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Efficacy of Using Variable Frequency Drives for Sugarcane Preparation Machines

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ABSTRACT

Conventionally, the sugarcane preparatory machines in the sugar factories are run by slip ring induction motors (SRIMs). The SRIM drives have inherent problems of huge slip power loss, poor speed regulation and unequal load sharing. Recently, in some of the factories in India Variable Frequency Drives (VFDs)have been implemented to run sugarcane preparation machines. Though, the VFDs proved better to the conventional SRIM drives in terms of efficiency, speed regulation, power factor and load sharing, but, at the same time these drives are associated with the problems of high harmonics in both input current as well as output voltage and motor current, high dV/dt stress on inverter switches and high common-mode voltage. The present paper presents a study to assess the efficacy of using VFDs for running sugarcane preparation machines. The study is based on the data collected from various sugar factories and a detailed comparison of the age-old SRIM drives and the recently inducted VFDs for sugarcane preparation machines.

Keywords: Sugarcane preparation, slip ring induction motors, variable frequency drive, harmonics.

INTRODUCTION

The sugarcane preparation is one of the most important processes during sugar manufacturing and it consumes around 25% of the total power consumption in a sugar factory. The machines for sugarcane preparation are a kicker (optional) followed by 1st cutter (or chopper), 2nd cutter (or leveler) and a shredder/fibriser. Such machines, with huge inertia, demands a high starting torque. Conventionally, SRIMs are used to run cane preparation machines in the sugar industry. For mitigating the surges in the motor load current, some part, typically corresponding to 15% slip at full load, of the starting resistance in the rotor circuit, known as slip resistance, is kept in line throughout the operation (Nicklin, 1967; Boshoff, 1994). For small capacity factories, only one SRIM is used and in the medium and large capacity factories, two mechanically coupled SRIMs are used. One such arrangement, showing twin coupled motor for shredder is shown in (Figure 1a). This kind of set-up results in an inefficient use of the motors as an appreciable amount of power, around 8-12% of the total power consumed in the process of sugarcane preparation, is lost in the form of heat in the slip resistance. The system also suffers from low power factor, poor speed regulation and load imbalances.

Of late, in a few factories in India, VFDs are installed to run cane preparation machines to overcome the problems associated with the conventional system. The setup is shown in (Figure 1b). But, since the very application demands a constant speed throughout the operation, at least for the same variety of sugarcane, it is imperative to evaluate the pros and cons of the implementation of such drives for the application.

In the present study the efficacy of using VFDs, for running cane preparatory machines, has been assessed. A detailed comparison of both, the age-old SRIM based electric drives and the recently inducted VFDs are presented based on the data collected from various sugar factories.

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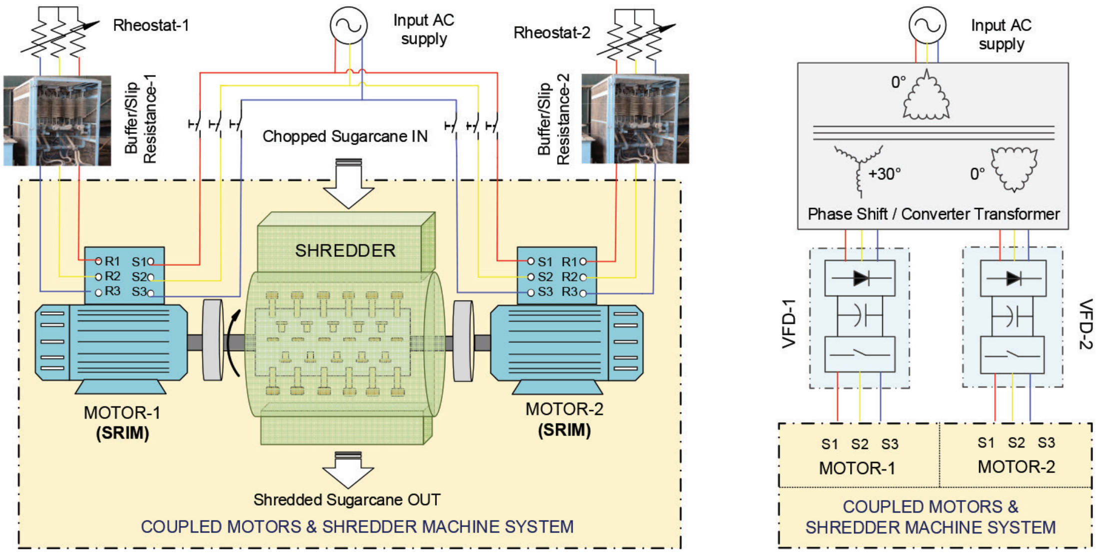


(a) (b)

Figure 1 : Electric drives for sugarcane preparation : (a) SRIM drive (b) Variable frequency drive

Comparison of srim drives and VFDs

In the 1970s the sugar industry began moving away from steam turbine driven shredders in favour of electric motor drives. To improve the cane preparation, due to the demand for higher PI of sugarcane, the shredder motor ratings had increased gradually which began to impact negatively on the power houses of the sugar mills and had the potential to result in loss of synchronism of the turbo-alternators (in co-generation section) and factory blackouts (Hall, 2009). In such isolated power systems for the issue of voltage oscillatory instability, one of the suggested solutions is through AVR compensation (de Mello and Feltes, 1996). However, the accepted solution, at that time, for sugar engineers was to keep a slip resistance in the rotor circuit of the SRIMs in line throughout the operation to relieve the stress on the power supply due to large load swings (Kumar and Kumar, 2021; Petersen, 2014).

The VFDs addressed the problems associated with the conventional system such as issues of load balancing, huge slip power loss and lowering of the rpm of the motor during peak load conditions, etc. For the coupled motors, generally, a converter/phase shift transformer is used to supply the individual VFD as shown in (Figure 1b). This kind of converter/phase shift transformer results in a 12-pulse rectifier effect at primary while using two single 6-pulse rectifier based VFDs with a 30° phase shift voltage waveform from the star-connected winding (secondary-2) with respect to the delta connected primary and secondary-1 winding.

Though the requirement at sugarcane preparation does not demand a variable speed, at least for the same variety of the sugarcane, still VFDs are installed at few factories in India. Therefore, to assess its efficacy a detailed comparison of the VFDs with the conventional SRIM drives is presented for overall efficiency, balanced load sharing, power factor and input current harmonics and common mode voltage

Overall efficiency

The modified rotor equivalent circuit after including the slip resistance, rslip, for the SRIM at sugarcane preparation machine has two resistive components one for the rotor winding (R2) and the other for slip resistance (rslip). The modified impedance of the rotor circuit is given by equation (1) and the modified power equation for the rotor circuit is given by equation (2).

$$Z_{eq}\ (modified) = X_2 + (R_2 + R_{slip}) + (R_2 + R_{slip})\ (1 - S) / S \qquad (1)$$

$$P_{in}\ (modified) = I^2\ (R_2 + R_{slip})\ (1\text{-}S) / S + I^2\ (R_2 + R_{slip}) \qquad (2)$$

One such waveform for the current through and the voltage across one leg of star-connected slip resistance as obtained using fluke-345 power quality clamp meter from the chopper motor running at around 60% load of a sugar factory named M/s Awadh Sugars Ltd., Seohara, UP (India) is shown in Fig. 2. It can be easily seen that the frequency for the rotor current is about 5.35 Hz making slip 'S', which is given by equation (3), to be 10.7%.

$$S = f_2 / f_1 = 5.35/50 = 0.107 \quad (3)$$

where, 'f_2' and 'f_1' are rotor and stator voltage frequency, respectively.

Since for such applications, R_{slip}: $R_2 \approx 14:1$, therefore, theoretically, around 14% of total input electrical power to the rotor is lost in the slip resistance. Practically, the percentage comes to 8-12% as some part of the power is lost in long cables, which are 10 to 30 meters in length depending upon the installation constraints, connecting the rotor winding to the external slip resistance. Also, since ($R_2+R_{slip} >> X_2$), therefore the power factor in the rotor circuit is expected to be unity.

Therefore, in this particular case, around 10.7% of total input power is lost in the rotor circuit, out of which a major share is in the slip resistance.

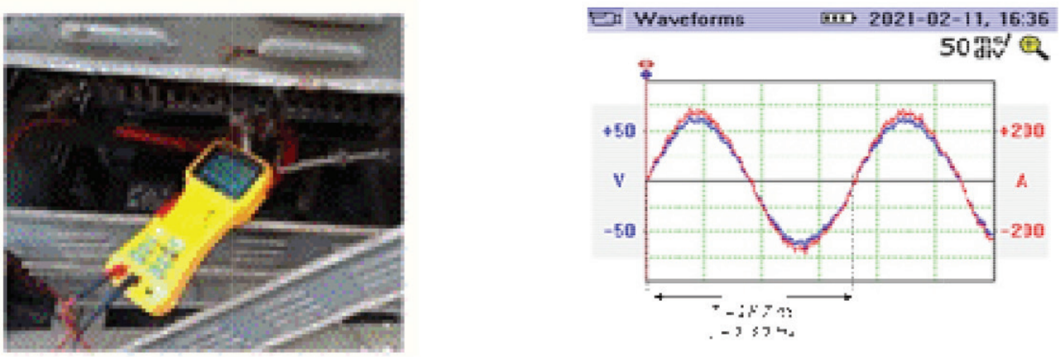


Figure 2 : Voltage and current for one leg of slip resistance as obtained from M/s Awadh Sugars Ltd., Seohara, U.P. (India)

Since squirrel cage induction motors are used in the VFDs for cane preparatory machines, there is no question of connecting external resistance like in SRIMs and hence there is no issue related to the power loss in slip resistance. As the slip % at full load for such large motors remains in the range of 1-2 %, therefore, only a meager (1-2 %) slip power loss takes place in the rotor which is usual and inevitable. Therefore, from the efficiency point of view the VFDs are much better than the conventional SRIM drive for sugarcane preparation machines.

Load sharing of the coupled motors

For the conventional system for the case of coupled motors, the preference is given for installing SRIMs of the same make and rating. But sometimes, in the case of old factories, the motor parameters becomes different in these two coupled motors because of rewinding, change in make, repair job, etc. (M. Rucinski 2013). The operating torque of the motor having higher rotor resistance becomes lower than that of the other motor having lower rotor resistance. This shifting of the operating point on the torque-speed graph results in one motor running in an overload condition, while the other motor is not yet fully loaded (Zhai and Pan 2010). One such example of unequal sharing of load by two coupled SRIMs (of the same rating) of chopper machine as obtained from the DCS of a sugar factory M/s. DSM Ltd., Rajpura, UP (India) is shown in Figure 3 (lower trace).

In the VFDs, the issue related to the unequal load sharing can be addressed in several ways such as by natural load balancing due to slip of the motor or by using scalar control with slip and torque compensations to form the appropriate characteristics by using one motor as the master, which creates a reference on the torque of the motor which is considered to be a slave for the system Figure 3 (upper trace) also shows one such case through the trends of the load current of VFD driven coupled induction motors with almost equal load sharing. Therefore, this feature is improved in the VFD fed motors in comparison to the conventional one.

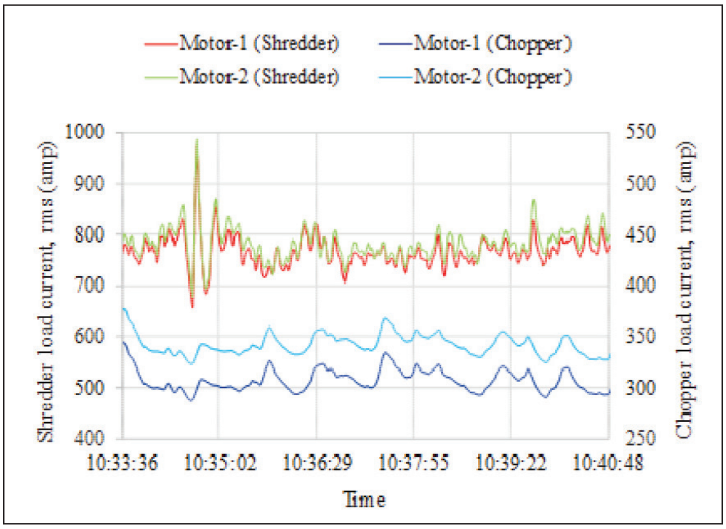
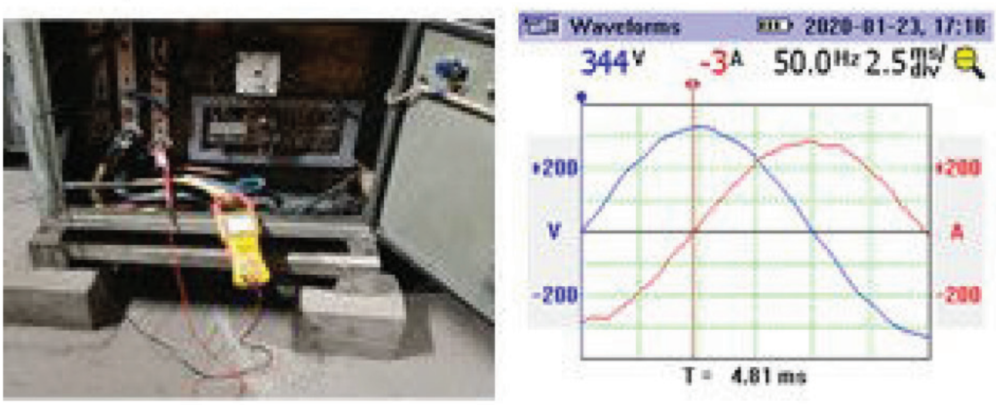


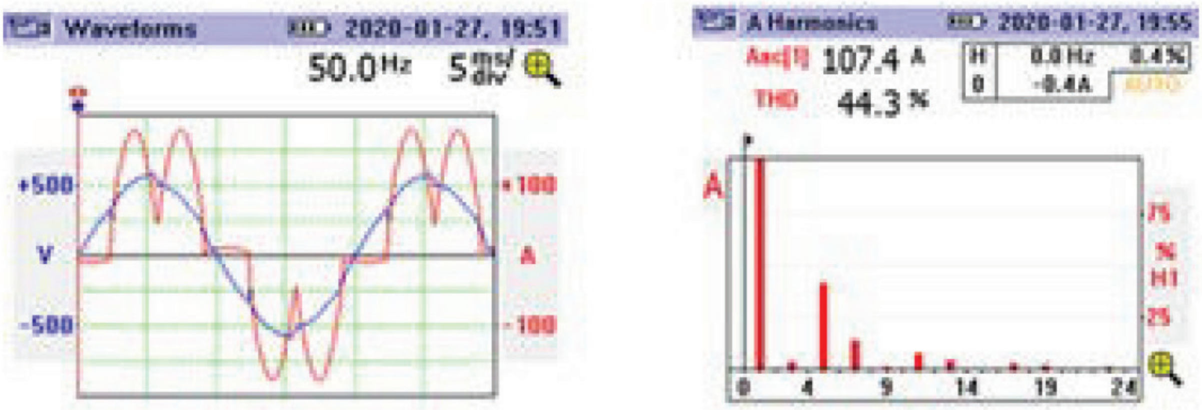
Figure 3 : Load Current (rms) by coupled SRIM drive and VFD of a sugar factory obtained from DCS at M/s DSM Ltd., Rajpura, India

Power factor and input current harmonics

The load at sugarcane preparation machines keeps on fluctuating upto +35% and -70% of the rated current of motors making the average current drawn to be too low than the rated current of the motor. Owing to the impact loads and the other limitations imposed by the nature of the load, the rating of the motor is recommended to be kept as 33% more than the average power required for the application (Hugot, 1986; Rein, 2007). Since the motor runs in under load condition during most of the time of its operation the power factor remains poor. Having a lower power factor in induction motor means consuming more reactive current than active current thus creating huge power quality problems in grid systems (Khodapanah et al. 2015). One such example of poor power factor as obtained using a power quality meter at a sugar factory named M/s DSCL, Hariawan, U.P. (India) is shown in Figure. 4(a). It can be seen that the phase difference between voltage (phase) and current (line) is 4.81ms. Therefore, the phase current lags behind the phase voltage by (4.81-1.67)ms or 86.58° – 30° = 56.58° and hence the power factor comes to be cos (56.58) = 0.55 lagging.



(a)



(b)

Figure 4(a) : V (Phase) and I (Line) for SRIM drive as obtained from M/s DSCL, Hariawan, U.P. (India), Fig. 4(b) V (Line) and I (Line) for VFD and harmonic spectrum of current as obtained from M/s Wave Industries, Bareilly, U.P. (India)

One of the advantages of using VFD based drives is the improvement in power factor. When a motor is operated by a VFD the displacement between the fundamental voltage and current is not reflected back to the input side of VFD due to the rectification. Diode and IGBT based rectification keeps the drive input current in phase with the supply voltage under all load conditions. Therefore, the power factor remains near unity (approximately 0.98) with VFD (Rucinski, 2013). But, one of the main disadvantages of VFDs is the injection of harmonics. 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, computers may fail, circuit breakers may trip and metering may give false readings (ABB, 2017). In the VFD based drives for coupled motors, the two drives use individual 6-pulse rectifier circuit because of its simple and low cost structure. This leads to the injection of harmonics in the input current. Also, the inverter used in these newly installed VFDs is a basic two-level inverter. Figure 4(b) shows input current waveform and harmonics for a 6-pulse rectifier based VFD connected directly to the bus (without the phase shift transformer) as obtained using a power quality meter at a sugar factory named M/s Wave Industries, Bareilly, U.P. (India). Figure 5 shows the simulation results for input current and inverter output voltage waveform if the VFDs are connected through a converter/phase shift transformer which results in a 12-pulse type arrangement. It can be seen that the harmonics is reduced in the 12-pulse rectifier realized using a converter/phase shift transformer.

Common mode voltage

Apart from the harmonics, the main problems reported to have been with VFD run motors is increase in insulation failures usually caused by turn-to-turn shortening or phase-to-ground faults due to the insulation di-electric breakdown between adjacent turns and common mode voltage making the current flow taking a path through various inherent parasitic capacitances in the motor. The increased cable length between the VFD and the motor worsens the situation (Liu and Skibinski 2017). The common mode voltages also result in rising problems such as ground leakage current, bearing current and conducted and radiated electromagnetic interference and with the power semi conductor technology keeps advancing, the ever increasing switching speed and switching frequency of power devices further add to the common mode voltage related problems (ABB, 2017; Rodriguez et al. 2005). Some of the practical solutions reported to mitigate the problems due to common mode voltage using chokes to suppress ground leakage current, using grounding brush or insulated bearings to reduce bearing current (ABB, 2017; Erdman, et al. 1996, A;

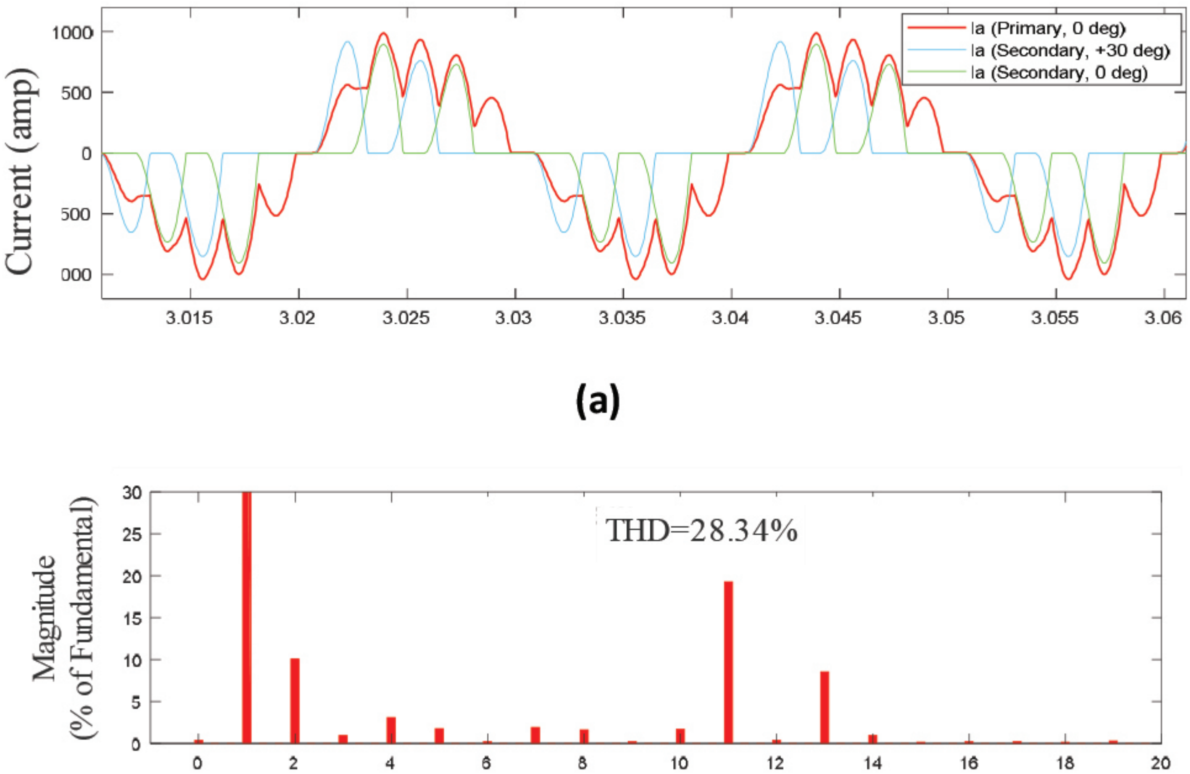


Figure 5 : Simulation results for the input current with harmonic spectrum with A12-pulse rectifier (a) current waveforms in different windings of the converter/phase shift transformer (b) Harmonic spectrum

Muetze and Sullivan 2011). However, these methods increase the complexity of modulation and control as well as the cost. Therefore, from issues resulting from the common mode voltage, the conventional drives are better than the VFDs.

CONCLUSIONS

The efficacy of using VFDs in place of the conventional SRIM drives for the sugarcane preparation machines has been assessed. To assess the utility, a detailed comparison of the existing drives (both the conventional, SRIM based, and the recently inducted, VFD) is presented for the sugarcane preparation machine of the sugar industry. It is observed that while the conventional SRIM based drive effectively mitigates the surges in the load current with the help of slip resistance, but, it suffers from the demerits of slip power loss, about 8-12%, in the rotor circuit and there is an appreciable drop in rpm (up to 15%) which affects the consistency of the cane preparation. It also suffers from the problems of poor speed regulation and low input power factor. The recently inducted VFDs proved better in terms of efficiency, speed regulation, improved power factor and load balance in coupled motors but VFDs are reported to have been suffering from ill-effects of high input current harmonics, high dV/dt stress and common mode voltage. Therefore, to implement VFDs for sugarcane preparation machines the inherent problems as presented in the paper are also to be addressed by various available methods used in other industries.

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