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# A Study on Harmonics due to Front-End Rectifiers in Electrical Drives at Milling Tandem of Sugar Industry

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**Abstract**— A modern sugar industry has around 80 to 90 Variable Frequency Drives (VFDs) beside an additional 300 electrical motors that run on different types of starters. Among these VFDs, the majority of the load is on sugarcane milling station. The mills, of 4 or 5 sets in tandem, consumes around 25-30% of total electrical power consumed by the industry. The front-end rectifiers in the electrical drives of these mills rollers are a major source of harmonics and thereby polluting power. In most of the places, two delta/delta-wye type converter transformers are used to feed motors of four mills through VFDs. By this, two individual 6-pulse rectifiers act as 12-pulse rectifier resulting in canceling of the $5^{th}$ and $7^{th}$ ordered harmonics and bringing the Total Harmonic Distortion (THD) down to around 10%. In some of the cases, if the motor rating is rather lower, then the drives are fed directly from the bus. This results in injecting harmonics of even the dominating $5^{th}$ and $7^{th}$ order harmonics resulting in much more THD than in the case of two converter transformer. The very application of sugarcane milling tandem can further be improved and a 24-pulse for 4 sets or 30-pulse for 5 sets in the tandem can be realized. This paper presents a simulation study on harmonics due to front-end rectifiers in the electrical drives of existing set up for sugarcane milling station. The simulation is carried out on MATLAB/Simulink.

**Keywords**— *VFD, DC Drive, Milling tandem, harmonics, THD, Converter Transformer, MATLAB/Simulink.*

## INTRODUCTION

The sugar-making process has broadly four steps, namely, cane preparation, milling, clarification and crystallization. To run the factory, there are more than 400 electrical motors rating from a few kW to few MW range. In this process, a share of around 25-30% of total installed power is in Sugarcane Milling station. In general, there are 4 or 5 sets of milling rollers in tandem. Each set has 3 rollers each accompanied with pressure feeders in most of the cases. The outline of the set-up is shown in figure 1 showing only three rollers and no pressure feeders. The prepared cane enters at one end and after the first mill, subsequent crushing of three to four times in tandem is done to extract maximum juice and leftover bagasse is sent to a boiler where it is used as fuel to generate electricity and heat energy in through co-generation [1]. The prime mover for these mill rollers can either be steam turbine in case of older factories and DC or induction motor driven by DC drive or VFD respectively. Almost all types of electrical drives prevailing at that time except the modern VFD based drives are covered in [2]. In the recent years, there has been a growing trend of using VFDs in the sugar industries. These drives give a precise as well as dynamic control of the speed/torque characteristics of the motor as per the requirement. However, these VFDs distorts

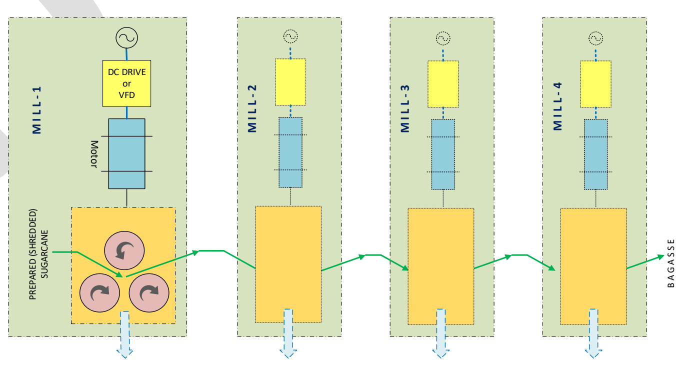


Fig.1. Four 3-rollers mills in milling tandem driven by DC Drive/VFD

the power quality by injecting the current harmonics in the power system. The effects of harmonics can include overheating of transformers, cables, motors, generators and capacitors connected to the same power supply with the devices generating the harmonics. Electronic displays and lighting may flicker, circuit breakers may trip, computers may fail and metering may give false readings [3][4]. Further, harmonic spectrums of electric drives depend on the type of drive (DC drive or VFD) and applied converters and circuit elements. Besides, the harmonic content depends on operating speed and torque value [5]. The limitations and practices related to harmonics is given in [6]. This paper presents a simulation study for assessing Total Harmonics Distortion (THD) due to the DC drives and VFDs used in the sugar industry at milling station. Three cases have been discussed, namely, the case of 4 mills driven by 4-DC drives, the case of 4 mills driven by VFDs and the case of 2 mills driven by DC drive and 2 mills driven by VFDs. For each case, two topologies are studied, first by directly feeding from the bus and second from the converter transformer (delta/star-delta type).

## ANALYSIS OF HARMONICS DUE TO ELECTRICAL DRIVES AT MILLING TANDEM OF A SUGAR MILL

### DC Drives at Milling Tandem

A typical three-phase DC drive is shown in figure 2. The equations related to torque and speed equations is shown in equation (1). To control the speed lower to the rated speed of the motor the armature voltage is controlled, also known as constant torque region, by controlling the firing angle of the thyristors of three-phase rectifier shown in the figure. To increase the speed beyond the rated value the motor is operated in field weakening mode, wherein the field is reduced by increasing the firing angle of single-phase rectifier feeding to the field winding.

$$\left.\begin{aligned} T &= K_a \phi I_a \\ \omega_m &= \frac{v_a}{K_a\,\phi} - \frac{R_a}{K_a \phi}\,T \end{aligned}\right\}$$

*Case-1: All the DC drives are fed directly from the bus*

In old and small factories the generated voltage is 415V, 50Hz. Therefore, mill drives are directly fed from the bus. This kind of arrangement results in the injection of harmonics due to each drive and the harmonics get summed in the bus. The optimum energy consumption has always been a matter of concern and accordingly various configurations were reported in the literature [7]. At any given instant of time, each drive faces marginally different load as the load is also a function of the density of the bagasse and mill roller grooving. Figure 3 shows the simulation circuit arrangement of four DC drives connected directly to the bus and through converter transformers. The input current waveforms for each drive is shown in common axes and waveform for total input current at the point of common contact is shown separately in figure 5. The harmonic spectrum is also shown for the total input current at the point of common contact. It can be seen that since the dc drive is not having a capacitor as a filtering device the THD is rather lower than the drives having capacitor as a filter unit. The THD for the total current drawn from the bus is 23.75% if all the drives connected directly to the bus and 13.06% if all the drives are connected through a converter transformer. This is higher than the norms as per IEEE-519. The IEEE Standard 519-1992 is now the norm for harmonic specifications in USA and countries with NEMA electrical standards [4].

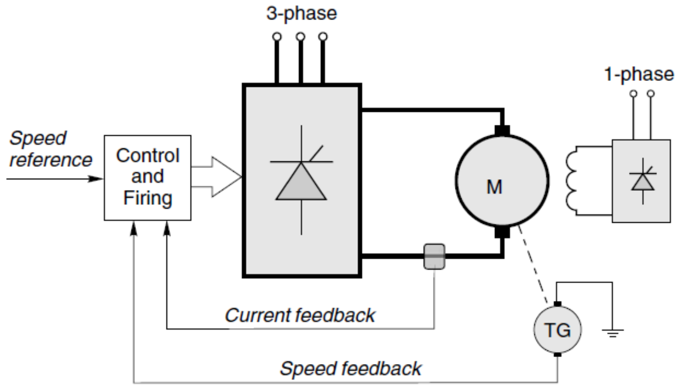


Fig.2 General arrangement of DC drive

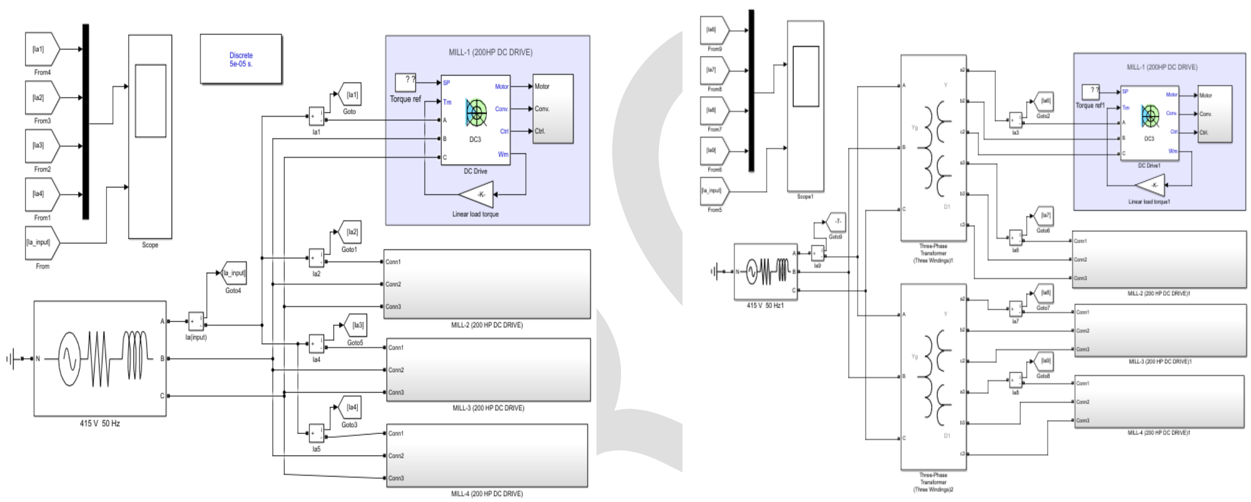

Fig.3. DC drives for four mills in tandem fed directly from bus *(left)* and through converter transformers *(right)*

*Case-2: All the DC drives are fed through converter transformer (Delta/star-delta)*

In a rather modern medium and large capacity plants where the generated voltage level is 11kV, 50Hz a converter transformer is required to step down the voltage level. The converter transformer used is a delta/star-delta type. In this type of transformer, a 12-pulse rectifier is realized and a 30° displacement results between two three-phase voltage sources canceling the 5$^{th}$ and 7$^{th}$ harmonics and the input current THD of around 10% can be achieved [8][9]. The major drawbacks are the need for special transformers and a higher cost than with the 6-pulse rectifier [3]. The THD in this case came out to be as 8.61%.

**VFDs at Milling Tandem**

Though DC drives are known for their ability to provide tight speed control and full torque at any speed but due to recent developments in AC drives the performances similar to DC motor and drive systems are achieved. However, for continuous operation for low speed, DC drives have edge over AC drives. As far as the harmonics are concerned, as with the DC drive, the VFDs also draw non-sinusoidal currents from the utility supply. As a result, it is common for a standard motor to have to be de-rated (by up to perhaps 5 or 10%) for use on an inverter supply [10]. While the growth rate for AC drives is around 8 % p.a., with the market's volume for DC drives remaining more or less stable. For general motor evaluation, many users adopt the following rather simplistic view: the DC motor is complicated and requires a lot of maintenance, which makes it expensive to run; it also has a lower degree of protection. The AC motor, on the other hand, is simple and sturdy, does not need much maintenance, is therefore, less expensive, and possesses a higher degree of protection into the bargain. However, A comparison of operating characteristics of DC and AC motors shows that the direct-current motor is advantageous to the asynchronous motor for continuous operation at low speeds and for high setting ranges at constant power [11]. The various types of electrical drives that were in use conventionally at the milling station of the sugar factory were discussed in [2]. The conventional and recent types of drives and future possibilities are discussed in [12][13]. However, nothing about harmonics due to these drives is discussed by the authors. The general arrangement of a typical VFD is shown in figure 4. The three-phase input ac supply is first fed to a three-phase rectifier followed by a three-phase inverter. Generally, a capacitor bank is placed at dc-link as a filter unit to reduce ripples in the dc voltage fed to the inverter. For the scalar control, the speed and torque are controlled as per the equation (2) by controlling frequency keeping the v/f ratio constant.

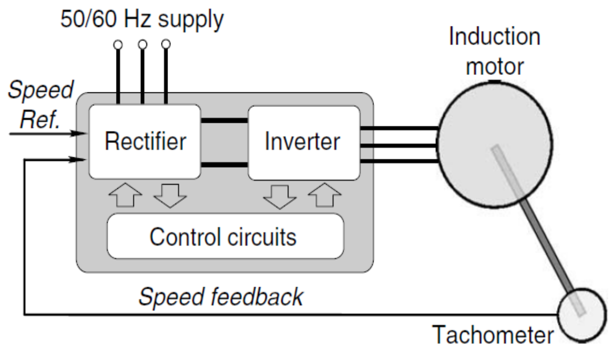


Fig.4 General arrangement for variable-frequency induction motor drive

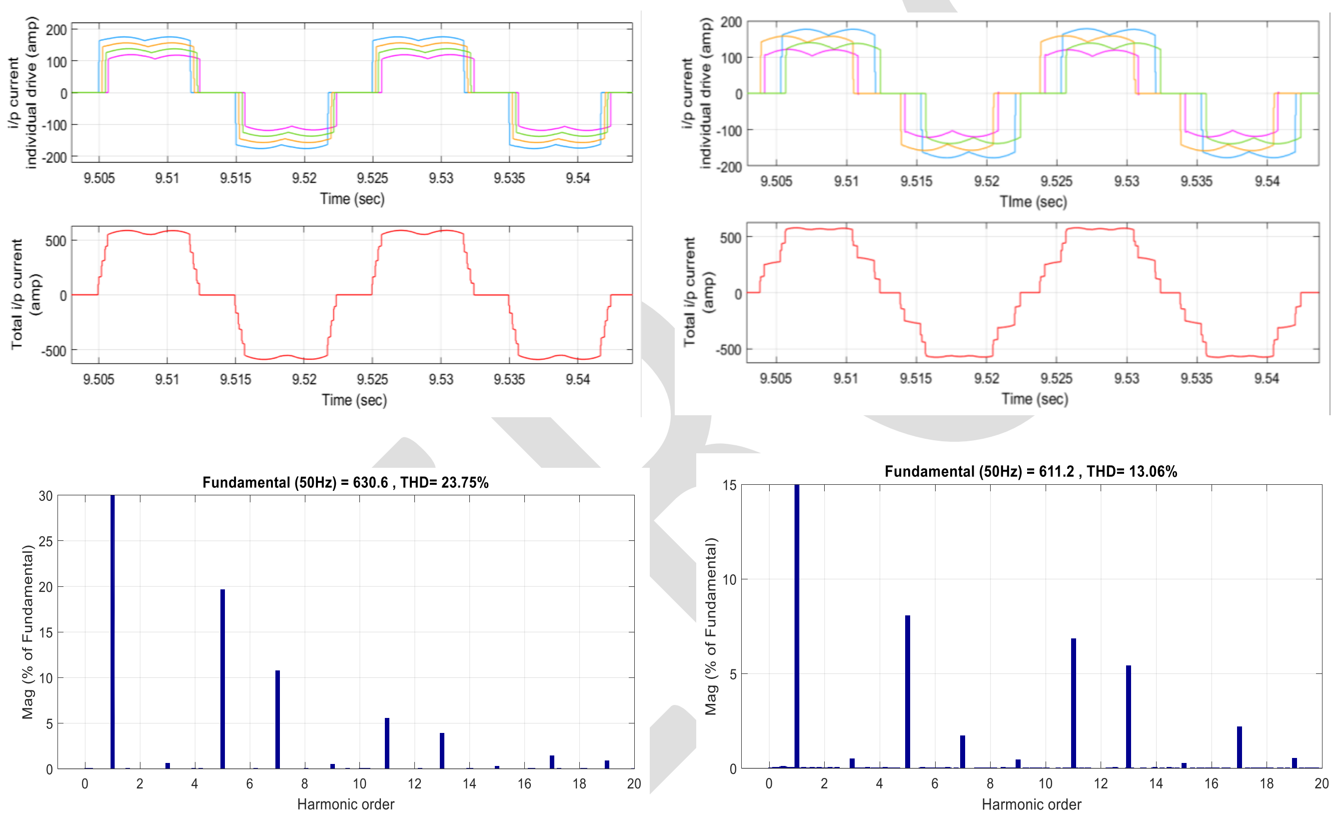


Fig.5 Waveforms for individual and total current alongwith its harmonic spectrum for circuit in figure 2. *(Left)* for DC drives fed directly from the bus. *(Right)* for DC drives fed through converter transformers

$$T_e = \frac{3R_r}{\omega_s} \frac{V_s^2}{\left(R_s + \frac{R_r}{s}\right)^2 + (X_{ls} + X_{lr})^2}$$

$$\omega_s = \frac{120f}{P}$$

(2)

*Case-1: All the AC drives (VFDs) are fed directly from bus*

As already explained above that for small factories and with generation of supply at 415V, 50 Hz, the drive at milling station are directly connected to the bus. Also, the load at different mills is marginally different due to the reasons cited before. The harmonics in the input current which is the sum of individual load comes to be much higher than the case-2 which is explained subsequently. The circuit diagram is similar to as shown in figure 3 but for induction motor drive. The THD for the input current at the point of common contact came out to be 61.59%.

*Case-2: All the AC drives (VFDs) are fed through Converter Transformers*

As in the case of dc drives, for the higher capacity sugar factories, the generation voltage level is taken as 11 kV, 50 Hz. For such cases, if the motors are of 415V, 50 Hz voltage rating, the converter transformers are used for both reducing the voltage level as well as harmonics in the input current. Figure 6 shows the waveforms of individual drive and the total current at the point of common contact for case-1 above and case-2 as well as harmonics spectrum of total input current in both the cases. The THD for the total current in this case came to be 8.61%.

**DC Drives & AC drives (VFDs) at milling tandem**

When any factory undergoes modernization in phases then some or all the DC drives are replaced with VFDs. The drives as mentioned earlier can directly be fed from the bus in case of a small factory where the generation itself is 415V, 50Hz, and through converter transformers for a higher level of voltage generated. The arrangement where two dc motor drives and two VFDs are installed with and

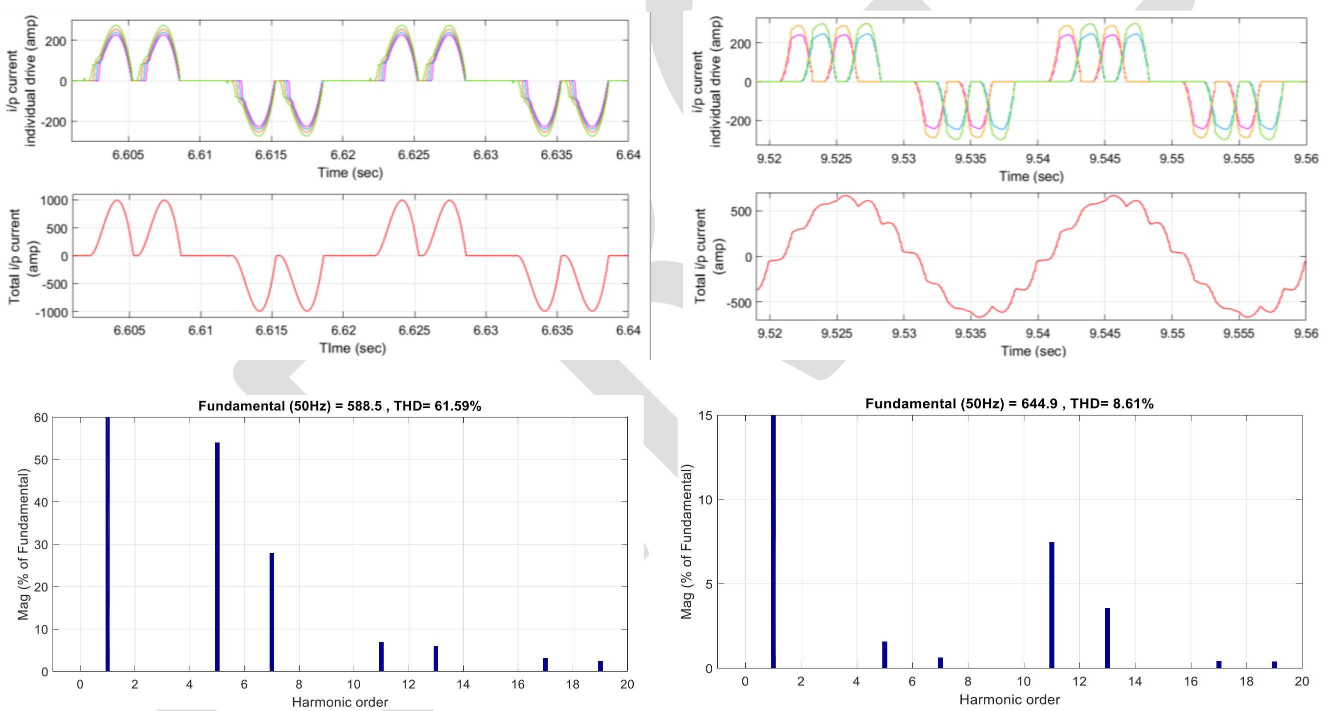


Fig.6. Waveforms for individual and total current along with its harmonic spectrum for VFDs at milling station fed directly from the bus *(left)* and fed through converter transformer *(right)*.

without converter transformer is similar to the figure 3 shown for dc drives. Only in place for four DC drives, two VFDs, and two DC drives are employed. For the case of drives fed through converter transformer, the two DC drives are fed through one converter transformer and the two VFDs are fed through another converter transformer. The waveforms in respect of input currents and harmonics spectrum for the total input current for both the cases as in earlier cases is shown in figure 7. The THD for the mill drives directly fed from the bus came out to be 27.57% and for the drives fed through converter transformer came out to be as 4.72%. The harmonics ($5^{th}$,

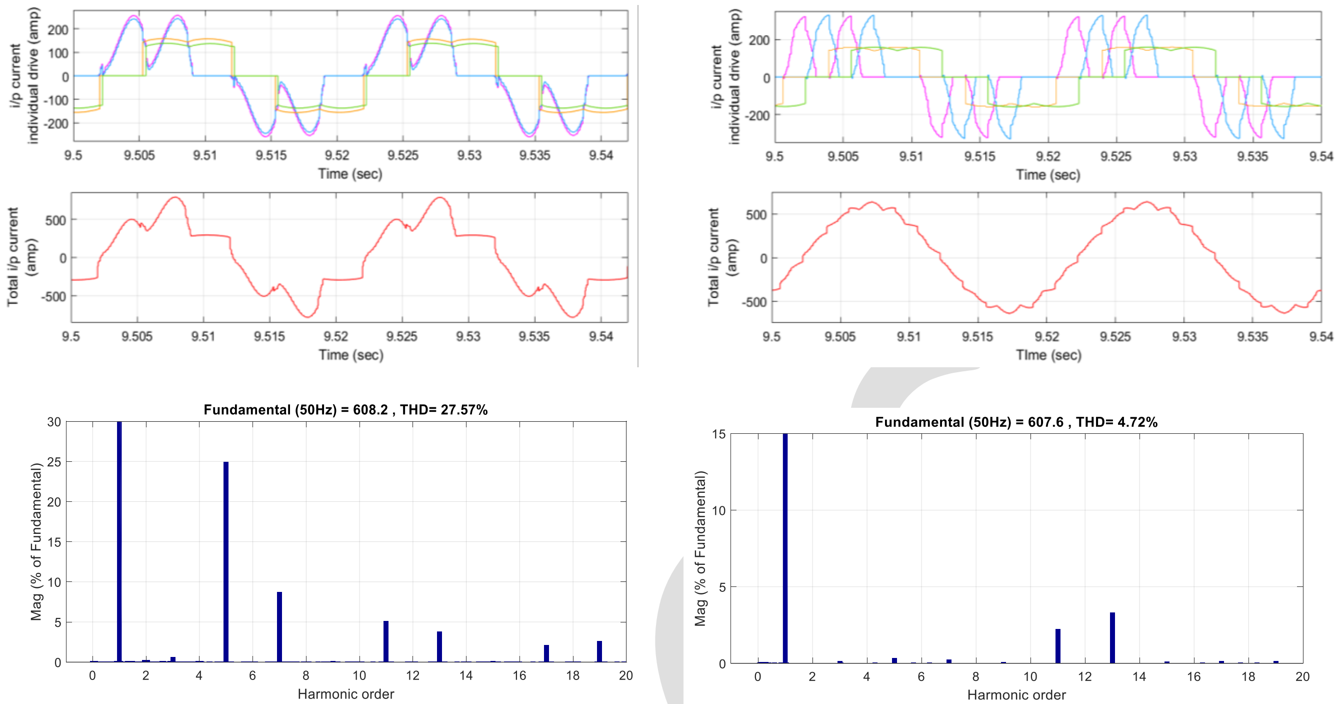


Fig.7 Waveforms for individual and total current along with its harmonic spectrum for DC Drive & VFDs combination at milling station. *(Left) F*ed directly from the bus. *(Right)* Fed through converter transformer.

TABLE I. COMPARISON OF PROMINENT ORDERED HARMONICS & THD FOR THE VARIOUS ARRANGEMENTS

| **Sl. No.** | **Type & no. of Drives** | **With /without converter transformer** | **% w.r.t. fundamental** | | | | | | **THD** |
|---|---|---|---|---|---|---|---|---|---|
| | | | **h-5** | **h-7** | **h-11** | **h-13** | **h-17** | **h-19** | |
| 1. | DC drives (four) | Without converter transformer | 19.5 | 10.77 | 5.57 | 3.9 | 1.46 | 0.91 | 23.53 |
| 2. | | With converter transformer | 8.0 | 1.74 | 6.86 | 5.44 | 2.2 | 0.55 | 13.06 |
| 3. | VFDs (four) | Without converter transformer | 53.92 | 27.90 | 6.86 | 5.91 | 3.10 | 2.40 | 61.59 |
| 4. | | With converter transformer | 1.58 | 0.64 | 7.48 | 3.58 | 0.43 | 0.40 | 8.61 |
| 5. | DC drives (two) & | Without converter transformer | 24.93 | 8.72 | 5.12 | 3.81 | 2.12 | 2.59 | 27.57 |
| 6. | VFDs (two) | With converter transformer | 0.34 | 0.26 | 2.23 | 3.31 | 0.15 | 0.15 | 4.72 |

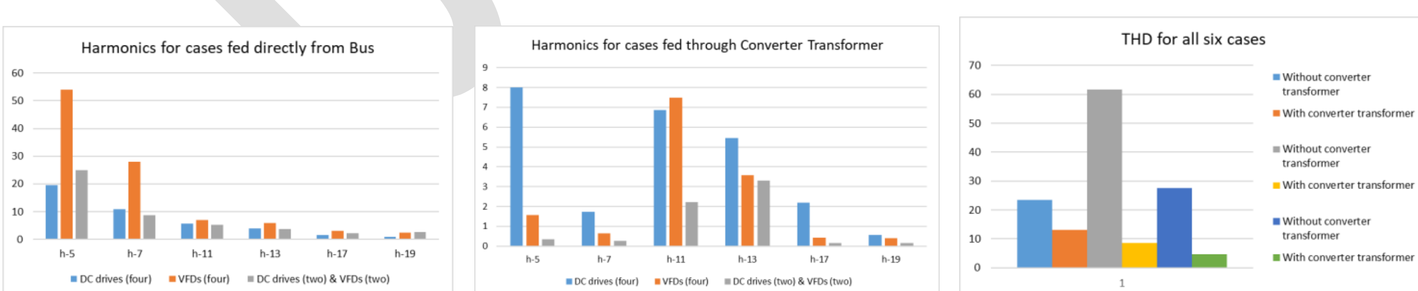


Fig.8 Bar graph showing Harmonics for cases fed directly from the bus , for the cases fed through converter transformers and THDs for all the cases.

$7^{th}$, $11^{th}$, $13^{th}$, $17^{th}$ & $19^{th}$) and THD for various cases that are discussed in the paper is tabulated in Table-I. The comparison for each case and for THDs is shown through bar graphs in figure 8.

## CONCLUSION

The electrical drives for milling tandem at a sugar factory are studied for input current harmonics at the point of common contact. For the cases of drives connected directly to the bus, the most prominent $5^{th}$ order harmonic seen to be the highest in case of VFDs and lowest in case of dc drives. For the drives fed through converter transformer, the $5^{th}$, $11^{th}$ and $13^{th}$ order harmonics were seen prominent with their value on higher side in case of VFDs and lowest in case of combination of drives. For drives fed directly from bus, THD is seen to be highest in case of VFDs followed by combination drive and then dc drives. Whereas, for the drives fed through converter transformers, THD is seen to be highest in DC drives followed by VFDs and then combination drives.

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