HARMONICS LEVEL IMPROVEMENT OF DISTRIBUTED GENERATION INTEGRATED DISTRIBUTION SYSTEM USING UNIFIED POWER QUALITY CONDITIONER

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Abstract: In this paper the use of active power filter to improve voltage and current distortion caused by the presence of dispersed generation in the distribution system is investigated. The harmonics produced by photovoltaic distributed generation sources is studied and the unified power quality conditioner is introduced as a technique of minimizing these harmonics generated by the presence of distributed generation. The network is modeled and simulated in ETAP 16.0 software environment and harmonic load flow results show an increase in harmonic level when DG is introduced into the network which is subsequently reduced by the introduction of UPQC into the network.

Keywords: active power, filter, distributed generation, harmonics, ETAP, UPQC

1. INTRODUCTION

The changes currently being observed, the world over, in power systems is driven by two major forces. One is the ever-increasing demand for electrical energy and the other is the demand for cleaner, greener, more environment friendly sources of power generation. Power industries, the world over, are thus driven by the need to expand capacity rapidly and at the same time come up with ways of doing so with minimal pollution and damage to the environment [1].

One way of bridging the gap between supply and demand of electrical energy is the use of non-centralized power generation sources. Non-centralized generation exist as against centralized, large scale power generation centres. Non-centralized generation also called distributed generation (DG) is any low level (less than 100 MW) source of power that is connected at the distribution level [2]. DG can come in different forms such as photovoltaic or solar systems, mini-hydro generation plants, or wind systems. Other forms include fuel-based systems, such as, fuel cells and micro-turbines.

The numerous advantages of DG notwithstanding its integration into the network comes at a cost. One of the cost implications of DG integration is the introduction of power quality (PQ) problems into the network. In renewable energy DG systems we can identify two major types of PQ problems. These are problems involving voltage and frequency fluctuations and then problems of harmonics. Of these PQ Problems harmonics appear to be most prevalent [3].

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Harmonics refer to waveforms whose frequency are integral multiples of the original waveform and whose presence in the system create a distortion in the waveform of current and voltage from the usual sinusoidal shape. In DG integrated systems harmonics are generated by power electronic systems which are used in renewable energy generation and integration [4]. Some major effects of harmonics include; transformer saturation, heating up of equipment, flickering of voltage mains, wrong operation of sensitive devices, false tripping of relay systems, shorter life of organic insulation and audible noise in power system equipment.

By using the proper active power filter (APF) PQ issues, including distortion of current and voltage waveshapes (harmonics) attributible to DG sources can be reduced. [5] suggests more popular APFs to be D-STATCOM, UPQC, DVR). The D-STATCOM is essentially a shunt APF while the DVR is a series APF. The UPQC is a combination of a D-STATCOM and DVR, making it more robust and desirable when placed side by side with other PQ improvement schemes [6].

The UPQC has in its structure a series active power filter (APF_{se}) and shunt active power filter (APF_{sh}) for same time adjustment of supply voltage and load end current issues in the network. The APF_{se} provides a voltage, V_{se}, in series with supply voltage in a way that at the voltage stays unaffected by disturbance, while the APF_{sh} is to supply a current which reduces the load current harmonics [7]. Illustrated in Figure 1 is the internal structure of the UPQC.

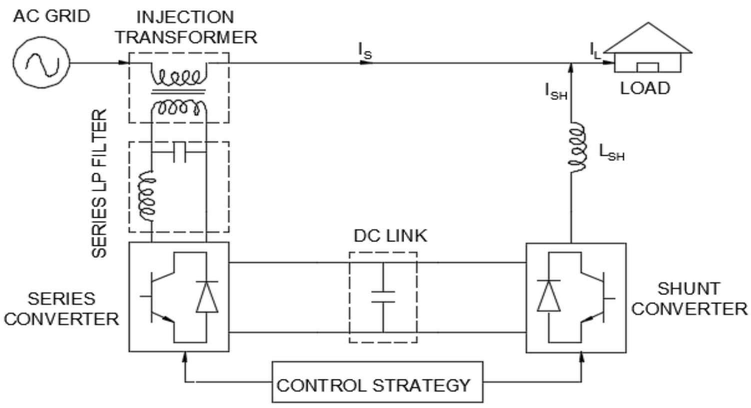


Fig. 1. UPQC: showing series and shunt APF.

The series APF (APF_{se}) of the UPQC behaves like a voltage controlled source, while the shunt APF (APF_{sh}) behaves like a current controlled source. No power supply is connected at the DC link. It is made of a small DC capacitor acting as an energy storage [8]. Depending on the position of shunt APF relative to the series APF the UPQC structure may be described as right shunt or left shunt APF.

The main function of the UPQC controller is to provide the reference compensating voltage V_{CC} and reference compensating current I_{CC} to the series and shunt converters which is produced by using PWM voltage and current control technique. The APF_{sh} can eliminate all undesirable current components, including harmonics [9]. In order, to eliminate harmonics created by a nonlinear load, the shunt converter should put in a current represented by the following equation:

$$I_{CC}(\Phi) = I_{SS}(\Phi) - I_{LC}(\Phi)A \quad (1)$$

where, $I_{CC}(\Phi)$, $I_{SS}(\Phi)$ and $I_{LL}(\Phi)$ represents the current introduced by shunt inverter into the network, current supplied from the source, and current reaching the load respectively and $\Phi = \omega t$ represents angular displacement of current where ω and t angular frequency and time, respectively.

The APF_{se} can eliminate problems associated with the supply voltage by supplying voltage in series to achieve distortion free voltage at the load terminal. The series converter needs to supply a voltage represented by the equation:

$$V_{CC}(\Phi) = V_{LC}(\Phi) - V_{SS}(\Phi)V \quad (2)$$

where, $V_{CC}(\Phi)$, $V_{LL}(\Phi)$ and $V_{SS}(\Phi)$ represents the voltage supplied by series inverter, load voltage, and actual voltage from source, respectively. The control procedure play a very important role in UPQC performance [10].

2. EXPERIMENTAL SETUP

This section has been divided into two. The first part presents the materials used in the research work while the research procedure is presented in the second part.

2.1. Materials

The materials used in this research paper include data obtained from the Otovwodo distribution network in Ughelli, Delta state. Data on the 85 substations in the distribution system were obtained from daily activities as well as physical measurements and interaction with station staff. The network modelling and simulation was done using ETAP 16.0 power system simulation software.

2.1.1. Network Description

The network under review is the 15 MVA, 33/11 kV Otovwodo distribution network, located at Otovwodo in Dleta state, Nigeria. To service its domestic and business customers the Otovwodo distribution network gets supply from Transmission Company of Nigeria (TCN) through its 30MVA, 132/33 kV injection substation. This is stepped down at Otovwodo 15MVA, 33/11kV injection substation and supplied to two 11 kV feeders, Isoko road feeder and Dumez road feeder. Between both feeders the network has 85 active distribution transformers that feed the different consumers.

Figures 2 shows Otovwodo 15 MVA injection transformer and switchyard and Figure 3 shows part of Otovwodo distribution network in Electronic Transient Analyzer Program (ETAP 16.0). Tables 1 and 2 presents some information from the two feeders used in the simulation exercise.

Fig.2. Otovwodo 15 MVA injection transformer and switch yard.

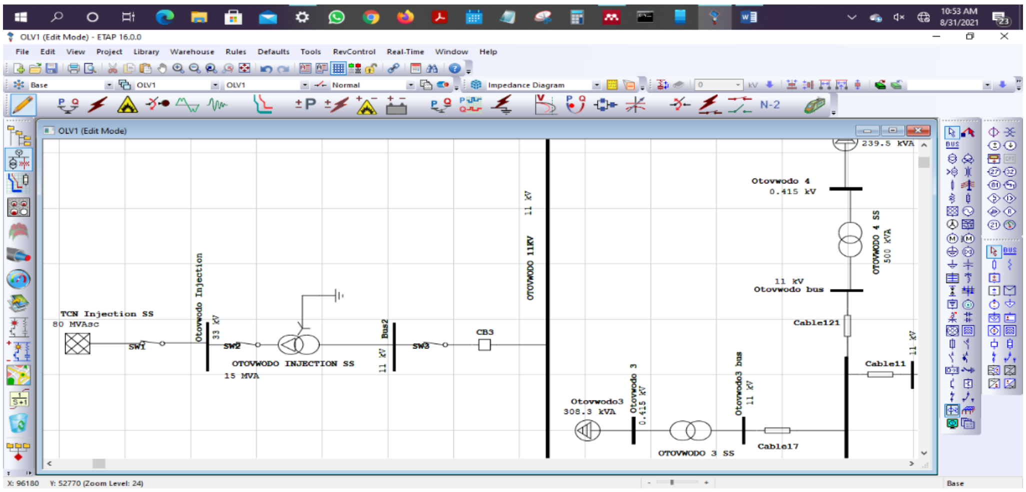


Fig. 3. One-Line Diagram Model of Otovwodo 15MVA Injection Substation In ETAP 16.0 Environment.

Table 1. Average peak and off-peak loads on distribution transformers attached to Isoko road feeder.

SN	Substation	Rating (kVA)	Distance (km)	Ave. Peak Load			Ave. Off-Peak Load		
				kW	P.F	kVA	kW	P.F	kVA
1	Ovie	500	0.49	393.5	0.90	437.2	248.2	0.95	261.3
2	Uduophori	300	0.86	198.4	0.89	222.2	110.8	0.93	119.1
3	Oviri-Ogor 2	300	2.67	47.6	0.95	50.1	28.5	0.82	34.8
4	Oviri-Ogor 1	200	3.03	135.4	0.91	148.8	58.3	0.90	64.7
5	Ogbalor Cold Room	300	0.86	38.5	0.68	58.6	28.9	0.71	40.7
6	Airtel SS	50	1.56	8.3	0.88	9.43	4.3	0.81	5.3
7	Makolomi	500	1.43	313.5	0.91	344.5	158.0	0.94	168.1
8	Onogharigho	300	1.90	240.0	0.92	260.9	173.8	0.96	181.0
9	Utoro	300	2.43	216.3	0.94	230.1	101.4	0.89	113.9
10	Upper Agbarho 5	300	1.84	151.2	0.95	159.2	54.7	0.91	60.1

Table 2. Average peak and off-peak loads on distribution transformers on Dumez road feeder.

SN	Substation	Rating (kVA)	Distance (km)	Ave. Peak Load			Ave. Off-Peak Load		
				kW	P.F	kVA	kW	P.F	kVA
1	Otovwodo 2	500	0.77	259.4	0.72	360.3	160.3	0.98	163.6
2	Otovwodo 3	500	1.31	277.4	0.91	304.8	166.8	0.97	171.9
3	Otovwodo 4	500	1.58	203.7	0.86	236.9	190.7	0.86	221.7
4	Bishop Emuobor	500	1.64	295.3	0.95	310.8	181.8	0.98	185.5
5	Agbarha Junction	300	0.33	197.4	0.76	259.7	113.3	0.98	115.6
6	Agbarha Road	500	0.48	134.1	0.73	183.7	46.6	0.97	48.0
7	Saniko	500	0.48	187.3	0.88	212.8	117.0	0.97	120.6
8	Slaughter House	300	1.25	85.7	0.94	91.2	79.2	0.98	80.8
9	Uduere 2	300	3.61	98.3	0.86	114.3	60.2	0.86	70.0
10	Uduere 1	100	3.23	63.2	0.95	66.5	49.4	0.98	50.4

2.2. Method

In this section the method through which the research has been carried out is presented. The first step was to gather the data required for simulation in ETAP 16.0 from the necessary locations on the network. The data gathered include injection substation rating, numbers of distribution substations on each 11kV feeder along with their ratings and distance from the injection substation (for estimation of cable length). Also, the peak and off-peak loads on each distribution transformer was also gathered. The research method include:

1. Collection of necessary network data. The network data collected include injection substation rating, number of feeders attached to the injection substation, number of distribution transformers on each feeder. Data was collected through interaction with distribution network staff as well as adoption of already existing data. The network data is summarized in Tables 1 and 2.
2. The data collected is used to model the distribution network in ETAP 16.0 software environment. This is illustrated in Figure 3.
3. A first harmonic load flow of the modelled Otovwodo network without DG is simulated in the ETAP 16.0 environment to determine the harmonics present in the network before introduction of DG. This is shown in Figure 4.
4. A second simulation of the network model with photovoltaic (PV) DG power sources present is carried out in ETAP 16.0. This gives a measure of the percentage of distortion put into the system due to integration of PV sources into the network. This is presented in Figure 5.
5. Finally, a third harmonic load flow of the network with photovoltaic DG sources and UPQC is done in ETAP 16.0. This third simulation measures the usefulness of UPQC in reducing percentage of harmonics. This illustration is in Figure 6.

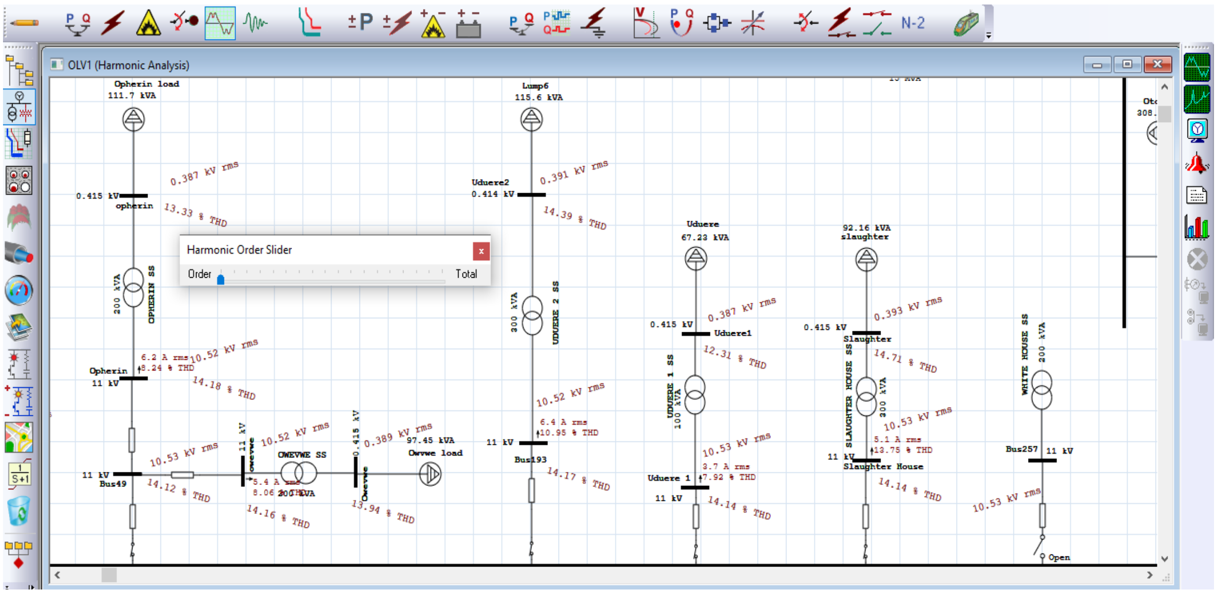


Fig. 4. Harmonic load flow of distribution network: showing percentage of harmonics present at several buses without photovoltaic DG sources.

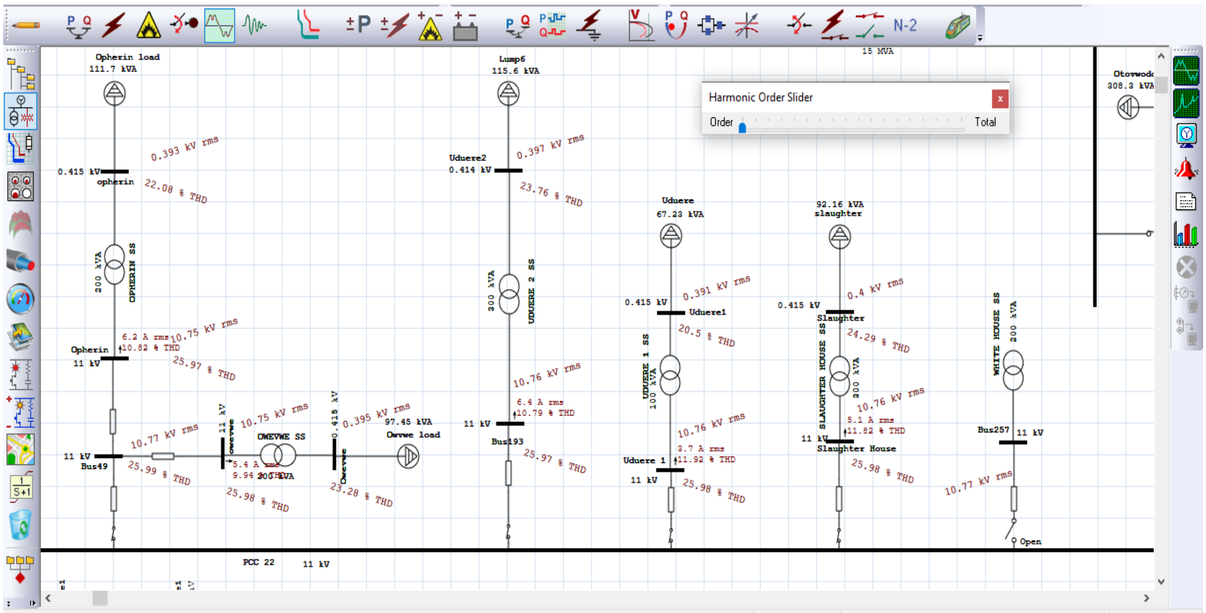


Fig. 5. Harmonic load flow of distribution network: showing percentage of harmonics present at several buses after addition of photovoltaic DG sources.

3. RESULTS AND DISCUSSION

This section presents the results of the different simulations carried out in ETAP 16.0 of the Otovwodo 11kV distribution network. In line with the aim of this research which is to reduce the level of harmonics introduced by the presence of DG three harmonic load flow simulations have been carried out. For simplicity the simulation results from 10 buses have been presented. However, the results can be extended to other substations in the network.

The percentage of voltage harmonic distortion (VTHD) and current harmonic distortion (ITHD) from the first simulation, which is without the inclusion of photovoltaic DG sources in the system is seen in Table 3 (WODG). The percentage increase in harmonics caused by photovoltaic DG, gotten from the second simulation is also available in Table 3 (WDG). The percentage of harmonics present in the system after addition UPQC is also in Table 3 (WUPQC).

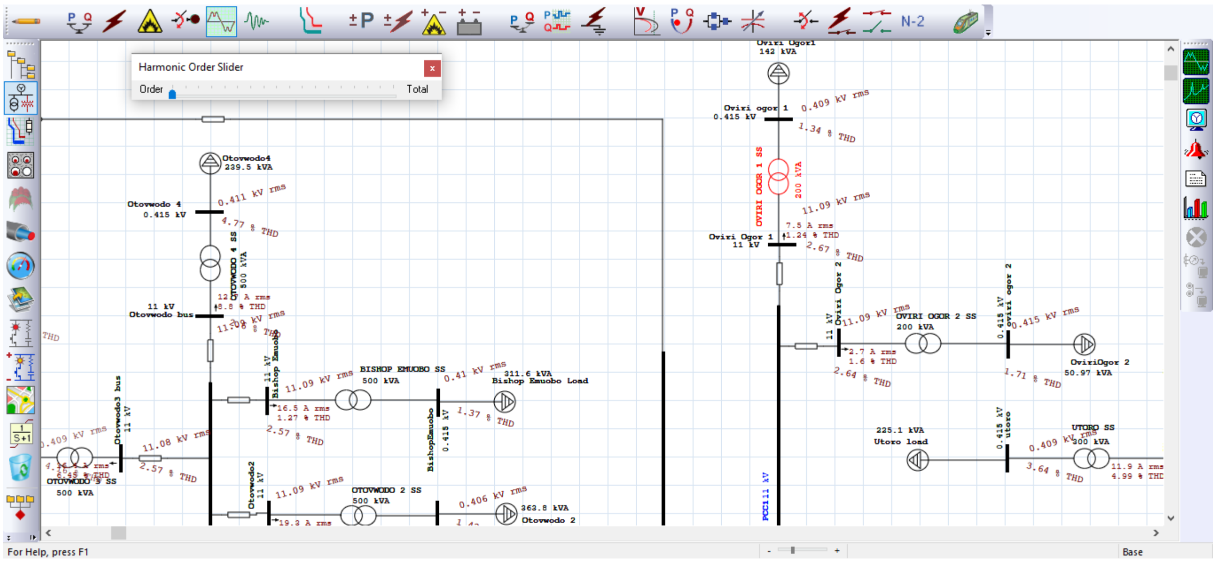


Fig. 6. Harmonic load flow of distribution network: showing percentage of harmonics present at several buses after addition of photovoltaic DG sources and UPQC.

Table 3. VTHD and ITHD for selected buses obtained from ETAP 16.0 simulations.

SN	ID	RATING (kVA)	VTHD (%)			ITHD (%)		
			WODG	WDG	WUPQC	WODG	WDG	WUPQC
ISOKO ROAD FEEDER								
1	Makolomi	500	12.33	20.82	1.32	7.62	12.15	1.26
2	Onogharigho	300	11.44	19.08	1.25	7.35	11.93	1.18
3	Oviri-ogor 1	300	12.13	20.52	1.34	7.29	11.98	1.24
4	Oviri-ogor 2	200	15.26	25.30	1.71	8.20	12.51	1.60
5	Airtel SS	50	15.83	26.09	1.79	9.37	14.57	1.53
SN	**ID**	**RATING (kVA)**	**VTHD (%)**			**ITHD (%)**		
			WODG	**WDG**	**WUPQC**	**WODG**	**WDG**	**WUPQC**
DUMEZ ROAD FEEDER								
6	Otovwodo 3	500	13.87	22.19	1.42	8.59	13.07	0.98
7	Bishop Emuobor	500	12.56	21.19	1.37	7.61	11.92	1.27
8	Slaughter	300	14.69	24.29	1.60	9.91	11.82	1.50
9	Uduere 2	300	14.37	23.76	1.57	10.94	14.79	1.33
10	Uduere 1	100	12.29	20.50	1.34	7.97	11.92	1.24

Note: WODG – without distributed generation; **WDG** – with distributed generation; **WUPQC** – with universal power quality conditioner

From Tables 3 it is seen that VTHD generally appear higher than ITHD though this is seldom the case. However the situation as presented in Table 3 could arise from a number of reasons including the presence of saturated transformers, use of long lengths of cables and also the presence of DG sources in the network. Generally, anything which leads to increase in system impedance will also lead to higher VTHD.

Figure 7 is a bar chart illustrating the increase and decrease in percentage voltage harmonic distortion (VTHD) while Figure 8 is bar chart presenting the changes in current harmonic distortion (ITHD) for the three cases under consideration. The green, red and blue bars respectively stand for percentage harmonics in the network before addition of PV DG, after addition of PV DG and after addition of UPQC. Figures 9 to 11 show the waveform at selected buses which can be extended to the entire network.

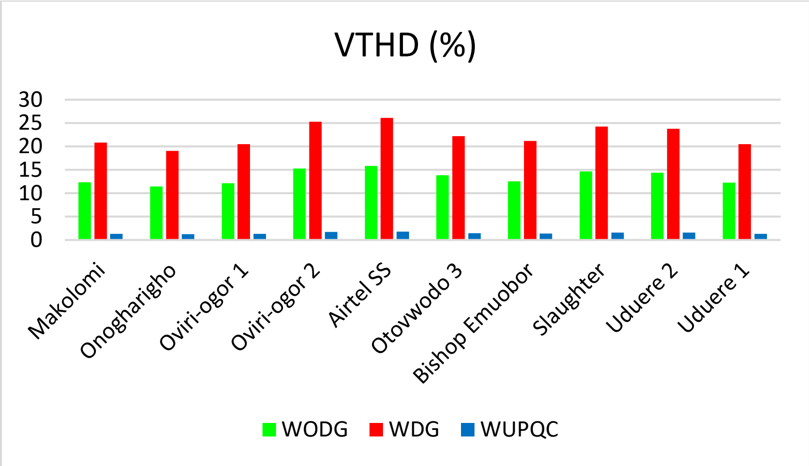


Fig. 7. Bar chart of increase and decrease in voltage harmonic distortion (VTHD) for cases WODG, WDG and WUPQC.

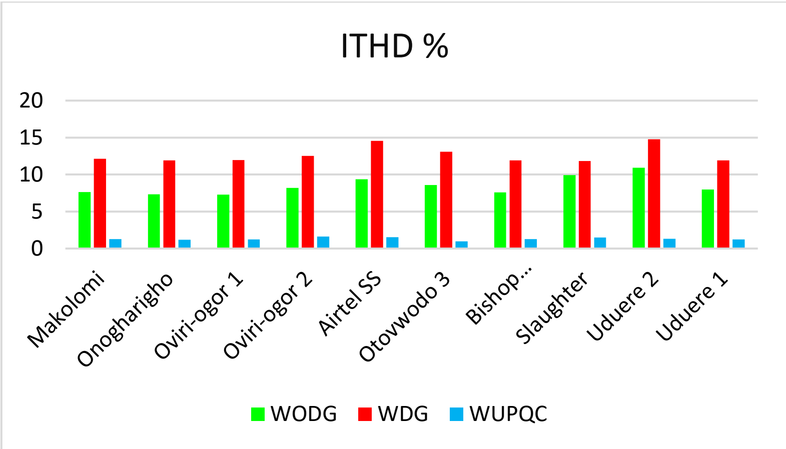
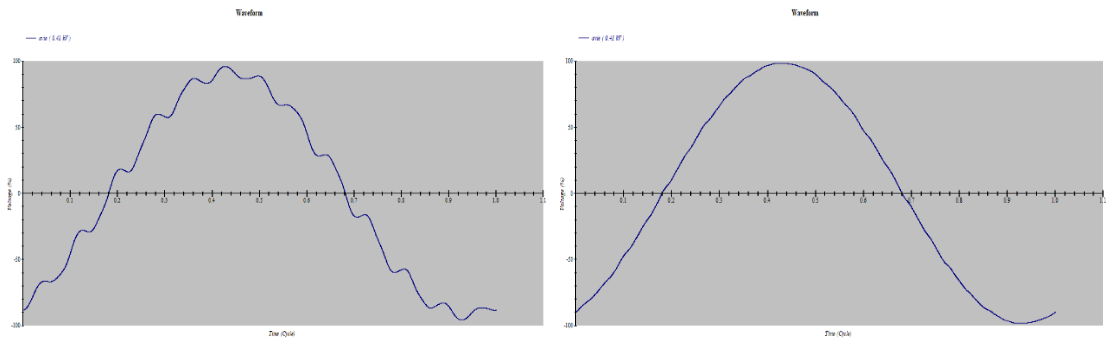


Fig. 8. Bar chart of increase and decrease in current harmonic distortion (ITHD) for cases WODG, WDG and WUPQC.

Table 3 shows the values of the voltage total harmonic distortion (VTHD) at the 10 selected buses before DG was introduced into the network (WODG), after DG was introduced into the network (WDG) and also after UPQC has been introduced into the network (WUPQC). Table 3 also presents the ITHD for the 10 selected buses of the network for the three different cases, without DG (WODG), with DG (WDG) and with UPQC (WUPQC).

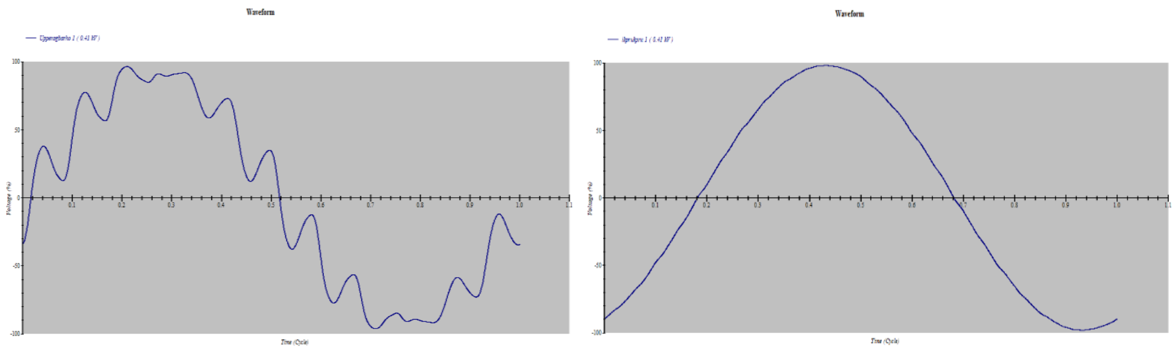
Figures 9 to 11 show the harmonic distortion of the waveform prior to the introduction of DG into the network, after the introduction of DG into the network and the effect of the UPQC in reducing the harmonic level which was increased by DG.

Based on IEEE-519 regulation VTHD should not exceed 5 % and ITHD should be less than 3 %. Now comparing values of Total Harmonic Distortion (THD) in Tables 3 prior to and after the addition of DG to the network a significant increase of 66.0 % is observed in VTHD and 49.3 % is observed in ITHD. Now comparing the values in Tables 3 prior to and after the addition of UPQC a significant reduction of 93.4 % in VTHD and 89.6 % in ITHD levels is seen which can be attributed to the effect of the UPQC.



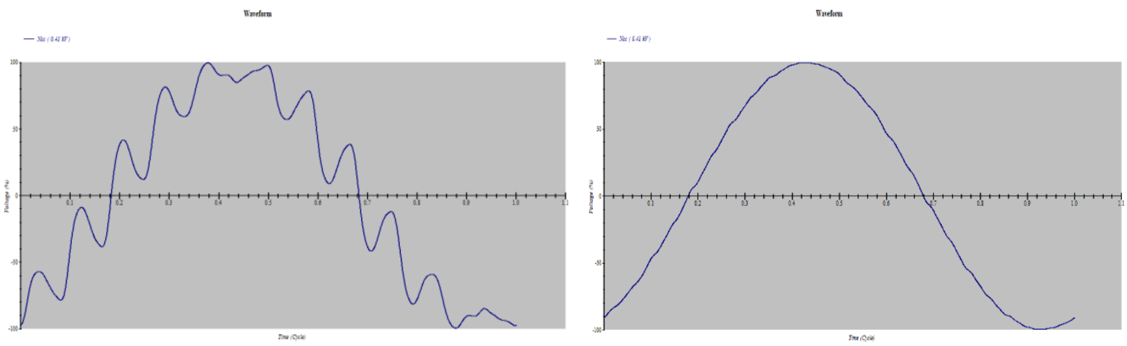
(a) (b)

Fig. 9. Voltage waveform at Slaughter bus: (a) before UPQC introduction (b) after introduction UPQC.



(a) (b)

Fig. 10. Voltage waveform at Makolomi bus: (a) before introduction of UPQC (b) after introduction of UPQC.



(a) (b)

Fig. 10. Voltage waveform at Airtel bus: (a) before introduction of UPQC (b) after introduction of UPQC.

4. CONCLUSIONS

From results obtained the following conclusions have been drawn:

- Distributed generation (DG), though beneficial, can increase the level of harmonics into the distribution network.
- Implementation of the Universal Power Quality Conditioner (UPQC) as a minimization technique has seen the voltage total harmonic distortion reduced by 93.4% and the current total harmonic distortion introduced by 89.6 %.

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