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ELECTRICAL VARIABLE SPEED DRIVE SELECTION

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Abstract

With the advances made in the power electronic field in terms of the range of products available, and increased load carrying capacity combined with improved reliability, a new range of variable frequency drives has emerged. Engineers now have a wider selection of drives from which to choose. Careful consideration of drive application, speed range, load requirement, environmental conditions, efficiencies, power factor, harmonics and cost has to be made to arrive at the best possible solution. This paper attempts to evaluate the DC and AC variable frequency drives available in terms of the above aspects.

Introduction

The DC drive in the sugar industry has dominated as a low voltage, wide speed range drive and its position has never seriously been challenged until the recent arrival of the pulse width modulation (PWM) variable frequency AC drive. Although AC drives have been available for at least 20 years in the form of current source inverters (CSI) and voltage source inverters (VSI), power electronics as such were very much in the pioneering stage and reliability of AC drives suffered. A great deal of research and development has been done in the semi conductor industry, resulting in improvements in device power ratings, switching times and reliability, and an increase in the range of products available. Combining this with digital control has led to the introduction of the PWM to the market.

What are the advantages of this type of drive - if any, and where can it be applied?

Basic Theory of Operation

DC Drives

The DC drive (Figure 1) usually consists of a stack of six thyristors, which convert the incoming 3-phase voltage to DC. The DC voltage is controlled by varying the firing angle X. The DC voltage is described by the formula of the form:

$$Udo = A \cos X$$

where A = constant dependent on pulse number and rms voltage

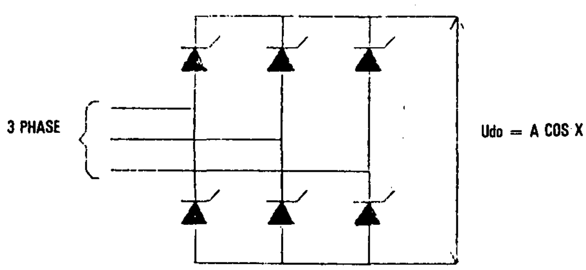

FIGURE 1 Full bridge thyrister stack

The speed of the DC motor will vary as the applied DC voltage is changed as shown by the formula:

$$N = \frac{V - TB}{C}$$

where B and C are constants for fixed field current

T = applied torque
V = DC voltage

Figure 2 shows the characteristics of a DC motor under armature voltage control and field control (varies constants B and C).

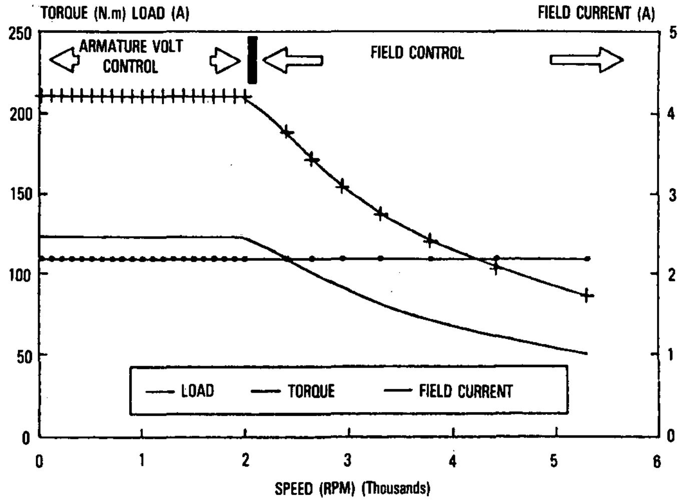

FIGURE 2 Armature voltage and field current control of a 44kW DC motor

AC Drives

In order to maintain constant torque through a large portion of the motor speed range, all AC variable stator frequency drives keep the voltage/frequency ratio constant in order to maintain constant flux. There are 2 basic types of AC drive: the current source inverter (CSI) where current and frequency are the controlled variables, or the voltage source inverter (VSI) where the voltage and frequency are the controlling variables. Figures 3 and 4 show the respective circuit configurations. Neglecting the effects of non-sinusoidal wave

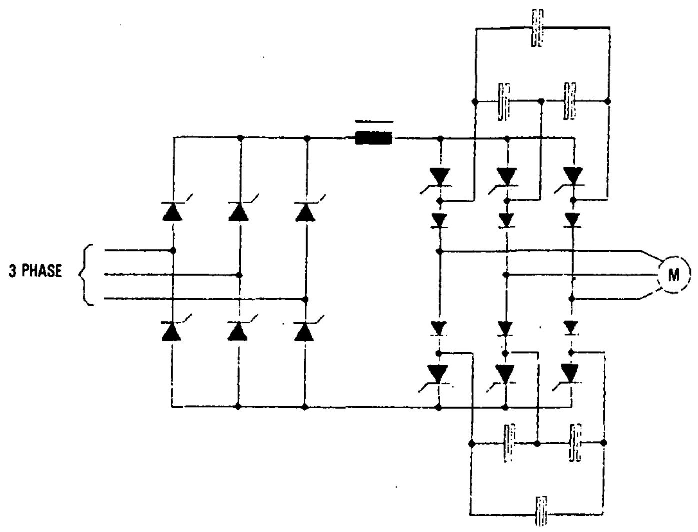

FIGURE 3 CSI power electronic circuit

forms, the torque/speed curves for the CSI and VSI controlled motors are represented in Figures 5 and 6 respectively (Say[3]).

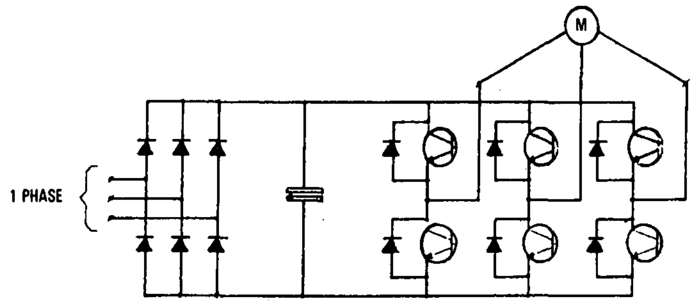

FIGURE 4 PWM power electronic circuit

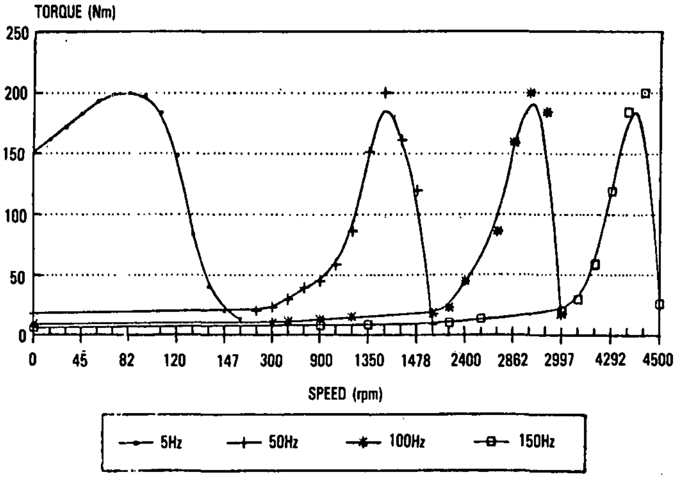

FIGURE 5 Torque/speed characteristics for CSI drive at different frequencies using a 4 pole AC motor

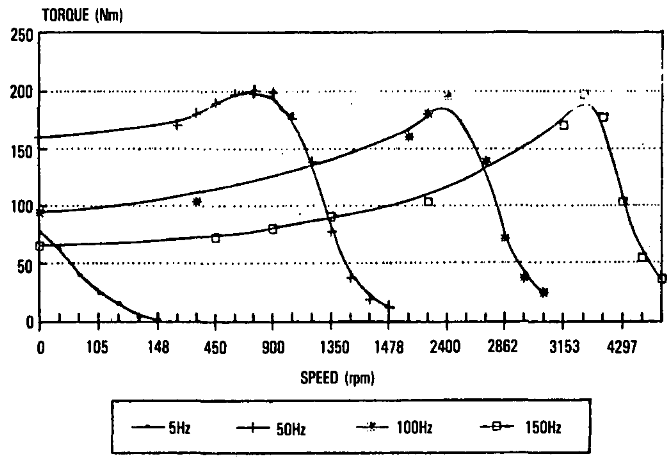

FIGURE 6 Torque/speed characteristics for PWM drive at different frequencies using a 4 pole AC motor

In reality the torques would be reduced by approximately 10% due to the presence of harmonics, which give rise to steady time harmonic torques rotating at $-5W$, $7W$, $-11W$, etc. (W = synchronous speed) and pulsating harmonic torques at $6W$, $12W$, etc., and additional losses in the stator (Odendaal[2]). If a totally enclosed fan cooled (TEFC) motor is used without additional cooling, further derating of the torque is necessary as shown in Figure 7, a torque curve of a PWM drive supplied by ABB. Note that torque decreases after reaching 50 Hz as the constant V/f ratio can no longer be maintained after V reaches the supply voltage.

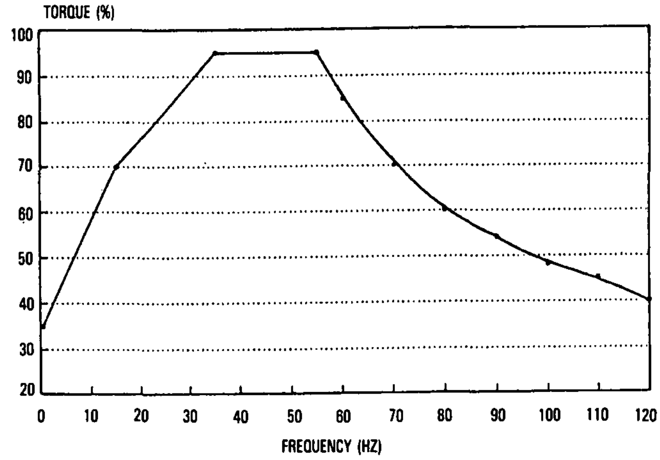

FIGURE 7 Torque derating curve for drives with only shaft mounted fan cooling (ABB Sami Mini-Star PWM drive catalogue)

Drive Application

Before comparing costs, efficiency and power factor, basic drive requirements must be considered. These are the type of load to be driven, the desired speed range, the response to change in control signals, steady state stability and the environment in which the drive is to be installed.

In a sugar mill, applications for both constant torque and torque proportional to speed squared drives exist. Examples of the former are conveyor belts, mill and diffuser drives, and of the latter are centrifugal fans and pumps. The bulk of the applications rarely need more than a 1:10 speed range, moderate response time and stability. The environment however is such that not less than an IP54 protection motor should be installed. High reliability is important where a standby system is either uneconomical or impractical.

The PWM variable stator frequency drive will satisfy the above requirements most of the time. However, where high torque and wide speed requirements exist simultaneously, careful calculations are necessary to ensure that the derated AC motor will provide sufficient starting torque at 1,5 times rated full load current. An equivalent DC drive will have a lower power rating, for example, a 44 kW DC drive compared with its 55 kW AC counterpart.

The CSI drive would not be recommended for constant torque drive applications with wide speed ranges (>1:10) especially if speed reduction through a gearbox is necessary. The CSI inverter section consists of slow switching thyristors which produce a very rough square waveform AC current output with high harmonic content. This creates torque pulsations which become noticeable at low speeds, and which would shorten the life span of a gearbox. They are suited to fan and pump applications where a small speed reduction produces a large power reduction. Gibson[1] claims vast savings in pump speed control using AC drives, as opposed to throttle control by means of control valves. Pumps and fans are usually driven directly or through a pulley reduction, thus torque pulsations pose no serious problem.

Both the CSI and PWM AC drives incorporate standard 3-phase AC TEFC motors, which are robust and require minimal maintenance (6-monthly maintenance schedules).

The benefits of using standard motors are that replacement delivery times are short, a common pool of spare motors can be used and the motors are relatively cheap. DC motors on the other hand require constant maintenance, brush replacement and IP54 degree of protection motors are very expensive. Two-weekly schedules amounting to 63 artisan hours on the diffuser drive alone were necessary during the

1989 season. As the DC drive incorporates a special motor, a spare must invariably be purchased and must be included in the initial capital outlay.

Due to the basic power circuit operation of AC and DC drives, certain inherent advantages exist and are available as a standard feature. The DC drive has the advantage of 2 quadrant operation with a standard 6 thyristor stack (i.e. motoring and regenerative braking in one direction of rotation).

The CSI has the capability of 4 quadrant operation, i.e. motoring and regenerative braking in both directions. The PWM is capable of motoring in both directions with a braking option, which is facilitated by diverting the generated current through a resistor connected in parallel with the DC link capacitor. A further advantage is that the PWM convertor can be used as a multi-motor drive. This is not possible with the CSI drive as close convertor and motor matching is imperative for trouble-free operation.

An added advantage for AC drives is that they can in certain circumstances be bypassed and driven direct on line if convertor failure should occur.

Cost

It is difficult to give a generalized cost comparison between the different drives as many alternatives exist in terms of cooling, supply voltage, base speeds and drive suppliers. However, a rough trend does exist. DC convertors are about one third the price of AC convertors, whereas AC motors are in the region of one third or less the price of DC motors. Therefore in some situations the price of a DC drive, including a spare, could be more expensive than an AC drive installation, especially in cases where the original oversized motor can be used.

Drive Efficiency

When comparing the different characteristics between drives, it is important to make these comparisons in the expected operating range. Figure 8 shows efficiencies of the various drives over the theoretical constant torque speed range. The efficiencies shown are fractionally higher than normal as power consumed for cooling has been neglected. The PWM and CSI are more efficient than the DC drive as DC motors are less efficient than AC motors, usually 1-3% difference.

The difference in energy units consumed over a season's running (30 weeks) between a 51 kW DC and 55 kW AC diffuser drive, is shown in Figure 9 for various speeds in the constant torque speed range.

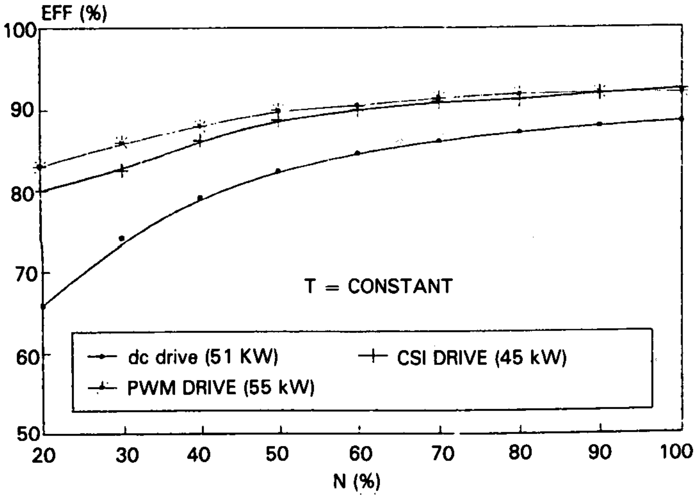

FIGURE 8 Efficiency of drives over constant torque speed range

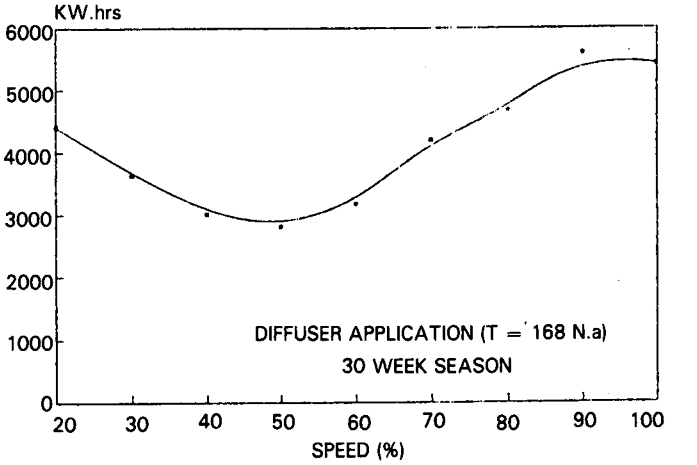

FIGURE 9 Expected savings in kW hrs over a season with PWM compaired to a DC drive for various operating speeds

The savings in Rands are not calculated, as the electricity tariffs vary between areas and priority on efficiency varies from mill to mill.

The effect of the efficiency curves when a $T = KN^2$ load is driven is shown in Figure 10.

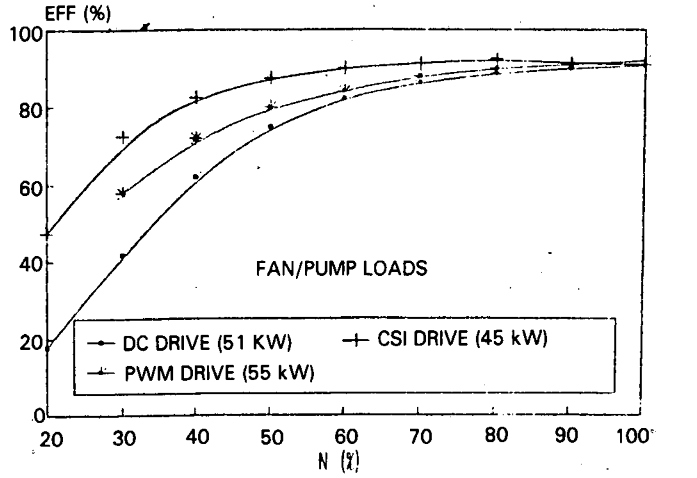

FIGURE 10 Efficiency for torque proportional to speed squared loads

Power Factor

The CSI and DC drives have a dramatically lower power factor in comparison to the PWM. This is due to the basic difference in the power electronics circuitry, namely a thyristor stack and diode bridge respectively. When installing a

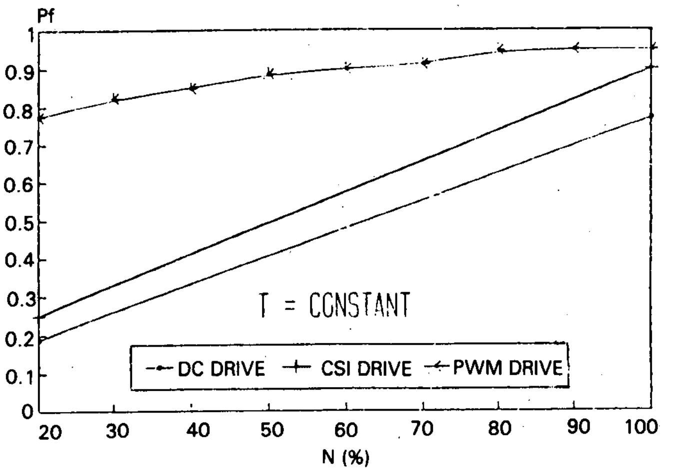

FIGURE 11 Power factor of drives over speed range with constant torque load

large number of drives, this will influence the required power factor correction capacity necessary. Figure 11 shows the power factors for the different drives and Figure 12 the resulting kVA difference between the PWM and DC drives.

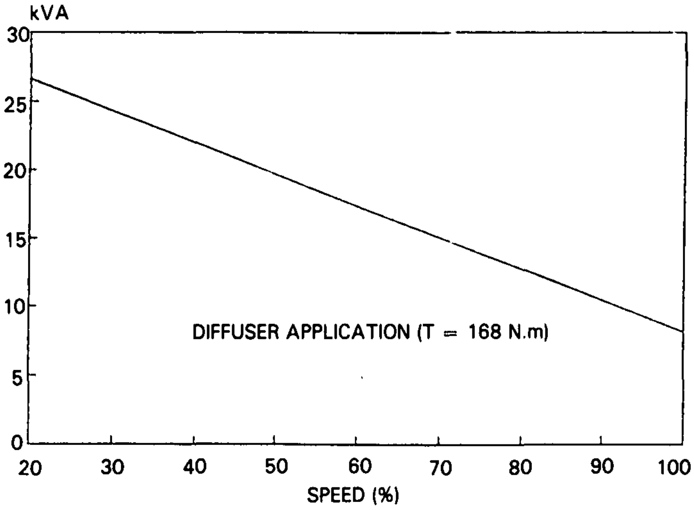

FIGURE 12 Difference in kVA between PWM and DC drive

The effect of $T = KN^2$ loads have on the power factor is shown in Figure 13.

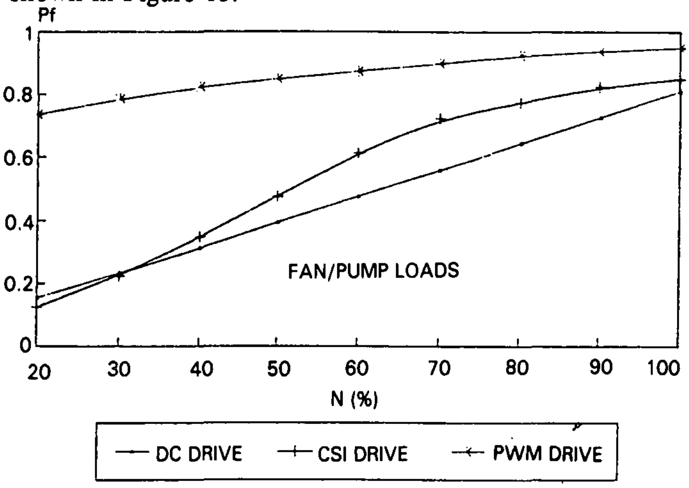

FIGURE 13 Power factor for torque proportional to speed squared loads

Harmonics

When installing large drives (in the sugar industry this would be above 1 MW) consideration must be given to the effect on the supply of the resulting harmonic currents generated. Firstly, the harmonics generated may lead to overloading of the power factor correction equipment. This can be limited to some extent by connecting the drive and power factor correction equipment as far apart as possible, thereby increasing the impedance between the two.

If this proves unsuccessful increasingly expensive measures can be taken, such as the installation of series reactors with the capacitors or harmonic filters.

Secondly, the harmonic currents increase the voltage distortion at the point of common coupling with other consumers. At present there are not official restrictions or penalties on harmonic currents generated and the resulting voltage distortion, but this will change in the near future. The Electricity Council Engineering Recommendation G5/3 suggests levels to which harmonic currents and voltage distortion should be limited.

Conclusions

Drives in the region of 50 to 55 kW were selected in order to show the effects of varying speed and different loads on the drives. The following trends exist.

The efficiency of drives tends to decrease with decreasing power rating and/or increasing number of poles.

Turbo load efficiency curves tend to have steeper gradients in comparison to constant torque loads. The power factor curves are relatively independent of power rating and pole number, but for the CSI drives the difference can be noticed at full speed. At this point increasing power rating and/or decreasing the number of poles results in an increase in power factor.

Harmonics are speed dependent. In the case of the PWM all harmonic currents decrease with decreasing speed. The converse is true to the DC drive. With the CSI the 5th and 11th harmonic increase and the 7th and 13th decrease with decreasing speed.

As stated previously, most drive requirements in the sugar industry can be met by the PWM AC drive. In fact, most applications where DC drives are used at present could be driven by PWM AC drives which are robust, more reliable and involve less maintenance and hence lower operating costs. The PWM drive has a higher efficiency and a vastly superior power factor. PWM drives can be used in $T = KN^2$ applications and are preferred to the CSI as the PWM convertor has a higher mean time before failure rating and is not machine parameter sensitive and runs at a higher power factor. The efficiencies of the CSI compared to the PWM can vary, and depend on the losses of the convertor which are small and which vary from supplier to supplier.

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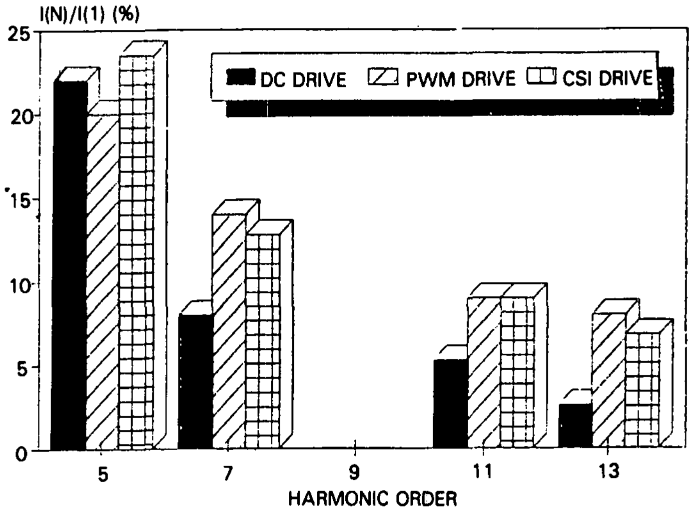

FIGURE 14 Maximum harmonic currents generated by drives on the supply

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