Installation And Operating Experience of 12- Pulse AC/DC Converter Fed AC Drives In Recovery Boiler

Maheswaran D., Kandasamy R. & Rajasekar N.

Tamil Nadu Newsprint & Papers Ltd., P.O. Kagithapuram - 639136 Dist., Karur (T.N.)

ABSTRACT

In this paper, the Installation and operating experience of Recovery Boiler drive power supply system and ID fan drive input current Harmonics in the 12-Pulse AC/DC converter fed AC Drives was studied. The 12-pulse Δ-Y type AC/DC converter will keep a balanced voltage with 30° phase shifted at the low coupling coefficient condition. Different converter arrangements for 12-pulse-based rectification are also studied and a novel harmonic mitigator capable of suppressing fifth and seventh harmonics in the supply current is presented. Finally Recovery boiler ID fan 585 kW, 690V, 12-pulse AC Drive Harmonic's measurements was presented.

Keywords: *12 Pulse AC/DC Converter, pulse width modulation, power quality.*

Introduction

The use of variable frequency drives has become very common in the industrial market place, especially in the Pulp and Paper Industry. It is now very common to use AC drives in every aspect of a paper mill, from boiler ID fans to feed water pumps. In fact, AC drives are now just as common in applications where DC VSDs were the norm, i e. kilns, sectional paper machine drives, etc. With this high use of non-linear loads, such as 6 pulse rectifying equipment used in AC and DC drives, creates some problem areas, the largest of which is current harmonics and the resulting supply waveform distortion along with power factor control. The most recent issue of IEEE 519 "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" now limits current as well as voltage distortion on electrical power systems. With this ever increasing awareness and concern with power system distortion, alternative power conversion techniques, that draw continuous current from network, need to be considered.

The harmonics in the power system are serious due to the wide applications of the electronic equipments in which the AC/DC converter are usually used. Therefore, it is an important topic to reduce harmonic components in the AC/DC converter. The harmonic problems can be solved by using the active filters which are usually operated at high switching frequency and are not suitable for high power applications. The power factor and harmonic components of the utility input line current can be improved by the poly-pulse AC/DC converter. The required capacity of the power transformer can be reduced by about 80 percent in the Δ-Y transformer connected 12-pulse AC/DC converter. This paper presents 12-pulse AC/DC converter in the development of a sinusoidal line side converter for use with a variable speed AC drive.

12-Pulse AC/DC Converter

In the mid 1960s when power semiconductors were only available in limited ratings, twelve-pulse drives provided a simpler and more cost effective approach to achieving higher current ratings than direct paralleling of power semiconductors. This technique is still employed today in very large drive applications.

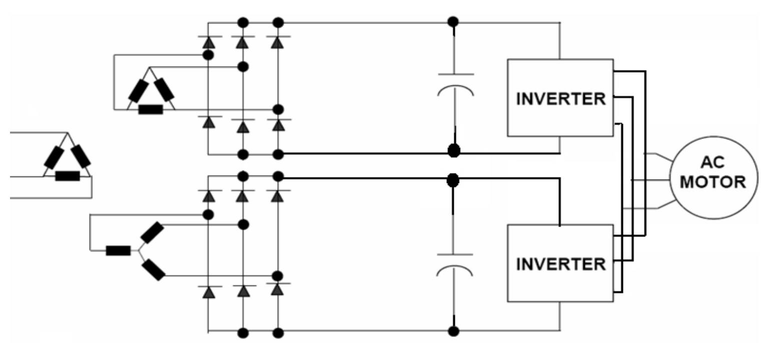

Fig.1. 12- pulse parallel connected AC Drive Power Structure

A typical diagram of a large twelve-pulse drive appears in figure 1. The drive's input circuit consists of two six-pulse rectifiers, displaced by 30 electrical degrees, operating in parallel. The 30-degree phase shift is obtained by using a phase shifting transformer.

The circuit in figure 1 simply uses an isolation transformer with a delta primary, a delta connected secondary, and a second star connected secondary to obtain the necessary phase shift. Because the instantaneous outputs of each rectifier are not equal, an inter phase reactor is used to support the difference in instantaneous rectifier output voltages and permit each rectifier to operate independently. The primary current in the transformer is the sum of each six-pulse rectifier or a twelve-pulse wave form.

Phase shifting involves separating the electrical supply into two or more outputs, each output being phase shifted with respect to each other with an appropriate angle for the harmonic pairs to be eliminated. The concept is to displace the harmonic current pairs in order to bring each to a 180^o phase shift so that they cancel each other out.

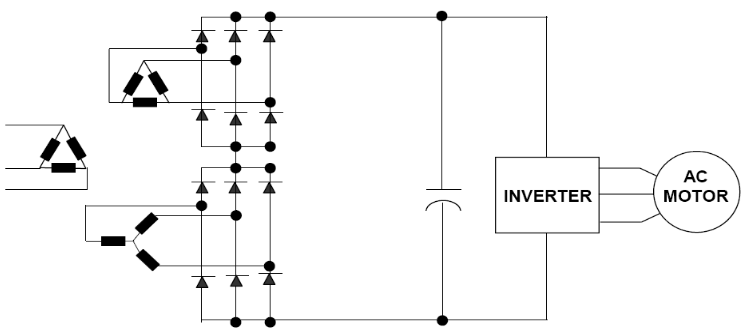

Fig.2. 12- pulse series connected AC Drive Power Structure

Positive sequence currents will act against negative sequence currents, where as zero sequence current act against each other in a three phase system. Recall that triplen harmonics are zero sequence vectors; 5^{th}, 11^{th}, 17^{th} harmonics are negative sequence vectors, and 7^{th}, 13^{th}, 19^{th} harmonics are positive sequence vectors.

Hence, an angular displacement of:

60^0 is required between two three-phase outputs to cancel the 3^{rd} harmonic currents.

30^0 is required between two three-phase outputs to cancel the 5^{th} and 7^{th} harmonic currents.

15^0 is required between two three-phase outputs to Cancel the $11^{th}$and 13^{th} harmonic currents.

For instance, in the case of two 6-pulse variable frequency drives of similar rating, installing a delta-star transformer (30^0 with respect to the primary) on one drive, and delta, delta transformer (0^0 with respect to the primary)on the other drive, gives an angular displacement of 30^0 between the two outputs, providing the equivalent of a 12-pulse system. On the common supply of both transformers on the primary, phase shifting between the systems will cancel the 5^{th} and 7^{th} harmonic currents. An angular displacement 15^o between outputs provides the equivalent of a 24-pulse system, but requires four 6-pulse loads. The above approach that is phase shifting non-linear loads can thus be used to reduce the effects of selected harmonics.

Plant History

Tamil Nadu Newsprint and Papers Limited (TNPL) was established by the Government of Tamil Nadu during early eighties to produce Newsprint and Printing & Writing Paper using bagasse, a sugarcane residue, as primary raw material. The Company commenced production in the year 1984 with an initial capacity of 90,000 tonnes per annum (tpa). Over the years, the production capacity has been increased to 2,45,000 tpa and the Company has emerged as the largest bagasse based Paper Mill in the world consuming about one million tonnes of bagasse every year. The Company completed a Mill Expansion Plan during December 2010 to increase the mill capacity to 4, 00,000 tpa. The mill consists of 3 Paper Machines with supporting pulp producing facilities. The utility facilities consist of *2* recovery boilers and 6 power boilers and 5 turbine generators.

The Recovery Boiler Power Distribution and 12- Pulse Drives Installation diagram is shown in Figure 3. The industrial plant is supplied from 24.5 MW T.G through Distribution transformers of 2 MVA, Dyn11, and 11kV/415V. In order to recover the chemicals, the black liquor is first concentrated in the evaporator. The heavy black liquor, concentrated in the evaporators, is burned in the Recovery Boiler where the lignin becomes fuel. The Recovery Boiler burning process is done by 4 burner groups. Each burner mixes the furnace oil/black liquor with a controlled flow of air given by 4 fans driven by 12-pulse drives. The fans control the furnace oil/black liquor burning process, each device running independently from the others, but

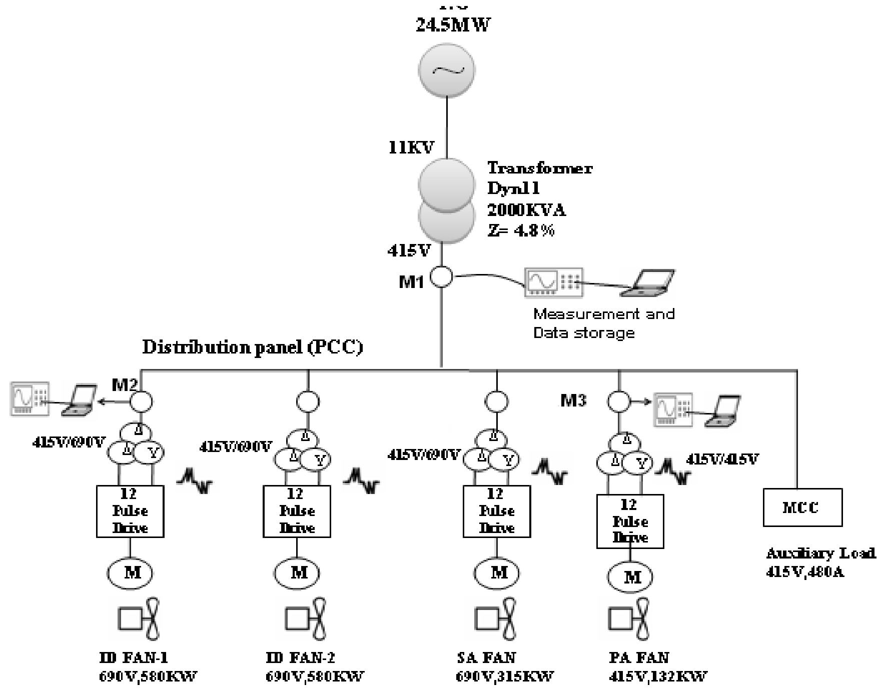

Fig.3. Recovery Boiler Power Distribution and 12- Pulse Drives Installation.

controlled by a closed control loop that keeps the burning process. Therefore, depending on the required burning process, the plant can have fans running at different speeds and different loadings. The table-I present connected load Nominal data and Drive Running data.

TABLE-I Nominal and Drive Running data

S.No	Load (Process name)	Nominal Data				Drive Runing Data				Converter Type (Adjustable Speed Drive)
		KW	V	FLC	R PM	KW %	V	RLC	R PM	
1	ID Fan-1	585	690V	595A	1000	17	335.5	262	486	12 Pulse converter
2	ID Fan-2	585	690V	595A	1000	18	345.7	286	493	12 Pulse converter
3	Secondary Air Fan	315	690V	312A	1500	27.8	428.2	147	910	12 Pulse converter
4	Primary Air Fan	132	415V	209A	1500	19.1	243.2	84.5	880	12 Pulse converter
5	TA Fan	90	415V	146A	1500	35	287.5	83.4	1014	6 Pulse converter

The mill has recently undertaken an extensive study of their power system and study results (M2 and M3) are presented. At the time of harmonics study the PA fan is running with 6 pulse drive, the voltage and current wave form and current harmonics spectrum are shown in figure 4. A six pulse converter would generate harmonic current of the order 5^{th}, 7^{th}, 11^{th}, 13^{th}, 17^{th}, 19^{th}, 23^{rd}, 25^{th}, etc. It is clear from this figures that the supply current has very high 73.45%THD mostly of 5^{th} and 7^{th} harmonics and the supply current becomes to non sin-wave. As a result of this study 12 pulse drive were installed to correct the present problem when looking for a variable speed drive for PA fan upgrade it was thought that if a 12 pulse VFD could be applied which would have minimal effect on their power system, additional PF correction and filtering would not be required in the future. The variable frequency drive with it's 12 pulse drive or sinusoidal rectifier was a potential solution, with minimal harmonic current distortion. After 12 pulse drive installed the supply current THD reduced from 73.45% to 15.5%. The voltage and current wave form and current harmonic spectrum are shown in figure 5.The PA fan drive measurement point is mentioned M3 in figure 3.

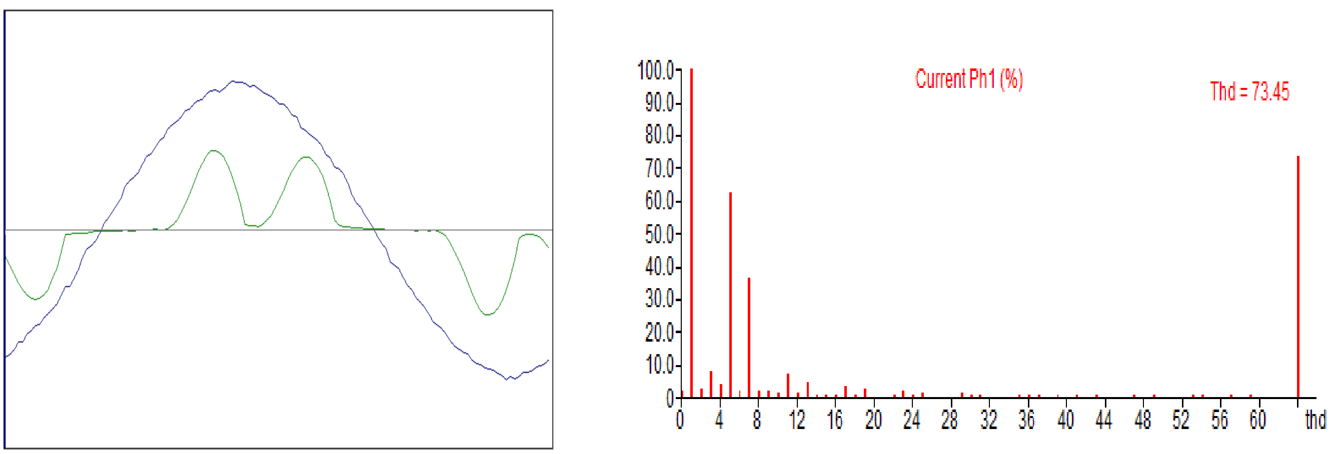

Fig.4. PA fan 6 pulse drive Line Voltage and Current Waveform with harmonic spectrum

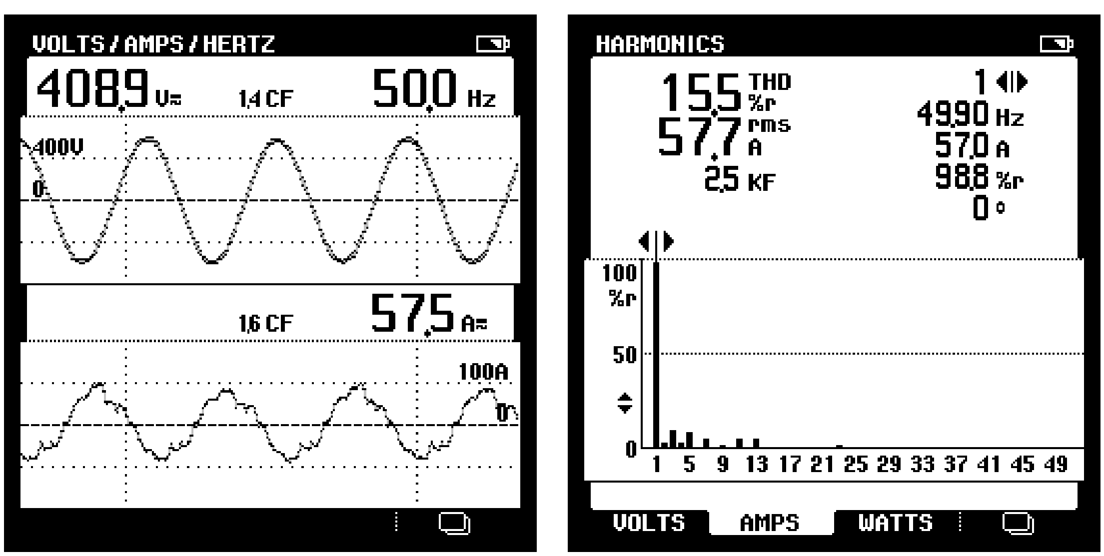

Fig.5. PA fan 12 pulse drive Line Voltage and Current Waveform with harmonic spectrum

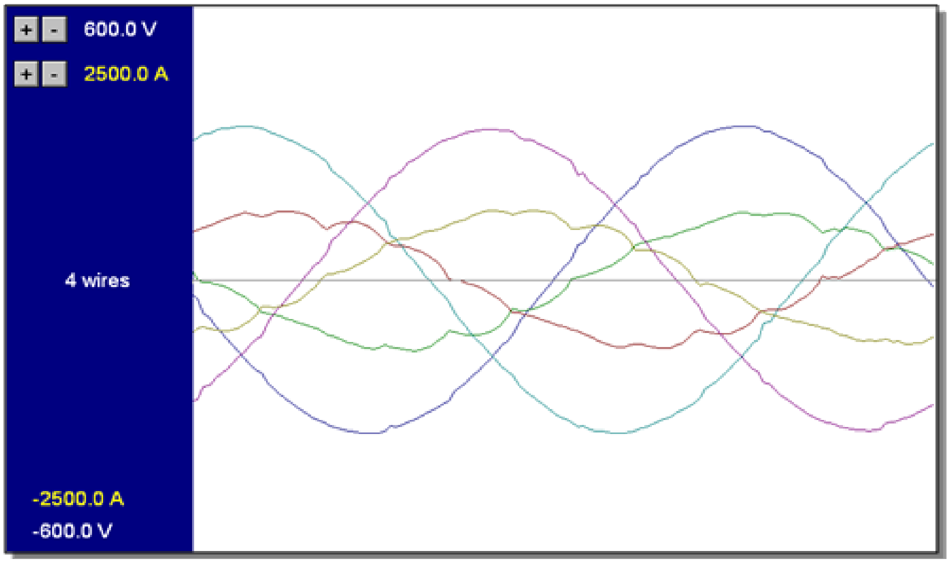

Fig.6. Line Voltage and Current Waveform

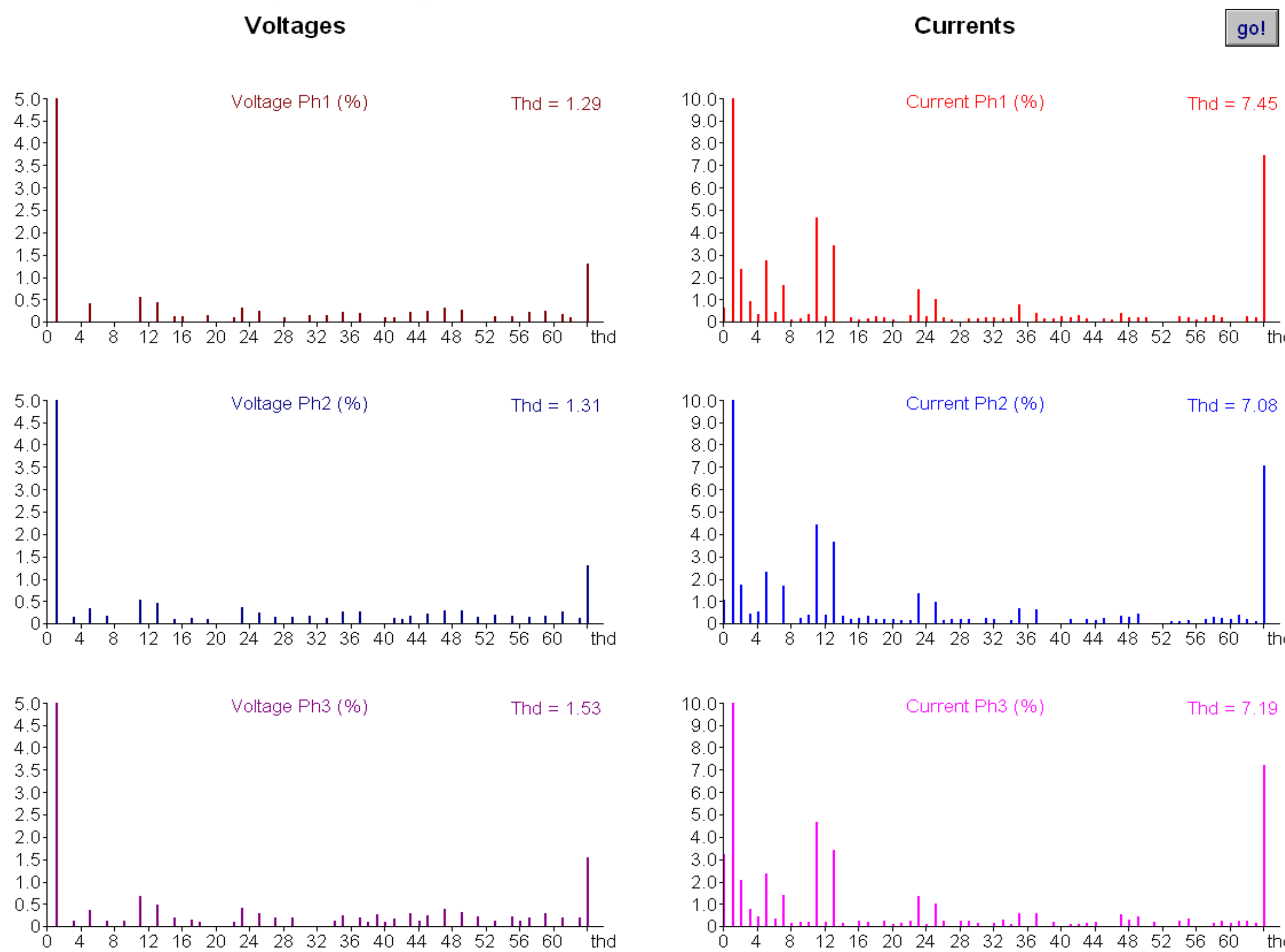

Fig.7. Line Voltage and Current Harmonic spectrum

The 585KW, 690V ID fan 12- pulse drive was investigated in Recovery Boiler. The two 6-pulse variable frequency drives of similar rating, installing a delta-star transformer 415/690V (30^0 with respect to the primary) on one drive, and delta, delta transformer 415/690V (0^0 with respect to the primary) on the other drive, gives an angular displacement of 30^0 between the two outputs, providing the equivalent of a 12-pulse system for the 700KVA rating. The three phase line voltage and current wave form and its Harmonic spectrum are shown in figure 6 and 7. A 12- pulse converter would generate harmonic current in the order 11th , 13^{th} , 23^{rd} ,25^{th} ,etc. The figure 8 shows the THD values at different load condition.

The 585KW, 690V 12- pulse drive was loaded from 20% to 100%. The THD varies widely as a function of load current I_L. The figure 8 shows the THD values in varies load (I_L) condition. The phase voltage and current wave form measured by using power quality analyzer and its Harmonic spectrum are shown in figure 9 and 10 . A 12- pulse converter would generate harmonic current in the order 11^{th} , 13^{th} , 23^{rd} ,25^{th} ,etc.

A six pulse converter would generate harmonic current of the order 5^{th}, 7^{th}, 11^{th} , 13^{th} , 17^{th} , 19^{th} ,23^{rd} ,25^{th} ,etc. Figure 11.a and

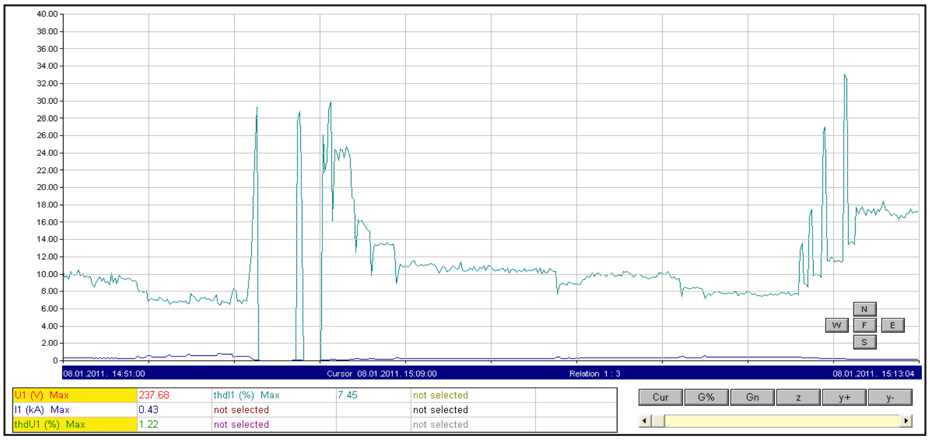

Fig.8. THD value in varies load (I_L) condition

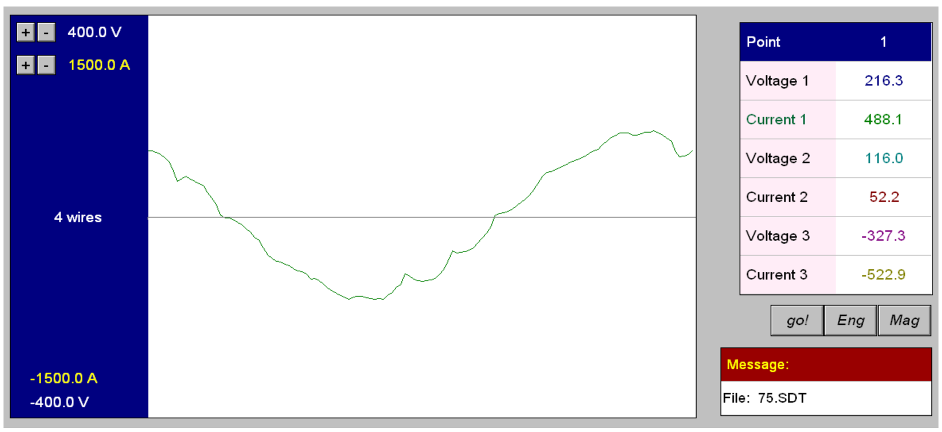

Fig. 9. Phase Current Waveform

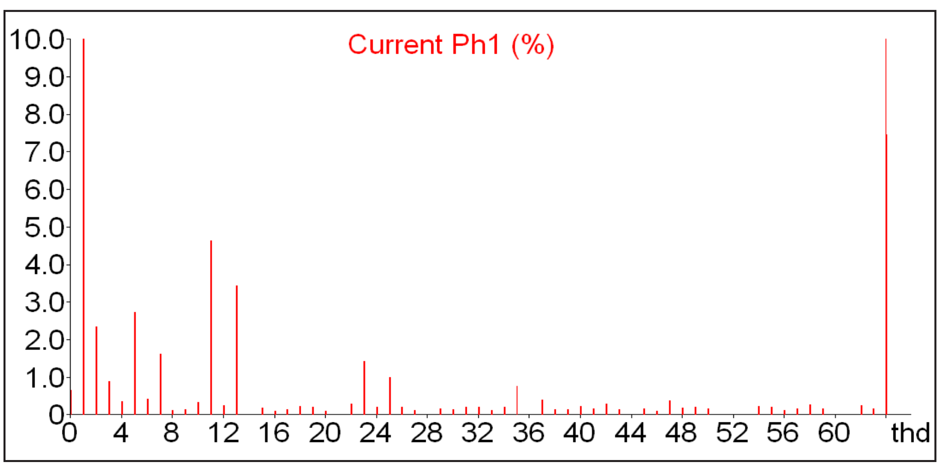

Fig.10. Phase Current Harmonic spectrum

11.b shows the phase current waveform and its FFT components with respect to phase voltage V_{ab} in star connected drive and figure 12.a and 12.b shows the phase current waveform and its FFT components with respect to phase voltage V_{ab} in delta connected drive . It is clear from this figures that the supply current has very high THD mostly of 5th and 7th harmonics and the supply current becomes to non sin-wave.

Conclusion

The analysis of a 12-pulse Diode rectifier is carried out, the two 6-pulse rectifiers has an important influence on input current THD, the THD varies widely as a function of load current I_L.This paper presents the harmonic study of 12-Pulses converters in industrial applications. Case study of harmonic analysis is performed for Pulp and Paper industry at TNPL, Karur, Tamilnadu, India. THD is used as the harmonic index and harmonic spectrum is presented for 12-Pulse drives and for the industrial drive system.

Acknowledgement

The authors would like to acknowledge the Electrical Department of Tamilnadu Newsprint and Papers Ltd (TNPL), Karur, Tamilnadu, India for providing the electrical supply distribution scheme to carry out the work.

References

[1] IEEE Guide for Application and Specification of Harmonic Filters, IEEE Std. 1573, 2003.

[2] D. A. Gongalez and J. C. Mccall, "Design of filters to reduce harmonic distortion in industrial power systems," *IEEE Trans. Ind. Appl.*, vol. IA-23, no. 3, pp. 504511, May/Jun. 1987.

[3] METREL **MI 2092**, Three-Phase Power Quality Analyzer Users Manual Catalog-2006.

[4] D. A. Paice, "Transformers for Multipulse AC/DC Converters," U.S.Patent no. 6 101 113, Aug. 8, 2000.

[5] S. Hansen, U. Borup, and F. Blaabjerg, "Quasi 12-pulse rectifier for adjustable speed drives," in *Proc. IEEE APEC Conf.*, 2001, pp. 806812.

[6] M.F. McGranaghan and D.R. Mueller, "Designing Harmonic Filters for Adjustable-Speed Drives to Comply with IEEE-519 Harmonic Limits," IEEE Transactions on Industry Applications, Vol. 35, No. 2, March/April, 1999, pp. 312-318.

[7] R.G.Ellis, "Harmonic Analysis of Industrial Power

System," IEEE Transactions on Industry Applications, Vol. 32, No. 2, March/April 1996, pp. 417-421.

[8] A. Siebert, A. Troedson, and S. Ebner, “AC to dc power conversion now and in the future,” *IEEE Trans. Ind. Appl.*, vol. IA-38, no. 4, pp. 934940, Jul./Aug. 2002.

[9] D. E. Rice, “A detailed analysis of six-pulse converter harmonic currents,” *IEEE Trans. Ind. Appl.*, vol. 30, no. 2, pp. 294304, Mar./Apr. 1994.

[10] Bimal. K. Bose, Modern *Power Electronics and ac Drives*. Prentice-Hall, 2005.

[11] M.Villablanca, J. Nadal, and M. Bravo, “A12-pulse ac-dc rectifier with high-quality input/output waveforms,” *IEEE Trans. Power Electron.*, vol. 22, no. 5, pp. 18751881, Sep. 2007.

[12] A. Siebert, A. Troedson and S. Ebner, “AC to DC power conversion now and in the future, “IEEE Trans. on Ind.Applicat. Vol. IA-38, No. 4, pp.934-940, 2002.

[13] J.R. Rodriguez *et al*., “Large current rectifiers: state of the art and future trends,” IEEE Trans. on Ind. Electron., Vol. 52, No. 3, pp.738-746, 2005.

[14] C. Rech and J.R. Pinheiro, “Line current harmonics reduction in multipulse connection of asymmetrically loaded rectifiers,” IEEE Trans. on Ind. Electron., Vol. 52, No. 3, pp.640-652, 2005.

[15] S. Fukuda and M. Ohta, “An Auxiliary-Supply-Assisted Twelve-Pulse Diode Rectifier with Reduced Input Current Harmonics,” IEEE IAS Annual Meeting, 2004.

[16] S. Fukuda, and I. Hiei, “An auxiliary-supply-assisted input current harmonic reduction in 12-pulse Thyristor Rectifiers,” IEEE Trans. on Ind. Appl. Vol. 44, No. 1, pp.205-212, 2008.

[17] F. J. M. de Seixas and I. Barbi, “A12 kW three-phase low THD rectifier with high frequency isolation and regulated dc output,” *IEEE Transactions on Power Electronics,* Vol.19, March 2004, pp. 371377.

[18] Hammond, “ Wye Connected 3-Phase to 9-Phase Autotransformer With Reduced WindingCurrents,” *U.S. Patent 6191968 B1*, February 20, 2001.

[19] D.A.Paice, “Simplified Wye Connected 3-Phase to 9-Phase Autotransformer,” *U.S.Patent 6 525 951 B1*, February 25, 2003.

[20] G. R. Kamath, D. Benson, and R. Wood, “A novel autotransformer based 18- pulse rectifier circuit”, *Proceeding of IEEE IECON'02*,2002 pp. 795801.