage unbalance, transients, flicker, interruptions, interharmonics and harmonics are due to incidents as shown in Figure 1 [11, 12, 14].

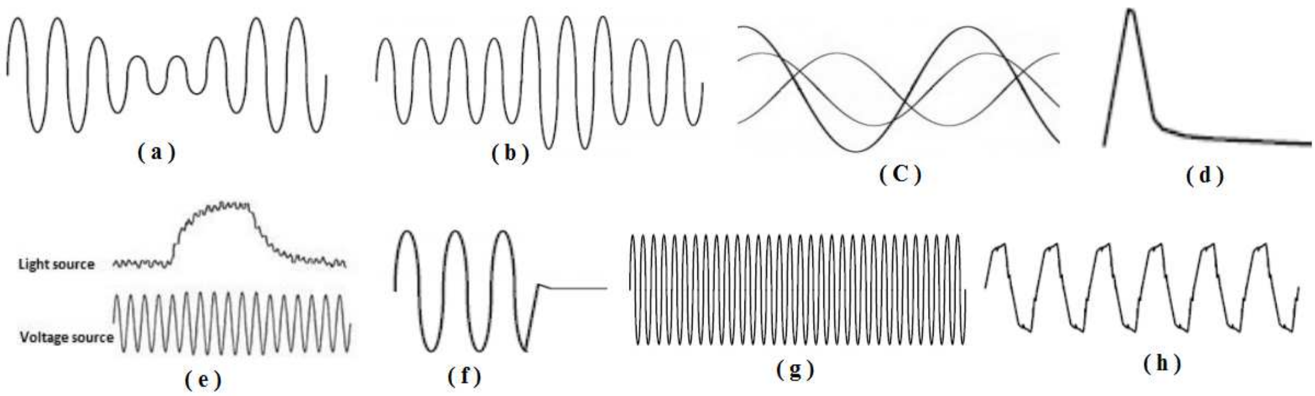

Figure 1. *Graphical illustration of power quality disturbances. (a): Voltage Sag; (b): Voltage Swell; (C): Voltage Unbalance; (d): Transients; (e): Flicker; (f): Interruptions; (g): Interharmonics; (h): Harmonics [11, 12, 14].*

2.2. Causes and Effects

The different causes and effects of the disturbance electrical networks identified have been lised in the table 2.

Table 2. *Causes and effects of the disturbances identified.*

Types of disturbances	Causes	Effects
Voltage Sags	Local and remote defects Inductive loading Switch on of large loads	Tripping of sensitive equipment Resetting of control system Motor stalling/tripping
Voltage surges	Capacitor switching Switch off of large loads Phase faults	Tripping of sensitive equipment, Damage to insulation and windings Damage to power supplies for electronic equipment
Overvoltages	Load switching Capacitor switching System voltage regulation	Problems with equipment that requires constant steady-state voltage
Harmonics	Industrial furnaces Non-linear loads Transformers/generators Rectifier equipment	Bad-operation of sensitive equipment and relays Capacitor fuse or capacitor failures Telephone interference

Table 2. *Continued.*

Types of disturbances	Causes	Effects
Power frequency variation	Loss of generation Extreme loading conditions	Negligible most of time Motors run slower De-tuning of harmonic filters
Voltage fluctuation	AC motor drives Inter-harmonic current components Welding and arc furnaces	Flicker in Fluorescent lamps Flicker in Incandescent lamps
Rapid voltage change	Motor starting Transformer tap changing	Light flicker Tripping of equipment
Voltage imbalance	Unbalanced loads Unbalanced impedances	Overheating in motors/generators Interruption of 3-phase operation
Short and long voltage interruptions	Power system defects Equipment failures Control malfunctions CB tripping	Loss of supply to customer equipment Computer shutdowns Motor tripping
Undervoltage	Heavy network loading Loss of generation Poor power factor Lack of var support	All equipment without backup supply facilities
Transients	Lightning Capacitive switching Non –linear switching loads System voltage regulation	Control system resetting Damage to sensitive electronic components Damage to insulation

Numerous other disturbance phenomena circulate on the systems and that depending on the uses, it may be necessary to characterize them so that they can be minimized or protection provided against them. It is sometimes difficult to deal with disturbance in that its origin and the routes it takes are complex. In addition to the known phenomena of lightning and switching, numerous new sources, in particular power converters, can cause disturbance in installations. This disturbance, which is generated by the installation itself or carried by the system from external sources or by the conductive parts, earthling circuits and shared elements, depends on the characteristics of the installation (impedances, short-circuit power, resonance, etc.).

Table 3. *Classification of the disturbances appearing on distribution networks (HTA) [14, 22].*

Permanent disturbances	Events
Harmonic distortions and inter-harmonics Flicker Unbalance Noises proper to the networks (thermal noise, etc.) and of measurement (acquisition chain)	voltage sags and power cut: 1. Single-phase defects, earth two-phase and isolated, three-phase, multiple and evolutionary Linked to the network functioning: 1. Batteries connection of compensation, 2. Connection/disconnection of decentralized productions, 3. Engine starting, 4. Grid connection discharge …

2.3. Disturbances Affecting the Distribution Networks HTA

An incident (HTA) is a great-scale (large-scale) disturbance. This power cut causes the cut of several stations (HTA/BT), therefore a cut of the customers (BT) connected to each of the stations (posts) [19-21]. Such an incident affects several thousand customers. Two distinct categories depending essentially on the duration of the phenomenon observed have been identified [14, 22-24]:

1) Permanent disturbances: present in the waveforms continuously;
2) Transient disturbances: impact on so-called permanent disturbances.

Short-circuits and the insulation defects are the main source of voltage sags type disturbances. They can affect the whole of the distribution network and endure until the protection of the source stations.

These defects are classified as a function of the number of the short-circuited phases and the presence of direct contact with the earth [25]. These defects have been listed:

1) Single-phase defects;
2) Isolated two-phase defects;
3) Two-phase earth defects;
4) Three-phase defects;
5) Evolutionary defects;
6) And multiple defects (simultaneous presence of several defects in different places downstream of the source station bar).

Only single-phase defects affecting distribution networks with compensated neutral behave differently [26-28]. The closing and starting untimely of a circuit breaker to send the current towards another zone are frequent events on the distribution networks due to the disconnection of a departure defect. The voltage drop observed at the starting is issue of the conjunction of the defect current due to magnetic saturation and the steady state current due to the loads reconnected to the networks [29, 30].

2.4. Source Substation (HTB/HTA) Characterizations

In the source posts (substations) are feeding by the 63 kV distribution network, and constituting the interface between the transport/distribution and the distribution networks. They are constituted in initial phase of a transformer fed by an arrival (HTB) (HT1).

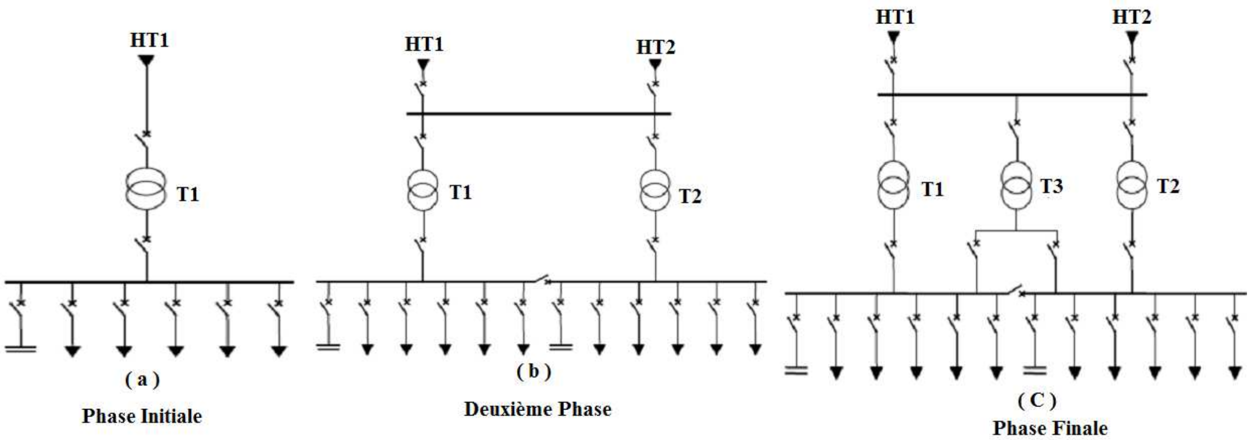

Figure 2. *Schematic diagram of the source posts (HTB / HTA).*

In the second phase, with increasing in the loads to serve, a second transformer is added Figure 2b, and the substation is generally connected to a second arrived line (HTB) (HT2) called "guarantee line". In the final phase, a third (or more) transformer is added in double attached Figure 2c. Departures (HTA) are grouped in half-ream as a function of their nature (overhead or underground) and the similarity of their load curve (type of customers connected). The network (HTA) has a radial arborescent structure most often in loop by another source station for the exploitation safety. It is constituted of a main frame and the deviations. According to the loads density to be served, the distribution network is realized whether by overhead lines or by underground cables.

2.4.1. Overhead Network (HTA)

The rural zones with low density are supplied by the overhead lines (HTA) in simple deviation, traditionally less costly than the hardwires buryed. The sizing of these structures is bound to the maximum admissible voltage drops due to the distance of the loads to be served.

2.4.2. Underground Network (HTA)

The Urban or mixed zones with high load density are supplied by the cables (HTA) buried in artery-cutting or in double deviation. In double deviation, the source substation (HTA/BT) are normally supplied by the cables (CT), and the emergency cable (CS) allow to guaranting à good continuity service in case of the defect. The artery-cutting technic is less cost than the previous and allows rapid isolation of the defects, but requires a longer intervention time. The underground sizing structures is mainly linked at the admissible currents in the cables due to the loads density to be served.

2.4.3. Voltage (HTA) Characterizations

The distribution network role is to supply electrical energy to the customers connected in (HTA) or (BT), ensuring a continuity of service and the electrical wave quality in the best conditions of safety and low cost. Therefore, the quality of the voltage wave delivered by the distributor must respond to the characteristics defined by European standard norm EN 50160 (NF C02-160) of May 2000 Table 2 [31]. In addition, the distributor contractually enlists to deliver in any point of the network a voltage (HTA) in the range of ± 5% around a contractual value Uc itself fixed in the range of ± 5% around the nominal voltage (typically 20 kV) Table 4.

Table 4. *Voltage (HTA) characterizations.*

Characteristics	Accepted values
Frequency	50Hz ± 1% during 99.5% of the time per year 50Hz+4% /- 6% during 100% of the time
Voltage	230V ± 10% during 95% of the time per week 20kV±10% during 95% of the time per week
Harmonics	Global rate of the harmonic distortion ≤ 8% U_{normal}
Voltage imbalance	$U_{inverce}$ ≤ 2% de U_{direct} during 95% of the time per week

2.5. Mathematical Models

According to previous study [32], almost all the PQ disturbances occur 70% or 80% of the time because of the customer and 30% because of the network side, in which the industrial devices are dominant, such as 43% of computers and microprocessor-based devices, 13% of variable speed drives, 8% of lighting equipment, 5% of motors, 1% of relays, and 30% of other equipment. Various signal processing techniques have been introduced such as: the Fourier transform (FT) [33, 34], the short-time FT (STFT) [35, 36], the fast Fourier transform (FFT) [37], and the discrete Fourier transform (DFT) [38, 39]. However, the FT is not enough for extracting the feature because of the transient natures of most of the PQ disturbances where time information is necessary [40] and it is not effective when the signal exists as short-term transient disturbances [41]. The DFT method is a frequency domain technique that estimates the individual harmonic components, and does not provide time domain information for non-stationary PQ disturbances signals. The FFT is a method used to obtain harmonic information about the monitored signals. However, this method is not suitable for detecting short or transient spikes. The STFT is an improvement of FT to overcome the DFT disadvantages. However, its disadvantage is that the size of the window is fixed for all frequencies, so there is a low resolution for high frequencies and unsuitability is found for the analysis of the non-stationary and transient PQ disturbances [42]. In these recent years, several other theories have been proven effective for detecting and studding PQ disturbances in power systems [19, 20, 43-57]. In sum, Power Quality (PQ) has become a significant issue for modern power industry in order to protect the electrical and electronic equipment by identifying the sources of the disturbances and providing a suitable solution to mitigate them.

In this work, the Fourier transform (FT) has been exploited. Data coming from the overhead line disturbances and underground cables in south-Benin, specifically from the source substations (MARIA-GLETA, VEDOKO, AKPAKPA, GBEGAMEY and SEME) have been analyzed and treated. These data have been collected and made in our disposal by the Beninese Electricity Energy Company (SBEE) over the period from 2010 to 2017. By simplifying some mathematical constraints, we defined two physical (quantities) greatnesses, in order to simulate the disturbances on the electrical distribution networks. The most frequently used: the harmonic distortion rate (THD) and the power factor. These two quantities respectively characterize the harmonic pollution and the reactive power consumption. In addition, we simplified and modeled the distribution substations (HTA) by the system represented by the Figure 3.

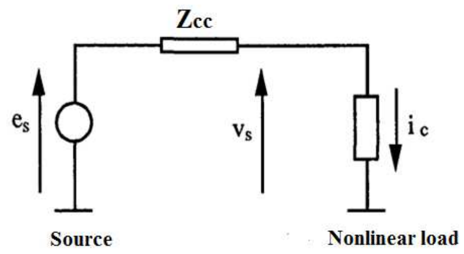

Figure 3. *Distributor-receiver model of the source substations (HTA).*

The energy distributor is a three-phase network modeled in single-phase by a voltage and current source. The Fourier series decomposition is exploited by the following equation:

$$i_c(t) = i_{cf}(t) + i_{ch}(t) \quad (1)$$

$i_{cf}(t)$: Fundamental current;
$i_{ch}(t)$: Harmonic current.

The current consumed by the load is supposed as a periodic signal which has been developed in Fourier series. It is assumed identical for each period of the network without the DC component. In this case, only the frequency harmonics multiple of the fundamental currents have been presented:

$$i_c = I_1\sqrt{2}\sin(wt - \varphi_1) + \sum_{i=2}^{\infty} I_n\sqrt{2}\sin\left[n(wt - \varphi_n)\right] \quad (2)$$

W: Pulsation;
I_1: RMS value of the Fundamental current;
I_n: Harmonic RMS value of order n;
$n\varphi_1$: Fundamental dephasing;
$n\varphi_n$: Harmonic phase of order n at time $t = 0$

Zccn: Represents the short-circuit impedance for order n harmonic, and deduced from Figure 3. The equivalent circuits for the physical quantities (fundamental and harmonic) are represented by the following Figure 4.

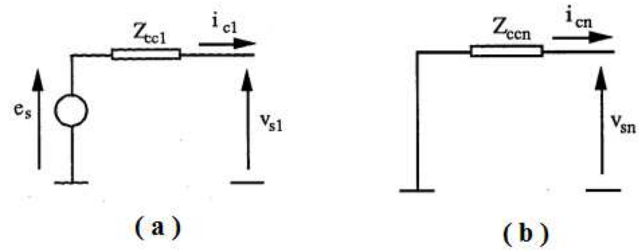

Figure 4. *Equivalent circuits. (a): fundamental component; (b): harmonic component.*

The voltage at the connection point of each post (substation) is calculated from equation (3)

$$V_s = V_{s_1} + \sum_{n=2}^{\infty} V_{s_n} \quad (3)$$

Where

$$V_{s_1} = e_s - |Z_{cc_1}| \cdot I_1 \sqrt{2} \sin(wt - \varphi_1 + \varphi_{cc_1}) \quad (4)$$

$$V_{s_n} = -|Z_{cc_n}| \cdot I_n \sqrt{2} \sin\left[n(wt - \varphi_n + \varphi_{cc_n})\right] \quad (5)$$

$|Zcc_n|$: Short-circuit modul

φ_{ccn}: Short-circuit argument.

From equation 3, the harmonic currents deform the voltage through the network short-circuit impedance. For harmonic currents generated by a polluting load, the voltage deformation is the more important than the network short-circuits impedance is the greater. The Harmonic Distortion Rate (TDH) resulting from each source substation is given by the following equation:

$$TDH = \sqrt{\sum_{n=2}^{\infty} \left(\frac{V_n}{V_1}\right)^2} \quad (6)$$

The Disturbance Rate (D_R), representing the Variation Coefficient of the different disturbances registered at the each source substation is evaluated from the following equation.

$$D_R = \frac{S_t D_{ev}}{\bar{X}} \times 100 \quad (7)$$

D_R: Disturbance Rate;

$S_t D_{ev}$: Standard deviation;

$\bar{X}$: Disturbance mean over the period from 2010 to 2017.

3. Results and Discussions

3.1. Databases

The high voltage distribution network in South-Benin is characterized by fourteen (14) source substations with a voltage range between 15 and 63 kV. The network regroups the underground lines form 6.2 km, and overhead lines from 18.13 km. The distribution network (HTA) has been chosen due to the consistency of the electrical network length these past ten years about 136.11 km, likewise the existence of the historical data recorded at the each source substation [2] is considerable. The network (HTA) topology in South-Benin is illustrated by the following Figure 5.

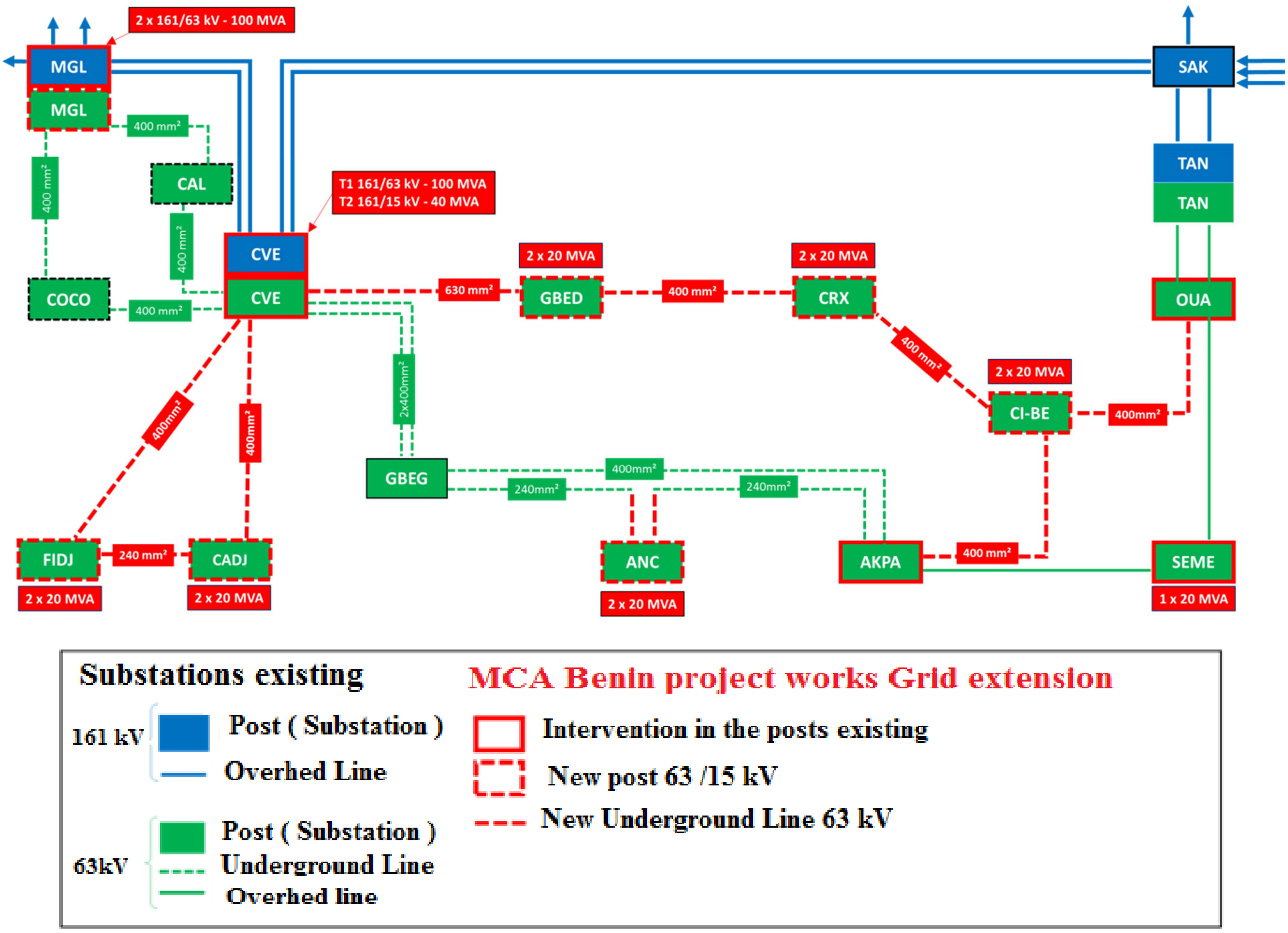

Figure 5. *Topology of the electrical distribution network in South-Benin [7].*

3.2. MARIA-GLETA Source Substation

MARIA-GLETA source Substations disposes:

1) a post of the Electrical Community of Benin (CEB) which has a 20 MW gas turbine (TAG);
2) a 30 MW thermal power production station by the partner Aggréko;
3) a station with two (02) gas turbines of 25 MW each installed on the same site by the partner (APR);
4) a station of eight (08) gas turbines of 10 MW each installed by SBEE in 2012. Only two turbines are operational on the all eight since its installation;
5) SBEE source post (substation);

Maria-Gléta source substation feeds (supplies) under 15kV several departures in energy:

1) Departure IITA;
2) Departure Calavi;
3) Departure Togba;
4) Departure SONEB.

CEB, AGGREKO and APR installations come to strengthen (reinforce) the production coming from NAGBETO in case of necessity. Despite all these infrastructures and power stations installed on the site, the electrical power cut is always frequent in the Abomey-Calavi locality for instance. The distribution of the five source substations is presented in the Table 5.

Table 5. *Distribution of the five source substations.*

Source Posts (Substations)		
01	*MARIA-GLETA*	HTA 15 kV
02	*AKPAKPA*	63 / 15 kV, (20+31,5) MVA
03	*HT1 (GBEGAMEY)*	63 / 15 kV, (63+20) MVA
04	*SEME*	63 / 15 kV, (7+3*5) MVA
05	*C442 (VEDOKO)*	HTA 15 kV

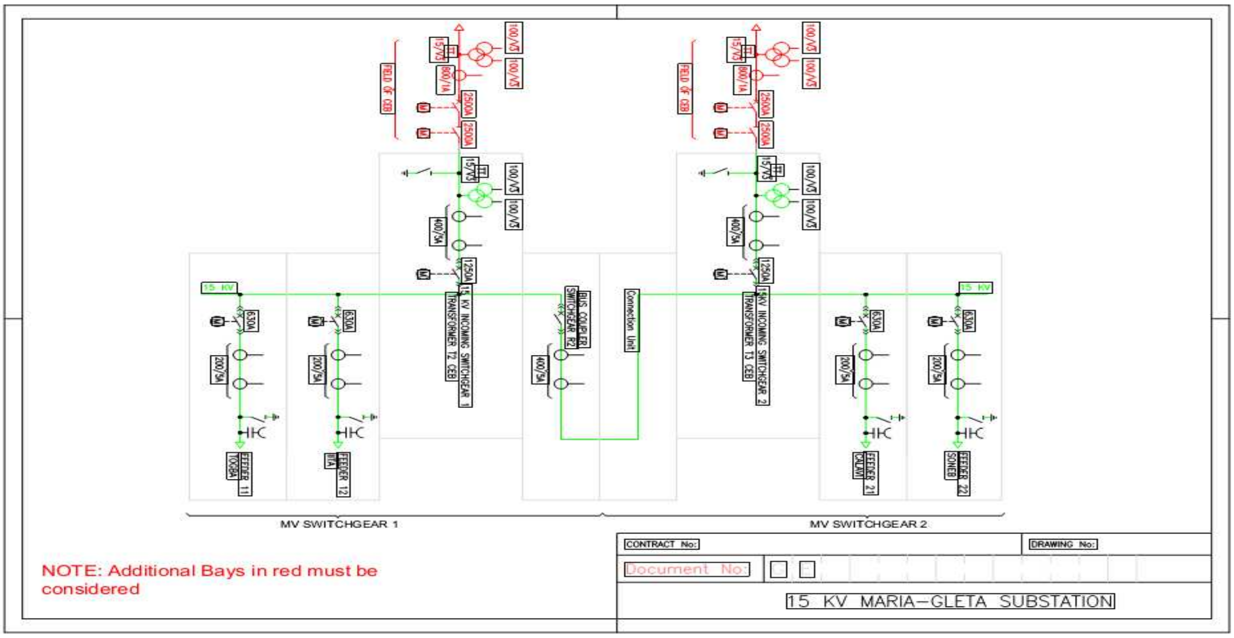

Figure 6. *Electrical distribution network topology of MARIA-GLETA.*

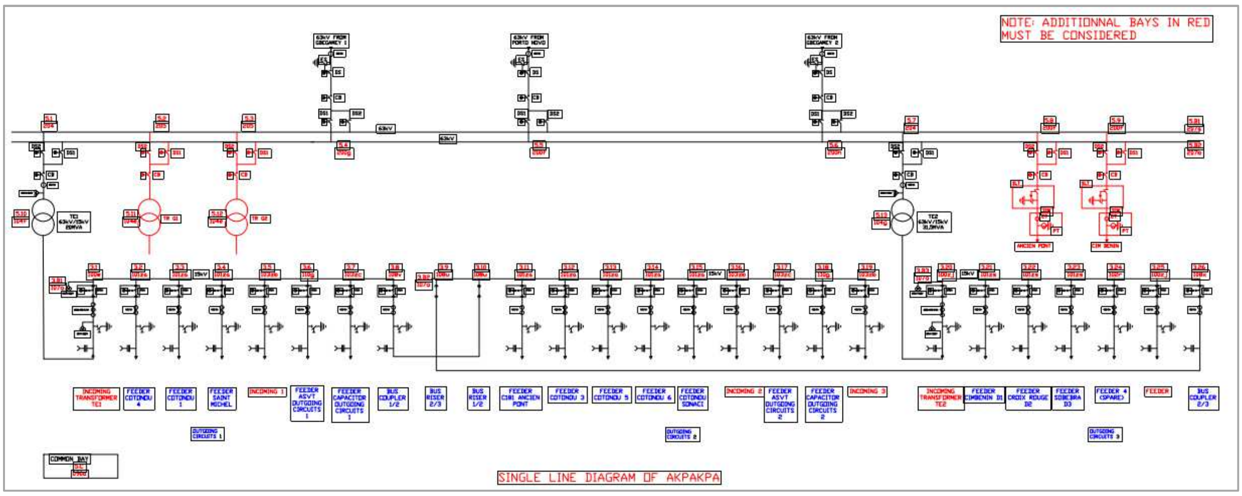

Figure 7. *Source post Topology of AKPAKPA.*

3.3. Disturbances Statistical

3.3.1. Disturbances Due to the Setting off Per Source Substation

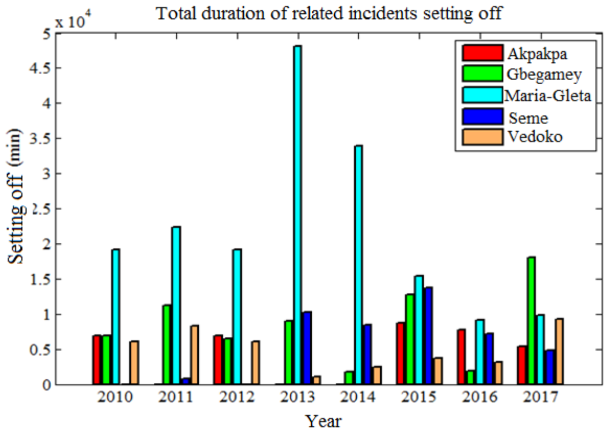

Figure 8. *Disturbances due to the setting off per source substation.*

3.3.2. Number of Related Incidents Setting off

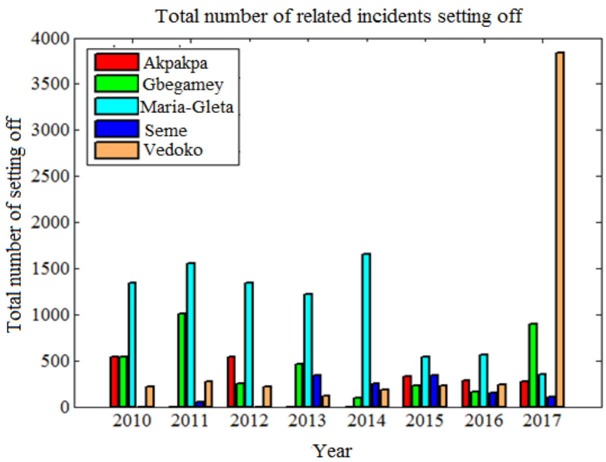

Figure 9. *Number of related incidents setting off.*

3.3.3. Number of Load Shedding Incidents

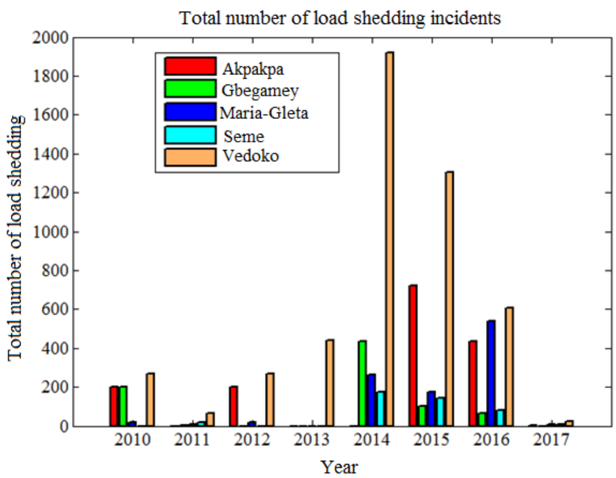

Figure 10. *Total number of load shedding incidents.*

3.3.4. Duration of Load Shedding Incidents

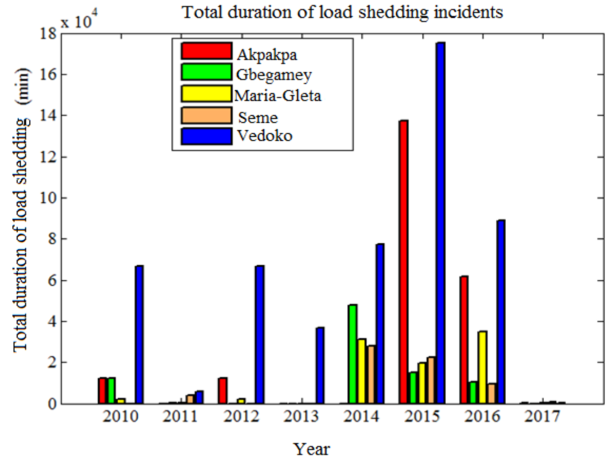

Figure 11. *Duration of load shedding incidents.*

3.3.5. Incidents Related to the Works

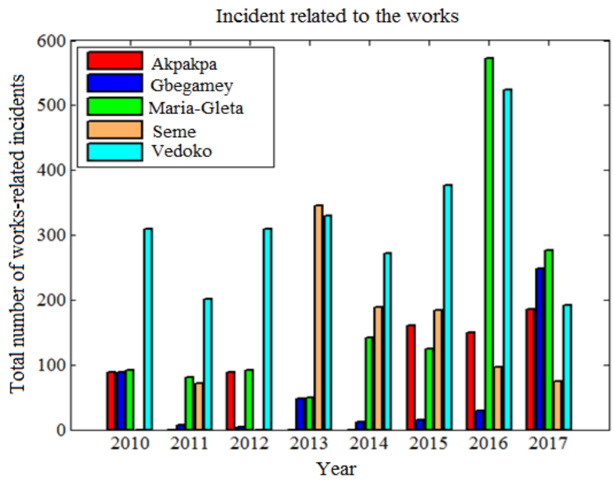

Figure 12. *Total number of works-related to the incidents.*

3.3.6. Incidents Related to the Works

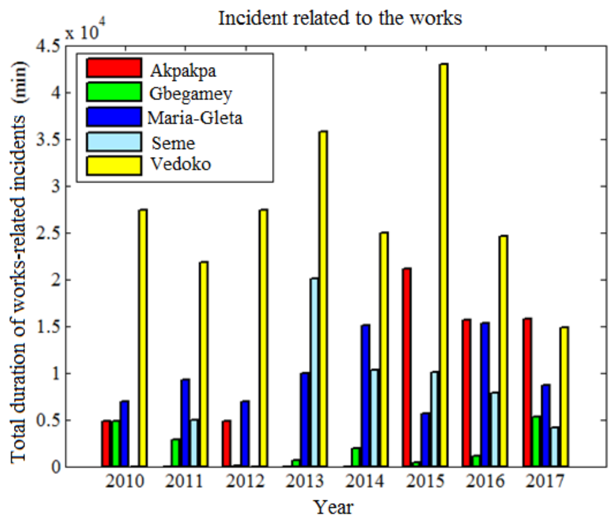

Figure 13. *Duration of works-related to the incidents.*

The Figure 8 to Figure 13 show the statistical evolution of number and duration of the power interruptions, and the electrical energy recorded from 2010 to 2017 at the main source substations HTB/HTA, and their distribution posts in south-Benin (VEDOKO, GBEGAMEY, MARIA-GLETA, AKPAKPA and SEME).

VEDOKO and *GBEGAMEY* feed (supply): the main business and commercial centers (Dantokpa, Ganhi, EREVAN, Banks and Restaurants, etc.), essential and critical infrastructures (CNHU Hospital, Maternity of Lagoon, Republic Presidency, Port Authority of Cotonou, Cotonou International Airport, the Ministers, the Chanceries, the Private and Public Companies).

AKPAKPA feeds: the cements works (NOCIBE, CIM BENIN), the brewery (SOBEBRA).

MARIA-GLETA supplies: the households, the residences but especially the secondary centers and the main borings of SONEB which supply 98% of the populations water needs of Cotonou, Abomey Calavi and South-Benin.

SEME supplies: the processing industries, and especially the Industrial Free Zone and other important places of cults (worships).

Consequently, the electrical network of South-Benin has been strongly and continuously impacted, by numerous untimely long-time interruptions from 2010 to 2017, marked specifically by:

VEDOKO: 500 to 2000 Interruptions of duration between 0.4×10^5 and 1.8×10^5 minutes, between 2013 and 2016 mainly due to a very critical load shedding. The dominance of the disturbances observed has been due exclusively to the incidents setting off and the load shedding incidents in 2017 (generated by the defects and the protections operation on a globally degraded network, as well as that generated by the unhooking and the discounts by part-time of the power stations hired (let out)). Then, from 2017 we observed an absence of the load shedding, thanks to the transitional emergency measures taken by the Benin's Government from 2016 (temporary renting of the installed thermal power stations (AGREEKO in VÈDOKO and GBÉGAMEY, APR in MARIA-GLÉTA) (*Figure 8 to Figure 13*);

1) *GBEGAMEY*: the same trend has been observed with 100 to 1000 Interruptions of duration between 0.1×10^5 minutes between 2013 and 2016 for the same analysis (*Figure 8 to Figure 13*);
2) *AKPAKPA*: We noted the same trend with 200 to 700 Interruptions of average duration 0.1×10^5 and 0.5×10^5 minutes between 2014 and 2016 for the same analysis (*Figure 8 to Figure 13*). It is likely that the interrupt data from 2011, 2012 and 2013 have not been consolidated by the SBEE, however the observations and results obtained do not change.
3) *MARIAGLETA*: The same trend has been observed with 300 to 1600 Interruptions of average duration 0.1×10^5 and 0.5×10^5 minutes for the same analysis, with the pronounced appearance of interruptions for the work owing to the electrical consignments necessary for the different great installation building sites and extension of the MARIA-GLETA power stations undertaken by the Government and which continue at this day (*Figure 8 to Figure 13*);
4) *SEME*: The same trends have been observed with 100 to 400 interruptions of duration between 0.05×10^5 and 0.27×10^5 minutes between 2013 and 2016 for the same analysis and the noticed appearance, in 2011 of nearly 300 interruptions of short duration cumulative around 0.05×10^5 minutes essentially due to the blackouts. Thus, 350 interruptions pursue over duration of 0.2×10^5 minutes for the extension works of the SEME source substation (*Figure 8 to Figure 13*).

According to the EN 50160 N standard, we chose two indicators to characterize the continuity, the availability and the quality of energy on the electrical distribution network:

$$\text{SAIFI} = \frac{\text{Total Number of customer Interruptions}}{\text{Total Number of Customer served}}$$

It characterizes the frequency of interruptions and measured in unit of interruptions per customer.

$$\text{SAIDI} = \frac{\text{Total duration of interruptions for a group of customer}}{\text{Nombre total de clients}}$$

It characterizes the duration of interruptions. We estimated these two indicators to freely characterize the evolution of the interruptions in the HTB/HTA posts studied, from data issue of the disturbances recorded.

The different performance parameters allowing evaluating the impact of the disturbances due to the setting off, the load shedding incidents and the incidents related to the works are summarized in the Table 6 to Table 8.

Table 6. *Statistics of the disturbances owing to the setting off.*

	2010	2011	2012	2013	2014	2015	2016	2017
Mean	9740	10620	9636	17077	11592	10857	5793	9461
Standard Error	3152	4493	3185	10535	7588	2091	1386	2372
Standard Deviation	6303	8985	6370	21070	15176	4675	3100	5303
Range	13090	21655	13090	47094	32199	11673	7203	13252
Minimum	6089	709	6089	980	1707	3707	1869	4812
Maximum	19179	22364	19179	48074	33906	15380	9072	18064
Sum	38958	42480	38544	68306	46368	54285	28964	47303
Count	4	4	4	4	4	5	5	5

Table 7. *Statistics of the disturbances due to the load shedding incidents.*

	2010	2011	2012	2013	2014	2015	2016	2017
Mean	23266	2536	20232	36734	45983	73948	41018	246
Standard Error	14617	1379	15664	0	11276	34183	15302	103
Standard Deviation	29234	2758	31329	#DIV/0!	22553	76435	34217	231
Range	64316	5694	66555	0	49387	160252	79311	507
Minimum	2239	139	0	36734	27766	15006	9652	0
Maximum	66555	5833	66555	36734	77153	175258	88963	507
Sum	93062	10143	80928	36734	183932	369741	205090	1229
Count	4	4	4	1	4	5	5	5

Table 8. *Statistics of the disturbances due to the incidents related to the works.*

	2010	2011	2012	2013	2014	2015	2016	2017
Mean	11024	9721	9830	16609	13059	16035	12884	9771
Standard Error	5484	4249	6033	7518	4804	7534	3955	2394
Standard Deviation	10967	8499	12065	15036	9608	16847	8844	5353
Range	22536	18931	27313	35140	23030	42493	23418	11608
Minimum	4874	2900	97	614	1941	416	1130	4186
Maximum	27410	21831	27410	35754	24971	42909	24548	15794
Sum	44097	38882	39320	66437	52234	80173	64418	48853
Count	4	4	4	4	4	5	5	5

Globally, the evolution of the disturbance duration due to the setting off has knew the variations from 2010 to 2017 with notably the decreases recorded in 2014 and 2016 at the level of the all source stations. The total number of the disturbance due to the setting off significantly decreased in 2014 and 2016 below 500. However, the number of related incidents setting off increased slightly with an abrupt increase recorded at the VEDOKO source post. This probably improves the quality of the production and the supply of the electrical energy served to the customers.

4. Conclusion

Quantitative study of the disturbances affecting the electrical distribution network (HTB/HTA) in south-Benin has been investigated. The source substations concerned are exclusively the substations of VEDOKO, MARIA-GLETA, AKPAKPA, GBEGAMEY and SEME. The data coming from the overhead lines disturbances and underground cables have been treated and analyzed. These data have been supplied by the Beninese Electricity Energy Company (SBEE) over the period from 2010 to 2017. The Harmonic Distortion Rate (TDH) and the Disturbance Rate (DR) have been determined in order to evaluate, the variation coefficient of the different disturbances registered at the each source substation. With the Fourier transform (FT), the Harmonic Pollution and the reactive power consumption have been characterized. Qualitatively, we noted that:

a. The Power quality (PQ) is closely owing to the quality of the voltage and the nature of the loads. Thus, the quality of the electrical power is often reduced to the quality of the voltage;
b. The voltage sags, voltage swells, voltage unbalance, flickers, Harmonic distortions, Impulsive transients, Voltage interruptions, inter-harmonics, Oscillatory transients, Voltage sags with harmonic distortions, Voltage swells with harmonic distortions, Voltage sags with oscillatory transients, Flickers with harmonic distortions and Voltage swells with oscillatory transients are the main defects affecting the quality of the electrical distribution networks, causing the major economic and infrastructure losses.

Quantitatively, the results obtained have shown the extent of the disturbances registered on the main substations (HTB/HTA) that almost serve 80% of the needs in electricity at south-Benin. *GBEGAMEY* registered 100 to 1000 interruptions of duration between 0.1×10^5 minutes between 2013 and 2016. The case of *VEDOKO* is very critical, 500 to 2000 interruptions of duration between 0.4×10^5 and 1.8×10^5 minutes, between 2013 and 2016 mainly due to a very critical load shedding. *AKPAKPA* presents 200 to 700 interruptions of average duration 0.1×10^5 and 0.5×10^5 minutes between 2014 and 2016. With *MARIA-GLETA*, we noted 300 to 1600 interruptions of average duration 0.1×10^5 and 0.5×10^5 minutes. In addition, the interruptions are very short, but very frequents. However, we registered 100 to 400 interruptions of duration between 0.05×10^5 and 0.27×10^5 minutes between 2013 and 2016. In 2011, 300 interruptions of short duration cumulative around 0.05×10^5 minutes essentially due to the blackouts have been registered. But, 350 interruptions pursue over duration of 0.2×10^5 minutes for the extension works of the SEME source substation.

In definive, the corrective actions of the Government's action program suppressed the load shedding in the short and medium term. But we note that the interruptions due to the setting off persist and it appears more than necessary to investigate on the major causes of these setting off, and their effects on the quality of the disturbances of the energy in order to propose the solutions to eliminate or attenuate durably their impacts on the quality of the energy and the stability of the electrical network.

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