Mid-Term Report for B.Tech. Project (EEN-400B)

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Project Title: Performance Analysis of Multi-Pulse Converters

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Table of Contents:

Objective and Motivation: Comparative study of Phase-Shifting Transformer topologies for mitigation of harmonics present in the supply side line currents drawn by Non-Linear Retrofit Loads.

Power Quality is a major area of research interest amongst technical researchers in today's date. A Non-Linear Retrofit Load (such as induction motor drive) connected to the three-phase, AC mains, draws non-sinusoidal currents from the supply side. This action pumps unwanted harmonics to the mains leading to effective fall in power factor at the supply side. Also, the existence of such current harmonics results into voltage distortion at the Point of Common Coupling (PCC) thereby affecting the nearby consumers connected to the same AC supply.

Use of Multi-Pulse converters (realised through an effective combination of uncontrolled converters with proper phase shift using phase-shifting transformers) is an intelligent, and robust solution for such cases wherein no strategic changes can be introduced into the existing Retrofit Non-Linear load. Awareness on the issue is more highlighted with the help of technical standards such as IEEE 519 which imply for such situations.

Work Done:

1. Study of Performance Characteristics of Phase Controlled Converters including:
   a. Harmonic Analysis of dc terminal voltage and ac input current for general p-pulse converters[1]
   b. Transformer topologies delta/wye, delta/zigzag/fork[2]
   c. Interphase Reactors[2]
   d. Pulse Doubling Circuit[3]
2. Computation of Transformer and Interphase Reactor ratings[2]
3. Simulation and comparison of 12-pulse D/y/d (with and without Pulse Doubling Circuit) and Fork connected Uncontrolled Converters.

Discussion:

1. D/y/d winding

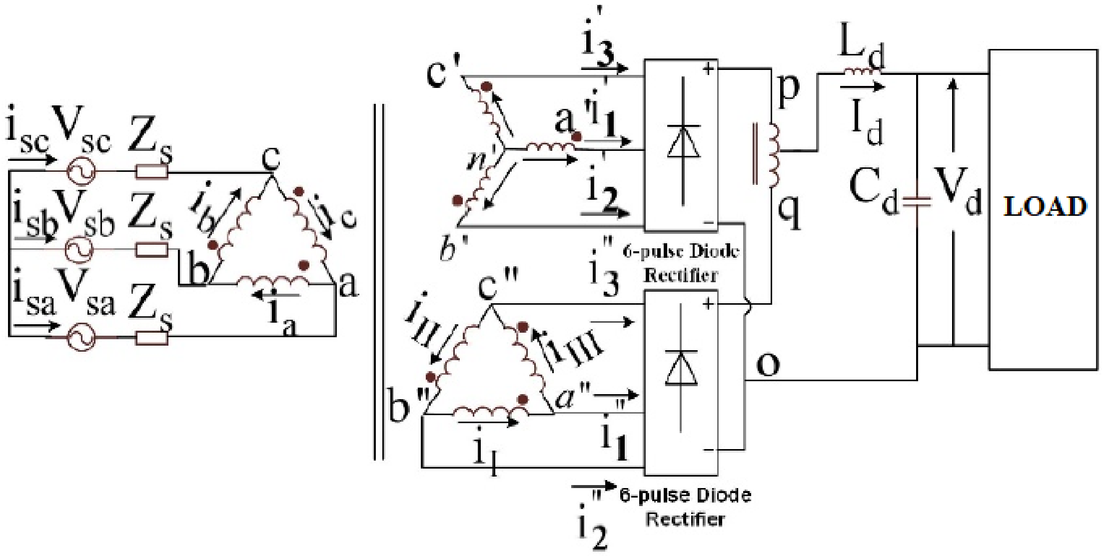

Fig.1. Block Schematic of D/y/d Transformer Supplying 12-Pulse, Uncontrolled Converter fed Retrofit Load

Fig.1 shows the block schematic of D/y/d connected transformer, supplying 12-pulse, uncontrolled converter. As the transformer has isolation, inter- converter currents are not possible. IPR connected between dc positive terminals of the converters neutralises instantaneous voltage difference between the two converters at the output port.

For design simplicity, it is assumed that the load current drawn from the DC link is constant in nature due to the highly inductive nature of the load. Fig.2 shows respective current waveforms at secondary and primary sides of the transformer and the resultant line current drawn from the utility.

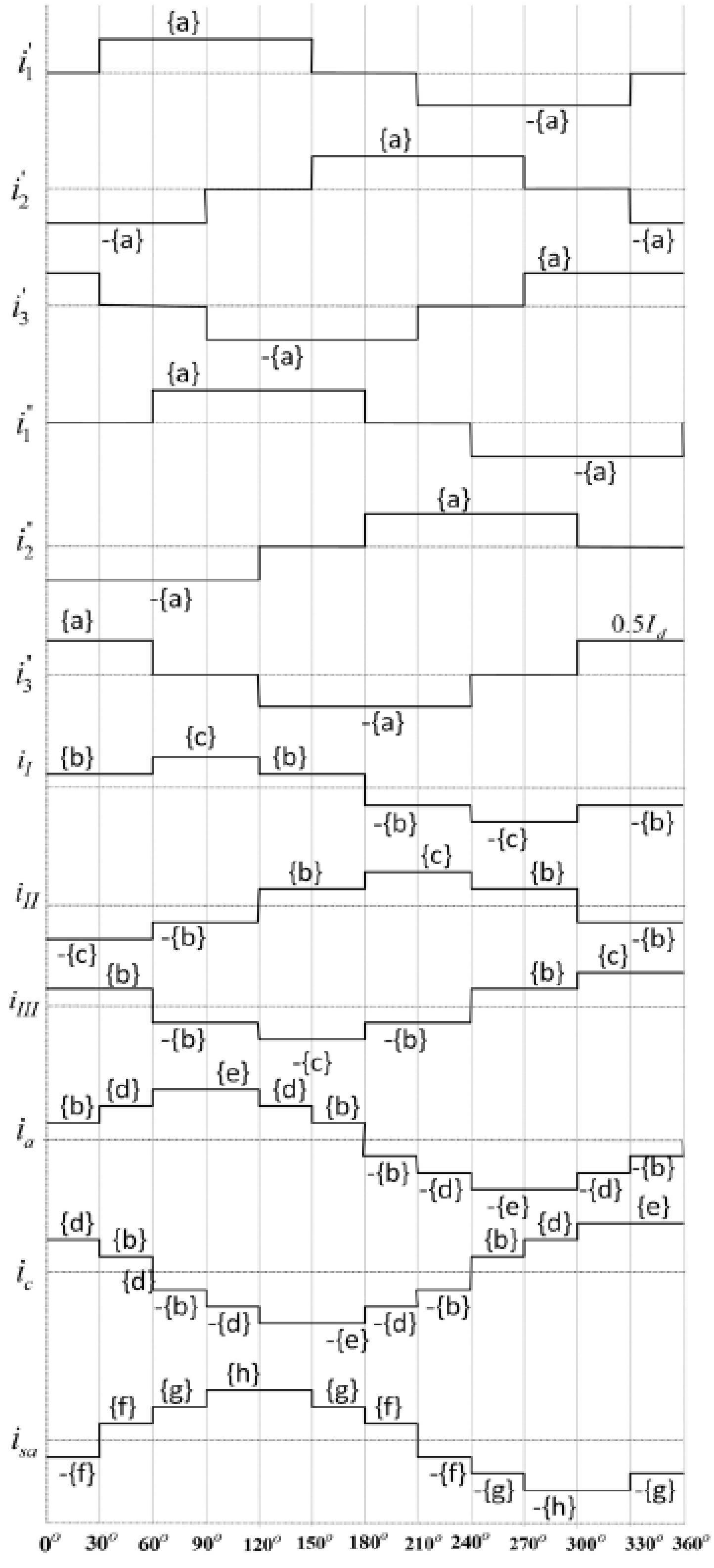

Fig.2. Current Waveforms for D/y/d transformer supplying 12-Pulse Uncontrolled Converter fed Retrofit Constant Current Load:
{a}=0.5 Id; {b}=0.0576 Id; {c}=0.1153 Id; {d}=0.0341 Id; {e}=0.5576 Id; {f}=0.9659 Id; {g} =1.1153 Id.

MATLAB Simulation and Results

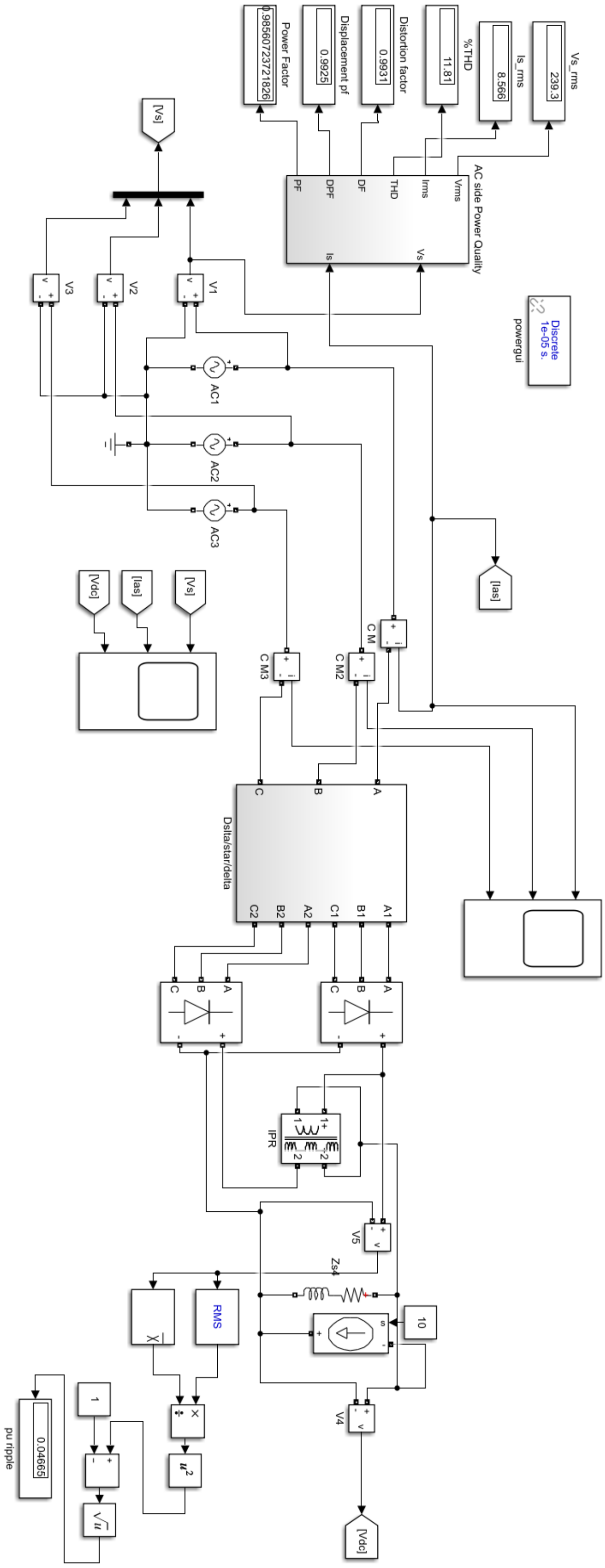

Fig.3. Simulink Model for D/y/d transformer supplying 12-Pulse Uncontrolled Converter fed Retrofit Constant Current Load

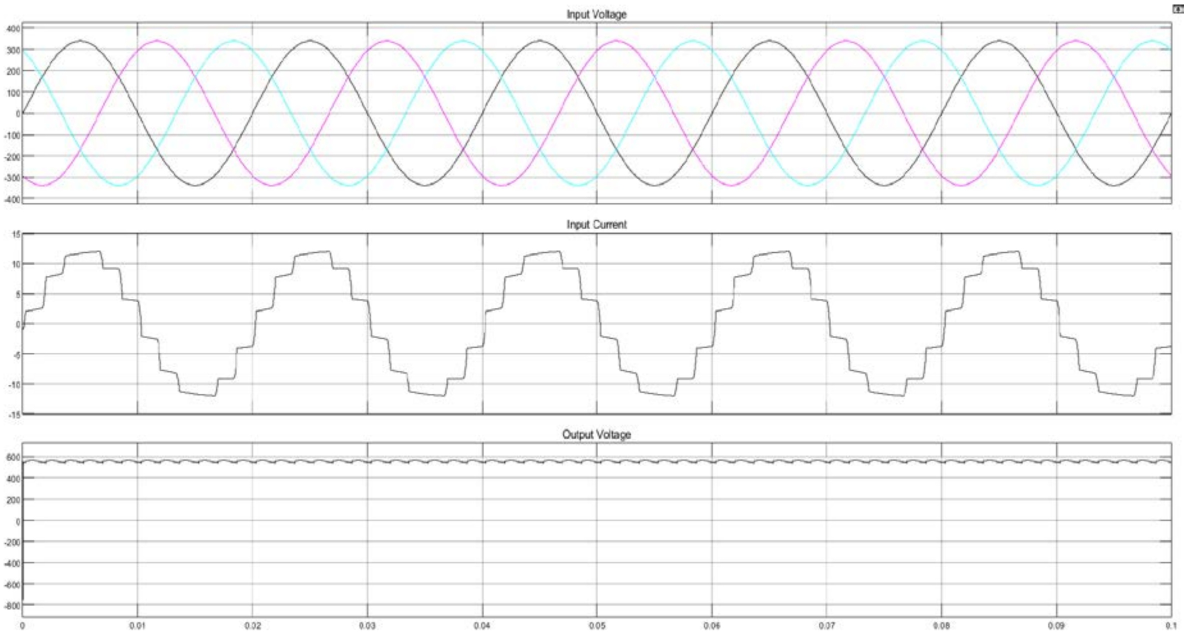

Fig.4. Supply current and output voltage waveforms

THD = 11.81%

Total Magnetic Rating = 106.71% of load

2. Fork Winding

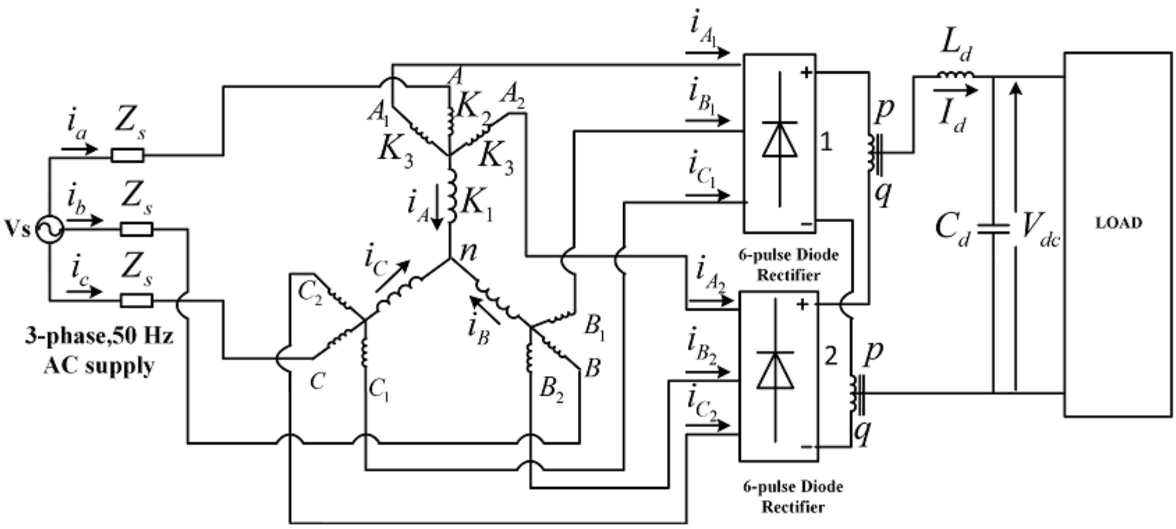

Fig.5. Block Schematic of Fork connected Auto-Transformer supplying 12-Pulse Uncontrolled Converter fed Retrofit Load

Fig.5 shows the block schematic for Fork connected auto-transformer supplying 12-Pulse, uncontrolled converter. K_1, K_2 and K_3 refer to the respective tapings.

As secondary windings are not isolated, there may be the possibility of inter converter current paths. To prevent such a situation, IPRs are connected in between respective positive terminals and in between respective negative terminals of the converters.

Winding connections are realised such that both secondary windings getting connected to converters I and II have respective phase voltages 15° lagging and leading w.r.t. the main supply.

K_1 = 0.1865, K_2=0.1835 and K_3=0.2988.

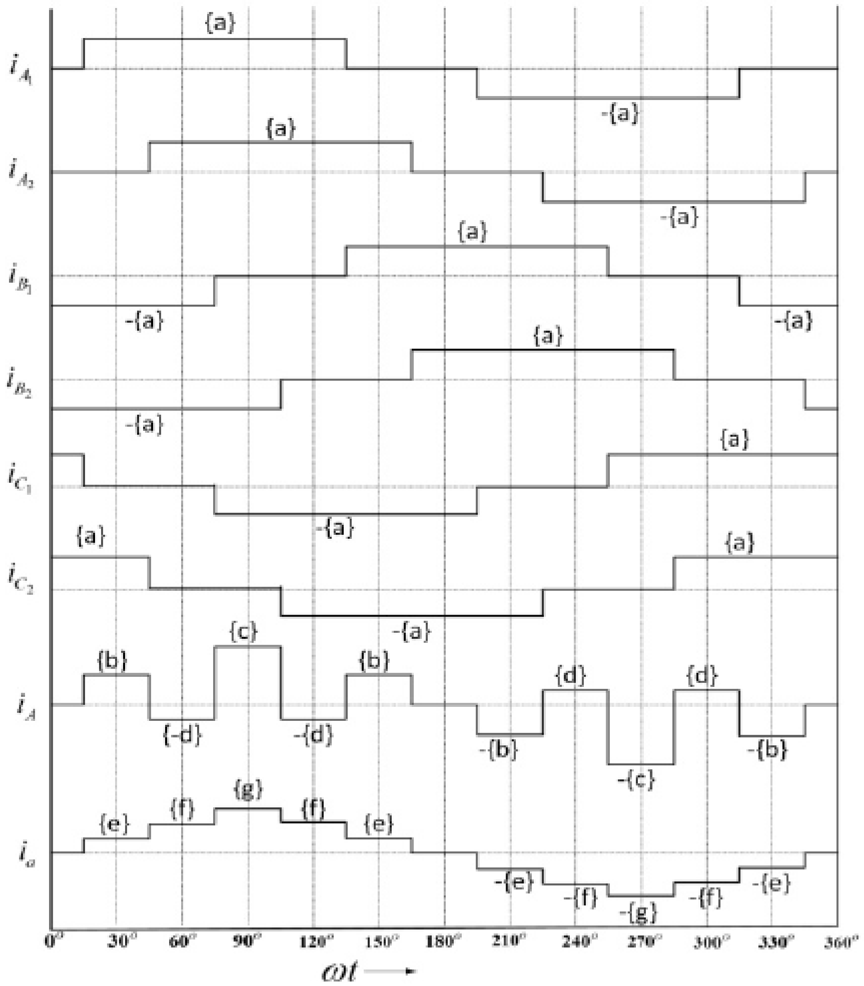

Fig.6. Current Waveforms for Fork Auto-Transformer Supplying 12-pulse, Uncontrolled Converter Fed Constant Current Load

{a}=0.5 Id; {b}=0.0576 Id; {c}=0.1153 Id; {d}=0.0341 Id; {e}=0.5576 Id; {f}=0.9659 Id; {g} = 1.1153 Id.

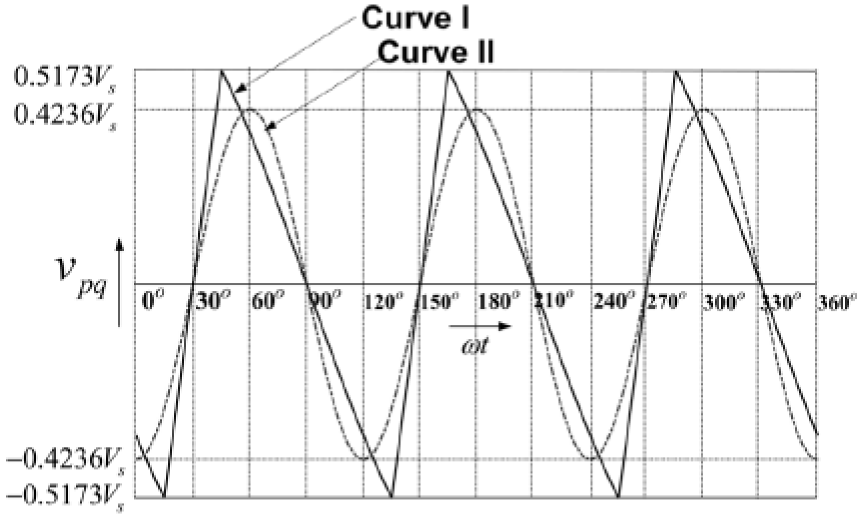

Fig.7. Voltage across IPR for Fork transformer
Curve I: Actual Voltage, Curve-II: Approximated Sinusoidal Voltage.

As transformers are normally rated for sinusoidal voltages and currents, the area under curve-I, is compared to that of Curve-II with RMS ‘V’.

MATLAB Simulation and Results

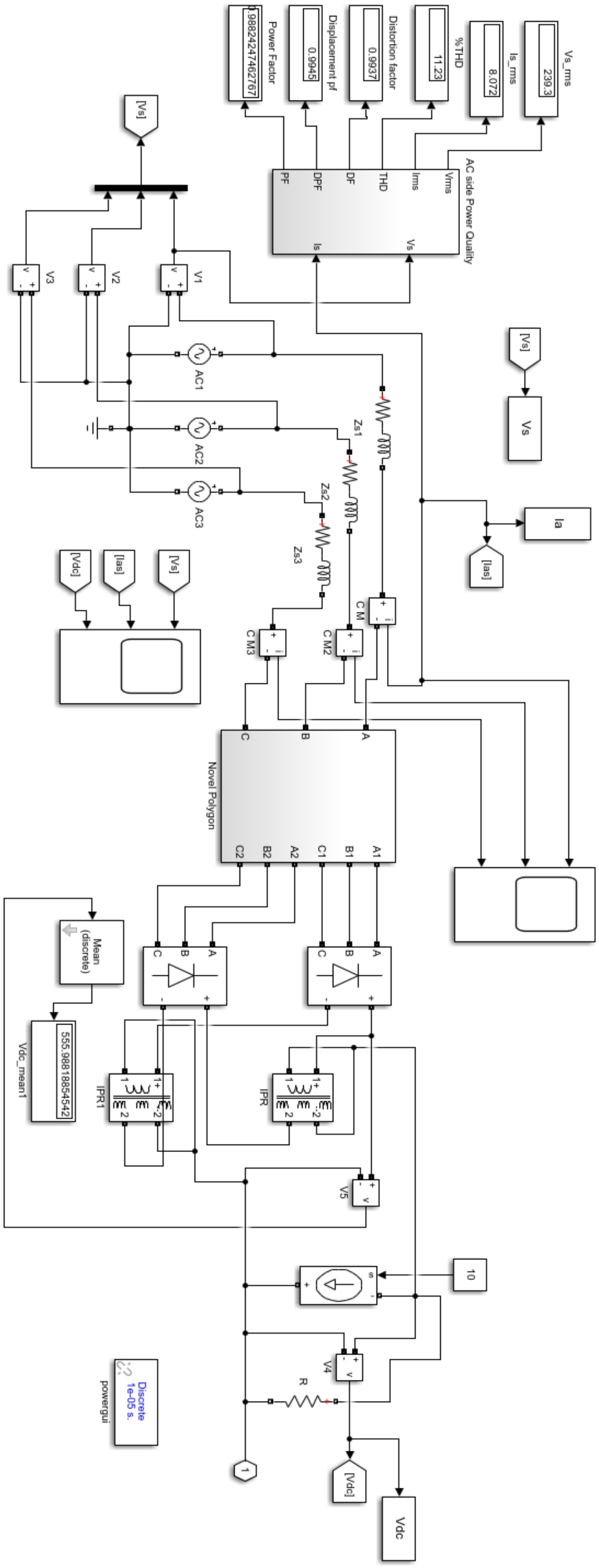

Fig.8. Simulink Model for Auto Connected Fork transformer supplying 12-Pulse Uncontrolled Converter fed Retrofit Constant Current Load

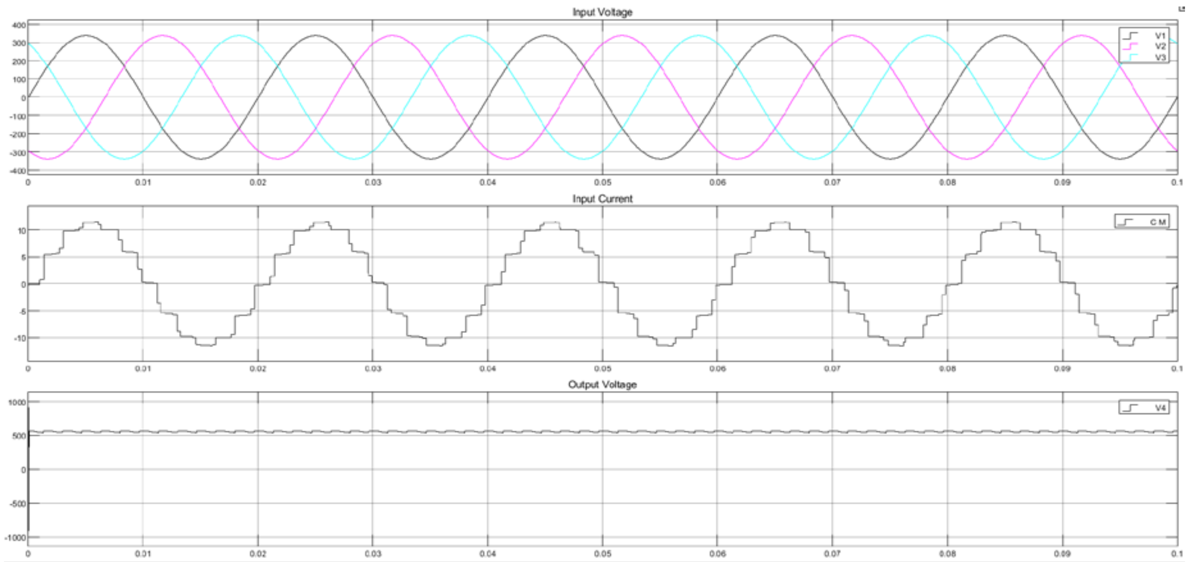

Fig.9. Supply current and output voltage waveforms

THD = 11.23%

Total Magnetic Rating = 40.89% of load

3. D/y/d Winding with Pulse Doubler

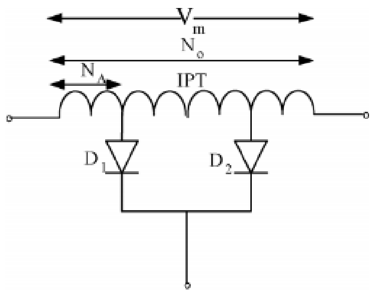

Fig.10 Pulse Doubling IPT

In this section, a pulse doubler circuit shown in Fig.10 have been utilised in conventional 12-pulse D/y/d converter. This results in 24-pulse operation due to alternate conduction of diodes. Depending upon the rectifier with higher voltage, the corresponding diode gets forward biased.

The turns ratio N_A/N_O is calculated from the Fourier analysis of input current I_A so as to give the desired input current characteristics. The 11^{th} and 13 harmonics should be absent in input current, giving ratio

$$\mathbf{k = N_A/N_O = 0.2457}$$ [3]

The circuit diagram has been shown in Fig.11 with the pulse doubler connected across output terminals of the two rectifiers.

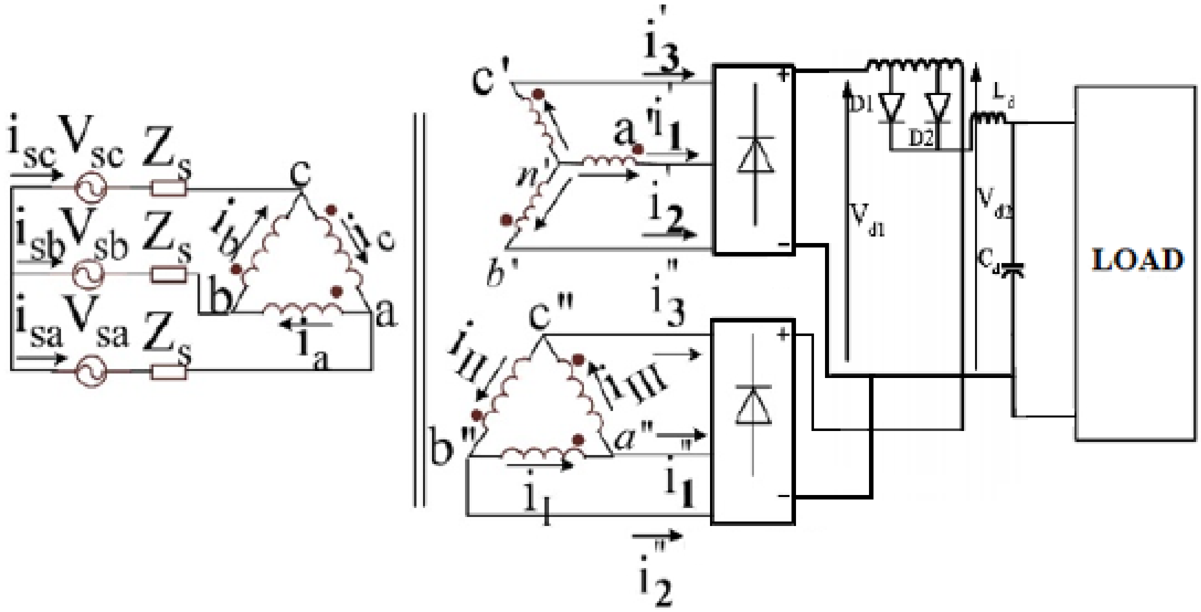

Fig.11 Block Schematic of 24-pulse D/y/d topology with pulse doubler IPT

The pulse doubler IPT supports the voltage difference across the two rectifiers as well as ensures 24-pulse operation. The required 24-pulse waveform has been observed in the voltage waveform as shown in Fig.13.

MATLAB Simulation and Results

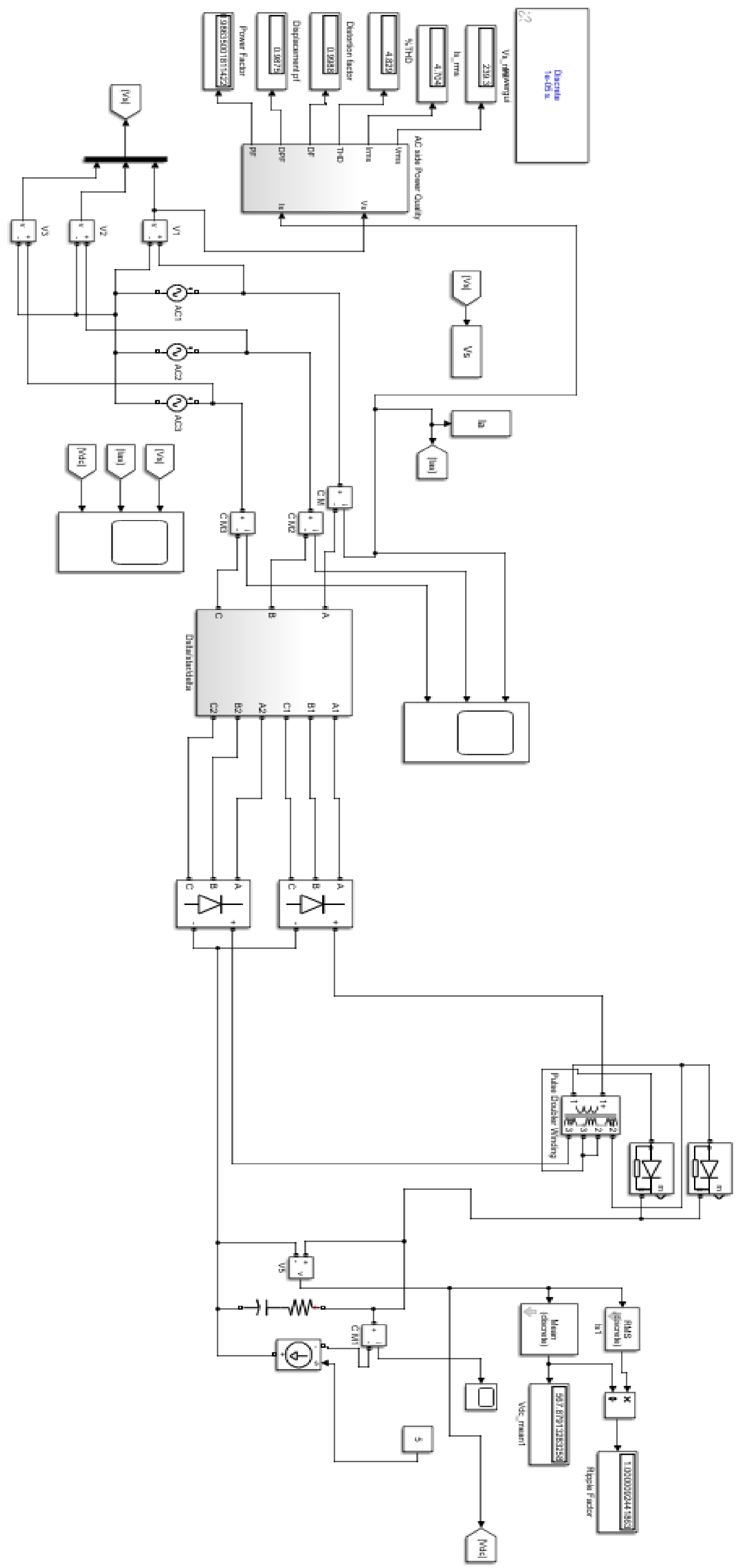

Fig.12 Simulink Model for D/y/d transformer supplying 24-Pulse Uncontrolled Converter fed Retrofit Constant Current Load

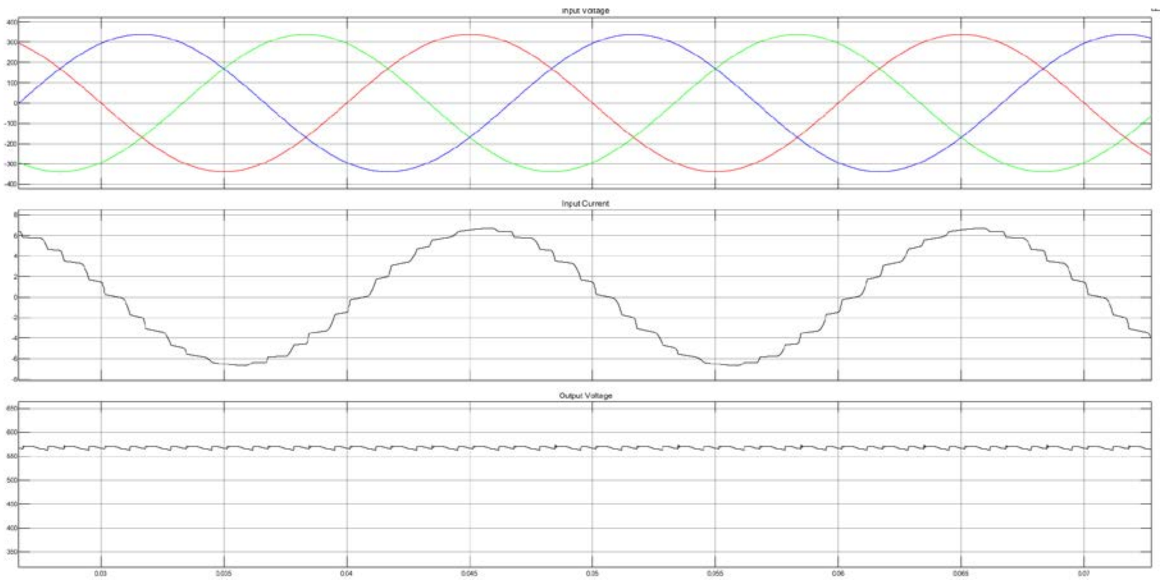

Fig.13 Supply current and output voltage waveforms

THD = 4.829%

Total Magnetic Rating = 120.92% of load

4. Conclusion

	D/y/d	D/y/d with Pulse Doubler	Fork
Power Transformer	102.91%	117.92%	28.09%
IPR / Pulse Doubler	3.80%	3.07%	12.81%
Total Magnetic Rating	106.71%	120.92%	40.89%
THD	11.81%	4.83%	11.23%

Fig.14. Comparison of Magnetic Ratings and THD of D/y/d (with and without Pulse Doubler) and Fork topologies

It is observed that the total rating for transformer and IPR amounts to 106.71% in D/y/d and 40.89% in Fork respectively of the total DC-link load for the same rating load. Although by incorporating pulse doubler in the D/y/d transformer connection, the magnetic rating is slightly higher (120.9%), it brings down the THD significantly. The comparison shows similar supply power quality aspects. Therefore, the use of Fork topology saves copper and leads to a reduction in cost and improvement in power quality.

Work to be done:

Mathematical Analysis and MATLAB Simulations of various other transformer topologies and understanding working of ZSBTs and comparisons of the same. VCIMD load is to designed and the validity of the topologies on retrofit load is to be tested.

References:

[1] B. R. Pelly, “Thyristor Phase-Controlled Converters and Cycloconverters” New York: Wiley, 1971. Chapter 4.

[2] Paice, D.A., “Power Electronic Converter Harmonic Multipulse Methods for Clean Power”; IEEE Press: New York, NY, USA, 1996. Chapters 1-4.

[3] Choi, S.; Lee, B.; Enjeti, P. “New 24-pulse diode rectifier systems for utility interface of high-power AC motor drives.” IEEE Trans. Ind. Appl. 1997, 33, 531–541.