APPLICATION OF SIMPLEX OPTIMIZATION ALGORITHM FOR REDUCING HARMONICS ON 500KVA DISTRIBUTION TRANSFORMER: Case Study of University of Abuja

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Abstract

Transformer experiences harmonic power losses when non-linear load are connected this result in increased operational costs in power system. The Transformers are normally designed and built for use at rated frequency and perfect sinusoidal load current and voltage in order to reduce losses, insulation fatigue, failure due to premature and transformer life reduction. This paper develops simplex optimization Algorithm for Reducing Power Harmonics of 500KVA distribution Transformer in engineering block of the University of Abuja.

The experimental measurement was conducted for two (2) weeks from 8am to 5pm every hour of each day of the two weeks in order to analyze the harmonic distortion in the faculty of engineering transformer. The instrument used to measure the parametric data of harmonic current is power harmonic analyzer (Fluke 123/124).

The collated data was analyzed using simplex optimization technique. MATLAB software was used to perform the simulation in order to reduced harmonic distortion in the transformer. MATLAB Software 2007 was used to carry out simulations to develop Simplex Optimization Techniques model for university 500KVA Transformer with aims to reducing Harmonic current. The results of the research reveal the Experimental Current harmonic without and with Simplex Optimization Algorithm. The Result showed that Experimental Current harmonic mean distortion without and with Simplex Optimization Algorithm were 0.263A and 0.1421A respectively. The Current harmonic distortion was decrease by 0.1209A, which is 29.84% decrease after the Simplex Optimization Algorithm is incorporated into the system.

Key words: Transformer, Harmonics, MATLAB, Optimization Algorithm

1. Introduction

The harmonic distortion is the change in the waveform of the voltage and current from the ideal sinusoidal waveform. It is caused by the wide use of non-linear loads that draw current in abrupt pulses rather than in a smooth sinusoidal manner. The flow of harmonic current has greatly increase worldwide due to the increase in loads on facility distribution systems which has generated different problems in the system. These problems include overheated transformers, motors, conductors, and neutral wires; nuisance breaker trips; voltage distortion, which can cause sensitive electronic equipment to malfunction or fail; and elevated neutral-to-ground voltage, which can cause local area networks to malfunction.

Harmonic distortion is common in all power systems. Basically, there is need to controll harmonics in order to protect the system from power quality problems. It is important to apply some method which can suppress, reduce, mitigate or reduce the harmonics by which power quality and system efficiency could improve. There are many options which can be used to mitigate harmonic distortion which including line reactors, harmonic traps, 12-pulse rectifiers, 18-pulse rectifiers, and low pass filters. Others solutions give genuine results and have no side effect on the power system, while the performance of some is greatly dependent on system conditions. Whenever non-linear loads are considerable part of the total load in the facility (more than 20%) there is a chance of harmonic problem. There are two main effects of harmonic currents on a distribution system[13].

Transformer is basic component of power system and designed to work on linear load. Harmonics produced by nonlinear load increases losses, heating, ageing of insulation, reduces capacity and results in premature failure of transformer. The increase of harmonic mitigation techniques are now essential including active and passive methods, and the arrangement of the best technique for a particular problem can be a complicated method process. The system is greatly dependent on the performance of some of these techniques, while others apply extensive system analysis to prevent capacitor failure and resonance problems.

In Power distribution system, distribution transformer is most important apparatus. It is designed to operate on power frequency with linear load. Due to the increasing amount of electronic devices used today which have non sinusoidal power supplies, distribution transformers are being subjected to excessive internal heating. Current waveforms from non-linear loads appear distorted; the non-linear waveform is the result of adding harmonic components to the fundamental current. The distorted current waveform produces additional heating in the transformer core and coils. This heat, along with the normal heat from the transformer under load, leads to insulation damage and reduction in transformer lifespan. The characteristics of the electric loads have changed dramatically from linear to nonlinear with the proliferation of new solid state controlled devices and sensitive computer type equipment. The Electric Power Research Institute (EPRI) analyzed with rough estimation that in 1992, 15 to 20% of the total electric load utility was nonlinear and with expected to reach 50 to 70% in the year 2020. The increase in the load electric profile from a linear type to greatly nonlinear, has develops increase in power quality problems which makes it difficult to detect the failure. Power quality is defined as any problem manifested in voltage, current or frequency deviation which results in failure or malfunction of customer equipment [14]. A major power quality concern is harmonics distortion which is caused by non-linearity of customers loads [6].

Harmonics are currents or voltage with frequencies that are integer multiples of fundamental power frequency. Nonlinear loads draw current in high amplitude short pulses, which creates distortion in current and voltage wave shape which is measured in term of total harmonics distortion (THD) .Total harmonics distortion of current is the contribution of all the harmonic frequency currents to the fundamental. Harmonics generation causes additional heating in transformer components which results in higher losses, degradation to transformer insulation which decreases the useful life of transformer and premature failure of transformer. Harmonics distortion increases both no load and full load losses. Increase in eddy current losses causes rise in temperature of transformer which results in premature failure of transformer. Loads with highly distorted current waveforms have a very poor power factor and due to this, they use excessive power system capacity and causes overloading [13] .

2. Power Distribution Systems

The efficiency of electric power distribution systems has more importance in last decades. Distribution companies are aimed to supply more reliable, sustainable and high quality electrical energy to their consumers. The power quality and Distribution losses are the

most essential problems facing Electric Power Distribution Companies (EPDC). Many studies are presented in literature about power quality problems and distribution losses. Also, large projects are carried out especially at developing countries for reducing the distribution losses and to improve the power quality. One of the main subjects of power quality is harmonic components of current and voltage waveforms [2]. Harmonics leads to the increase of power quality disturbances and losses in distribution systems.

Harmonic components at power systems have increased due to the increase of nonlinear loads. Particularly the loads which are used in residential areas have nonlinear characteristics [14]. Therefore; investigations of harmonic impact on distribution systems is of a great importance. Electric power distribution system losses are classified into two groups: technical losses and non-technical losses [1], [10]. Technical losses occur due to energy transfer. The main sources of these can be described as line conductor losses and transformer no-load and load losses. The general causes of non-technical losses are electricity theft, metering problems, problems of billing and collection, loose due to connections, etc. [1], [4].

Technical experiences about the loss reduction projects carried out in Iran are given in [1]. Causes of losses and loss reduction methods are presented in this study. In another study which is realized for a Brazilian distribution company, distribution system is divided into eight segments and a methodology for calculating the technical losses is proposed [11]. A very useful study for distribution system loss minimization techniques is presented as a bibliographical survey in [8]. The accurate estimation of losses in distribution system is a significant subject for EPDC.

2.1 Review of Power Harmonic Reduction

Reference [8] shows the Usages of DC power instead of AC power on the secondary distribution system creates a lot of harmonics. The researcher eliminates the harmonics onto the system and due to the limited specification of filter it has not been possible to reduce all the harmonics in the secondary distribution system. If this trend continues, the impact of harmonics on customer end will reach a level which might be detrimental and redundant to both loads and grid.

Reference [3] develop a comprehensive literature review of techniques for harmonic related power quality improvement of electrical generation systems. The greatly increase in interest of power quality is due to the ever more stringent power quality requirements, generated from new grid codes and compliancy standards, aimed at limiting waveform harmonic distortion at all points of the distribution network.

Reference [9] analyzed the effects of harmonics in a power system and to minimize the effects of the power system harmonics. This harmonic distortion will produce a low power quality and also improved disturbances in power system. Therefore this harmonic technique is used to improve the power quality.

References [5] develop distribution systems which is used in commercial and industrial installations and therefore power systems harmonics is an area that merits a great deal of attention. Advancement in semiconductor devices has fuelled an increase in the use of non-linear loads which are the main causes of harmonic distortion in three-phase, four-wire distribution systems. Integration of harmonics in three-phase, four-wire electrical power distribution systems that generate balanced and unbalanced non-linear loads was therefore conducted. The researcher proposes an approach to compensate for harmonics in a three-phase four-wire power distribution system. The principle is illustrated, and some interesting filtering characteristics are discussed.

Reference [7] analyzed Power consumption of harmonic drawing loads is an increasing concern for cost conscious facility managers and engineers. The researcher show that up to

8% kW reduction can be generated by eliminating harmonic current at various points in a power distribution system, with the greatest benefits achieved with harmonic integration applied at the point of use.

Reference [12] develop the existing network technologies, LVDC system is one of the emanating technology renovations for Smart Grid application to the distribution of electricity and a highly interesting challenge. The salient purposes beyond this development of the LVDC network is to improve the power quality and increase security experienced by the end users of the electricity for ameliorating the distribution economy.

3. Materials and Method

Harmonic power distortion Experiment was carried out on the 500KVA substation controlling engineering block of the University of Abuja. The experimental measurement was conducted for two (2) weeks from 8am to 5pm everyday in order to analyze the harmonic distortion of the university Transformer. The instrument used to measure the parametric data of harmonic current is power harmonic analyzer (Fluke 123/124). The simulation was performed using **MATLAB 2007 SOFTWARE** in order to reduce harmonics on 500KVA distribution transformer of the Engineering block.

Table3.1 TRANSFORMER PARAMETERS

Rated Power	500KVA
Primary Voltage(High Voltage)	11KV
Secondary Voltage(Low voltage)	415V
Load Losses	1600W
HV Current	695.6A
LV Current	26.24A
LV Winding Resistance	0.0443Ω
HV Winding Resistance	179.415Ω

Table3.2 THE DATA OF 500KVA TRANSFORMER HARMONICS DISTORTION OF ABUJA UNIVERSITY

HARMONICS(h)	HARMONIC CURRENT(I _h)
1	95.2
3	21.68
5	15.29
7	8.76
9	5.02
11	3.126
13	2.456
15	1.346
17	0.968
19	0.512
23	0.263

3.1 Mathematical modeling

When a transformer is utilized under non-sinusoidal voltages and currents, due to loss increase results, increase of temperature, and its rated power must decrease. The maximum permissible current of transformer in harmonic load must be determined as its loss would be equal to the loss in hot spot and under sinusoidal current condition.

$$P_T = P_{NL} + P_{LL} \quad (1)$$

Where P_T = Total Power Loss(watt)

P_{NL} = Load Power Loss (watt)

P_{LL} = Rated Load Loss

$$P_{LL} = P_{i^2R} + P_{EC} + P_{OSL} \quad (2)$$

P_{i^2R} is winding Loss

P_{EC} = Eddy current Loss

P_{OSL} = other stray loss

The rated losses of a transformer can be calculated from the experimental data performed.

$$I_{1-Rated} = \frac{P(KVA)}{\sqrt{3}V_1} \quad (3)$$

$$I_{2-Rated} = \frac{P(KVA)}{\sqrt{3}V_2} \quad (4)$$

Hence the I^2R Losses can be formulated:

$$P_{I^2R-Rated} = K(I_{1-Rated}^2 R_1 + I_{2-Rated}^2 R_2) \quad (5)$$

Where $K=1.5$ for three phase transformer

$$P_{LL-Rated} = P_{i^2R} + P_{TSL} \quad (6)$$

I_1 = Current of Primary side of Transformer

I_2 = Current of Secondary side of Transformer

R_1 = Primary DC Resistance

R_2 = Secondary DC Resistance

P_{TSL} = Total Stray Loss

Harmonic Loss is expressed as:

$$P_h = 3I_{h(1)}^2 R_{h(1)} + 3I_{h(2)}^2 R_{h(2)} \quad (7)$$

The total transformer Losses is:

$$P_T = \sum_{h=1}^{h=h_{Max}} (3I_{h(1)}^2 R_{h(1)} + 3I_{h(2)}^2 R_{h(2)}) \quad (8)$$

Therefore the equation for non-Linear Loads is:

$$F_{HL} = \frac{\sum_{h=1}^{h_{max}} I_h^2 h^2}{\sum_{h=1}^{h_{max}} I_h^2} = \frac{\sum_{h=1}^{h_{max}} \left(\frac{I_h}{I_1} \right)^2 h^2}{\sum_{h=1}^{h_{max}} \left(\frac{I_h}{I_1} \right)^2} \quad (9)$$

$$F_{HL-STR} = \frac{\sum_{h=1}^{h_{max}} I_h^2 h^{0.8}}{\sum_{h=1}^{h_{max}} I_h^2} = \frac{\sum_{h=1}^{h_{max}} \left(\frac{I_h}{I_1} \right)^2 h^{0.8}}{\sum_{h=1}^{h_{max}} \left(\frac{I_h}{I_1} \right)^2} \quad (10)$$

F_{HL} is the harmonic loss factor for winding eddy current.

F_{HL-STR} is the other stray loss factor.

Therefore the total loss is $P_{LL-Rated} = I_R^2 R_{dc} + F_{HL} P_{EC-R} + F_{HL-STR} P_{OSL-R}$ (11)

$$P_{LL-Rated} = 1 + P_{EC-R} + P_{OSL} \quad (12)$$

Where 1 is per unit amount of DC losses

$$P_{LL-Rated} = I^2 (pu) \times (1 + F_{HL} P_{EC} + F_{HL-STR} P_{OSL-R}) \quad (13)$$

So, the maximum permissible Load Current to determine the capacity of reduction of transformer Harmonic is:

$$I_{Max}(pu) = \sqrt{\frac{P_{LL-Rated}}{1 + (F_{HL} P_{EC}) + (F_{HL-STR} P_{OSL-R})}} \quad (14)$$

The eddy current loss is increased by the factor F_{HL} and the other stray losses are increased by a factor F_{HL-STR} in the presence of Harmonics.

3.2 Optimization Model of Transformer Harmonics

The optimization algorithm implemented in this research paper, starts with the design of the objective function. The objective function design helps in removing transformer constrain and complexity in modeling from the experimental analysis. The objective function is design to minimize harmonics in Transformer. After the proper design of the objective function, the optimization algorithm starts by an arbitrary point from the objective and proceeds in a stepwise form towards the maxima or minima of the designated objective function by successive improvements. The simplex algorithm stops when the step towards the maxima or minima is smaller than a preset tolerance value determined from the data collected. The analysis was performed using **MATLAB** Optimization Program. This solution leads to optimize the controlled parameters for different operating conditions with a great advantage in avoiding running separate optimization procedures for each of the expected range of operating conditions and consequently saving time and resources.

Fig 3: Flow Chat of the Optimization

Maximize $Z = 1.02x + 0.01785y$
Subject to

$$1.02x + 0.01785y \leq 95.2$$

$$1.02x + 0.01785y \leq 21.6$$

Where

X and y are harmonic distortion

Z = total harmonic distortion

4. Discussion of Results

The result of Experimental analysis of 500KVA Transformer substation controlling engineering block of the University for Reduction of Harmonic distortion is demonstrated. The experimental measurement was conducted for two (2) weeks from 8am to 5pm every hour of the day of the two weeks in order to analyze the harmonic distortion of the university Transformer. The instrument used to measure the parametric data of harmonic current is power harmonic analyzer (Fluke 123/124).

Fig 3.1 shows an optimized harmonics distortion which has a total harmonics distortion Z = 21.7. The program indicate the reduction model for University 500KVA Transformer of Engineering Block.

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File Edit Text Go Cell Tools Debug Desktop Window Help
1 % Maximize = 1.02x + 0.01785y
2 % Subject to
3 % 1.02x + 0.01785 y <= 95.2
4 % 1.02x + 0.01785y <= 21.6
5 % Where
6 % X and y are harmonic distortion
7 % Z = total harmonic distortion
8
9 f = [-1.02; -0.01785];
10 A = [1.02 0.01785; 1.02 0.01785];
11 b = [95.2; 21.6];
12 Aeq = [0 0];
13 beq = [0];
14 LB = [0 0];
15 UB = [inf inf];
16 [X, FVAL, EXITFLAG] = linprog(f, A, b, Aeq, beq, LB, UB)
17 Optimization terminated.
18 X =
19     1.0e+003 *
20     0.0000
21     1.2169
22 FVAL =
23     -21.7217
24 EXITFLAG =
25     1
26

```

Fig 3.1 optimized harmonic distortion

Fig.3.2. Shows MATLAB Simulink model for reducing harmonics on distribution transformer using simplex optimization Algorithm. The Simulink shows the Experimental measurement and optimization Algorithm of 500KVA distribution Transformer in order to reduced harmonics distortion in the system.

Fig 3.3 shows conventional/Experimental harmonics of 500KVA distribution transformer. This shows that the highest coordination of harmonics current verses Time occurred at (95.2, 1) while its least occurred at (0.263, 22). This indicates that when the harmonic current increases the Time will reduce. With this results the transformer experience over current,

thereby causing power failure from the distribution transformer. Therefore the greater the Harmonics Current the lesser the Transformer Time of operation.

Fig 3.4 shows optimized current harmonic in the distribution transformer. The least harmonics current verses time coordinate occurred at (0.02327, 19). This shows that low power factor, over current is minimized as the harmonics current is reduced thereby minimizing power failure in the distributed transformer.

Fig 3.5 shows Comparing conventional current harmonics with optimized current harmonics. With these results, it shows that optimized method reduced harmonics than the conventional method. The result shows that there will be improve in power supply in optimized Algorithm than Experimental Approach. Therefore the results insinuate that Experimental Current harmonic mean distortion without and with Simplex Optimization Algorithm were 0.263A and 0.1421A respectively. The Current harmonic distortion was decrease by 0.1209A, which is 29.84% decrease after the Simplex Optimization Algorithm is incorporated into the system.

Fig 3.2 designed MATLAB Simulink model for reducing harmonics on distribution transformer using simplex optimization technique.

Table 4.1 Conventional current harmonics

CONVENTIONAL HARMONIC	CURRENT	TIME
95.2		1
21.68		3
15.29		5
8.29		7
5.02		9
3.126		11
2.456		13
1.346		15
0.968		17
0.512		19
0.263		23

Fig 3.3 Conventional current harmonics

Table 4.2 Optimized current harmonics

Optimized current harmonics	Time (s)
4.327	1
0.9855	3
0.695	5
0.3982	7
0.2282	9
0.1421	11
0.1116	13
0.06118	15
0.044	17
0.02327	19
0.1421	22

Fig 3.4 Optimized current harmonics

Table 4.4 Comparing conventional current harmonics with optimized current harmonics

CONVENTIONAL CURRENT HARMONIC	Optimized current harmonics	TIME
95.2	4.327	1
21.68	0.9855	3
15.29	0.695	5
8.29	0.3982	7
5.02	0.2282	9
3.126	0.1421	11
2.456	0.1116	13
1.346	0.06118	15
0.968	0.044	17
0.512	0.02327	19
0.263	0.1421	23

Fig 3.5 Comparing conventional current harmonics with optimized current harmonics

Conclusion

Harmonic current is a major factor in power quality and efficiency problems which causes nonlinear loads in the system. The experimental measurement was conducted for two (2) weeks from 8am to 5pm every hour of the day of the two weeks in order to analyze the harmonic distortion of the university Transformer. The instrument used to measure the parametric data of harmonic current is power harmonic analyzer (Fluke 123/124).

The current harmonic Transformer was analyzed and modeled from measured data. The experimental analysis was conducted using Fluke power quality analyzer to present the trend and harmonics unbalance on the Transformer. The meter measures for each phase current and voltage harmonics amplitude, phase angle and inter-harmonics in a step-wise manner of 1hours. The collated data was analyzed using simplex optimization Algorithm. This can be done by determining the Total harmonic mean distortion of current (THDi) from a given harmonic distortion data, optimizing the mean from a given distortion data, designing a Simulink model for reduction of harmonics on the distribution transformer using simplex optimization Algorithm. **MATLAB Software 2007** was used to carry out simulations to develop Simplex Optimization Algorithm model for university 500KVA Transformer with aims to reducing Harmonic current. The results of the research reveal the Experimental Current harmonic without and with Simplex Optimization Algorithm. The Result showed that Experimental Current harmonic mean distortion without and with Simplex Optimization Algorithm were 0.263A and 0.1421A respectively. The Current harmonic distortion was decrease by 0.1209A, which is 29.84% decrease after the Simplex Optimization Algorithm is incorporated into the system.

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