

**HARMONIC MITIGATION FOR POWER QUALITY IMPROVEMNT BY
DESINING PHASE-SHIFTING TRANSFORMERS FOR NON-LINEAR
LOADS**Poonam N. Parmar¹, Dr. Chirag K. Vibhakar², Rima M. Pujara³*Assistant Professor, Electrical engineering department, GTU/V.V.P. Engineering College**Professor, Electrical engineering department, GTU/V.V.P. Engineering College**Assistant Professor, Electrical engineering department, GTU/V.V.P. Engineering College*

Abstract—Electricity supply should invariably show a perfectly sinusoidal voltage signal at every customer location. Due to number of reasons, utilities often find it hard to preserve such desirable conditions. The deviation of the voltage and current waveforms from sinusoidal is described in terms of the waveform distortion, often expressed as harmonic distortion which degrades the power quality. Harmonic mitigation techniques are available for harmonic problems in three phase power systems. Users of adjustable speed drives (ASD) and other three phase (rectified) non-linear loads have many choices available when it comes to harmonic mitigation. In the consideration of various alternatives, much depends on the user's objectives as well as the severity of harmonics contributed by internal loads. As the even harmonics are generally cancelled out due to symmetry of waveform of quantity but odd harmonics are present in the system, where lower order harmonics have worse effect. Number of methods is available for mitigation of harmonics which are explained here. Main concentration of the paper is on mitigation of harmonics by designing different PST(phase shifting transformer).PST extensively used for improving power quality to reduce harmonics in AC mains. As rectifier widely used in industry and it is also the non linear load. So PST is also used to reduce THD for any non linear loads of the system.

The Phase Shifting Transformer (PST) is essential gradient that provides desired phase shift in supply voltage by different connections like star, delta, polygon and zigzag. The level of harmonic currents may be reduced by using phase-shifting techniques and low impedance plays a crucial role in reducing voltage distortion. These topologies can be found in aircraft power systems, motor drives, Dc Arc furnace and other applications that require low total harmonic distortion of the input line current.

The quality and reliability of the electrical system can be considerably improved through the use of PST

Keywords—Phase Shifting Transformer (PST), THD, Power quality, Harmonic distortion, Polygon winding

I. INTRODUCTION

The major problem in power sector is that a need a treatment of quality up gradation is termed as power quality event. Power quality provides the solution of all these problems in a very efficient and optimized way. These problems, if not mitigated would cause heavy economics as well as technical disturbances. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment [1].” Voltage dip and swells, voltage unbalance, flicker and harmonics are degrading the power quality..

Over a last few years the use of electronic devices, microprocessor based equipments, variable frequency drives, AC/DC converter is increased, which are non linear loads. A nonlinear load draws distorted (non-sinusoidal) current from the supply, which distorted current passes through all of the impedance between the load and power source. The associated harmonic currents passing through the system impedance because voltage drops for each harmonic frequency based on Ohm's Law.

The most used nonlinear device is perhaps the static power converter so widely used in industrial applications in the steel, paper, and textile industries. Other applications include multipurpose motor speed control, electrical transportation systems, and electro domestic appliances.

New low impedance phase-shifting transformers have been designed to allow the treatment of harmonic currents while providing a path of low impedance. Moreover, these transformers have been designed to withstand the additional overheating caused by harmonic currents and therefore are K-rated.

II. Negative effects of harmonics

a) Capacitors are installed in industrial plants and commercial buildings. Fluorescent lighting used in these facilities also normally has capacitors fitted to improve the light fittings own power factor. The harmonic currents can interact

with these capacitances and system inductances, and occasionally excite parallel resonance which can over heat, dis rupt and/or damage the plant and equipment.

b) "EMI noise" has an adverse effect on telephones, televisions, radios, computers, control systems and other types of equipment. Power cables carrying harmonic currents act to produce EMI (electromagnetic interference) in signal or control cables via conducted and radiated emissions.

c) Any telemetry, protection or other equipment which relies on conventional measurement techniques or the heating effect of current will not operate correctly in the presence of nonlinear loads. The consequences of under measure can be significant; overloaded cables may go undetected with the risk of catching fire. Busbars and cables may prematurely age. Fuses and circuit breakers will not offer the expected level of protection. It is therefore important that only instruments based on true rms techniques be used on power systems supplying nonlinear loads.

d) At the installations where power conductors carrying nonlinear loads and internal telephone signal cable are run in parallel, it is likely that voltages will be induced in the telephone cables. The frequency range, 450 Hz to 1000 Hz (9th harmonic to 20th harmonic at 50 Hz fundamental) can be troublesome.

e) There is also the possibility of both conducted and radiated interference above normal harmonic frequencies with telephone systems and other equipment due to variable speed drives and other nonlinear loads, especially at high carrier frequencies. EMI filters at the inputs may have to be installed on drives and other equipment to minimize the possibility of inference.

f) Conventional meters are normally designed to read sinusoidal-based quantities. Nonlinear voltages and currents impressed on these types of meters introduce errors into the measurement circuits which result in false readings.

III. Evaluation of System Harmonics

In order to prevent or correct harmonic problems that could occur within an industrial facility, an evaluation of system harmonics should be performed if: n A plant is expanded and significant non-linear loads are added n A power factor correction capacitor banks or a line harmonic filters are added at the service entrance or in the vicinity. A generator is added in the plant as an alternate stand-by power source. The utility company imposes more restrictive harmonic injection limits to the plant. Often, the vendor or supplier of non-linear load equipment, such as variable frequency drives, evaluates the effects that the equipment may have on the distribution system. This usually involves details related to the distribution system design and impedances, similar to performing a short circuit study evaluation. [2]

IV. POWER QUALITY STANDARD FOR CONVERTER

1. IEEE STANDARD IEEE-519

- Often, Established in 1981 as the "recommended practice and requirements for harmonic control in electrical power system"
- This standard limits harmonics distortion at PCC. Recognizing that voltage distortion results from currents and it also gives limits on harmonics injected by customers. Limit for current is 5 % to 20 % of total demand distortion (TDD)

2. IEC 61000

- The equipments are categorized in four groups
- CLASS- A, B, C AND D, are categorized for the purpose of harmonic current limitation

V. HARMONIC MITIGATION BY PST TECHNIQUES

PST has many numbers of secondary but the main objective of PST is to improve power quality at input ac mains by cancelling the harmonics. The main drawbacks of conventional ac-dc converters have been harmonic injection into ac mains which results in poor power factor, poor utilization of distribution system, EMI, RFI. Similarly ripples in dc output voltage a cause derating of loading equipment etc. PST is also used for Multipulse converter and it is quite effective to improve power quality at ac mains and output dc loads [3].

VI. Remedies to Reduce Harmonic Problems

(1) Over sizing Neutral Conductors

- In three phase circuits with shared neutrals, it is common to oversize the neutral conductor up to 200% when the load served consists of non-linear loads. For example, most manufacturers of system furniture provide a 10 AWG conductor with 35 amp terminations for a neutral shared with the three 12 AWG phase conductors.
- In feeders that have a large amount of non-linear load, the feeder neutral conductor and panel board bus bar should also be oversized.

(2) Using Separate Neutral Conductors

- On three phase branch circuits, another philosophy is to not combine neutrals, but to run separate neutral conductors for each phase conductor. This increases the copper use by 33%. While this successfully eliminates

the addition of the harmonic currents on the branch circuit neutrals, the panel board neutral bus and feeder neutral conductor still must be oversized.

- **Oversizing Transformers and Generators:** The oversizing of equipment for increased thermal capacity should also be used for transformers and generators which serve harmonics-producing loads. The larger equipment contains more copper.

(3) Passive filters

- **Passive Filters:** Passive or 'trap' filters employ 'passive' elements (capacitors and inductors) to 'trap' or absorb harmonics. An inherent benefit of all passive filters is power factor correction. Passive filters are generally configured to remove only one or two specific harmonics. Passive filters are generally regarded as unsuitable for filtering 3rd harmonics. For this reason, they are best suited for applications in which 3rd harmonics are not an issue, power factor correction is required, and specific harmonics such as 5th or 7th are creating the problem. Passive filters are ideal for systems that have a high percentage of 6 pulse drives and other linear loads.

(4) Active Filters

- **Active Filters:** In contrast to passive filters, active filters monitor the load current and inject a harmonic current of equal magnitude but opposite polarity to dynamically cancel harmonic load currents. The active harmonic filter can be an economical solution for applications where the harmonic load is either 30% of the total transformer capacity or several hundred kVA. They provide a cost-effective alternative to 18-pulse technology when several drives are installed in one location. Unlike

(6) Special Metering

- Standard clamp-on ammeters are only sensitive to 60 Hertz current, so they only tell part of the story. New "true RMS" meters will sense current up to the kilohertz range. These meters should be used to detect harmonic currents. The difference between a reading on an old style clamp-on ammeter and a true RMS ammeter will give you an indication of the amount of harmonic current present.
- The measures described above only solve the symptoms of the problem. To solve the problem we must specify low harmonic equipment. This is most easily done when specifying electronic ballasts. Several manufacturers make electronic ballasts which produce less than 15 % harmonics. These ballasts should be considered for any ballast retrofit or any new project. Until low harmonics computers are available, segregating these harmonic loads on different circuits, different panel boards or the use of transformers should be considered. This segregation of "dirty" and "clean" loads is fundamental to electrical design today. This equates to more branch circuits and more panel boards, thus more copper usage.

7) Isolation transformers

- As mentioned previously, triple-N currents circulate in the delta windings of transformers. Although this is a problem for transformer manufacturers and specifiers – the extra load has to be taken into account it is beneficial to systems designers because it isolates triple-N harmonics from the supply.
- The same effect can be obtained by using a 'zig-zag' wound transformer. Zig-zag transformers are star configuration auto transformers with a particular phase relationship between the windings that are connected in shunt with the supply.

(6) K-Rated Transformers

- Special transformers have been developed to accommodate the additional heating caused by these harmonic currents. These types of transformers are now commonly specified for new computer rooms and computer lab facilities.

(7) Special PST Transformers

- There are several special types of transformer connections which can cancel harmonics. For example, the traditional delta-wye transformer connection will trap all the triplen harmonics (third, ninth, fifteenth, twenty-first, etc.) in the delta.
- Additional special winding connections can be used to cancel other harmonics on balanced loads. These systems also use more copper. These special transformers are often specified in computer rooms with well balanced harmonic producing loads such as multiple input mainframes or matched DASD peripherals.

VII. PST winding connection

Primary and secondary windings of transformers could be any combination of delta and wye connections. The polygon, zigzag and extended delta windings are special winding connection. Primary winding is connected in series, so current sharing will be same. They offer new features but still keep certain characteristics from wye or delta windings. A zigzag winding has each electrical phase linked equally by two phases. It is also used to provide phase-shifting in rectifier transformers. Polygon winding and extended delta winding are mainly used in phase shifting transformers for harmonic mitigation purpose [4,5]. The winding connection and voltage vector diagrams are shown in figures.

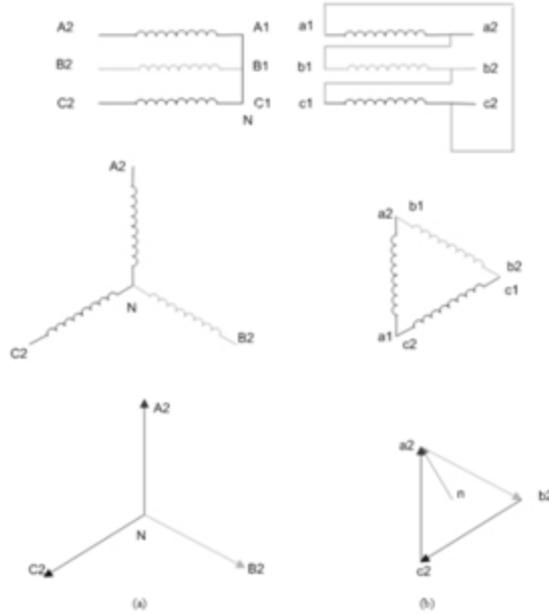


Fig. 1 (a) Star connection (b) Delta connection

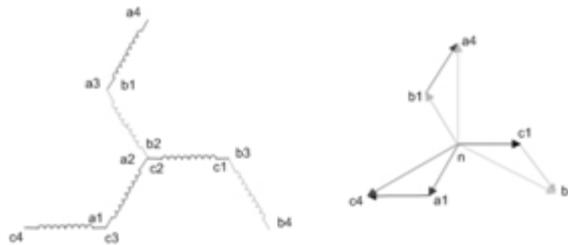


Fig. 2 Zig zag connection & voltage vector dia.

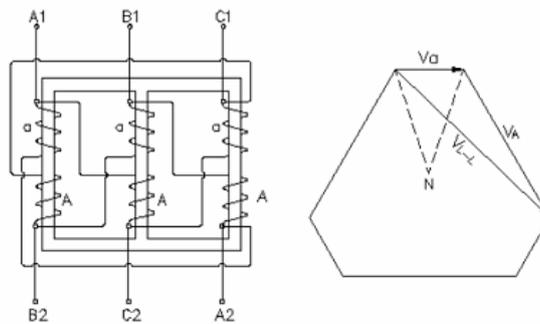


Fig. 3 Polygon connection & voltage vector dia.

Kva calculation for different transformer windings

1. Polygon windings

These connections are used in phase shifting transformers, and it is characterized by hexagon relationship between voltage vectors, shown in fig.4.

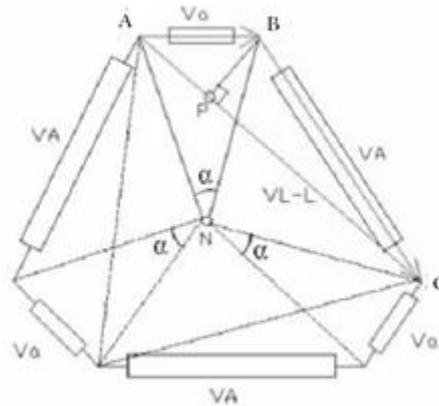


Fig. 4 Voltage vector of polygon winding

Polygon has two windings small and long. It is same as delta winding connection but asymmetric.

- V_a - small winding voltage
- V_A - long winding voltage
- V_{L-L} - Line-to-line voltage
- α - phase shifting angle

$$\text{Phase shift} = \frac{60^\circ}{\text{no of converters}}$$

One bridge converter generates 6 pulses so for 12, 18, 24 pulses 2, 3, 4 converters are required respectively. Hence for 12 pulse converter 30°shifting, 18 pulse 20°shifting, 24 pulse 15°shifting from primary voltage is needed. So phase shifting angle α calculated from fig.5

2. Zigzag windings

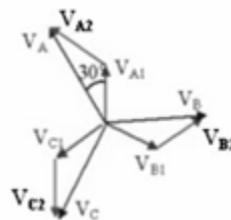


Fig. 5 zig. voltage vector

A special purpose transformer with zigzag or ‘interconnected star’ winding connection is shown in fig-5. The most common zigzag transformer application is for the derivation of a neutral connection from an ungrounded 3-phase system and the grounding of that neutral to an earth reference point. Zigzag transformers are also used to control of triplen (3rd, 9th, 11th, 15th etc) harmonic currents, to supply 3-phase power as an autotransformer (serving as the primary and secondary with no isolated circuits)[4].

Series connection of two windings voltage is 60° out of phase. For required phase shift angle voltage magnitudes of two windings can change. V_A is vector sum of two voltages on same leg.

$$V_{ph} = V_A = 2V_A \cos(30) = \sqrt{3} V_{A1} \tag{12}$$

Similar to star connection

$$V_{L-L} = \sqrt{3} V_{ph}$$

$$I_L = I_{ph}$$

$$Kva_{zig} = \sqrt{3} V_{L-L} I_L = 3 V_{ph} I_{ph} = 3\sqrt{3} V_{A1} I_{ph}$$

$$Kva_{star} = \sqrt{3}V_L I_L = 3V_{ph} I_{ph} = 3(2V_{A1})I_{ph}$$

Hence zigzag winding supplies 86.6% Kva of star connection to the output circuit.

A. *Delta-Zigzag Transformer* (0° or -30° primary-secondary angular displacement)

The primary of this transformer has a delta connection and its secondary has a zigzag connection. Although there is only one secondary three phase output, the electromagnetic effect of its secondary winding with a zigzag connection ends up cancelling the 3rd, 9th and 15th (triplen) harmonic currents. Transformer features include:

- A capacity for handling non-linear loads
- Low impedance cancellation of the 3rd, 9th and 15th harmonic currents (zigzag-connected secondary)
- A reduction in voltage distortion (3rd harmonic voltage reduced by low zero-sequence impedance)

When two transformers with a delta-zigzag connection (-30° and 0°) are used for phase-shifting, the 3rd harmonic currents are cancelled due to the secondary windings with a zigzag connection and the 5th and 7th harmonic currents are cancelled in the electrical supply common to both transformers due to the 30° phase shift.

If a single delta-zigzag transformer (0°) is used in a system made up of delta-wye transformers (-30°), the 5th and 7th harmonic currents originating from the delta-zigzag transformer (0°) will attempt to cancel the 5th and 7th harmonic currents originating from the delta-wye transformer (-30°) already present. This reduces the 5th and 7th harmonics in the system with the actual reduction dependent on how similar the secondary loads are in magnitude.

B. *Double-Output Transformer* (0° and -30° primary-secondary angular displacement)

The primary of the transformer has a delta connection and its secondary has a double-output zigzag connection. Although there is only a 30° angular displacement, the electromagnetic effect of its secondary windings with a zigzag connection ends up cancelling the 3rd, 9th and 15th harmonic currents. Transformer features include:

- A capacity for handling non-linear loads
- Low impedance cancellation of the 3rd, 9th and 15th harmonic currents (zigzag-connected secondary)
- Attenuations of the 5th and 7th harmonic currents (30° phase shift between the outputs)
- A reduction in voltage distortion (3rd harmonic voltage reduced by low zero-sequence impedance)

If two of these transformers are used, with the primaries of each phase shifted 15° with respect to one another, then cancellation of harmonics up to the 19th are achievable.

3.

VIII. SIMULATION

The non isolated delta to double polygon transformer is modelled and simulated in MATLAB. These are fed from 440V, 50Hz AC supply. The load is resistive. The simulations of 12 pulse delta/delta-star and delta/double polygon are carried out for same supply and load conditions to compare their performance. A special design of low voltage high is design for application like DC arc furnace, chemical electrolysis etc, which need high current at low voltage. Fig.6 shows interconnection of polygon transformer converter.

The interconnection of polyphase transformer is shown below. The simulink model is shown where multi winding 1,2,3 are for upper polygon secondary connection for -15° shifting of voltage which fed to one bridge rectifier, so connection 4,5,6 are connected to bridge. Connection 1,2,3 are supply to primary of transformer. Another multi winding 4,5,6 for $+15^\circ$ shifting and fed to second rectifier bridge. Turn ratio for multi winding is T1 and T2 for upper and lower polygon respectively which are 2.73 and 0.36.

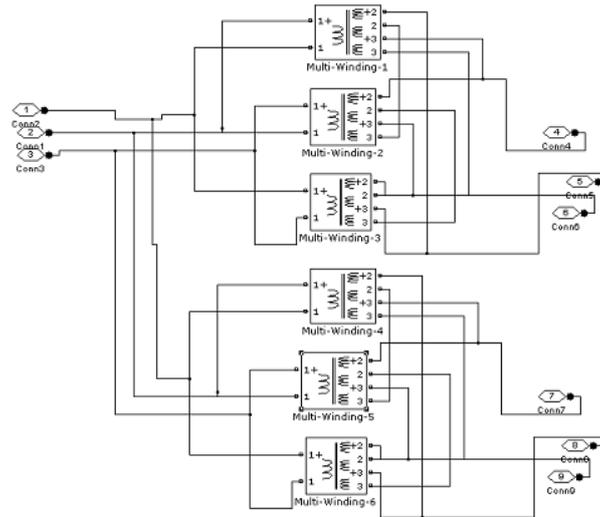


Fig. 6 Model of delta/double polygon transformer for 12 pulse converter application

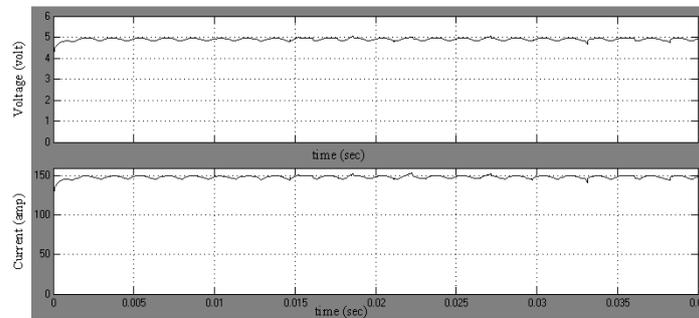


Fig. 7 Low output voltage and high output current of PST

Converter provides continuous load current 12 pulses per cycle of the supply frequency. At any instant, load current ($\frac{I_{dc}}{2}$) to be shared by each bridge rectifier through four diodes simultaneously, two in the top and two in the bottom bridge.

Secondary currents are trapezoidal wave with 30° phase shift as shown in fig. 8.

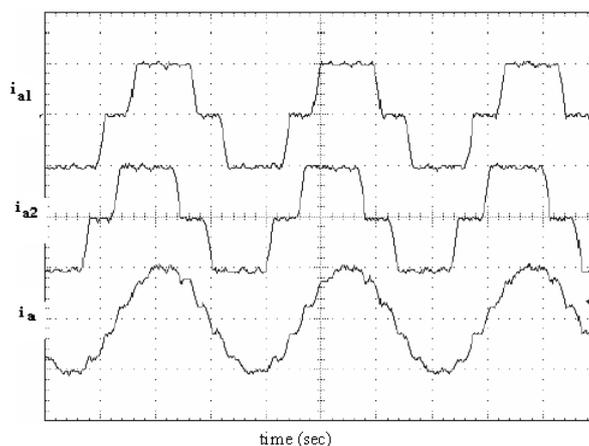


Fig. 8 source current and secondary side voltage

Low voltage high current is accomplished by this topology of converter with PST. The line current THD in source side is low with polygon transformer connection as compare to delta/delta-star transformer connection locations.

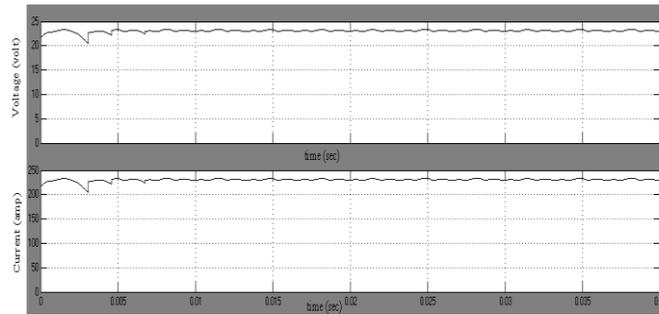


Fig. 9 Low voltage high current output of 18 pulse by PST

IX. CONCLUSIONS

A comprehensive review of phase shifting transformer has been carried out for two configuration pulse with zig zag connected transformer. It is considered as better alternative because of simple construction, low cost, low THD in source current. The proposed transformer is also well suited for low voltage high current (LVHC) application.

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