Energy Saving Using Variable Frequency Drive in Industry: A Review

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Abstract — In this paper variable frequency drive is discussed and also application, advantages and the cost discussed. Numerous industrial uses necessitate variable fluid flow control. (air, chemical gases, water and liquid chemicals). Since most drives run at part load the majority of the time, the cumulative energy savings, or the accompanying financial benefit, may be significant over time. Given the prevalence of this form of fluid flow control in industry, widespread use of variable-frequency drives with power electronics can contribute significantly to energy savings. The conventional approach to this type of flow control involves using a 50-Hz power source and an induction motor running at a constant speed to control the flow. When run at variable speed using a VFD, many fixed-speed motor load applications that are powered directly from AC line power can reduce their energy consumption. These energy cost savings are particularly useful in uses for variable-torque centrifugal fans and pumps, where the torque and power of the load change in proportion to the square and cube, respectively, of the speed. In comparison to fixed-speed operation, this change results in a significant power reduction for a relatively minor drop in speed. Additionally, a large amount of power is saved by using a variable frequency drive to regulate the fluid flow while the throttle is completely open. This paper's primary goal is to implement a VFD to properly regulate flows while reducing energy consumption.

Keywords: Variable Frequency Drive; Energy Saving; Motor Efficiency; Energy Audit; Industrial Energy Audit; Microcontroller; Affinity Laws; Utility Cost Saving

I. INTRODUCTION

In recent years, the field of power electronics and variable frequency drives has become a significant and crucial subject in electrical engineering. In its most basic form, power electronics deals with the conversion and control of electrical power for a variety of applications, including DC- and AC-regulated power supplies, heating and lighting control, electrical welding, electrochemical processes, induction heating, active harmonic filtering and static reactive power generation, control of DC and AC machines, and so forth. The fundamental ingredient for existence is energy in all of its forms. It is similarly crucial for the enhancement of life quality[3]. The nation's sovereignty and entire socioeconomic growth are impacted by the energy crisis. Due to the expansion of industry and population, there has been a dramatic rise in the world's energy consumption in recent years. It is now imperative to work harder on the development, improvement, and upgrading of renewable sources of energy while protecting and conserving current conventional sources because our conventional energy sources, or fossil fuels, are running out. Energy conservation is the process of reducing the quantity of energy used in a system, process, organization, or society through efficiency and the elimination of waste[8].

Because of the wide range of uses for which they are used, such as computer peripheral drives, machine tool and robotic drives, pump and blower drives, textile and paper mill drives, electric vehicle and locomotive propulsion, ship propulsion, cement mill and rolling mill drives, and so forth, electrical machine drives, also known as motion control, are particularly fascinating and difficult areas in the field of power electronics. Future growth in the use of power electronics and variable frequency drives is anticipated due to the current pattern of industrial automation around the world[3].

Energy conservation is essential because, in order to satisfy the demand for electricity, which is only expected to rise, new generating units must be installed in addition to existing ones. Electrical derives in a plant use a significant part of the electrical power. The use of effective and rigid electrical drives can save a sizable quantity of electrical energy. One of the many well-known energy-efficient motors is the variable frequency drive[11].

A variable frequency drive is known to as an inverter in the industry. Other titles for the speed controller include variable speed drive. (VSD). Variable Voltage Variable Frequency Drive (VVVF) and Adjustable Speed Drive (ASD) (VVVF) [8].

Power electronics also play an important role in energy conservation, which can reduce environmental pollution. This role has only lately come to light. It has been calculated that the widespread use of power electronics in devices like variable speed drives, high-frequency electronic ballasts for fluorescent lamps, and other similar devices can save between 10% and 15% of the electrical energy produced. Additionally, photovoltaic and wind energy resources, which are both clean and ecologically friendly, have a promising future. The possibility for wind energy is enormous. Rough calculations show that even if only 10% of the available wind energy is used, all of the world's electrical requirements can be satisfied. The cost of photovoltaic electricity is still very high[3].

Due to its capacity to regulate the speed of induction motors, which are the most frequently used motors in sectors, variable frequency driven is becoming more and more popular: An induction motor is typically used for purposes that require constant speed and constant torque as well as when variable speed or torque is needed. It uses a coiled ac motor or a DC motor. However, modern uses for variable speed use AC induction motors with variable frequency drives. These drives improve the energy efficiency of plants while reducing the energy usage of motors [8].

A variable-frequency drive is a device that regulates the frequency of the electrical power delivered to an alternating current electric motor in order to manage the motor's rotational speed. It is a specific type of adjustable-speed drive. AC drives and inverter drives are other names for variable-frequency motors[8].

II. OVERVIEW

Two-thirds of the energy used in industry is for electric motors, so any opportunity to reduce this load even by a few percentage points is very important. Industry should seize the possibility to reduce energy use by up to 50% if given the chance. However, only a small percentage of apps have variable speed drives (VSDs) installed. The main cause is frequently that those who create these applications are separate from those in charge of the energy account. However, those in control of the energy bill are frequently not engineers and are unaware of the advantages VSDs can provide[9]. Fans with variable-frequency engines use less energy because the amount of air they move can be adjusted to meet system demands. Power consumption in applications with variable speed varies approximately as the cube of the speed. These are known as the "Affinity laws," and they outline the connections between speed and strength. The captive power plant is able to save about 23% of its electrical energy usage thanks to the use of variable frequency drives[8].

An electronic device known as a variable frequency drive (VFD) is used to regulate the frequency and voltage of the power delivered to an electric motor in order to manage the motor's speed. It functions by changing the AC power source into DC power, which is then converted back to AC power with adjustable frequency and voltage levels.

VFDs are frequently used in industrial and commercial uses, such as pumps, fans, and conveyor systems, where it is necessary to modify the motor speed to meet the demands of the situation. VFDs can decrease energy usage, enhance process control, and increase equipment longevity by regulating motor speed[3].

The availability of power semiconductor devices with improved electrical properties has been directly linked to improvements in the performance of variable frequency drives. The size, weight, and price of the complete power electronic system have been found to depend on the device performance. An ideal power device for power-switching applications must be able to support a very high voltage in the off-state with minimal leakage current, transport a large amount of current in a small space with little voltage drop, and transition between the on- and off-states quickly.

Additionally, it is better for the device to be able to limit the current in the circuit under problematic operating circumstances without the aid of external circuit components and to control the rate at which current rises when it is turned on. Although significant progress has been made towards reaching these objectives, the power semiconductor designer still struggles to create the ideal device, which serves as a powerful incentive for additional research and development in this field[3].

Industrial processes are characterized by the requirement for process variation and improvement in order to produce quality products and to find the most effective and affordable way of production[11]. To achieve the most favorable condition in relation to the numerous plant variables, it is necessary to regulate the flow rates of materials throughout the plant[8].

A variable frequency drive (VFD) is a form of adjustable speed drive used to regulate the frequency and voltage applied to an alternating current electric motor to control the motor's rotational speed. Many different pieces of machinery, such as fans, pumps, and air turbines, are propelled by electric motors[8].

Motors typically drive equipment at a constant rate, despite the fact that equipment can typically work at speeds lower than the maximum design speed. Through the use of a throttling mechanism, such as a valve, damper, or bypass, flow and pressure are controlled. To regulate varying flow rates and pressures more effectively, use a variable frequency drive[8].

By regulating the motor's speed to ensure that it operates no faster than is necessary, variable speed drives decrease the output of an application component, such as a pump or fan. Other control techniques, such as using a valve to decrease the flow through a pipeline, operate the motor at maximum speed while throttling the output flow. Because the motor continues to operate at its nominal speed regardless of the demand, this is wasteful. The pump operates at its full capacity, and any extra energy is reduced at the valve, where it is lost through friction[9].

III. OPERATION OF VFD IN INDUSTRY

In general, VFDs offer accurate and effective control over the speed of AC electric motors, resulting in increased energy efficiency, decreased mechanical stress, and better process control in a variety of industrial and commercial uses. Up to 60% less energy can be used by an engine thanks to a VFD. This is because they can change the frequency and, as a result, the power provided to the motor, which controls its speed. A variable frequency drive (VFD) is a piece of technology that modifies the frequency of electrical electricity sent to an AC electric motor to regulate its speed. Here is a quick rundown of how a VFD functions:

"Using a rectifier circuit, the VFD transforms the AC power it gets from the power source into DC power. After that, the DC power is filtered to eliminate any obtrusive noise or voltage spikes. Using an inverter circuit, the purified DC power is then transformed back into AC power with adjustable frequency and voltage[8]. The inverter circuit modifies the voltage and frequency of the AC electricity sent to the motor to regulate its speed. The frequency and voltage of the AC power are adjusted by the VFD to keep the desired speed while it constantly monitors the motor speed. Other controls may also be offered by the VFD, including fault detection, overload safety, and soft start and stop[3][11]."

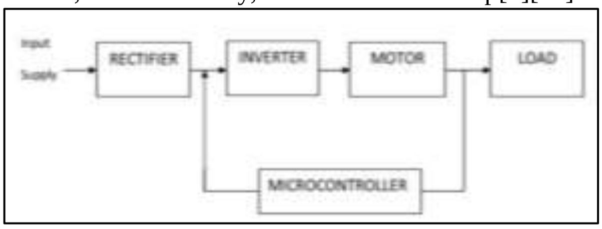

Fig. 1.1: Block diagram of VFD

An induction motor's speed is immediately correlated with its stator frequency. The following gives the induction motor's synchronous speed formula.

$$N_s = \frac{120f}{p}$$

i.e.

F = Stator Supply Frequency
Ns = Synchronous Speed of Induction Motor
P = Number of Poles of the Motor

An induction motor's speed can typically be regulated by varying the frequency and supply voltage using a variable frequency drive (VFD). Power Electronics Device manufactures the variable frequency drive (VFD). The Rectifier, Inverter, and Microcontroller are the three most crucial components of that gadget. As a result, altering the number of poles allows for changing the synchronous speed. By changing the connections of the stator winding with the aid of straightforward switching, the number of poles can be altered. As a result, our pace differs[8].

The majority of HVAC machinery is built to operate at peak loads. During the working year, these loads are infrequent. Flow control devices like dampers, valves, inlet guide vanes, and bypass systems are used to regulate flow during off-max load situations. Although these "throttling" gadgets work, they are not energy-efficient. The equipment can satisfy the partial load requirement and conserve energy by using variable frequency drives (VFD), which change the speed of fans and pumps according to the "affinity laws". Pump and fan performance are affected by a number of factors, including torque, shaft speed, and power. Affinity laws are used in hydraulic and HVAC systems to describe the relationship between these factors.

Speed is directly proposed to flow;

$$\frac{N1}{N2} = \frac{Q2}{Q1}$$

Torque required is proportional to speed squared;

$$\frac{T2}{T1} = \left(\frac{N2}{N1}\right)^2$$

Power required is proportional to the cube of the shaft speed;

$$\frac{P2}{P1} = \left(\frac{N2}{N1}\right)^3$$

The accompanying example demonstrates the potential energy savings from installing a VFD. Think about an engine that propels a centrifugal pump with 25 horsepower. For 365 days a year, 24 hours a day, the pump runs at maximum capacity. The formula used to determine running costs is as follows:

Cost(100%) = Power (kW) * Running Time * Cost/wh

So, when constantly running at 100% speed (and assuming Ra.5/kWh), the cost is

Cost (100%) = 25hp * 0.746 kw/lip * 365 *25 * 5/kWh
= Rs. 8,16,870/-

A variable frequency drive can be used to lower the pump's motor speed because this particular pump can handle varying loads and does not need to run continuously at full speed. The pump's load schedule is 20% at 50% full speed, 50% at 80% full speed, and 30% at 100% full speed. The savings from installing a VFD to regulate a motor are calculated based on the pump affinity laws, which predict that a motor's power consumption is proportional to its speed cube.

At 50% speed for 20% of time;

$$\text{Power (50\%)} = \text{Power(100\%)} \left\{\frac{\text{Speed(50\%)}}{\text{Speed (100\%)}}\right\}^3$$

= 25 * {50/100}^{3}
= 3.125 hp

Cost (50%) = 3.125 * 0.746 * (20% * 8760hr) * 5kWh
= Rs. 20421.75/-

At 80% speed for 50% of time;

$$\text{Power (80\%)} = \text{Power(100\%)} \left\{\frac{\textit{Speed}(80\%)}{\textit{Speed}\ (100\%)}\right\}^3$$

= 25 * {80/100}^{3}
= 12.8 hp

Cost (80%) = 12.8 * 0.746 * (50% * 8760hr) * 5kWh
= Rs. 209118.72/-

At 100% speed for 30% of time;

Power (100%) = 25 hp

Cost (100%) = 25* 0.746 * (30% * 8760hr) * 5kWh
= Rs. 30632.625/-

Annual cost savings from installing a VFD on the motor is;
= 8,16,870- (20421.75+209118.72+30632.625)
= Rs. 617962.155/-
= 75 % of the cost

IV. ADVANTAGES OF VFD

There are many benefits to using variable frequency drive management. The ability to lower electrical energy demand and consumption from motor-driven operations is the main advantage.

When compared to conventional motor control strategies like direct-on-line (DOL) starters or soft starters, variable frequency drives (VFDs) have a number of benefits. Some of the major benefits of VFDs include the following:

– Energy conservation: By managing the motor speed and adjusting it to the demands of the load, VFDs can increase the energy economy of electric motors. Reduced operating expenses and energy savings are the result of VFDs' ability to greatly reduce the motor's energy consumption by reducing its speed.
– Enhanced motor performance: VFDs can offer exact control over the motor speed and torque, enabling more precise control over the performance of the motor. As a result, there may be less downtime and improved product quality in motor-driven processes that are more accurate, consistent, and reliable.

VFDs can provide a motor with controlled, smooth acceleration and deceleration, reducing the mechanical stress on the motor and the driven machinery. By doing so, the equipment's lifespan and maintenance and repair expenses can be increased.

Additionally, the expenses associated with system maintenance could be decreased with the use of variable frequency drives. When a motor is controlled by a VFD, it is possible to "soft start" the motor, which allows for a gradual increase in running speed as opposed to a sudden start and halt. Similar to this, operating the motor at lesser speeds increases the lifespan of other parts of the machinery, such as the shafts and bearings.

The other advantage of VFD is that it is possible to interface VFDs to wider process control systems such as supervisory control, data acquisition (SCADA) systems and building management systems (BMS). Hence VFD is able to compute intelligence and communication systems.

V. APPLICATIONS OF VARIABLE FREQUENCY DRIVE (VFD)

Depending on the requirements of the particular application, VFDs can be programmed to work in various modes, such as constant torque mode, variable torque mode, or constant horsepower mode. To increase functionality and management, they can also be integrated with other control systems, such as PLCs and SCADA systems.

By adjusting the speed of electric motors according to the demands of the load, variable frequency drives (VFDs) can provide substantial energy savings in a variety of industrial applications. Here are a few instances of how VFDs can contribute to energy conservation in commercial settings:

– Pumping applications: The motor is frequently oversized for the load needs in many pumping applications, including water purification, HVAC, and irrigation systems. The motor uses less energy and can save a lot of energy when the speed is adjusted using a VFD to match the load, particularly under partial load conditions.
– Fan Applications: Pumping applications are not the only ones that VFDs can help with; they can also be used in fan applications, including HVAC and ventilation systems. VFDs can lower the energy consumption of the motor and increase system efficiency by adjusting the fan speed to meet the air flow requirements.
– Conveyor systems: To meet production demands, conveyor systems used in industrial settings like material handling and food preparation frequently need variable speed operation. Conveyor systems can save energy and boost manufacturing efficiency by using VFDs to regulate the motor speed.
– Compressed air systems: Systems for compressed air are used extensively in many industrial uses, including manufacturing, transportation, and food processing. The system can keep a constant pressure while using less energy by using VFDs to regulate the speed of the air compressor motor, resulting in significant energy savings.
– Energy efficiency: By lowering the energy consumption of electric motors, VFDs are frequently used to increase energy efficiency in industrial and commercial applications. A thesis could examine the efficiency of VFDs in reducing energy consumption and study the variables that can affect this efficiency, such as the type of motor used, the characteristics of the load, and the working environment.
– Automation and control: By integrating VFDs with other control systems, it is possible to increase the functionality and level of control over a motor's functioning.
– Applications and case studies: A thesis could concentrate on particular VFD applications in various sectors, such as HVAC, water treatment, or manufacturing, and look into the advantages and difficulties of doing so. Additionally, the thesis could examine real-world case studies of VFD installations and analyse the outcomes in terms of energy savings, process enhancements, and other measures.
– Future advancements and trends: In VFD technology, such as the use of sophisticated control algorithms, the incorporation of renewable energy sources into VFD technology, or the use of VFDs in new applications or sectors. The VFD could also take into account how these advancements might affect sustainability, industrial automation, and energy economy in general.
– Applications in industrial processes: For optimum performance, many industrial processes, including mixing, agitating, and milling, call for variable speed operation. These processes can save energy and increase total process efficiency by using VFDs to regulate the motor speed. VFDs provide a flexible and affordable way to cut energy use and increase the effectiveness of motor-driven processes in a variety of industrial uses.

VI. Conclusion

In this paper Variable frequency drives are addressed, along with applications, benefits, and cost. Variable fluid flow control is required for many commercial applications. (air, chemical gases, water and liquid chemicals). The traditional method for this type of flow control entails using a 50-Hz power source and an induction motor operating at a constant speed to regulate the flow. According to the findings of this research, the speed control of induction motors using variable frequency drives can reduce energy consumption. This presumption states that even a minor speed reduction can result in significant energy.

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