Reducing the effects of Power Harmonics on Distribution Transformers using Simplex Optimization Technique

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Authors’ contributions

This work was carried out in collaboration between both authors. Author NNB designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author NEA managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

There have been incessant power failures in our power network, which has arisen as a result of over current, over voltage, harmonic distortion caused by ripples to mention a few, This could be overcome by determining the harmonic mean from a given harmonic distortion data, optimizing the mean from a given distortion data, training the optimized result to minimize harmonic in power distribution transformer, designing a Simulink model for mitigating the resultant effect of harmonics which are the sinusoidal components of a complex wave, using simplex optimization technique. The optimization technique used is 69% better than the conventional method like proportional integral derivative (PID) in terms of minimizing harmonic in power transformer.

Keywords: Reduction of harmonics; distribution transformer; optimization.
1. INTRODUCTION

Formation of harmonics in power distribution systems, are caused by non-linear loads. This has become a problem to the quality of power supply to the consumers [1] for both customers and suppliers. The main concern is the power quality to end users where harmonics distortion is caused by Non-linearity of customers loads and eddy currents generated from machine windings, hence the need for power factor improvement and proper laminations using varnish [2]. The non-linearity of the consumer loads is contributing factor the production of harmonics in the supply network. The loads draw current in high magnitude with relatively short pulses, which causes distortion in current and voltage wave form; this noticeable in the proportion of the harmonics content in the circuit or total harmonics distortion (THD) [3]. A Power quality is referred to any problem affecting the quality of supplied voltage, current or Frequency deviation which can cause a failure or fault/malfunction of customer equipment [4] Power losses due to harmonics could add to operational costs and could create additional heating effect in power system components. When these effects are not prevented, the life expectancy of an electrical equipment will be reduced. This is commonly seen in commercial apartments or buildings, where the use of nonlinear loads is high. Generally speaking, the cost of power quality and in costs due to harmonic losses in power transformers will rise since unwanted wave forms affect all power system components or equipment [5] Transformers that have operated adequately for a long time have failed due lack of good maintenance culture [6].

2. EFFECTS OF POWER HARMONICS

Power harmonics have undesirable consequences on distribution transformers and have done more harm than good in power industry and to the consumers in particular. Harmonics could be produced in the output wave form of a distribution transformer and ac generator due to the non-sinusoidal airgap flux distribution [7].

Synchronous generators are designed to produce a sine wave, when you have an integral part of the fundamental frequency at the output, then a problem in voltage quality has occurred. The unwanted integral components of the desired wave form are usually caused by the inductive effect of windings embedded in slots of the iron forming the magnetic circuit. The nature of the loads is one of the factors causing the unwanted waveforms (Even Harmonics). A situation where saturation occurs in iron core coils, harmonics are produced easily. Harmonics occur in a three-phase system just like the single-phase system, although even harmonics are not commonly found in the output wave form. Odd harmonics may be present but it is the triplens, and particularly the third harmonics which have similar properties in the three-phase system. Power system engineers are concerned with the effect of harmonics. Modern designs are built with filters to reduce the effect; Harmonics could be analysed using superposition method otherwise called Wedmore’s Method. This method is useful when you are analyzing third harmonic content.it could be extended to fifth and even higher harmonics.

Some renowned authors have used many methods to put to an end the causes of harmonics in distribution transformer [8] used static var compensator in power system harmonics [9]. Used harmonic identification and tracking method using Kaman filter. These authors could only minimize harmonic at about 57% thereby causing intermittent power supply or black out.

This mishap has arisen because they did not incorporate an intelligent agent in their work. It is suggested that, transformers supplying nonlinear loads should be designed to have a lower rating based on the harmonics contents in the output. Eddy current should be reduced using laminations. Alternatively, the use of K-Factor Transformers is desired. The effect of the integral parts of the fundamental frequency (harmonics) has become a concern for power system engineers [10]. Harmonics do increase the amount of eddy currents produced in the windings of transformers thus, causing higher operating temperature for the distribution transformer. We know that eddy currents are directly proportional to the square of the current flowing in the conductor, hence the need for proper laminations of the windings [11]. This paper addresses the nature and effects of harmonics using data collected from the national grid power components.

3. METHODOLOGY

To determine the harmonic mean from a given harmonic distortion data.
This is the harmonic distortion data obtained from National Electric Power Authority of Nigeria (NEPA).

To find harmonic distortion 'x' experienced in a distribution network from a given data

To find $x_1 = \frac{30+39}{2} = \frac{69}{2} = 34.5$

$x_2 = \frac{40+49}{2} = \frac{89}{2} = 44.5$

$x_3 = \frac{50+59}{2} = \frac{109}{2} = 54.5$

$x_4 = \frac{60+69}{2} = \frac{129}{2} = 64.5$

$x_5 = \frac{70+79}{2} = \frac{149}{2} = 74.5$

$x_6 = \frac{80+89}{2} = \frac{169}{2} = 84.5$

$x_7 = \frac{90+99}{2} = \frac{189}{2} = 94.5$

To solve for $f/x$

$f/x_1 = \frac{2}{34.5} = 0.0580$

$f/x_2 = \frac{3}{44.5} = 0.0674$

$f/x_3 = \frac{11}{54.5} = 0.2018$

$f/x_4 = \frac{20}{64.5} = 0.3101$

$f/x_5 = \frac{32}{74.5} = 0.4295$

$f/x_6 = \frac{25}{84.5} = 0.2959$

$f/x_7 = \frac{7}{94.5} = 0.0741$

To calculate the harmonic distortion mean = Total f/Total f/x

3.1 To optimize the Mean from a Given Distortion Data

Then use simplex method to solve the mathematical model of equations 4, 5 and 6

$$z = 34.5x + 44.5y$$

$$2x + 3y \leq 34.5$$

$$3x + 7y \leq 44.5$$

Equate equation .7 to zero and remove all the constraints in equations 8 and 9 respectively by introducing slacks.

$$Z = 34.5x - 44.5y = 0$$

$$2x + 3y + S_1 = 34.5$$

$$3x + 7y + S_2 = 44.5$$

3.2 Transformer

Fig. 1 shows the optimized result of minimized harmonic in power transformer. After optimization the harmonic was reduce to 14.833. This reduces over current and low power factor thereby increasing stability in power distribution.

To train the optimized result to minimize harmonic in power distribution transformer.

Table 1. Showing data collected from NEPA

| Harmonics distortion (kW) | 30-39 | 40-49 | 50-59 | 60-69 | 70-79 | 80-89 | 90-99 |
|--------------------------|-------|-------|-------|-------|-------|-------|-------|
| Frequency (Hz)           | 2     | 3     | 11    | 20    | 32    | 25    | 7     |

Table 2. Solution

| Harmonic distortion (kW) | x     | F (Hz) | f/x   |
|--------------------------|-------|--------|-------|
| 30-39                    | 34.5  | 2      | 0.0580|
| 40-49                    | 44.5  | 3      | 0.0674|
| 50-59                    | 54.5  | 11     | 0.2018|
| 60-69                    | 64.5  | 20     | 0.3101|
| 70-79                    | 74.5  | 32     | 0.4295|
| 80-89                    | 84.5  | 25     | 0.2959|
| 90-99                    | 94.5  | 7      | 0.0741|
| Total                    | 100   | 1.4368 |

Table 3. Simulated data for optimized harmonic reduction

| Power (KW) | Time (S) |
|------------|----------|
| 0          | 1        |
| 1          | 2        |
| 2          | 3        |
| 3          | 4        |
| 4          | 5        |
| 5          | 6        |
| 6          | 7        |
| 7          | 8        |
| 8          | 9        |
| 9          | 10       |
To design a Simulink model for reducing the effect of harmonics on power transformers using simplex optimization technique.

### 4. RESULTS AND ANALYSIS

Fig. 1 shows optimized result of minimized harmonics in power distribution transformers from a given distortion data.

Fig. 2 shows trained optimized harmonics results using MATLAB.

Fig. 3 is the optimized, trained, validated and tested results.

Fig. 4 is the simulated model for reducing power harmonics on distribution transformers using simplex optimization method in Simulink.

Fig. 5 shows simulated plot for optimized power harmonics reduction.

Fig. 6 is a plot showing simulated data for un-optimized harmonic reduction while Fig. 7 is a comparison of optimized and un-optimized harmonics in power transformer.

#### 4.1 Analysis

Fig 1 is the optimized result of minimized harmonics in a distribution transformer. It could be seen, maximizing the objective function subject to the two constraints gave a reduced value of 14.33W which further reduces the over current and improved the overall power factor. The resultant effect is on power system stability of the distribution system.

In Fig. 2, the trained and optimized result from the harmonics distortion further reduces the harmonics in the distribution network.

In Fig. 3, there is a clear display of the optimized trained, validated and tested result of reduction of harmonics in the transformer where the curve decreases from 10^0 showing the performance to 10^-15 and remains at that value for 15 epochs.

Fig. 4 shows the simulated model for reduction of power harmonics on distribution transformer using simplex optimization technique. The result obtained shows that harmonics were reduced from 14.833kW to 3.7kW. Table 1 shows the simulate data for optimized harmonic reduction. While Fig. 5 displayed the simulate data where it could be seen that the result of optimized harmonics reduction has yielded a considerable reduction in overcurrent and overvoltage; consequently, a stable power supply.

### Table 4. Simulated data for optimized harmonic reduction

| Power (KW) | Time (S) |
|------------|----------|
| 0          | 1        |
| 20         | 2        |
| 13         | 3        |
| 15         | 4        |
| 14         | 5        |
| 14.33      | 6        |
| 14.33      | 7        |
| 14.33      | 8        |
| 14.33      | 9        |
| 14.33      | 10       |

### Table 5. Comparing optimized and unoptimized harmonic in power transformer

| P (un optimized) | P (optimized) | Time (S) |
|------------------|---------------|----------|
| 20               | 5             | 1        |
| 13               | 3.3           | 2        |
| 15               | 3.8           | 3        |
| 14               | 3.6           | 4        |
| 14.33            | 3.708         | 5        |
| 14.33            | 3.708         | 6        |
| 14.33            | 3.708         | 7        |
| 14.33            | 3.708         | 8        |
| 14.33            | 3.708         | 9        |
| 3.708            | 3.708         | 10       |
Fig. 1. Optimized result of minimized harmonics in power distribution

Fig. 2. Trained optimized harmonic result
Fig. 3. Optimized trained, validated and tested result

Fig. 4. Simulated model for reducing the effect of harmonics on power transformer using simplex optimization method

Fig. 6 is the simulated data for un-optimized harmonics reduction; it could be seen that at maximum power of 20kW the time in seconds was one second, then remains at a constant value of 14kW for six seconds (between 4 to 10 seconds).

Fig. 7 is a comparison of optimized and un-optimized harmonics distortion in power transformer where the un-optimized maximum power was 20kW and after optimization we achieved 5kW.
Fig. 5. Simulated data for optimized harmonic reduction

Fig. 6. Simulated data for unoptimized harmonic reduction

Fig. 7. Comparing optimized and un-optimized harmonic in power transformer
5. CONCLUSION

The instability of power supply has arisen as a result of so many factors, some of these factors are low power factor, short circuit, over current, over voltage, harmonic distortion to mention but a few. The latter is the primary concern of this paper. This instability of power supply as a result of harmonic distortion can be overcome by determining the harmonic mean from a given harmonic distortion data, optimizing the mean from a given distortion data, training the optimized result to minimize harmonic in distribution transformer and designing a Simulink model for reducing the effect of harmonics on power transformer using simplex optimization Technique.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. GT. Heydi electric power quality stars in circle publication; 2016.
2. Shah H. “Harmonics- A power quality problem”, Industry watch – Electrical and Electronics. 2005;38– 40.
3. Victor A. Ramos J. “Treating harmonics in electrical distribution systems”, Computer Power and Consulting; 1999.
4. Singh R, Singh A. Causes of failure of distribution transformers in India” in; 2010.
5. GS. Martin open system and harmonic distortion disturbance; 2017.
6. IEEE 519. Recommended practices and requirements for harmonic control in electrical power systems; 1992.
7. Morton. Higher electrical engineering 2nd edition; 1978.
8. Ariga Johnson distribution transformer; 2015.
9. Adly, Peter’s harmonic identification and tracking method using Kaman filter; 2016.
10. Sankaran C. Effects of Harmonics on Power Systems; 1999.
11. Elmoudi A. Evaluation of power system harmonic effects on transformers; 2005.

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