Energy Conservation Using Variable Frequency Drive in Pumping Application

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***Abstract*- Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50% of the energy usage in certain industrial plant operations[1].Pumping systems consume a significant portion of the electricity, Variable frequency drives (VFD's) are often recommended as a way to save pumping energy. Actual energy savings will vary greatly depending on how the discharge pressure of the constant speed pump is controlled and how it is operated after the VFD is installed. In the present work, the flow of pump has been controlled by two different methods, Matlab simulations and experimental work has been carried out and comparative statement is given in this paper.**

***Index Terms* - Centrifugal pump, flow control, throttling, variable frequency drive(VFD),Energy saving,Pulse Width Modulation(PWM).**

I. INTRODUCTION

Now to save electricity for our future generation we should be aware of concept of energy conservation. With energy saving of 0.01% there is so much benefit to us [1]. So we have to be aware that where and when electricity should be conserve [2]. The cost of generation of 1 MW power is Many Crores of Rupees and takes longer years to generate. The cost of 1 MW power conservation is only less than Rs. 1 Crore. If Conservation done in morning of the day, the same evening the industry can reap the rewards of its conservation efforts. First step is to reduce the defects inside your system and automatically the Conservation happens to you [3].
Due to the renewed interest in energy saving, it has become more popular to utilize Electrical Variable Frequency Drives (VFD) to power pumps which results in significant energy savings versus mechanical means for adjusting the flow of the pumping system. Due to the characteristics of pumps it is easy to misapply motors in VFD pump applications [5].

II. VARIABLE FREQUENCY DRIVE

Variable frequency drives (VFD's) are often recommended as a way to save pumping energy. Actual energy savings will vary greatly depending on how the discharge pressure of the constant speed pump is controlled and how it is operated after the VFD is installed [12].
The speed of the motor can be changed by various methods such as hydraulic or eddy current coupling, variable pulley, gear box system etc., but most efficient one method is change the supply frequency and voltage to the motor. The variable frequency drive (VFD) varies the frequency and hence varies the speed of the motor as per the requirements by the load [13].
Speed control of AC/DC motors can be achieved by the variable speed drive (VSD) unit as shown in fig.2.1. DC drives are used for special applications such as few low-speed, low-to-medium power applications because of problems with mechanical commutation and expensive at large size. Usually AC drives especially squirrel cage induction motor is widely used due to its rugged construction, easy installation and maintenance, higher efficiency and low cost [14].

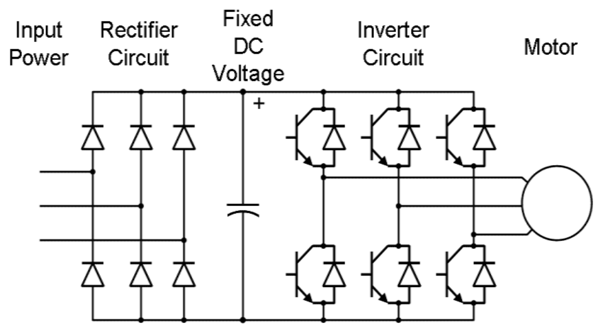


Figure 2.1 Basic block diagram of VFD.

The variable frequency drive (VFD) converts the supply frequency and voltage to the required frequency and voltage to drive a motor. Hence, VFD converts the supply frequency and voltage to the frequency and voltage required to drive a motor at a desired speed other than its rated speed [15].
The synchronous speed of an induction motor is given by the equation as:

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

But actual running speed is always lesser by 2 to 6% of its speed.
The gap between synchronous speed and running speed is called the slip.

$$\% S = \frac{Ns-N}{Ns} \times 100 \quad \ldots\ldots (1)$$

Running speed, N = Ns (1-S)

$$N = \frac{120f}{P}(1-S) \quad \ldots\ldots (2)$$

So, $N \propto f$ or $N \propto \frac{1}{P}$

Thus the running speed of induction is directly proportional to the supply frequency. If the frequency changes the actual running speed of motor also changes. VFD controls the frequency from supply and adjusted to the present requirement [15].
The basic functions of variable speed drive are to control the frequency of the supply to the motor and power transfer efficiently from supply mains to the motor drive shown in fig.2.1 [15].

III. VFD SPEED TORQUE CHARACTERISTICS

Fig.3.1 shows the basic T/F characteristics of VFD drive.
Blue = Horsepower
Red = Torque
Green = Motor Nameplate Frequency (60 Hz)
Motor HP = Torque x RPM…………………………..….... (3)
As per above equation (3), It has been explained following two modes:
As shown in fig.3.1,
In Constant Torque Area - VFD supplies rated motor nameplate voltage and motor develops full horsepower at 60 hertz base frequency [16].
In Constant Horsepower Area - VFD delivers motor nameplate rated voltage from 60 Hertz to120 hertz (or drive maximum). Motor horsepower is constant in this range but motor torque is reduced as frequency increases [16].

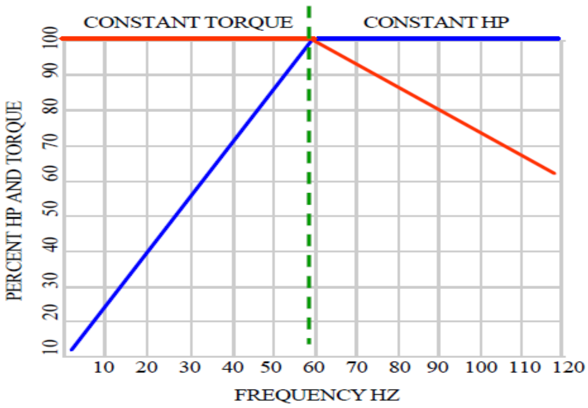


Figure 3.1 VFD Speed Torque Characteristics

IV. PULSE WIDTH MODULATION

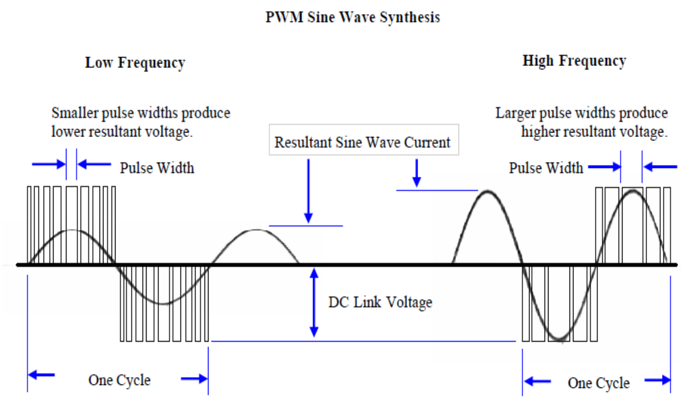


Figure 4.1 PWM Scheme of VFD
VFD drive DC link voltage is constant.
Pulse amplitude is constant over entire frequency range and equal to the DC link voltage as per above fig 4.1.
Lower resultant voltage is created by more and narrower pulses.
Higher resultant voltage is created by fewer and wider pulses.
Alternating current (AC) output is created by reversing the polarity of the voltage pulses.
Even though the voltage consists of a series of square-wave pulses, the motor current will very closely approximate a sine wave. The inductance of the motor acts to filter the pulses into a smooth AC current waveform.
Voltage and frequency ratio remains constant from 0 - 60 Hertz. For a 460 motor this ratio is 7.6 volts/Hz.
To calculate this ratio divides the motor voltage by 60 Hz. At low frequencies the voltage will be low; as the frequency increases the voltage will increase [17].

V. RESULTS

5.1 Simulation for performance of three phase Induction motor without VFD.

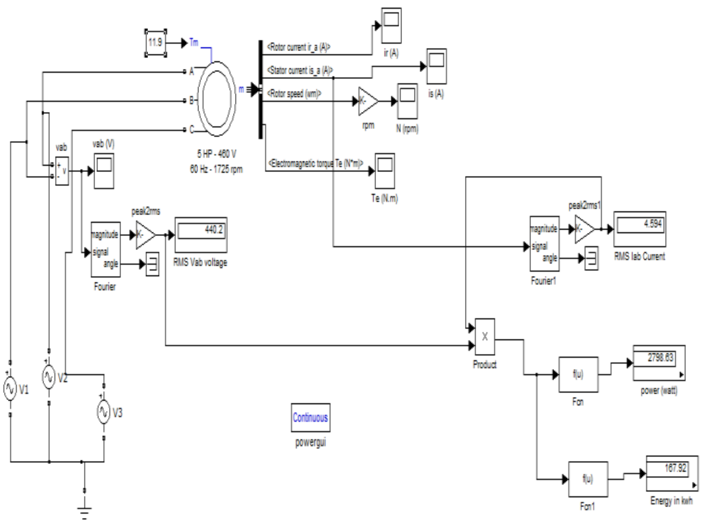


Figure 5.1 Simulation model for performance of three phase Induction motor without VFD

5.2 Simulation for performance of three phases Induction motor with VFD.

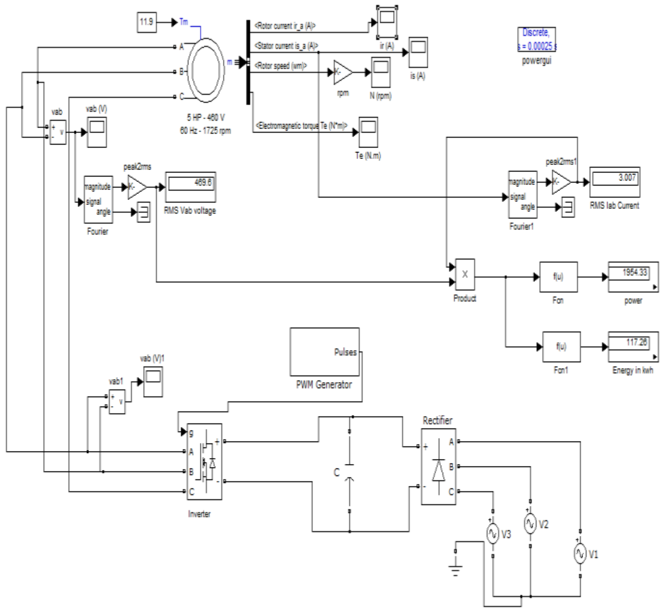
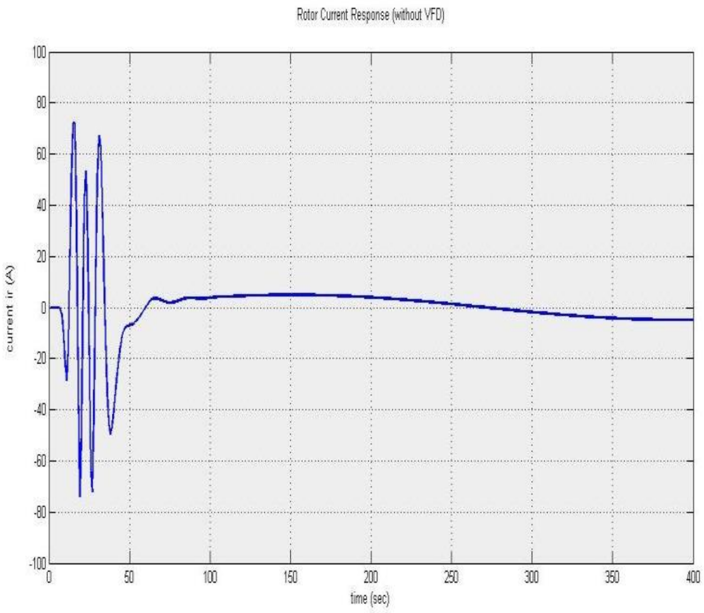


Figure 5.2 Simulation model for performance of three phase Induction motor with VFD

5.3 Rotor current response without VFD



F Figure 5.3 Rotor current response without VFD

5.4 Rotor current response with VFD

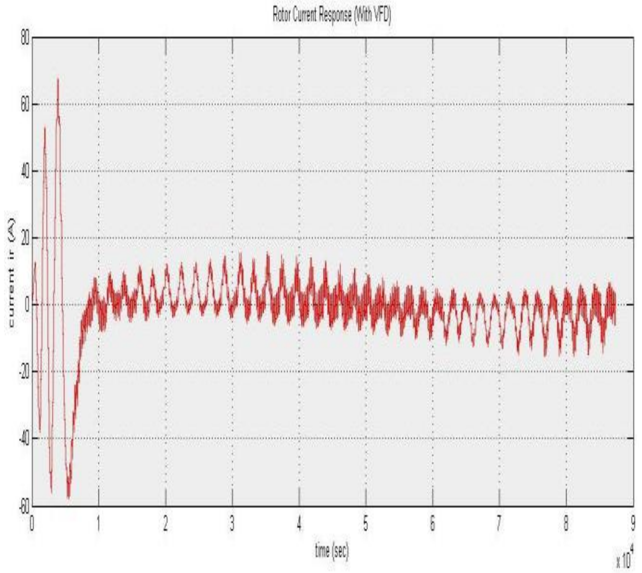


Figure 5.4 Rotor current response with VFD

5.5 Stator current response without VFD

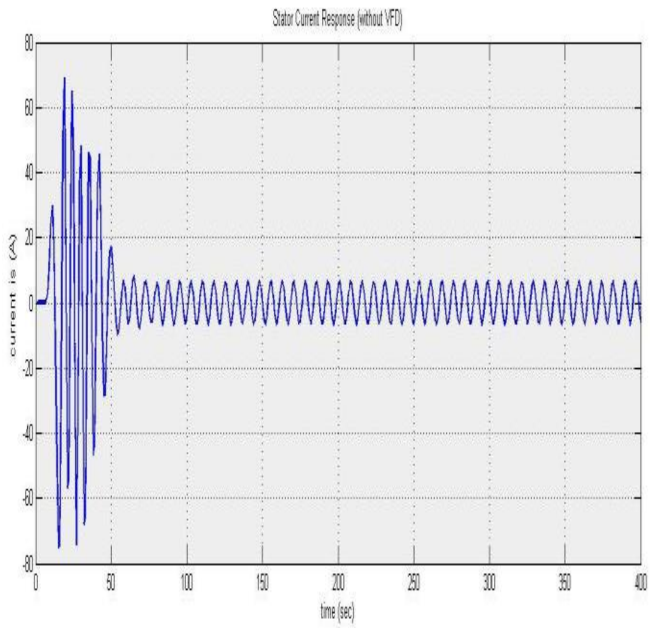


Figure 5.5 Stator current responses without VFD

5.6 Stator current response without VFD

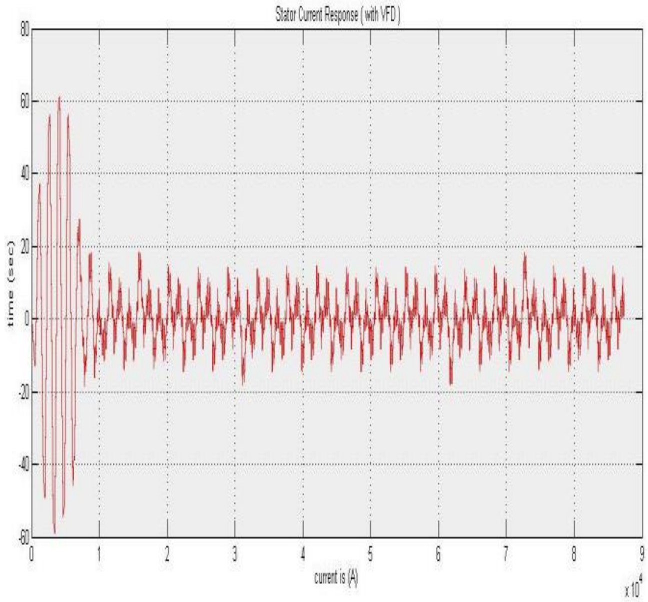


Figure 5.6 Stator current responses with VFD

3 5.7 Speed response without VFD

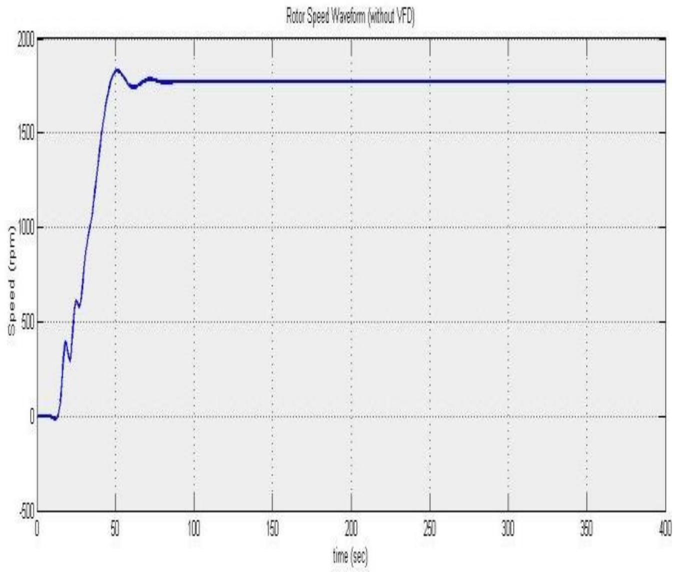


Figure 5.7 Speed Waveform without VFD

5.8 Speed response without VFD

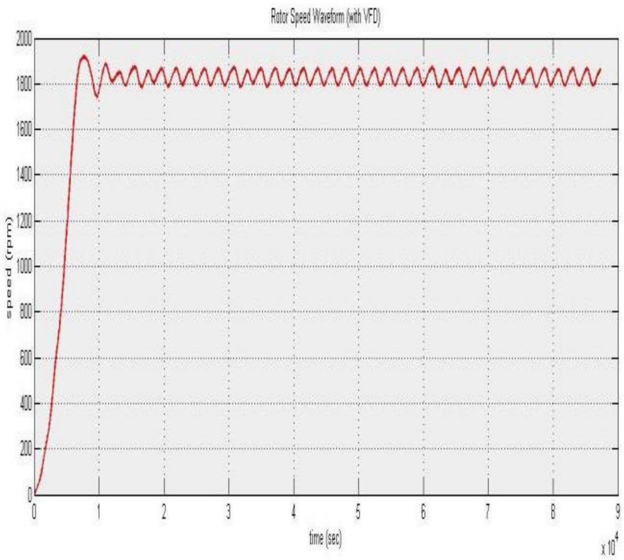


Figure 5.8 Speed Waveform without VFD

Table 5.1 Comparison between with & without VFD in pumping system

Torque (Nm)	Without VFD			With VFD			save
	Is Amp	P Watts	E kWh	Is Amp	P Watts	E kWh	
8	4.043	2337.04	140.22	2.614	1698.52	101.91	38.31
10	4.233	2535.05	152.10	2.785	1809.63	108.38	43.72
12	4.625	2814.76	168.89	3.02	1962.85	117.77	51.12
14	5.248	3087.35	185.24	3.306	2148.85	128.93	56.31
16	5.625	3263.22	195.79	3.631	2359.64	141.38	54.41

Table 5.1 Comparison between with & without VFD in pumping system

5.9 Comparison between with & without VFD in pumping system

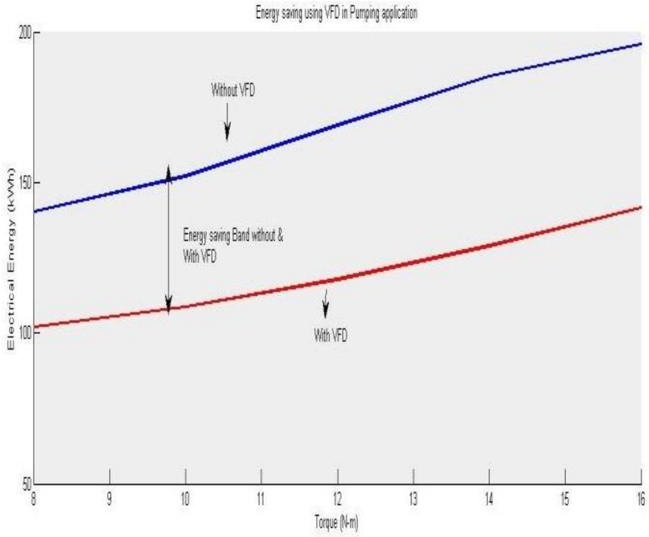


Figure 5.9 Energy Saving Band With & without VFD

VI. TEST SETUP

The schematic diagram of test rig is shown in figure 6.1. It consists of a water tank, a centrifugal pump, magnetic flow meter, pressure gauges, and ball valve. The specification of parts is listed below

- Pump Description (Crompton Greaves minimaster III)
  - KW/hp :- 0.75/1.00
  - Head :- 6/45 m
  - Discharge :- 4000/900 lps
  - Pump No :- KFPM06914
- Flow meter
  - Magnetic flow meter (ELMAG-200M)
- HMI Panel (CVM-NRG96)
  HMI panel is used for manual control of VFD drive.
- PLC
  - Siemens S7 200 PLC
  PLC is used to control the whole pumping system, measure input parameters and compare it and give feed back to the SCADA system.
- Pressure Gauges

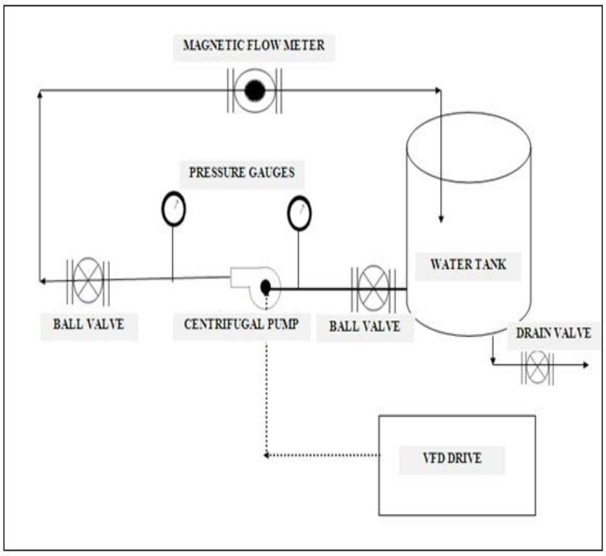


Figure 6.1 Schematic diagram of test rig

Figure 6.2 Photo of actual setup

VII. EXPERIMENTAL WORK :

The flow of centrifugal pump has been first controled by throttling. During test, different electrical and mechanical paremeter has been recorded which are shown in table 7.1.

Table 7.1 Observation Table (Throttling)

Flow	**Head**	**Active Power**	**Reactive Power**	**Apparent Power**	**Power Factor**	**Pump Efficiency**
m^3/hr	**m**	**KW**				**η**
3.81	4.23	0.134	0.232	0.26791	0.50	40.95
3.50	6.9523	0.155	0.2436	0.28878	0.53	53.47
3.20	10.1536	0.172	0.2456	0.29989	0.57	64.54
2.90	14.2547	0.18167	0.246	0.30580	0.59	77.23
2.50	20.3225	0.20567	0.2423	0.31784	0.64	84.14
2.12	25.2479	0.232	0.2406	0.33428	0.69	78.57
1.51	34.0963	0.256	0.2433	0.35319	0.72	68.49

Table 7.1 Recorded Electrical and Mechanical DATAs Experimental without VFD.

Now, flow of centrifugal pump has been controlled by VFD. During test, different electrical and mechanical parameter has been recorded which are shown in table 7.2.

Table 7.2 Observation Table (VFD)

Flow	**Head**	**Active Power**	**Reactive Power**	**Apparent Power**	**Power Factor**	**RPM**
m^3/hr	**m**	**KW**				
3.81	5.7791	0.1413	0.033	0.1451	0.97380	2919
3.50	5.1055	0.1183	0.02733	0.1214	0.97434	2703
3.20	4.8520	0.099	0.02266	0.1015	0.97477	2465
2.90	4.1120	0.082	0.01633	0.0836	0.98073	2235
2.50	3.8996	0.065	0.012	0.0661	0.98338	1933
2.12	3.5542	0.0526	0.01	0.0536	0.98244	1632
1.51	3.0254	0.039	0.006	0.0394	0.98837	1172

Table 7.2 Recorded Electrical and Mechanical DATAs Experimental with VFD.

VIII. CONCLUSION

As by control the flow of pump with throttling, net head increases and to overcome this extra head motor draw extra power as shown in table no7.1 & 7.2. VFD offers a very good response to pumping system. Reduces the flow with VFD, motor consume very less power. So significant amount of power can be saved with the help of Variable Frequency Drive as table no7.1 & 7.2.

As per Matlab Simulations Fig.5.1 (three phase Induction motor without VFD) and Fig. 5.2 (three phase Induction motor with VFD) as per result shown in fig.5.9 that electrical energy can be save by VFD in pumping application. Using VFD, there are harmonics introduced in above given simulation results but it can be removed by proper passive or active filters.

VFD also serves as Soft Starter, during starting motor draws 6 times more current than rated current. While starting with VFD, motor draws very less current and also provide a smooth stopping of motor. So the losses occur in motor can be eliminated.

VFD also improve the Power Factor, Form the table it can be clearly seen that while controlling the flow with Throttling, Power Factor remains very low compared to VFD which maintain the Power Factor near to unity and because of this the losses regarding to low Power Factor like Increase the I^2R and I^2X losses, Increase thermal stresses, increase size of conductor, circuit breaker etc. reduces.

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Biographies

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