

# Optimum and Non-Optimum 16-Pulse Scott Connection Based AC-DC Converters

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**Abstract**— This paper deals with a multi-pulse AC-DC converter that generate DC output voltage having 16 pulsations, fed from orthogonally connected transformers. The orthogonal supply voltages are obtained from the special transformer connection called Scott connection. In this paper the two configurations, canonical and non-canonical arrangements, which are suitable for 16-pulse generation are modelled and analysed. The output voltage ripples are small and the total harmonic distortion in input current (THDi) is also improved compared to the conventional 6-pulse and 12-pulse AC-DC converters.

**Keywords**— Scott transformer; Multi-pulse AC-DC converter; THD; Canonical; Orthogonal supply voltage

## I. INTRODUCTION

Multi-pulse AC-DC converters are described by number of researchers to improve power quality at its input, simultaneously reducing the output voltage ripples [1] by increasing the converter pulse number. In Scott connections, two transformers are employed to produce orthogonal AC supply voltages when three-phase to two-phase transformation (or vice-versa) is required. The 2-phase orthogonal AC voltages can be rectified to have certain advantages. The pulse number of such rectifiers is 4, 8, 12, 16, etc. During the rectification of orthogonal voltages, different number of windings is needed, corresponding to the number of pulsations required at output. Each winding must have mathematically well-founded turn numbers to increase the frequency multiplicity of pulsations of rectified voltage [2-5].

If the rectified voltage wave has identical pulsations with their corresponding extreme values located at the same level and the shearing angles between adjacent phasors of rectified voltage in a phase plane are equal then the wave shape of such a rectified voltage is called as canonical. However if the pulses have different durations with insignificant amplitudes, the extreme values have different levels and the shearing angles between adjacent phasors of rectified voltage are different, then the wave shape of such a rectified voltage is called as non-canonical [4].

The main advantage of orthogonal rectifiers with a non-canonical shape of pulsations is that the secondary windings are realized with only two values of turn numbers for any pulse number. Moreover, the number of secondary windings of each transformer is decreased by one compared to the transformer of the corresponding rectifier with a canonical formation.

The orthogonal power supply is produced with the help of two transformers-main transformer and teaser transformer. Usually, two secondary windings in each transformer are required for 8-pulse rectifiers, three for 12-pulse rectifiers, four for 16-pulse rectifiers, five for 20-pulse rectifiers, etc [3].

## II. TRANSFORMER ARRANGEMENT BASED ON SCOTT CONNECTION

When it comes to three phase equipment to be used with one of the three phases failed then it is urgently required to a system that it can convert the available one and/or two phase supply into equivalent & nearly balanced three phase supply. It can be achieved with a transformer which is based on Scott connection, generally called as “Scott transformer”. There are two individual single phase transformers, connected in such a fashion that the output will be balanced there phase supply of equal voltage & phase difference are shown in Fig.1. It is Reverse Scott connection. Reverse Scott connection means two phase to three phase conversion. It can be used in 3-phase to 3-phase or 3-phase to 2-phase conversion or vice-versa.

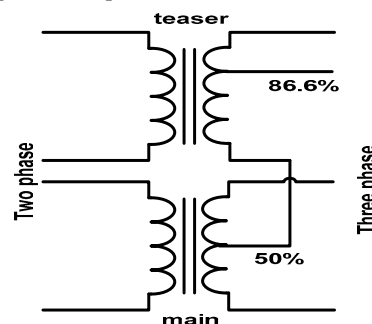


Fig.1. Transformers based on Scott connection scheme

*A. Generation of orthogonal supply voltage*

For the analysis and synthesis of rectifier schemes fed with orthogonal power supply, the method of phasor diagrams can be utilized. This method is completely applicable to the different rectifier configurations with different pulse numbers. Moreover, any of the known schemes of rectifiers may be analyzed with the help of this method.

The angular shift between the neighbouring vectors of voltages for a rectifier system can be given as  $\frac{2\pi}{n}$  where ‘n’ is the number of pulsations in the rectified voltage in one cycle of supply voltage. Hence, phase shift of  $22.5^\circ$  between the voltage phasors is required for obtaining a 16-pulse rectifier, as shown by in Fig.2.

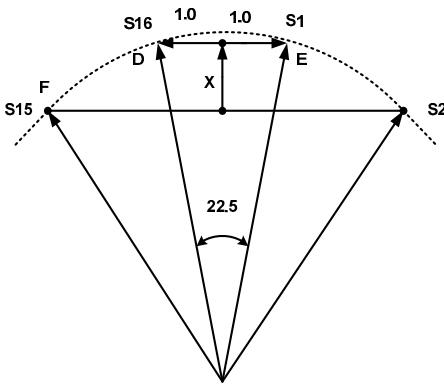


Fig.2. Fragment of vector diagram of resultant voltages for a 16-pulse rectifier

*B. A 16-Pulse Non-optimum AC-DC converter*

On the basis of Scott connection, a 16-pulse non-optimum AC-DC converter produces the canonical output pulses. Fig.3 shows the schematic diagram for 16-pulse non-optimum rectifier.

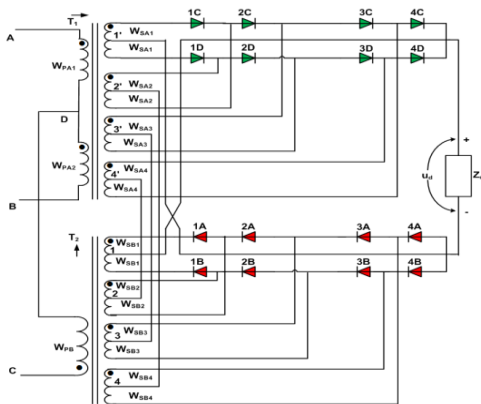


Fig.3. Schematic diagram for Non-optimum 16-pulse AC-DC converter

Fig.4 shows the winding connection diagram for 16-pulse non-optimum rectifier.

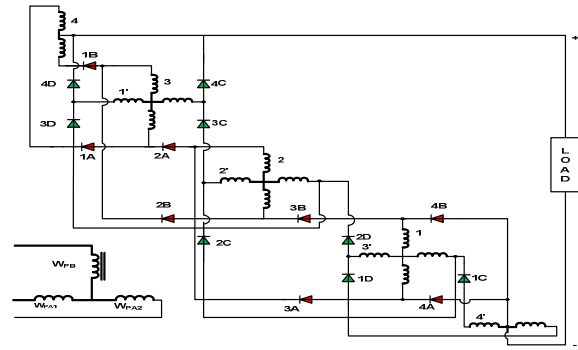


Fig.4. Winding connection diagram for Non-optimum 16-pulse AC-DC converter

*C. A 16-Pulse optimum AC-DC converter*

Another configuration for the Scott connected 16-pulse rectifier is represented in Fig.5. It is called as 16-pulse Optimum AC-DC converter as the number of secondary windings has reduced in this configuration.

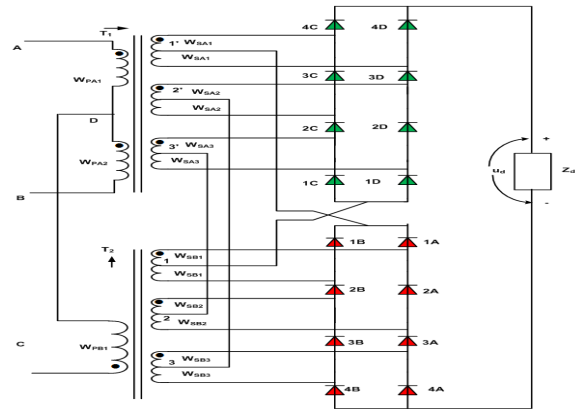


Fig.5. Schematic diagram for Optimum 16-pulse AC-DC converter

Fig.6 gives the winding connection diagram for the Optimum 16-pulse AC-DC converter.

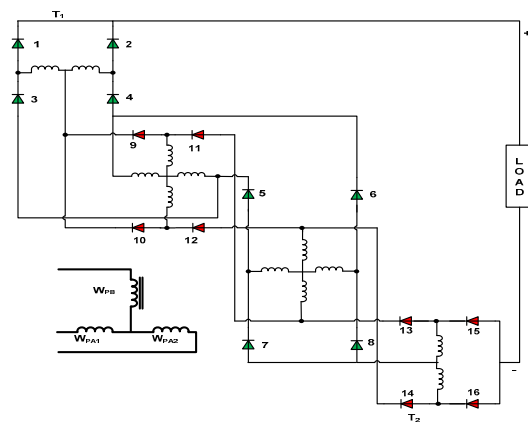


Fig.6. Winding connection diagram for Optimum 16-pulse AC-DC converter

It is clear from figures that the Optimum converter requires less number of windings as compare to the non-optimum converter, for a same number of pulsations at output. Hence, the total magnetics used for the converter is reduced and this results in reduced cost and size of the converter system.

### III. MATLAB SIMULATION

The simulation is carried out in MATLAB environment employing SIMULINK and Power System Blocksets (PSB). In the simulation supply voltage of 415V is feeding a 20 kW load. The MATLAB/SIMULINK models for non-optimum and optimum 16-pulse converters are described in this section for investigation.

#### A. MATLAB models for Non-optimum converter

Fig.7 shows the MATLAB model of proposed 16-pulse non-optimum AC-DC converter.

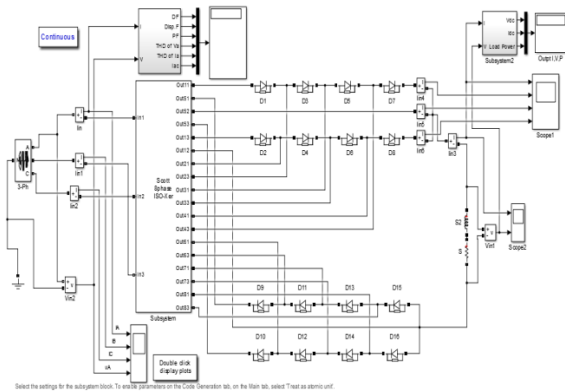


Fig.7. MATLAB model for Non-optimum 16-pulse AC-DC converter

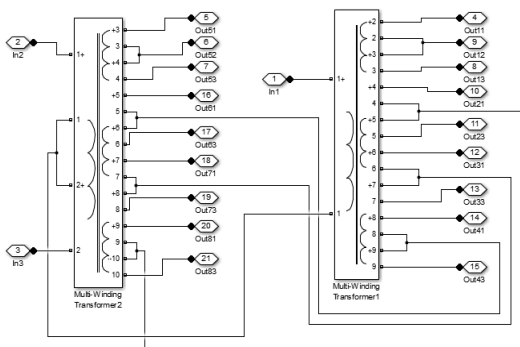


Fig.8. MATLAB model of orthogonally connected transformers used in non-optimum 16-pulse AC-DC converter

Fig.8 shows the MATLAB model of Scott connection based transformer arrangement used in this converter. Results and waveforms obtained from the simulation of this converter are given in next section.

#### B. MATLAB models for Optimum converter

In the Fig.9 the MATLAB model for the 16-pulse Optimum converter is shown and Fig.10 shows the MATLAB model for the transformer arrangement used in this converter.

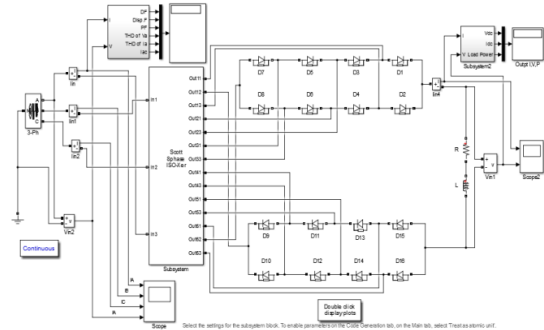


Fig.9. MATLAB model for Optimum 16-pulse AC-DC converter

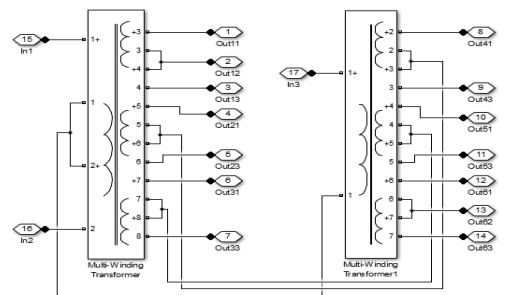


Fig.10. MATLAB model of transformer used in Optimum 16-pulse AC-DC converter

### IV. RESULTS AND DISCUSSIONS

Figs. 11-16 show the various waveforms and harmonic spectrums for various quantities. Fig.11 shows the waveform for the supply current, its harmonic spectrum and THD at full

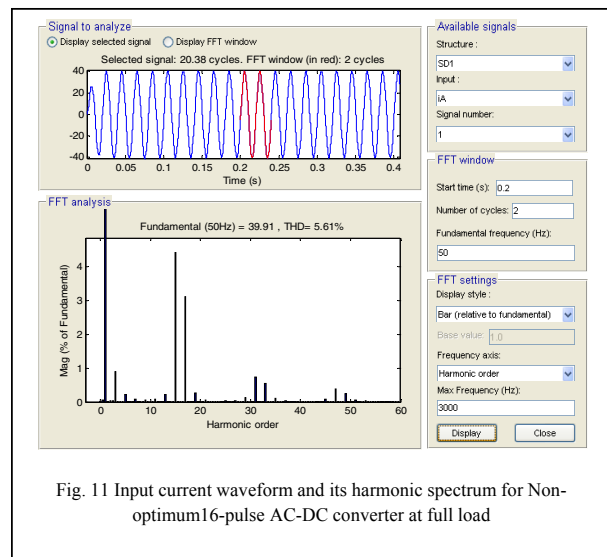


Fig. 11 Input current waveform and its harmonic spectrum for Non-optimum 16-pulse AC-DC converter at full load

load for the Non-optimum 16-pulse AC-DC converter based on Scott connection. The value of THDi can be seen as 5.6%. The characteristics harmonics can be seen to have values as  $16n \pm 1$ .

Fig.12 shows the waveforms for input and output voltages and currents at full load for 16-pulse Non-optimum AC-DC converter.

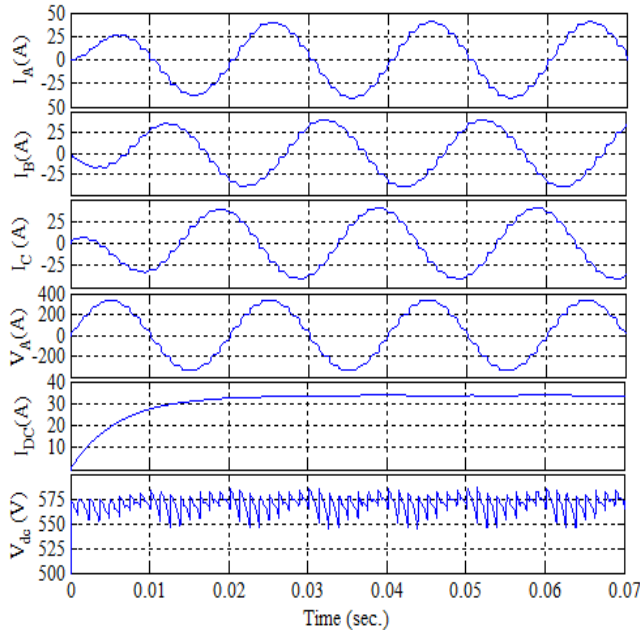


Fig.12. Input and output waveforms of Non-optimum 16-pulse AC-DC converter at full load

currents at the input, the output current and voltage waveforms.

The variation of THDi and power factor with varying loads in two cases is shown in Fig. 15 and 16, respectively. It can be seen that the value of THDi and power factor variation is nearly same in two cases. The insignificant advantage of canonical (non-optimum) topology is present over the non-canonical topology (optimum) at the cost of additional windings in two transformers. The value of THD in output voltage in optimum configuration is found to be better. The variation of various quantities like input and output current, voltages, power, THD, etc. with varying load can be seen in Table I.

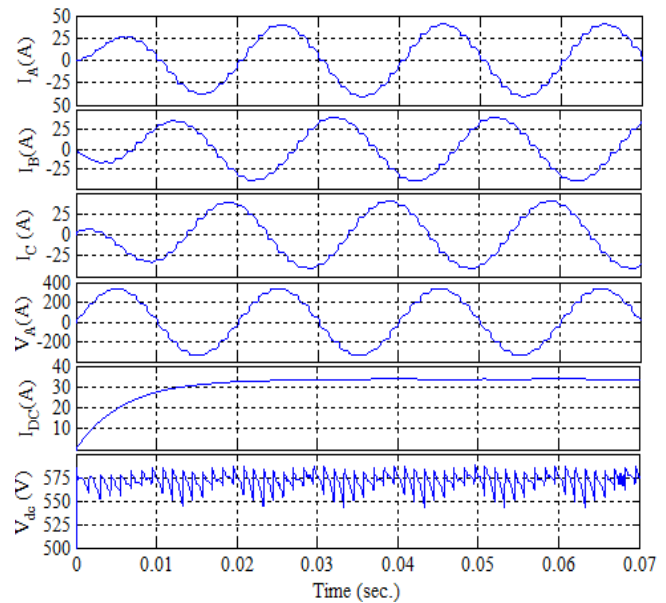


Fig.14. Input and output waveforms of Optimum 16-pulse AC-DC converter at full load

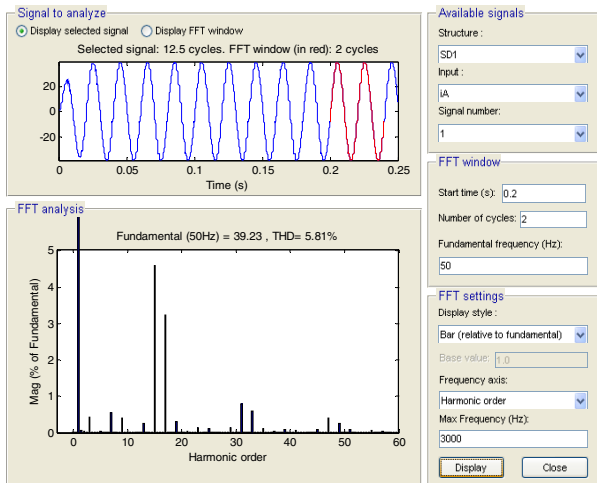


Fig.13. Input current waveform and their THD spectrum for Optimum 16-pulse AC-DC converter at full load.

Fig.13 shows an input line current waveform, its harmonic spectrum and THD at full load for the case of optimum 16-pulse AC-DC converter. The value of THDi is observed to be slightly higher at 5.81%. Fig.14 depicts the three phase

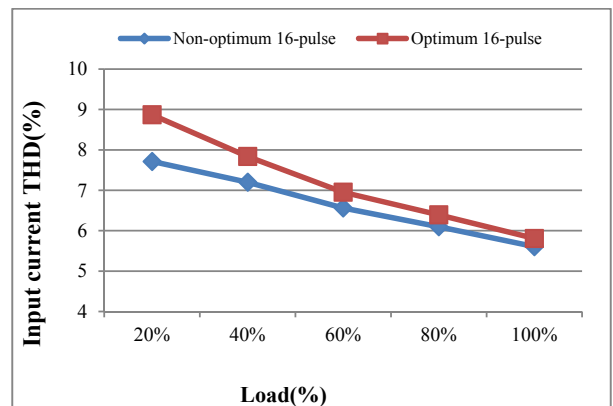


Fig.15. Variation of THD of supply current at different values of load for two 16-pulse topologies.

Table I  
COMPARISON OF POWER QUALITY PARAMETERS OF SCOTT CONNECTED NON-OPTIMUM AND OPTIMUM 16-PULSE, AC-DC CONVERTER AT DIFFERENT VALUES OF LOAD

Topology	Load (%)	AC mains current $I_A$ (A)	THD of $I_A$ (%)	Distortion Factor	Displacement Factor	Power Factor	DC voltage ( $V_{dc}$ )	Load current $I_{dc}$ (A)	Load power (kW)
Non-optimum 16-pulse	20%	6.427	7.714	.9970	.9994	.9965	585.8	6.892	4.037
	40%	12.01	7.199	.9974	.9979	.9954	581.9	13.69	7.967
	60%	18.19	6.563	.9979	.9966	.9945	577.6	21.23	12.26
	80%	22.94	6.098	.9981	.9958	.9939	574.4	27.03	15.53
	100%	28.27	5.610	.9984	.9950	.9935	570.7	33.57	19.16
Optimum 16-pulse	20%	5.802	8.869	.9961	.9977	.9938	587.0	6.909	4.056
	40%	11.43	7.837	.9969	.9964	.9934	583.1	13.72	8.001
	60%	17.65	6.952	.9976	.9953	.9929	578.7	21.29	12.32
	80%	22.42	6.393	.9980	.9945	.9925	575.4	27.10	15.59
	100%	27.84	5.810	.9983	.9939	.9922	571.6	33.70	19.26

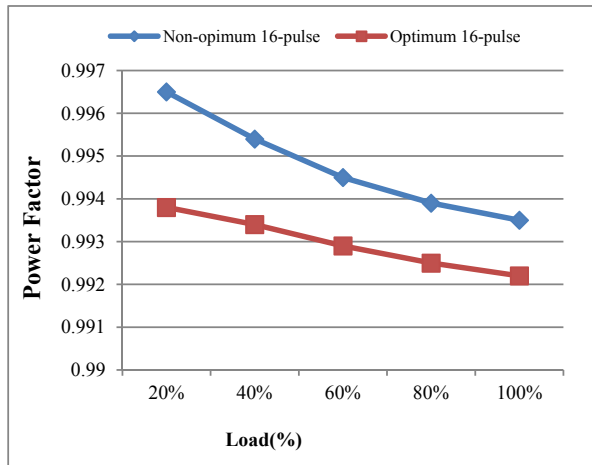


Fig.16. Variation of Power Factor at different loads for the two topologies.

## V. CONCLUSION

It has been observed that both the proposed converter configurations are capable to provide satisfactory performance. But from the simulation result given in Table-I it is concluded that optimum/ non-optimum 16-pulse AC-DC converters are found capable to minimize THD in input current by improving supply AC current as well as DC output voltage for a wide range of varying load. The power factor is better in the Non-

optimum 16-pulse converter especially at lower loads which are shown in the Fig.14 by a graph between load and power factor.

It is clear from the winding connection diagrams that the Optimum converter requires less number of windings compared to the Non-optimum configuration. The total magnetics required for its construction is comparatively less. The results show its compactness and cost effectiveness as compared to non-optimum converter.

## REFERENCES

- [1] Singh, B., Gairola, S., Singh, B.N., Chandra, A. and Al-Haddad, K. (2008), "Multipulse AC-DC Converters for Improving Power Quality: A Review", *IEEE Transactions on Power Electronics*, Vol. 23, No. 1, pp. 260–281, January 2008.
- [2] Vorfolomeev, G.N., Evdokimo, S.A., Schurov, N.V. I. and Malozyomov, B.V. (2004), "Optimum Multi Pulse Rectifiers based on the Scheme of Charles Scott", *7<sup>th</sup> International Conference, APEIE-2004*.
- [3] Vorfolomeev, G.N., Myatezh, S.V., Schurov, N.I. and Tsiulina, I.A. (2001), "Power Saving Multi-Pulse Rectifiers with the Transform Converters of Phases Number", *Electronics and Electrotechnology, KORUS-2001*.
- [4] Vorfolomeev, G.N., Evdokimov, S.A. and Shchurov, N.I. (2007), "Synthesis of Schemes of Multipulse Rectifiers with Orthogonal Supply Voltages", *Russian Electrical Engineering Journal*, Vol. 78, No. 5, pp. 261–266.
- [5] Lopatkin, N.N. and Zinoviev, G.S. (2006), "Three-Level Rectifiers of Three Phase Orthogonal System of Voltages", *8<sup>th</sup> International Conference, APEIE-2006*.
- [6] Kalpana, R., Bhuvaneswari, G., Singh, Bhim, Singh, Shikha and Gairola, Sanjay (2013), "Autoconnected Transformer based 20-pulse AC-DC Converter for Telecommunication Power Supply", *IEEE Transactions on Industrial Electronics*, October 2013.