Variable Speed Drive: Is It a Black Box that Saves Electric Energy?

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IN Malaysia, at least 80% of the motor systems use induction motors as they are prone to less maintenance problems compared to DC motors. A report in 2010 by the Energy Commission of Malaysia stated that Tenaga Nasional supplied approximately 40.071GWhr (or about 44% of the total 89,621GWhr) of electric energy to the industrial sectors. In any industry, motor systems consume about 60% to 70% of the total amount of electric energy.

That is why the variable speed drive (VSD) system has been introduced to replace electromechanical starters such as direct online (DOL), star-delta and autotransformer to achieve better control and save electric energy. Electric motors controlled using electromechanical starters are very inefficient, simply because they do not control speed and torque (or mechanical power). In addition, motor systems controlled by electromechanical starters do not have the benefit of features that enhance the smoothness of operation.

The performance of a motor system is, to a large extent, dependent on the load that determines the torque required to run the shaft of the motor at the expected speed. Mechanical power generated by a motor is simply the product of torque and speed. Hence, unless we control one or both of the parameters, we will not see any savings in electric energy.

Electric energy is a product of electric power (which is the sum of mechanical power and losses) and the duration of operation *(see Equation 1)*.

$$W_e = \left[(T_m \times \omega) + P_l \right] \times t \quad (1)$$

where W_e = electric energy (kWhr), T_m = motor torque (Nm), ω = mechanical speed (rad/sec), P_l = losses (W) and t = duration of operation (hr).

Let us take an example of a pump system running with a DOL starter where full voltage with the rated frequency, 50Hz source, is applied to the pump motor when the contactor is energised. If the pump drives an 80% load at all times and the system does not require any change in pressure, then the motor system with the DOL starter is efficient enough as far as electric energy is concerned.

On the other hand, if the pump system runs for many hours at variable or light load with an equivalent load torque of less than 70%, and the system requires changes in

pressure which is currently achieved with the help of valve arrangement, the installation of VSD for the system will significantly help to reduce electric energy usage. This is possible since VSD applies the required voltage to produce the required torque which reduces iron losses in the motor.

Secondly, VSD controls the pressure by varying the motor speed (by changing the supply frequency). Thus mechanical valves are not required, minimising mechanical losses. Thirdly, since speed and torque are controlled, the mechanical power consumed by the motor is the actual power required by the pump system. As such, the same work can be done using the VSD system with lesser mechanical power and losses. This in turn consumes lesser electric energy.

However, it is not a rule of thumb that changing to a VSD system will guarantee electric energy saving. You may end up prolonging your payback period. Surprisingly, if you check your current motor system, you will find that they mostly run at 60% or lesser load at all times. This is because the motor is usually oversized to overcome temperature and overloading problems. If this is true, by default, the installation of VSD will allow the motor system to use lesser electric energy to do the same job.

There are many manufacturers producing various brands of VSD, and although each manufacturer boasts of different types of features and performances, the same power conversion technology is used. Generally, a fixed voltage, fixed frequency AC source is converted to a DC source by using an arrangement of diodes and/or insulated gate bipolar transistors (IGBTs). The DC source is then smoothened by a group of capacitors. The smoothened DC source is then converted into a variable voltage, variable frequency AC source using the arrangement of IGBTs.

In general, we can categorise problems associated with the VSD system into two types. In the first category are problems created due to the nature of the operation of the VSD system itself. For example, current harmonics are created due to the usage of rectifier and capacitors. Short time charging DC current produces spike shaped input AC current which contains harmonics. Some other problems in this category include thermal issues on the VSD and motor, bearing current.

Fortunately, most manufacturers have incorporated solutions or can provide proper solutions to minimise these problems. Problems in the second category are more severe and are created by the operators themselves.

Usually these problems are created when improper parameters are set in the VSD. Improper parameter setting usually happens due to a lack of knowledge on how the VSD works that is when the VSD is assumed to be a black box.

IMPROPER PARAMETER SETTINGS

It is important for any motor system operator to understand that the motor is a mechanical system. Starting with a DOL starter gives a completely different impact on the motor compared to when a VSD system is used to operate the same motor. As explained earlier, the VSD is a high power electronic system or simply an electronic system capable of controlling both high current and high voltage at frequencies in the kilohertz range.

Every setting that one makes on the VSD directly impacts the motor. For example, the VSD can be set to produce an output voltage with a frequency of 200Hz. Can you imagine what will happen to a 4-pole induction motor with a rated speed of 1,470rpm (for 50Hz source) when such a high frequency source is given? The following are several examples of impacts on the motor system when the VSD is operated without sufficient knowledge.

Acceleration and deceleration time are two common parameters set at least by every VSD user. Unfortunately, the VSD can simply trip and indicate either over current or short circuit faults whenever the motor starts (upon improper acceleration time setting) and whenever the motor stops (upon improper deceleration time setting). This can be explained based on the motor dynamic equation (*see Equation 2*).

$$\Delta t = J \, \frac{\Delta \omega}{(T_m - T_l)} \qquad (2)$$

Where Δt = acceleration/deceleration time (sec.). J = moment of inertia (kgm²). $\Delta \omega$ = speed change (rad/sec). T_m = motor torque (Nm). T_l = load torque (Nm).

The acceleration or deceleration time is a function of the motor system's moment of inertia, speed variation and how much motor torque there is compared to the required load torque.

Setting very short acceleration time for a high load torque system [when $(T_m - T_l)$ is small] will force the motor to draw a high current which the VSD recognises as over current. In contrast, setting a very long acceleration time for the same system may also trigger the overload alarm as the VSD senses high current being drawn for a longer period of time. Hence, an appropriate acceleration and deceleration time has to be determined by conducting several tests on each motor system by monitoring the starting current every time the motor starts and stops.

Another simple yet serious issue in the industry is the tripping of the VSD due to high temperature. High power semiconductor switches operating at a high frequency produce a much larger amount of heat than a microprocessor in your laptop. So, placing the VSD at a poorly ventilated and hot environment will trigger the heat sink temperature sensor that trips the VSD. This point is important especially when the system is upgraded from electromechanical starters to the VSD. The motor control panel has to be moved or modified to provide the required environment.

Heating may be also generated due to pulsation current waveforms at the motor. Pulse width modulated (PWM) based generated voltage produces pulsation phase current to the motor which produces a higher ripple in torque and causes mechanical jerking. To smoothen the current, operators are usually advised to increase the switching frequency setting in the VSD which typically can be varied from 4kHz to 20kHz. However, setting a higher switching frequency increases heat across the power semiconductors and heat sink, which can cause the VSD to trip.

There are many more parameters that are incorporated into the VSD, and any improper setting of those parameters will negatively impact on the motor system.

CONCLUSION AND RECOMMENDATION

The VSD may be assumed to be a black box, but when problems associated with the motor system appear, engineers will be left with no choice but to understand the black box. The VSD does wonders for process optimisation and energy savings that electromechanical starters cannot do. However, it is extremely important to know that those wonders are not achieved by simply replacing the electromechanical starter with the VSD. If you operate without understanding the black box, you may mess up the whole motor system.

It is timely to introduce the VSD system with hands-on training at skill-based training institutions. Also, a skilled workforce must be equipped with enough knowledge to face new issues and challenges when dealing with the VSD system. Universities are more focused on the control technologies for the VSD such as vector control and direct torque control. Students should be introduced to the practical problems associated with the VSD system in industry. They should also be exposed to some practical work to understand the importance of the VSD compared to electromechanical starters. As for practising engineers, it is important to understand the VSD before handling it. Participating in job training and reviewing manufacturer manuals may be a good move at this point of time. ∎

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