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Mitigating Harmonics by using K-transformer

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Abstract: Power quality (PQ) is a general term that is commonly used to refer to uninvited disturbances in the electricity supply. One of PQ problems is harmonics. Harmonic currents affect the efficiency and reliability of the electrical supply and may pose potential safety hazards. Mitigating harmonics in the power supply is essential for delivering a stable power supply and maintaining the efficiency of all devices in the system. The first objective of this project is to investigate the PQ problem of harmonics using a conventional transformer in a test case. Then, based on the investigated harmonic problem, design a K-transformer to mitigate the harmonic problem. To achieve this objective, the test case for the harmonics problem, and mitigation technique is designed in MATLAB. Based on the result, the K-transformer is only unable to eliminate harmonic distortion (HD) on the secondary side due to simulation setup limitations for certain parameters. As a result, we added a harmonic filter bank to the secondary side of the system to mitigate all harmonics. Overall, this project demonstrated that K-transformers are effective at eliminating PQ harmonics and extending the lifespan of the transformer when compared to the conventional transformer. In order to obtain the best result for this project, one recommendation for future work is to use the different tools of simulation to fulfil the parameters of the K-transformer.

Keywords: Power Quality, Harmonics, K-transformer, Test Case

1. Introduction

PQ is a significant challenge for utilities worldwide [1], [2]. HD is one of the PQ problems at the electrical equipment in the power system (PS). HD results from non-linear equipment's such as power converters, computers, variable speed drive and the increased usage of renewable resources [3]. Electronic devices are used to automate the current power system, which results in increased HD.

These harmonic currents decrease the performance and dependability of the electrical supply and may potentially pose safety issues. It is vital to minimize these harmonics in order to protect the equipment and save money on the electricity bill. There are several equipment's that can be used to mitigate the harmonic such as active, passive, hybrid filter and etc. [4]. In this study, the mitigation technique will be focused on K-transformer to minimize and eliminate the harmonics. This method

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advantages are to reduce iron or copper losses and increase efficiency. As a result, the non-linear overload will be delivered without causing significant voltage distortion, overheating or exceeding the transformer's rated capacity [5].

In this project, we want to investigate the PQ problem of harmonics in a test case with conventional transformer. Then, we will design the mitigation technique of K-transformer from the investigated harmonic problem. Lastly, we will use designed K-transformer to mitigate the harmonic problem. To achieve this objective, the test case for the steady-state, harmonics problem, and mitigation technique is designed in MATLAB software.

2. Methodology

2.1 Mitigation technique with K-transformer

Transformer with a K-rating was intended to withstand non-linear loads which conventional transformers are incapable of handling. The K-transformers are constructed of heavier gauge copper and have a double-sized neutral conductor. They have a larger magnetic to resistive ratio than conventional transformers, allowing them to withstand the heat produced by harmonic currents [6]. Figure 1 shows the flowchart of designing K-transformer.

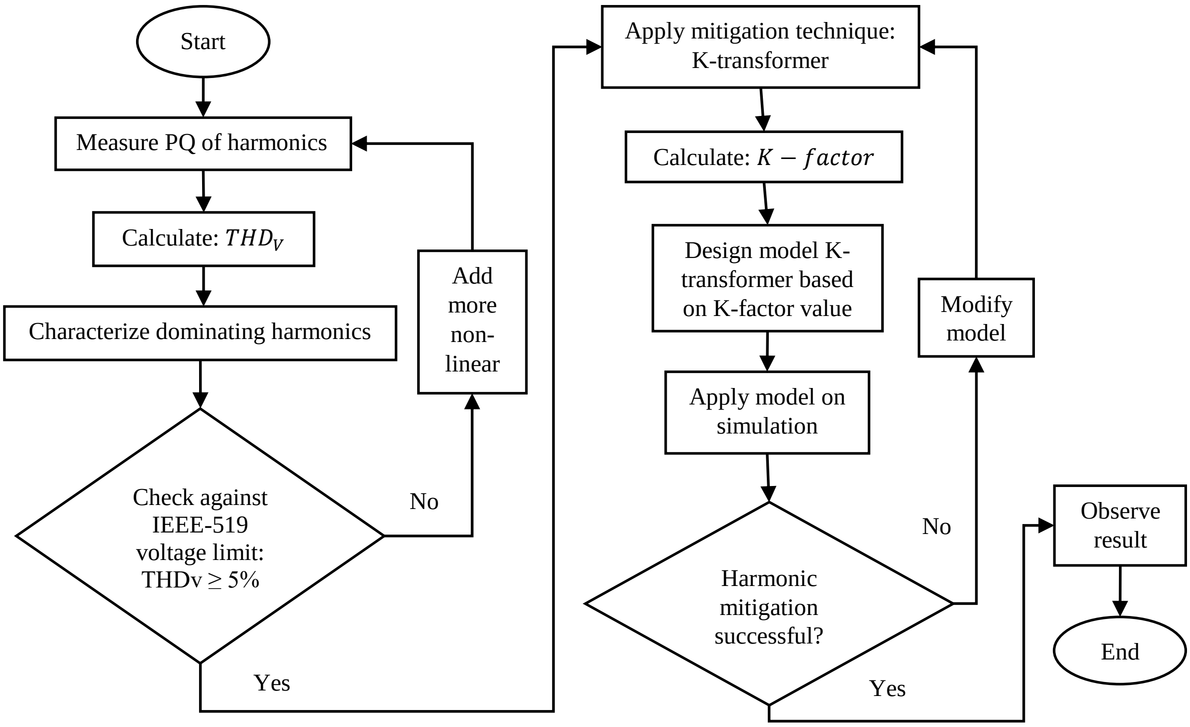


Figure 1: Flowchart of designing K-transformer

2.2 Mathematical Modelling for K-transformer

This is a procedure for determining the K-factor for the primary and secondary sides by using Eq. (1) [7]. This step is essential for ensuring that the final design fits all the required specifications. The reason is to first determine the K-factor. Subsequently, indicate a K-factor for the transformer that is equal to or greater than the estimated value. As a consequence, the transformer rating size can be increased without derating.

$$K - factor = \sum_{h=1}^{h=max} h^2 \left(\frac{I_h}{I_R}\right)^2 \quad (1)$$

Table 1 shows the result calculation K-factor for primary and secondary sides. Based on the result, the highest K-factor is 9.3929 on the secondary side. From the result, the K-transformer should use K-13 or above according to standard K-transformer rating.

Table 1: The K-factor value for primary and secondary sides

Side	K-factor
Primary	7.9939
Secondary	9.3929

2.3 Model Test Case

The arrangement of equipment set-up for the test case which was used in this project is shown in Figure 2 (conventional transformer) produces HD using nonlinear load and Figure 3 (K-transformer) mitigation technique to eliminate HD in the system. The primary source of the system was set up at 11 kV. A step-down transformer with a 250MVA rating and an 11kV/400V rating was used in the system. The nonlinear load used is the bridge rectifier, and phase-shifted by 30 degrees. DC current is increased from 1000A to 2000A at 0.1 seconds.

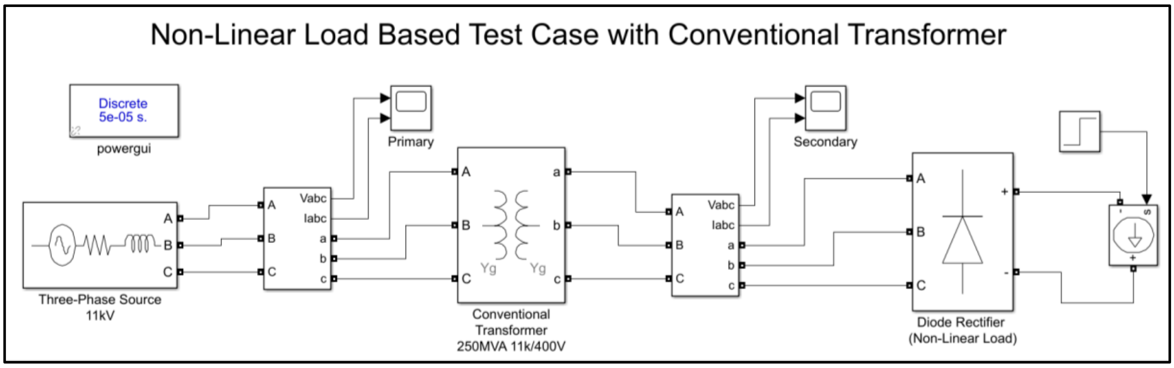


Figure 2: Test case with harmonics condition using conventional transformer

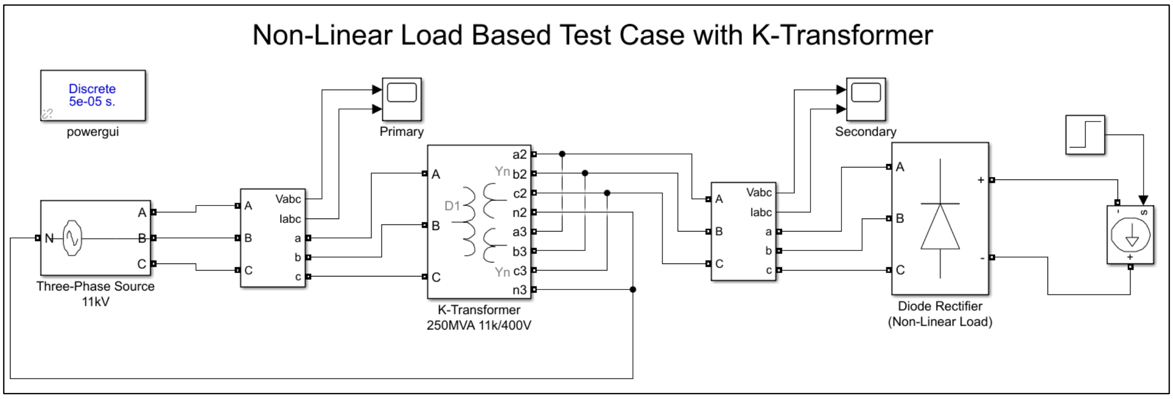


Figure 3: Test case with mitigation technique of K-transformer

Figure 4 shows the setup with the mitigation techniques of the K-transformer and harmonic filter bank. The reason for using a harmonic filter bank is that total harmonic distortion (THD) on the secondary current side cannot be eliminated because of a limitation in the simulation for K-transformer set up. So, the system has been added with a harmonic filter bank in parallel in order to mitigate the harmonics on the secondary side. It has also been added with a block to calculate P, Q, and PF for the system. Thus, it will simplify the process of calculating the PF.

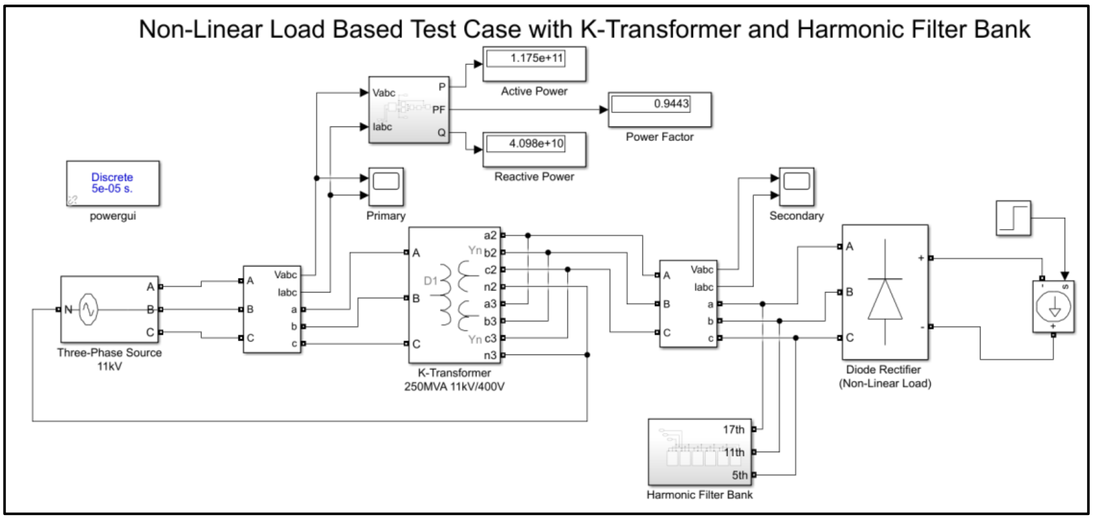


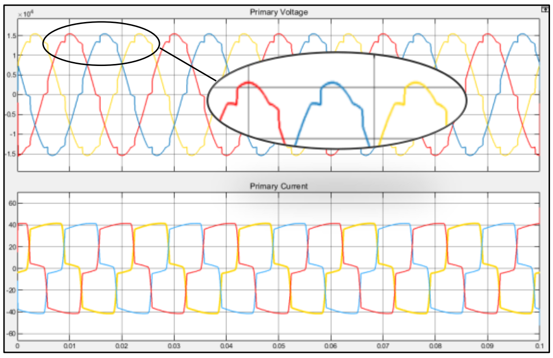
Figure 4: Test case with mitigation technique of K-transformer and harmonic filter bank

3. Results and Discussion

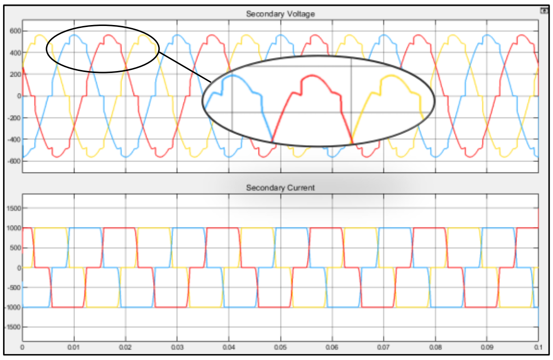
The result shows PQ problem conditions, where in the system shows the disturbance produced by nonlinear load. Mitigation techniques were applied to the test case to eliminate the harmonics. The test cases were simulated for 0.1 seconds.

3.1 PQ problem condition result

Figure 5 shows the output waveform of PQ problem condition result. HD is noticeable along 0°, 70°, 110°, 180°, 250°, 290°, and 360° of each cycle waveform in the voltage waveform. Primary side, harmonic distortion is lowered and differs from secondary is due to the star/star connection of the transformer.



a) Primary side

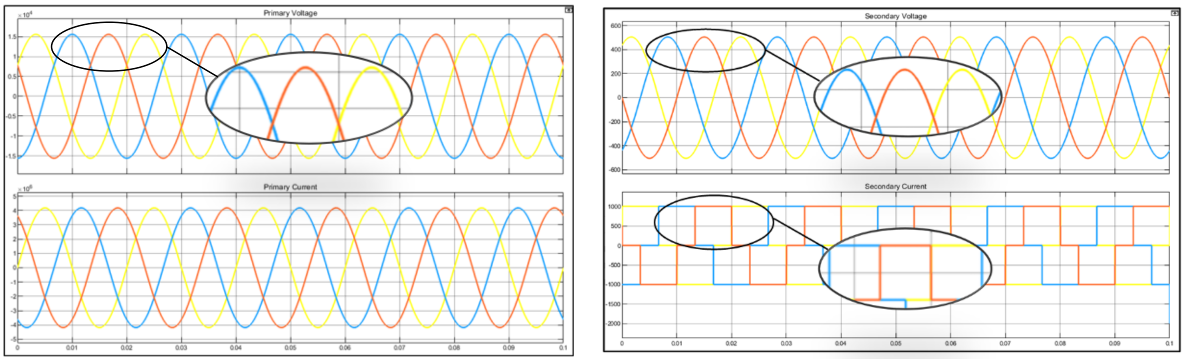


b) Secondary side

Figure 5: Result of voltage and current on the primary and secondary side of the transformer during PQ problem condition

3.2 Mitigation condition result with K-transformer

Figure 6 shows the output waveform of the mitigation condition with K-transformer. Primary, secondary voltage, and primary current have sinusoidal waveforms. This happens because, by lowering the set-up parameters for induction core flux density, it can avoid HD. Based on the results, the K-transformer is able to mitigate HD in the system, but due to the limit set-up of the K-transformer in the simulation, it cannot double the size of the neutral conductor. So, we cannot reduce the effect of third-order harmonics that gather in the neutral conductor. Due to that, secondary currents still have HD.

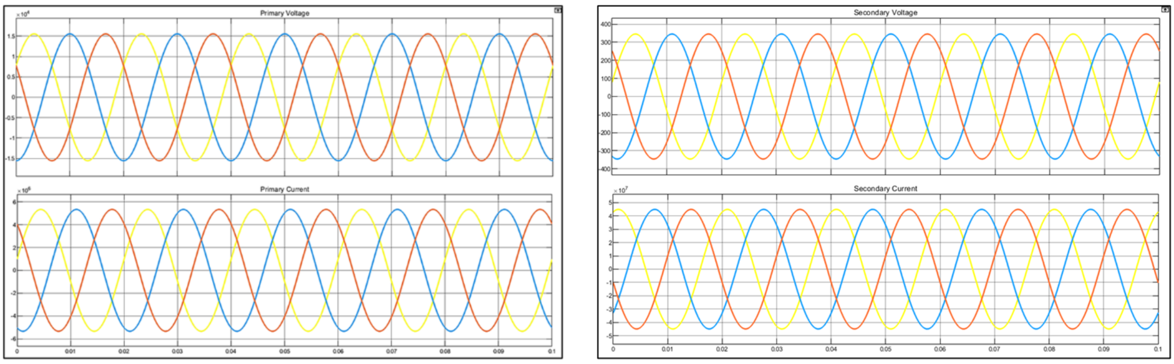


a) Primary side b) Secondary side

Figure 6: Result of voltage and current on the primary and secondary side of the transformer during mitigation condition with K-transformer

3.3 Mitigation condition result with K-transformer and harmonic filter bank

Figure 7 shows the output waveforms of mitigation condition result with K-transformer and harmonic filter bank. All the waveforms for primary and secondary have sinusoidal waveforms. Based on the results, the K-transformer and harmonic filter bank are able to mitigate HD in the system. The harmonic filter bank set-up parameter in this simulation is able to suppress harmonic currents on the secondary side.



a) Primary side b) Secondary side

Figure 7: Result of voltage and current on the primary and secondary side of the transformer during mitigation condition with K-transformer and harmonic filter bank

3.4 THD result for all test case conditions

Table 2 shows the THD result for all test case conditions. Based on the results, K-transformer can eliminate the HD from the system but are unable to eliminate HD on the secondary side due to limitations in the simulation of some parameters. After adding the harmonic filter bank on the secondary side, the HD on the secondary current can be removed from the system, and all THD does not exceed the IEEE 519 standard.

Table 2: THD result for all test case conditions

THD	Conventional Transformer	K-Transformer	K-transformer & harmonic filter bank
Primary Voltage	6.62 %	0.00 %	0.00 %
Primary Current	23.21 %	0.00 %	0.01 %
Secondary Voltage	7.65 %	0.00 %	0.04 %
Secondary Current	25.76 %	30.70 %	0.04 %

4. Conclusion

In this project, three test cases have been simulated to observe the result. The first test case uses a nonlinear load to produce the harmonics with the conventional transformer. In the second test case, we use a K-transformer to mitigate HD. As a result, the K-transformer is able to mitigate the HD at primary and secondary voltage and the THD does not exceed the IEEE 519 Std but is unable to eliminate HD on the secondary current side due to limitations in the simulation of some parameters. In order to eliminate harmonics on the secondary current side, the system has been applied with a harmonic filter bank in parallel to the system. As a result, compared before and after applying the filter, the THDi on the secondary side can be reduced from 30.70% to 0.04%. Therefore, this project is still not perfect and needs to be tried on other software that has no limitations in the parameters.

Acknowledgement

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