

# AC/DC Power Conversion System Using 3/9 Multiphase Transformer

Ahmad Hoteit<sup>1</sup> and Gaitov Hamidovich

Kuban State Technological University  
Krasnodar, Russia

## Abstract

*The main idea of this paper is to build a 3/9 AC multiphase transformer for conversion into DC power through the rectifier circuit which contains 18 pulse rectification with a ripple factor less than 0.8% produced by the odd phase number 9. This modeling has been simulated using Orcad simulation software, the nine phases are out of the main three phase power lines, each phase is shifted from the other by  $40^\circ$  ( $360^\circ/9$ ), this type of transformer is often required in aerospace, railway and automobile applications.*

**Keywords:** Multiphase transformer, three phase power lines.

## 1. Introduction

A transformer is a static device that transfers electric power from one circuit to another without a change of frequency. The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux. It is often used to raise or lower voltage and also for impedance transformation. The transformer is an important element in the development of high-voltage electric power transmission. Transformers can be classified into various types (step up, step down and matching transformers) according to the ratio of the numbers of turns in the coils (turns ratio), as well as whether or not the primary and secondary are isolated [1]. In all cases, the primary or the secondary windings, or both may have taps that allow selection of one of several different ratios of primary to secondary turns.

For a given voltage, the universal e.m.f equation of the transformer indicates that the maximum flux density in the core will be lower, at higher frequency. This implies that a core can have a smaller cross-sectional area and thus be physically more compact without reaching saturation. It is for this reason that the aircraft manufacturers and the military use 400 hertz supplies. They are less concerned with efficiency, but are more concerned with saving weight. Similarly, flyback transformers which supply high

voltage to cathode ray tubes operate at the frequency of the horizontal oscillator which is many times higher than 50 or 60 hertz, allowing thus for a more compact component [2]. Toroidal transformers are built around a ring-shaped core, which is made from a long strip of silicon steel or permalloy wound into a coil, or ferrite wound into a coil, depending on frequency. This construction ensures that all the grain boundaries are pointing in the optimum direction, making the transformer more efficient by reducing the core's reluctance, and eliminating the air gaps inherent in the construction of an EI core [4][5]. The primary and secondary coils are wound concentrically to cover the entire surface of the core. This minimizes the length of wire needed, and also provides screening to prevent the core's magnetic field from generating electromagnetic interference.

Toroidal cores used at frequencies up to a few tens of KHz may be made of ferrite material to reduce losses. Such transformers are used in switch-mode power supplies. Toroidal transformers are more efficient (around 95%) than the cheaper laminated EI types. compared to EI types, it includes smaller size (about the half), lower weight (about the half), less mechanical hum, lower exterior magnetic field (about one tenth), low off-load losses (making them more efficient in standby circuits), single-bolt mounting, and more choice of shapes.

For three-phase power, three separate single-phase transformers can be used, or all three phases can be connected to a single three-phase transformer. The three primary windings are connected together and the three secondary windings are connected also together. The most common connections are Y- $\Delta$ ,  $\Delta$ -Y,  $\Delta$ - $\Delta$  and Y-Y. If a winding is connected to earth (grounded) the earth connection point is usually the center point of a Y winding. There are many possible configurations that may involve more or fewer than six windings and various tap connections.

The multiphase transformers have at the primary three phases and at the secondary an even number of phases as 6 and 12, or an odd number as 5 and 9. The main element of

the phase multiplication method is a multi-phase transformer which is supplied from a three phase source and generates a multiphase AC supply for conversion into DC power [6].

The phase shift between the voltages at the secondary phases of the 3/6 AC multiphase transformer is  $60^\circ$ ; this produces a ripple factor of 7% at the output of the rectifier circuit which performs 12 pulse rectification. For the 3/12 AC multiphase transformer the phase shift is  $30^\circ$  with a ripple factor of 1.72% at the output of the rectifier circuit of 24 pulse rectification. And for the 3/5 AC multiphase transformer the phase shift is of  $72^\circ$ , with a ripple factor of 2.48% at the output of the rectifier circuit of 10 pulse rectification [7][8]. Therefore, for more applications, we are needed to decrease the value of the ripple factor, the focusing was about the 3/9 AC multiphase transformer (figure 1), it has the phase shift between the voltages at the secondary  $40^\circ$ . Many advantages relates in this type: it produces the ripple factor less than 0.7% at the output of the rectifier circuit which performs 18 pulse rectification, simple design, low losses, high efficiency and low cost.

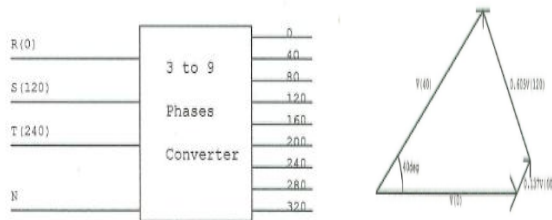


Fig. 1 A 3/9 AC multiphase transformer.

## 2. Description

Each of the conventional three phases power lines have the same voltage but having phase shifting of  $0^\circ$ ,  $120^\circ$  and  $240^\circ$ . From these three main phases we can generate 9 phases with the same voltage but with  $40^\circ$  phase shifting from each other ( $0^\circ$ ,  $40^\circ$ ,  $80^\circ$ ,  $120^\circ$ ,  $160^\circ$ ,  $200^\circ$ ,  $240^\circ$ ,  $280^\circ$ ,  $320^\circ$ ).

To do this, we should add a combination of voltages from the main three phases, to each other. For example, to generate a voltage which its phase shifted by  $+40^\circ$  with respect the phase ( $0^\circ$ ), we should add three sinwave voltages to each other as follow (figure 2.1):

$$V(40^\circ) = V(0) + 0.137xV(60^\circ) + 0.605xV(120^\circ).$$

N.B:  $V(60^\circ) = V(240^\circ)$  shifted  $180^\circ$ .

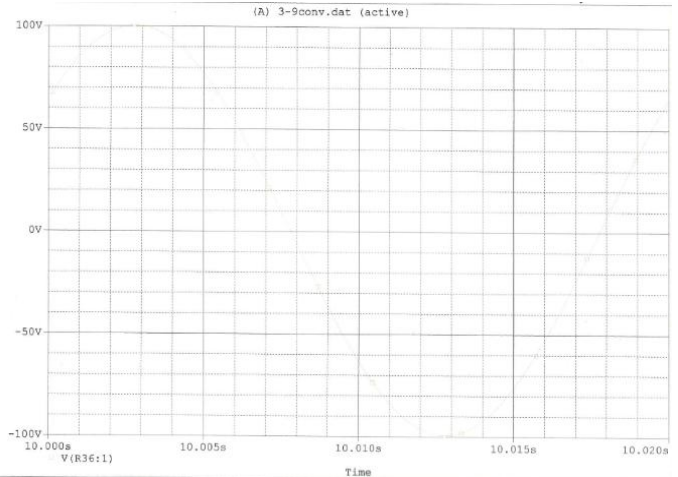


Fig. 2: Typical waveforms of a 12-pulse circuit with two 6-pulse bridges and interphase inductor.  
 (Supply current: 50A/div, Time axis: 0.5 ms/div)

To realize this equation, we use the circuit shown in figure 3; this circuit contains three single-Phase transformers with the primary of each transformer connected to one of the three Phases with reference to the neutral.

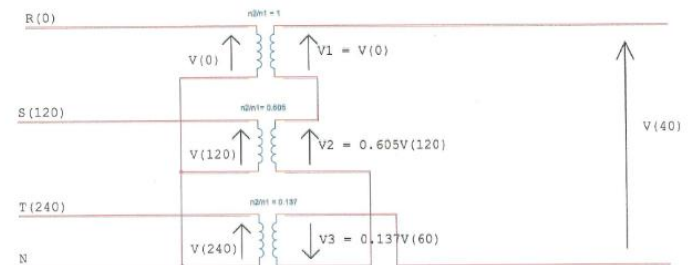


Fig. 3 Circuit of three single-Phase transformers

Each transformer has a transformation ratio according to the secondary voltage needed for this phase. For our example, the phases R, S, T are respectively  $0^\circ$ ,  $120^\circ$ , and  $240^\circ$ .

The transformation ratio of the first transformer is 1, so the secondary voltage is equal to the primary voltage and the phase  $V_1 = V(0^\circ)$ . The second transformer has 0.605 transformation ratio, so the secondary voltage is  $0.605V$  (The single phase primary voltage) with the same phase and  $V_2=0.605xV(120^\circ)$ . The third transformer has 0.137 transformation ratio and generates a secondary voltage  $V_3=0.137xV(240^\circ)$ , if we revert the secondary wires then  $V_3=0.137xV(60^\circ)$  ( $180^\circ$  phase shifting).

After the connection of all the secondary windings in series, we realize the following equation:

$$V(40^\circ) = 1xV(0^\circ) + 0.137xV(60^\circ) + 0.605xV(120^\circ)$$

The result is a sinewave with a voltage equals to the voltage of single phase and its phase shift of  $+40^\circ$  (figure 2.2).

We can apply the same method to generate the other phases as follow:

$$V(80^\circ) = 1xV(120^\circ) + 0.137xV(60^\circ) + 0.605xV(0^\circ).$$

$$V(160^\circ) = 1xV(120^\circ) + 0.137xV(180^\circ) + 0.605xV(240^\circ).$$

$$V(200^\circ) = 1xV(240^\circ) + 0.137xV(300^\circ) + 0.605xV(0^\circ).$$

$$V(320^\circ) = 1xV(120^\circ) + 0.137xV(300^\circ) + 0.605xV(240^\circ).$$

Figure 4 shows the phasor diagram of the 3/9 AC multiphase transformer.

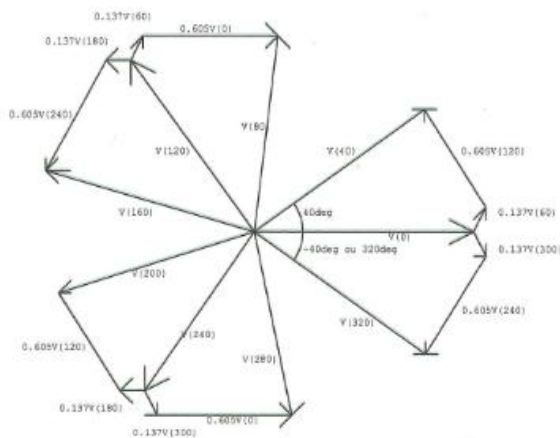


Fig.4 The phasor diagram of the 3/9 AC multiphase transformer.

### 3. Modeling and implementation of the transformer

Orcad simulation software has been used to build the schematic (figure 5) of the 3/9 AC multiphase transformer.

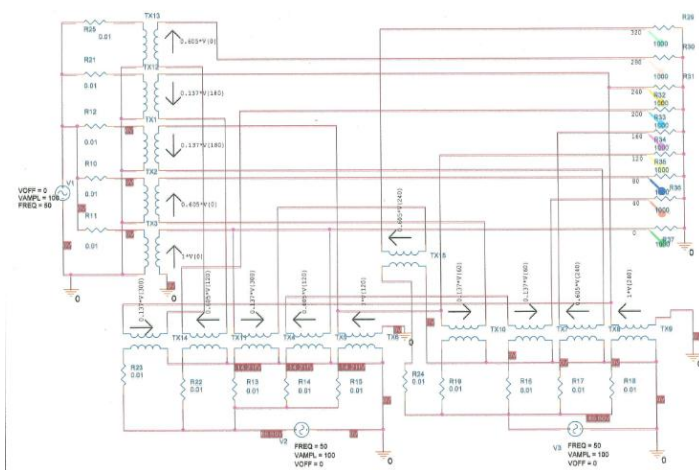


Fig. 5 Schematic of the transformer.

### 4. Configuration of the autotransformers

The configuration of the autotransformers is shown in figure 6.

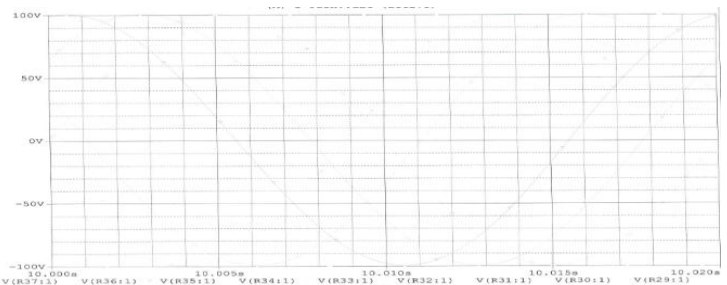


Fig. 6 Configuration of the basic and variant autotransformers for 18-pulse rectification.

### 5. Conclusions

The 3/9 AC multiphase transformer is a suitable solution to supply DC systems with low ripple factor reaching 0.8%. Based on a real example, a modeling methodology has been developed. This method requires the main data of the transformer, the phase shifting angles as well as the windings connections. The 3/9 AC multiphase transformer has been simulated using Orcad simulation software, which proved to be a powerful tool to simulate such complex transformers. The ripple factor analysis of simulation results (elimination of the ripple factor of phase 9) has validated the proposed methodology.

### References

- [1] Furmanczyk, F., and M.stefanich, "Demonstration of very high power airborne AC to DC Converter", Paper No.2004-01-3210, Power systems conference, Reno, Nevada, Nov.2004, 12 pages. Cited by other.
- [2] Furmanczyk, F., and M.stefanich, "Overview of Multiphase Power Converters for Aerospace Applications," Paper No.2008-01-2878, Power Systems Conference, Seattle, Nov.2008, 13 pages. Cited by other.
- [3] Furmanczyk, F., and M.stefanich, "Power Conversion Technologies for reducing Harmonics on the more Electric Aircraft," Paper No.06PSC--27, Power Systems conference, New Orleans, Nov.2006, 11 pages. Cited by other.
- [4] Citing patent: US6335872, Filing date: Jul 14, 2000, Issue date: Jan1, 2002, Original Assignee: Rockwell Automation Technologies, Inc, Title: Nine phase transformer.
- [5] Citing patent: US6525951, Filing date: Jan 25, 2002, Issue date: Feb 25, 2003 .Title: Simplified wye Connected 3-phase to 9-phase auto-transformer.
- [6] Citing patent: US6650557, Filing date: Feb 1, 2002, Issue date: Nov 18, 2003, Original Assignee: Honeywell International Inc. Title: 18-pulse rectification system using a wye -connected autotransformer.

- [7] Citing patent: US7474188, Filing date: Mar 21, 2005, Issue date: Jan 6, 2009, Original Assignee: Thales. Title: 40° phase-shifting autotransformer.
- [8] Citing patent: US7796413, Filing date: Jan 22, 2008, Issue date: Sep 14, 2010, Original Assignee: ELDEC Corporation. Title: AC/Dc power converter for aerospace applications.