

The Impact of Power Quality on VFD Application in Motor Fan Dust Collector

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Abstract - The technology to control the motor speed according to load requirements is variable frequency drive (VFD). The motor fan dust collector operates using a VFD to reduce the speed during idle smelting conditions. In addition to energy efficiency, the power quality of the electrical energy system is important to consider. Non-linear loads from VFDs cause harmonics in the industry that affect electrical power. Power quality measurement and analysis to determine the harmonic and unbalance values of voltage and current are important for improving power quality. This paper discusses the effect of VFDs on power quality, as a real case study, data from existing VFDs in the steel industry are taken to analyze power quality. A large current harmonic of 45% occurs when the VFD decrease the motor speed during idle smelting operation and drops to 5% when the motor speed returns to full speed during smelting operation on. The average maximum current unbalance value is 10.8% and the voltage unbalance is 0.36%, which is still below the standard maximum limit whether the motor is at full or low speed.

Keywords: VFD, Power Quality, Harmonic, motor fan.

I. INTRODUCTION

Motor fan dust collector operates to filter and remove dust and gas from smelting in the steel industry to the outside air [1]–[3]. The steel melting process operates with on and idle conditions, where in idle conditions, the melting process stops to pour liquid steel into the ladle furnace and refill scrap material into the melting furnace [4]–[6]. The installation of a VFD is carried out to regulate the rotation of the dust collector fan motor during idle conditions to a low rotation, because reducing the motor rotational speed as needed will reduce the energy consumption of the fan motor [7]–[10]. This energy efficiency step is carried out because it is important so that environmental sustainability and electrical energy resources are maintained [11]. So that electrical energy becomes very important to supply for every industrial and household sector. Because electric power is very important hence the electric power quality is a major concern. Good and bad power quality can be measured and analyzed.

The analysis is based on several parameters, like voltage, current, frequency, harmonic and system imbalance. Changes in these parameters are associated with standards to describe the status of power quality [11], [12]. In power systems, the effect of non-linear loads has increased over the past decade. Nowadays, power systems and power quality have been concerned about the adverse effects of harmonics generated by modern electronic devices such as speed control systems, filter controls, etc. [12]. Under ideal conditions, electrical power in a network is supplied at a constant frequency and at a certain voltage known as the fundamental frequency. But in practice, under different circumstances the frequency and voltage deviate from the specified values. The deviation of the waveform from a perfect sinusoidal is expressed in terms of harmonics. The presence of harmonics in the voltage and current waveforms causes signal distortion in the voltage and current, and the signal becomes non-sinusoidal causing malfunction or damage to the load[13].

There are a few factors that can decrease the value of power quality. The modules of power electronic have an essential function in the use of VFDs as a non-linear loads and retrieved harmonic currents and cause disruption in the electricity network. This also happens in three-phase non-linear systems that cause system unbalance, significant neutral currents, resulting in poor power quality and reduced efficiency [14]. In addition to harmonics, power quality also leads to sudden dip voltage and rises in a short time and system unbalance[15].

Various of the power quality must come from predefined of standards, the standards are governed by IEEE and IEC. IEEE Standard-519 offers a variety of limits for harmonic current and voltage in power systems. EN 50160 also provides voltage limits for public distribution networks. These standards will be maintained for healthy network conditions. In this research, measurements will be made to see the impact on harmonics and voltage and current unbalances of VFDs, and as a real case study, data on the use of VFDs is taken from the steel industry.

II. METHODOLOGY

2.1 Variable Frequency Drive

VFD is heavily applied in industry, most specifically for electric motor loads used in the process their operation. VFDs have great advantages such as control the speed by changing frequency and voltage which results in energy savings and limits the electric motor starting current. VFDs are very helpful for large motor systems and help increase energy efficiency in the industry by 25%, VFDs are also known for their advanced technology and modern reliability developments, but VFDs are also considered a source of harmonics. VFDs convert the 50 Hz frequency into a new frequency corresponding to the load requirements by controlling through two stages, namely the rectifier stage and the inverter stage. The conversion process combines three functions as shown in Figure 1, including:

- Rectifier stage:** An electrical device that can convert alternating current (AC) into direct current (DC). This three-phase AC supply is converted into a three-phase DC supply which is used as the input of the inverter.
- Inverter stage:** An inverter is an electronic device that converts direct current (DC) to alternating current (AC) by switching. The output of the inverter is an AC voltage and is grouped into three waveforms namely square-wave, pulse width modulation (PWM) and sinusoidal..
- Control system:** An electronic device that receives feedback information from sensors on a driven electric motor and adjusts the output voltage or frequency to a selected value. Usually the output voltage is set to produce a constant voltage to frequency ratio (V/Hz). This controller can incorporate many complex control functions.

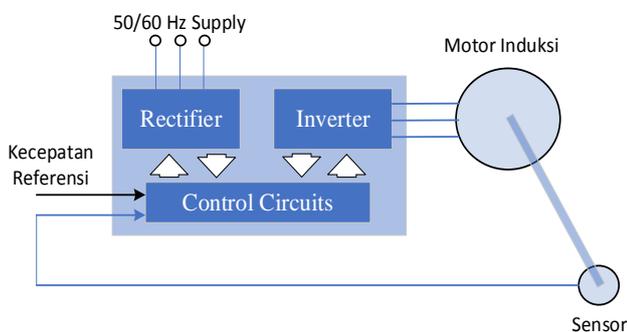


Figure 1: Variable Frequency Drive

VFDs give several benefits, the most significant being reduced energy consumption and demand for processes that are driven by electric motors with high efficiency values even when the electric motors are operating at low capacities. Even small reductions in motor rotation speed can provide significant energy savings [16].

2.2 Measurement

Data collection was carried out by recording daily electrical data from the motor fan dust collector installed with a VFD. All electrical parameters were measured with a Hioki PW 3360-21 Power Logger. The following electrical measurement points are shown in Figure 2.

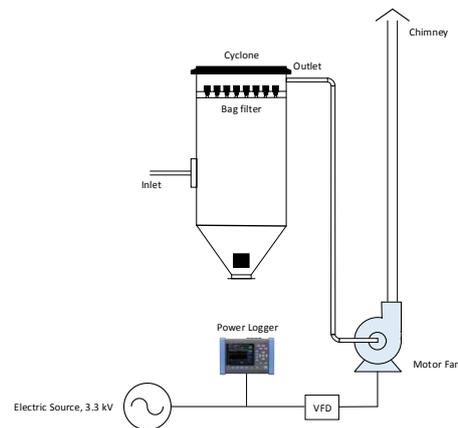
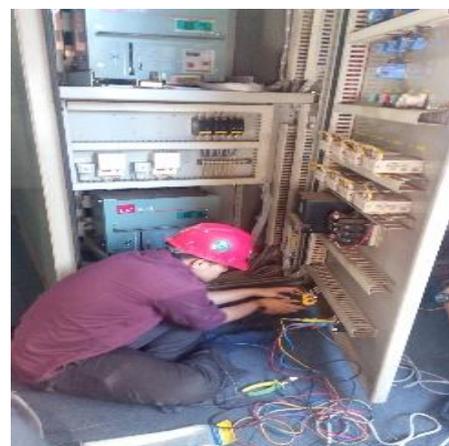


Figure 2: Electrical Measurement Point

The motor fan dust collector has a power capacity of 1,100 kW with a medium voltage supply of 3.3 kV measured using a Hioki Power logger PW 3360-21 as shown in Figure 3 below.



(a)



(b)

Figure 2: (a) Motor fan dust collector; (b) Electrical measurement

In this study, measurements were taken during the smelting process, both in the on and idle conditions with a data recording interval of one minute.

2.3 Evaluasi Power Quality

To reduce the impact of harmonic distortion on electric power systems and other supporting equipment, IEEE Standard was created in 1982 and updated in 1992, 2014 and 2022 [17]. As for the standard of electric power quality from voltage and current imbalance using Permen ESDM No.4, 2009 [18] and SPLN D5.004-1: 2012 regarding power quality [19]. IEEE 519 Standard proposes the limit of harmonic current supply from users to the supply network so that the voltage harmonic level in the power system remains within acceptable limits. The standard also addresses power system response characteristics, harmonic effects and provides recommended limits for current and voltage distortion. Table 1 below shows the harmonic current distortion limits imposed by this standard. The limits are based on the ratio of the available short circuit current (I_{sc}) in the PCC and the maximum load current (I_L).

Table 1: Current distortion limits for systems nominally rated 120 V through 69 kV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order						
I_{sc}/I_L	$2 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h < 50$	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

Table 2: Voltage distortion limit

Bus voltage V at PCC	Individual harmonic (%) $h \leq 50$	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV < $V \leq 69$ kV	3.0	5.0
69 kV < $V \leq 161$ kV	1.5	2.5
161 kV < V	1.0	1.5

III. RESULTS AND DISCUSSIONS

3.1 Voltage and Current Harmonic Distortion

From the measurement results of the Hioki Power Logger PW 3360-21 which is installed on the inlet side of the main breaker and records data over several melting cycles, it samples data every 1 minute and records the minimum, average and maximum values. Since the voltage source of the

dust collector fan motor is 3.3 kV. The maximum recommended voltage distortion is 3% for individual voltage harmonics and 5% for Total Harmonic Distortion (THD) as shown in Table 2.

The voltage distortion measurement results, shown in Figure 3 below, the THD value of the voltage during the measurement of the motor fan dust collector using a VFD is 2%, which is still below the IEEE-519 standard limit of 5%. As for individual harmonics, the largest is the 11th harmonic which is 1.78%, but this value is still below the IEEE-519 standard of 3%. From the results of this comparison, the voltage distortion value due to the installation of a VFD on the motor fan dust collector fan is still in good condition.

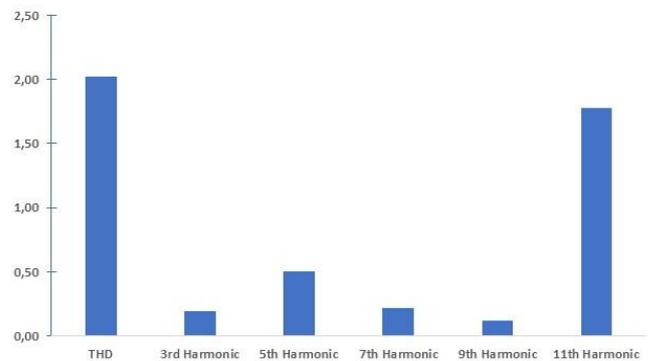


Figure 3: Actual % Voltage Distortion

For the current distortion analysis results, the maximum value of short circuit current (I_{sc}) at the Point of Common Coupling (PCC) point is 22,820 based on the data available in the transformer specifications. While the maximum value of demand current (I_L) during measurement is 200 A. from this data, the I_{sc} / I_L value can be known as:

$$\frac{I_{sc}}{I_L} = \frac{22.820 \text{ A}}{200 \text{ A}} = 114 \text{ A}$$

This ratio value is included in the maximum Total Demand Distortion (TDD) value with a limit of 15% as found in Table 1. From the measurement results using a power logger, the value contained in the measuring instrument is the Total Harmonic Distortion (THD) value, the TDD value will be calculated first with the following formula:

$$TDD = \frac{I_1}{I_L} \times THD \quad (1)$$

Where,

I_1 = Measured fundamental current value

I_L = Maximum rated current value

Because the I_1 value is always lower than the I_L value, so the analysis results show that the TDD value is lower than the

THD value as shown in Figure 4. Figure 4 shows the TDD calculation value from the THD measurement results for each smelting operation cycle. Where during the on smelting cycle, the dust collector fan motor works at full load (100%), while during the idle smelting cycle, the fan motor works with a 5% load.

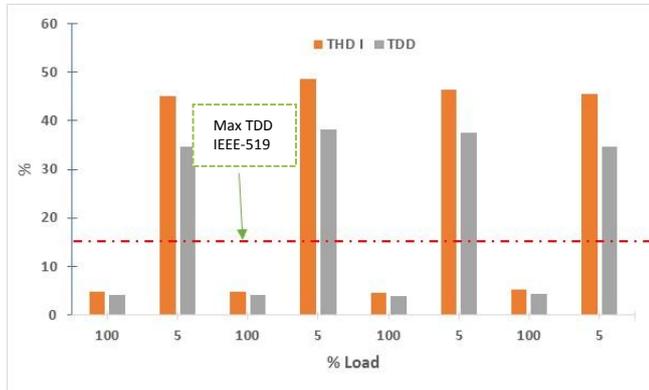


Figure 4: Actual % THD and % TDD

From Figure 4, it can be seen that there are two VFD operating conditions, namely low and high, where in low conditions or at 5% load due to idle smelting operations for a moment the TDD value increases to an average value of 45% and decreases again when the smelting operation is back on or at full load, which is an average of 5%. When the VFD operates to reduce the rotational speed, the TDD value increases beyond the maximum limit of the IEEE-519 standard of 15%. This condition can lead to increased power loss and increased temperatures in the stator and rotor of the induction motor. Temperatures above the rated value of the motor will lead to reduced motor life. Applying harmonic limits as defined in IEEE-519 in VFD implementations is useful for monitoring the power quality of the power grid. To overcome this problem, a harmonic filter can be installed to reduce the harmonic values that occur when the VFD is operating.

3.2 Current and Voltage Unbalance

The analysis of current and voltage imbalance uses the standards of Permen ESD No.4 of 2009. Where for the standard the maximum current unbalance is 20% and the maximum voltage unbalance is 3%. Analysis of voltage and current unbalance will be carried out using the following equation defined by the National Electrical Manufacturers Association (NEMA):

$$\% VUnbalance = \frac{\text{Maximum deviation from average Voltage}}{\text{Average of Three Phase Voltage}} \times 100 \quad (2)$$

$$\% IUnbalance = \frac{\text{Maximum deviation from average current}}{\text{Average of three phase current}} \times 100 \quad (3)$$

The results of the calculation of voltage and current imbalances from the measurement results at intervals of every one hour during on and idle smelting operations can be seen in Table 3 below:

Table 3: Voltage Unbalance Calculation

Cycle	Condition	Voltage (kV)			Voltage Unbalance (%)	Information
		R	S	T		
1	On	3,2	3,2	3,2	0,36	As per standard
	Idle	3,3	3,3	3,3	0,36	As per standard
2	On	3,2	3,3	3,2	0,37	As per standard
	Idle	3,3	3,3	3,3	0,36	As per standard
3	On	3,3	3,3	3,3	0,36	As per standard
	Idle	3,3	3,3	3,3	0,36	As per standard
4	On	3,2	3,3	3,3	0,36	As per standard
	Idle	3,3	3,3	3,3	0,35	As per standard

From the calculation results in Table 3, it can be seen that the voltage unbalance from the operation of the VFD on the dust collector fan motor still meets the standard, where the maximum standard is 3%. The results of the current unbalance calculation can be seen in table 4 below:

Table 4: Current Unbalance Calculation

Cycle	Condition	Current (A)			Current Unbalance (%)	Information
		R	S	T		
1	On	145,1	149,3	147,1	1,42	As per standard
	Idle	6,9	8,1	6,9	10,98	As per standard
2	On	144,1	148,3	146,3	1,41	As per standard
	Idle	7,2	8,4	7,1	10,81	As per standard
3	On	136,2	140,4	138,2	1,57	As per standard
	Idle	6,9	8,0	6,7	11,42	As per standard
4	On	135,8	139,8	137,8	1,46	As per standard
	Idle	7,2	8,3	7,1	10,39	As per standard

From the calculation results in Table 3, it can be seen that the current unbalance from the operation of the VFD on the dust collector fan motor increases during idle conditions, namely when the VFD works to reduce the rotational speed of the motor, but the value still meets the standard, where the maximum standard is 20%.

IV. CONCLUSION

This study was conducted by measuring and analyzing voltage and current harmonics, as well as voltage and current imbalances, which are one aspect of monitoring and

controlling power quality after the installation of VFDs in controlling dust collector fan motors in the steel industry. From this analysis, the criteria for determining the standard recommended values can be determined. The operation of the VFD during on and idle melting operations does not affect the value of voltage harmonics. The resulting voltage harmonics value is 2% for THD and 1.78% for the largest individual harmonic, this value is still below the maximum recommended limit of IEEE-519. The harmonic value of the current generated when the smelting operation condition is on or at full load is 5%, this value is still below the IEEE-519 maximum limit of 15%. However, when the smelting operation is idle and the VFD works to reduce the rotational speed of the motor, the value of current harmonics increases to an average of 45%, this can lead to increased power loss and increased temperature in the stator and rotor of the induction motor. Temperatures above the motor's rated value will lead to reduced motor life. Installation of harmonic filters must be done to reduce the harmonic value that occurs. The next research will be conducted to determine the size of the harmonic filter needed to reduce the harmonic value of the current that occurs.

In addition to current and voltage harmonics, the voltage and current unbalance values of the VFD implementation were also analyzed to compare them with the standard. From the analysis, the voltage unbalance value, which averages 0.36%, is still below the maximum limit of the standard of Permen ESD No.4 of 2009 of 3%. As for the current imbalance, although it increased by an average of 11% when the VFD worked to reduce the motor rotational speed, the value was still below the maximum limit of the ESD Regulation No.4 of 2009 standard of 20%.

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