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Harmonics Reduction in Distribution Systems by Using Phase Shifting

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Abstract*— Since the invention of the first power grid in the early 1900s, the problems of harmonics that arise as a result of increasing nonlinear loads in the electrical grid have become of great interest. Since 1970, with the discovery and expansion of the use of power electronics in switching from AC to DC using DC motors as well as changing the speeds of AC motors, the high level of harmonics has become alarming for engineers and technicians in the field of electricity. In 1980, the use of non-linear loads and the increasing use of modern electronic devices with nonlinear loads increased with the effect of harmonics in the electrical grid. The expansion of the use of electronic speed changers in industrial processes as well as the use of computers in industry and control and the use of fluorescent lamps with electronic ballast in the lighting of commercial buildings all this led to increase the level of harmonics in the electrical network, which led to distortions in current and voltage waves. With increasing sources Harmonics in the electrical network The current and voltage currents have become more distorted and thus the diffraction in the quality of electrical power has become one of the biggest problems now, so the nonlinear loads change the characteristics of the electric waves and make them non-pure.

***Keywords*— Harmonics reduction, phase shift transformer, Zig-zag transformer.**

I. INTRODUCTION

Increased economic and industrial growth and increased energy demand have forced existing power supply, transmission and distribution institutions to seek appropriate solutions to ensure the quality of electrical recharge. And because of the rapid progress in the use of technology and the existence of modern equipment based on high frequencies. The aim is to improve the quality of electrical recharge by addressing the presence of harmonics in the electrical grid, which is an important indicator of the assessment of electric power.The conversion of the precious equipment in the electrical network shall be done in the air, ground or secondary stations. Therefore, attention to this equipment shall be equal to its importance. The interest in the transformer shall begin by choosing the best type with the ideal specifications and high quality through inspection of this equipment and conformity to the required technical specifications, Protected from high currents, high temperatures and unsuitable conditions that are designed to operate within their boundaries and carry out required maintenance.

II. PHASE SHIFT TRANSFORMER

One of the characteristic ways to reduce harmonies in the network is to make harmonics cancel each other (Harmonic cancellation) This idea was built on the basis of each of the value and angle (Magnitude and Angle) If we can combine harmonics so that the total trend is equal to zero in the case of Balanced Three Phases, we have prevented it from appearing without using filters and without worrying about the resonance phenomenon.This paper contains a Zig-Zag Transformer diagram, its function and the types of harmonics found in the electrical grid, and how to process and reduce these adaptations in the electrical distribution system to obtain a more stable electrical network using the phase shift transformer. [1][2]

III. MATHEMATICAL REPRESENTATION

The equivalent circuit to represent the phase shift is shown in fig"1" It is represented by an ideal transformer with an internal impedance of zero (Z = 0) and another transformer connected in series respectively with a conversion ratio of 1: 1 and an internal impedance of ($Z_T=R_T+_JX_T$). [1]

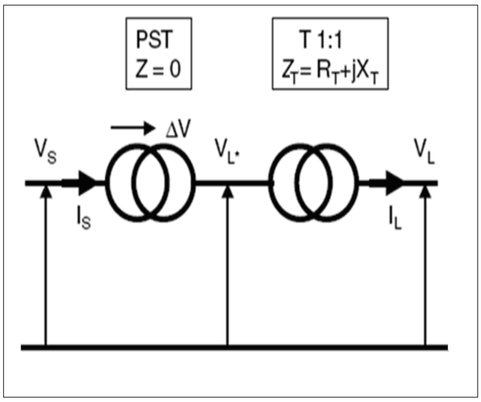

Fig.1 (equivalent circuit) [1]

The phase diagram of the equivalent circuit above is shown in fig.2. [1]

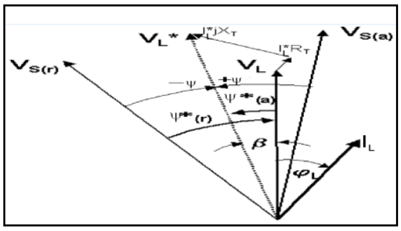

Fig.2 (phase diagram) [1]

Where:-

$V_{s(r)}$: Source voltage at delay at phase angle (-).
$V_{S\,(\alpha)}$: Source voltage at the phase angle (+).
I_L: Current load.

Z_T: Converted impedance bound, respectively, with the ideal transformer.

β : Load angle (impedance) for phase displacement.

Ψ (+, -) The angle of the phase shift when applying and delaying at the phase angle.

The distortion in the current and voltage wave and the reduction in the power factor caused by the nonlinear load and increase, especially in the current time in the field of industry, reflected on the quality of electric power and thus negatively affected the power plants and the electrical network in general. For example, if the load is not linear and the source is pocket, in this case the distortion will be distorted in the current of the current. Therefore, we will need to inject the harmonics into the system as shown in equation (1). [1]

$$P.F = \cos\emptyset * \frac{\mathrm{Im}}{\mathrm{I}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where:-

Im = Basic current.

I=Total current including harmonics current and base current.

Equation (1) that the (Im / I), which represents the distortion factor, decreases by increasing the harmonics. The more we want to improve the power factor, the distortion factor should be approximated from the 1 (distortion factor) The base and the base voltage, which is) and depends on the type of load. The process of making the current wave close to the sinusoidal waveform, as well as improving the power factor, contribute greatly to the improvement of the electrical power quality of the system. This is done by offsetting the need for nonlinear loads by removing the harmonics from the source with another source of compatibility. The process of connecting the winding of phase shift transformers can be illustrated by the fig.3 and fig.4. [3]

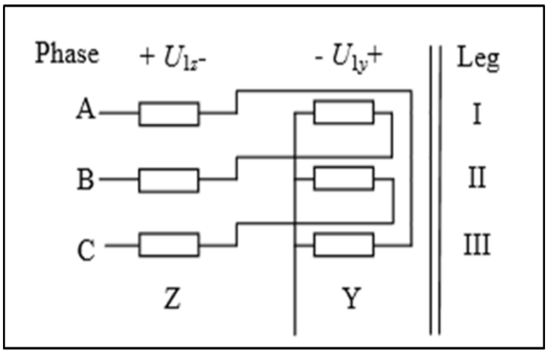

Fig.3 (Late binding of phase shift transformer) [3]

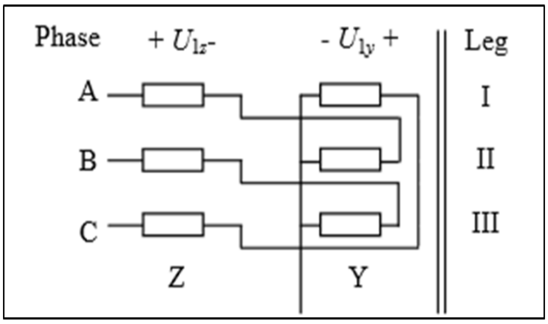

Fig.4 (Lag binding of phase shift transformer) [3]

Where:

V_{1Z}: Primary winding voltages.

V_{1y}: Secondary winding voltages.

Z: The primary winding of the transformer

Y: The secondary winding of the transformer.

In the case of lagging phase shift transformer as shown in Figure (3), the end of the primary phase (A) file is connect to the end of the secondary winding of phase (C) and the end of the phase (B) winding is connect to the end of the secondary phase (A) winding, While the end of the initial winding of the phase (C) is connected to the end of the secondary winding of phase (B). Finally, the secondary winding starts of the three phases together and thus we get the late link of the negative phase shift. If you want to obtain the advanced connection, the end of the primary winding of phase (A) is connected to the end of the secondary winding of phase (B) and the end of the phase (B) winding is connected to the end of the secondary winding of phase (C) with the end of the secondary winding of phase (A). Finally, the secondary winding starts for the three phases together as shown in fig.5. [3]

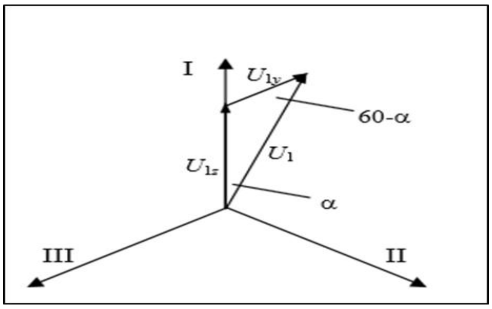

Fig.5 (calculation of phase shift angle) [3]

Where:

$n = | V_{1Y} / V_{1Z} | = \sin(\alpha) / \sin(60 - \alpha)$

V_{1Z}: Primary winding voltages.

V_{1y}: Secondary winding voltages.

α: phase shift angle.

n: the ratio between V_{1Z} & V_{1Y}

Phase shift transformers are divided into two types. [4][5]

1-**Direct phase shift transformer**: which depends on the three phase triple heart, in this type we can get the phase shift by connecting winding in a suitable manner.

2-**Indirect phase shift transformer**: which depends on two separate transformers. The first is a transformer connected directly to the transmission line and the second is a excitation transformer which injects a vertical voltage on the input voltage of the line.

The two previous types can be classified according to the method of obtaining the phase shift to:

Symmetric phase shift transformer in this type keeps the amount of voltages constant in the secondary part of the transformer.

Asymmetric phase shift transformer in this type of transformer The voltage of the secondary part of the transformer is variable.

One of the advantages of the phase shift transformer is that it is different from the star-delta coupling transformers.

Through phase shift, we can change the phase offset of the voltages even if the transformer is in the case of the load. Such as the star-delta transformer in which the phase shift is fixed at (30^O) between the input and output voltages of the transformer, and the hexagonal coupling, we can only change phase shift if the transformer in the case of the no load.

IV. METHOD OF CONNECTED THE ZIGZAG TRANSFORMER TO THE ELECTRICAL GRID

Connect the winding of zigzag transformer to the electrical grid in the form of parallel between the source and load and are usually close to the load side as shown in fig.6 [2]

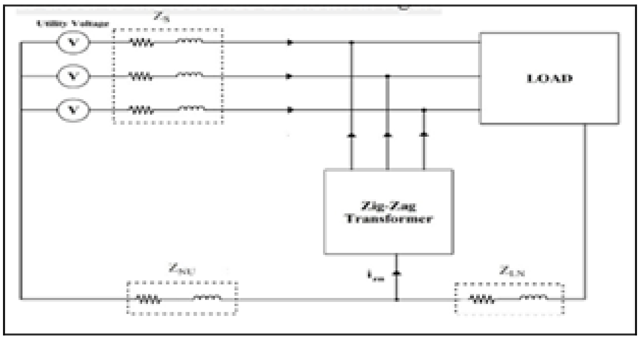

Fig.6 (Connect Zig-zag transformer) [2]

We can connect zigzag transformer by connect a three single phase transformer as showing in Fig. 7

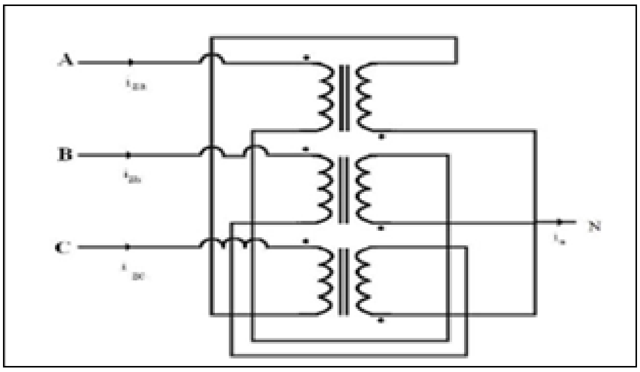

Fig. 7 (Connect the circuit of Zig-zag transformer) [2]

So that the zero sequence phase current of the three-phase transformer is the same magnitude and the same phase in the electrical distribution system. This can be explained by the following equations. [2]

$$i_{a0}(t) = i_{b0}(t) = i_{c0}(t) \ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$i_n(t) = 3\, i_{a0}(t) \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where the current of equalization is equal to the sum of the zero sequence current of the three phases and the current inside the primary part is equal to the current in the secondary part because the conversion rate of this type of transformer is 1: 1 which does not increase or decrease the voltage and current, And so we get the. [2]

$$i_{za}(t) = i_{zb}(t) \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$i_{zb}(t) = i_{zc}(t) \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$i_{zc}(t) = i_{za}(t) \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Through the equations above, it is clear to us that the current of the three phases current through the three winding of the transformer must be equal. Thus, the zero transient currents of the current of the load will flow in the transformation of the zigzag. **[2]**

V. MATLAB/SIMULINK SIMULATION MODEL

This part contains the effect of phase shift transformer to enhance the stability of the electric power system and reduce the compatibility of nonlinear loads using the Matlab program. The phase angles (90º, 60º, 45º, 30º) were used to compare the results obtained (IEEE model), which contains two power generators and four linear loads. The base value of the power (100 MVA), and fig .8 illustrates the IEEE 5-General System.

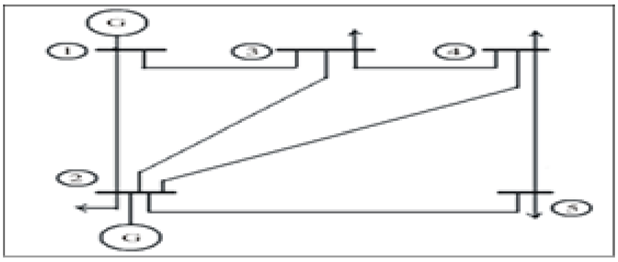

Fig.8 (5 Buses system IEEE)

Simulation Simulink of the phase shift transformer to the electrical grid.

Table 1. (Zig-zag transformer at α = 15º)

With Using Zig-Zag Transformer α = 15º					
Current			Voltage		
Scope	Fund.	THD	Scope	Fund.	THD
Source	79.52	29.19 %	Source	9830	1.88 %
Load 1	14.39	30.41 %	Load 1	9585	14.11 %
Load 2	1.773	42.15 %	Load 2	9646	21.72 %
Load 3	34.62	24.49 %	Load 3	9702	24.27 %
Load 4	17.42	30.61 %	Load 4	9093	5.23 %
Line 6	28.09	10.11 %	Line 6	9646	21.72 %

Table 2. (zig-zag transformer at α = 45º)

With Using Zig-Zag Transformer α = 45º					
Current			Voltage		
Scope	Fund.	THD	Scope	Fund.	THD
Source	364.4	6.19 %	Source	9421	1.95 %
Load 1	13.8	30.28 %	Load 1	9037	14.83 %
Load 2	1.696	40.43 %	Load 2	9114	20.46 %
Load 3	33.46	27.31%	Load 3	9204	21.02 %
Load 4	17.1	30.46 %	Load 4	8877	3.17 %
Line 6	75.08	6.30 %	Line 6	9114	20.46 %

Table 3. (Zig-zag transformer at α = 30º)

With Using Zig-Zag Transformer α = 30º					
Current			Voltage		
Scope	Fund.	THD	Scope	Fund.	THD
Source	223.4	10.89 %	Source	9501	2.04 %
Load 1	14.19	29.7 %	Load 1	9382	15.32 %
Load 2	1.741	42.12 %	Load 2	9451	21.34 %
Load 3	34.56	28.29 %	Load 3	9522	22.25 %
Load 4	17.36	30.29 %	Load 4	9005	5.34 %
Line 6	51.89	7.77 %	Line 6	9451	21.34 %

Table 4. (Zig-zag transformer at α = 90°)

With Using Zig-Zag Transformer α = 90°					
Current			Voltage		
Scope	Fund.	THD	Scope	Fund.	THD
Source	743.2	2.12 %	Source	8936	1.36 %
Load 1	11.2	30.75 %	Load 1	7113	13.27 %
Load 2	1.412	26.8 %	Load 2	7317	17.93 %
Load 3	27.61	25.38 %	Load 3	7565	18.2 %
Load 4	16.11	30.78 %	Load 4	8342	5.41 %
Line 6	136.3	2.32 %	Line 6	7317	17.93 %

Table 5. (Without Using Zig-Zag Transformer)

Without Using Zig-Zag Transformer					
Current			Voltage		
Scope	Fund.	THD	Scope	Fund.	THD
Source	74.03	30.83 %	Source	9523	1.49 %
Load 1	14.59	30.74 %	Load 1	9613	13.62 %
Load 2	1.798	40.70 %	Load 2	9684	21.78 %
Load 3	34.58	19.97 %	Load 3	9741	24.73 %
Load 4	17.51	30.26 %	Load 4	9137	6.42 %
Line 6	7.674	50.81 %	Line 6	9684	21.78 %

Table 6. (with using Y-Δ transformer)

With Using Y-Δ Transformer					
Current			Voltage		
Scope	Fund.	THD	Scope	Fund.	THD
Source	359.5	5.81 %	Source	9306	1.8 %
Load 1	14.12	31.17 %	Load 1	9149	13.49 %
Load 2	1.801	28.95 %	Load 2	9287	21.13 %
Load 3	33.49	22.29 %	Load 3	9392	23.53 %
Load 4	17.47	29.98 %	Load 4	9080	3.96 %
Line 6	47.54	14.44 %	Line 6	9287	21.13 %

Note from Tables above that in the case of the angle 90°, it was observed that the harmonics were processed in the current and voltages, where the total harmonic distortion (THD) decreased to 1.36% for the voltage and 2.12% for the current While the total harmonic distortion (THD) when not using phase shift is 1.49% for voltages and 30.83% for current, the table 7. shows the comparison of the coupling results in the case of angles (90°, 45°, 30°, 15°) and between the use of transformer Delta- Star.

Table. 7 (Comparison of the ratio of harmonics in cases of connecting transformers).

With Using Zig-Zag Transformer					Without using zig-zag transf.	
Harm. Ord.	α=15°	α=30°	α=45°	α=90°	Y-Δ	Normal Transf.
Harm. fund..	100%	100%	100%	100%	100%	100 %
H 3	0.02	0.01	0.01	0.00	0.03	0.1
H 5	28.8	10.52	5.97	2.06	0.01	30.63
H 7	2.65	2.29	1.33	0.48	5.62	2.44
H 9	0.14	0.01	0.02	0.01	0.88	0.18
H 11	2.39	0.80	0.34	0.08	0.04	1.77
H 13	1.67	1.25	0.86	0.03	0.14	0.6
H 15	0.05	0.01	0.00	0.00	1.05	0.06

From table. 7, When connecting at 90 ° we notice the third harmonic removal that is present at a certain rate when connected to angles (15°, 30°, 45°). The higher-level harmonics show less value than shown when connected using other angles, making the 90° angle the best result THD and make it within the permissible deformation value.

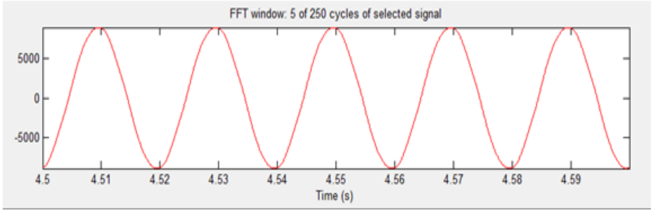

Fig. 9 (Voltage wave at α=90°)

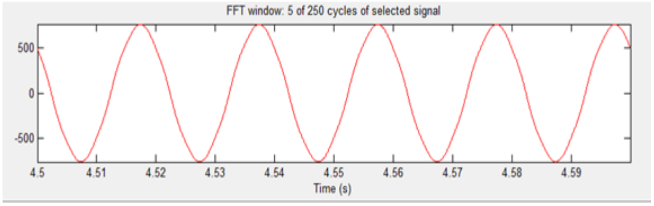

Fig. 10 (Current wave at α = 90°)

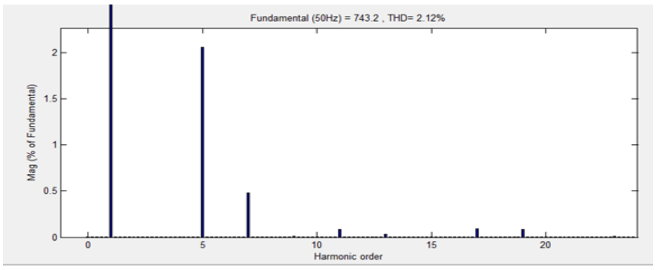

Fig. 11 (THD at α = 90°)

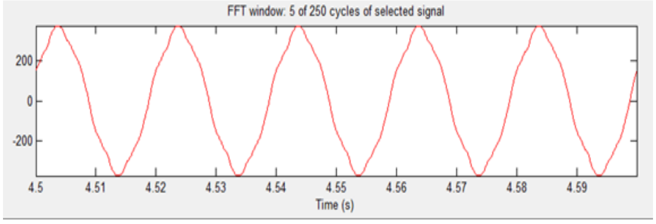

Fig. 12 (Current wave with usingY-Δ transformer)

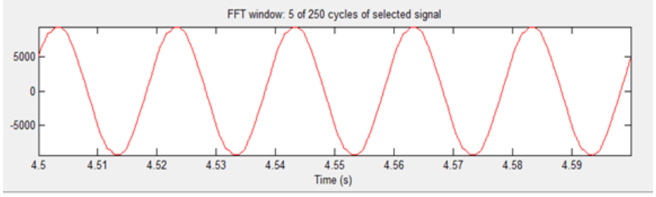

Fig. 13 (Voltage wave with using Y-Δ transformer)

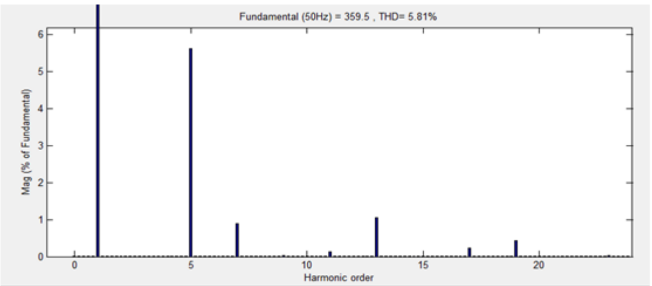

Fig. 14 (THD with using Y-Δtransformer)

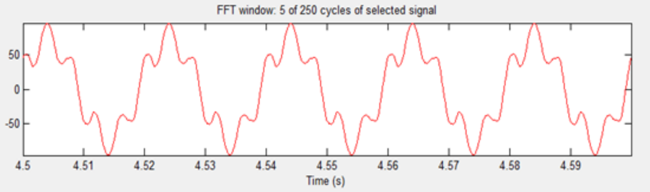

Fig. 15 (Current wave without using zig-zag transformer)

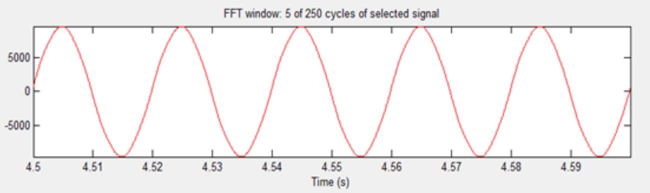

Fig. 16 (Voltage wave without using zig-zag transformer)

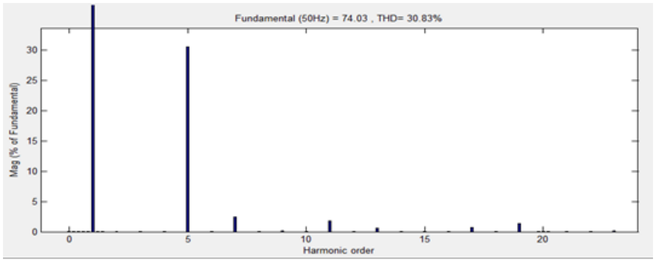

Fig. 17 (THD without using zig-zag transformer)

Harmonic currents can be reduced by using phase shift techniques, and low impedance plays a critical role in reducing voltage distortion. New low-phase transformers resistance have been designed to allow for the processing of harmonic currents while providing a low impedance path. Moreover, these transformers are designed to withstand the excessive heat generated by the harmonic currents, and are therefore manufactured to significantly improve the quality and reliability of the electrical system by using one piece of equipment.When using a delta type transformer at the primary end and using the zigzag winding type transformer at the secondary end, the electromagnetic effect of the secondary coil with a zigzag connection leads to the deactivation of harmonics 3, 9 and 15.Case studies show that phase shift transformer works as promoted, can significantly reduce harmonics, and improves overall power factor. But its ability to control the harmonics depends on how well individual loads are matched with the transformer.The best way to eliminate harmonics is to use phase shift technology, which involves the separation of the load-supply voltage into several stages of output; each phase is displaced at a suitable angle from the other phase of the harmonics phase.

VI. CONCLUSION AND FUTURE ENHANCEMENT

Improving the efficiency and rationalization of electricity is the most important option at present, as it is seen as an alternative to the production of this energy. In most cases, if not all, it is less expensive for the economy than setting up new power plants. In the course of the research, it is possible to improve the efficiency of electrical energy consumed in industrial plants by applying some possible procedures. The results of this study showed that the standards of this quality can be raised by the use of phase shift transformers to reduce harmonics. The future enhancement adding the filter with zig-zag transformer, and using several zig-zag transformers.

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