



# Measurements and Evaluation of Flicker in High Voltage Networks

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**Abstract.** This paper presents a case study about the impacts of industrial loads on power quality. A review of flicker causes, negative impacts, mitigation techniques, quantification indices and limits are presented. Moreover, flicker measurements at three grid station that supply the three main industrial areas located in the main interconnected system (MIS) of Oman are conducted. Measurement results are compared with limits specified by national and international standards.

# Key words

Power Quality, Flicker, Measurements, Standards, Arc furnace.

# 1. Introduction

Heavy industrial loads are often connected to transmission networks at high voltage levels such as 132 kV and 220 kV. These loads may include rolling mills often driven by thyristor-control DC Drives, or could be an Electric Arc furnace or induction furnaces needing large reactive power. These types of loads can deteriorate the supply quality of other loads connected to the same point of common coupling (PCC).

To study the impact of heavy industrial customers on the power quality of the high voltage network, measurement of the existing distortion levels is important. In this paper, flicker measurements are conducted at selected industrial load grid stations of Oman Electricity Transmission Company (OETC) network [1]. The on-site measurements are performed at the 132kV side of the substation transformer feeding the industrial customers. The measured levels of flicker distortion are analyzed and compared with appropriate standards. The study outcome and recommendations can be used to further improve the grid code and connection agreements for heavy industries. After this introduction, the paper proceeds with presenting an overview of the voltage flicker, its impacts, typical sources and mitigation techniques. In section three, flicker

sources and mitigation techniques. In section three, flicker indices and limits are reviewed. Measurement results are discussed in section four. Finally the main conclusions are presented.

# 2. Flicker

Flicker is simply the fluctuation of light intensity. According to the International Electro technical

Vocabulary (IEV), it is defined as: "Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral fluctuate with time" [2]. In many cases, the term 'Flicker' is used to describe the voltage fluctuations themselves.

Since the inception of electric lighting, flickering of lights has been a reality for most consumers. Flicker is relatively an old topic. According to [3], it was the flicker that determined the standard frequency for the electric power system to prevent visible flickering in open-type arc lamps in America in 1891 to be 60Hz. Europeans select 50 Hz based on the flicker response of enclosed-type arc lamps [3].

## A. Effect of Flicker

Light flicker is just a symptom perceived by the human eye of the original problem, which is voltage fluctuation caused by rapid variation of the load current. If voltage fluctuations occur with certain frequencies (0.05-35 Hz), the fluctuation in light intensity, perceived by the human eve, could lead to unpleasant feeling and health problems. The most severe disturbing effect occurs when the frequency of the fluctuation is 8.8 Hz. The flicker phenomena can be so subtle as to not be consciously detected by those affected but at the same time can induce discomfort in the form of nausea or headache and in turn affects the work efficiency. Normally flicker is perceived as annoyance and distraction. But in some extreme cases, it can cause epilepsy seizures to those who are borne to it. It has been reported that flicker causes seizures in about 4% of the patients with epilepsy [4].

Voltage fluctuations can cause other problems other than light flickers. These include triggering of UPS units to switch to battery and problems with some sensitive electronic equipment, such as in medical laboratories, which require a constant voltage. When the voltage magnitude varies, power flow into the equipment will also change. If the variation is large enough or within a critical frequency range, the performance of equipment can be affected [5]. Usually, complaints about light flicker will occur well before any disturbances on other loads show up [6]. As an example to this fact, the ITI (CBEMA) curve shows the faultless operation zone of the IT equipment as a function of nominal voltage change and the duration of that change. This curve describes an AC input voltage envelope which typically can be tolerated by most Information Technology Equipment (ITE) [7].



Fig. 1. Faultless operation zone of the IT equipment (ITI curve)

#### B. Causes of Flicker

In principle, any switching operations of industrial processes and electrical appliances connected to the supply system can cause voltage changes and in turn light flicker. Generally, flicker phenomenon can be divided into two general categories, cyclic and non-cyclic. Cyclic flicker is caused by periodic load fluctuation/switching operations. Non-cyclic flicker is caused by occasional load fluctuations/switching operations. Some sources of flicker can cause both cyclic and non-cyclic flicker. The typical sources of light flicker are listed below [5].

- Arc furnaces cause fast voltage fluctuation occurs due to the high current and the unstable nature of the arc during the process.
- Resistive welding machines draw high repetitive welding currents that cause the voltage to fluctuate in the same manner.
- Large electric motors can cause flickers during starting due to the inrush starting current and if the load is varying. Examples of such motors are rolling mills, stone crushers, elevators and pumps.
- on/off switching of large loads such as large capacity copy machines, medical imaging machines and color organs in discos.
- on/off switching of compensating elements and changing of transformer taps cause a sudden increase/decrease of the voltage.
- The operation of intermittent types of distributed generation facilities such as wind turbines and PV systems.
- Pulsated loads such as Harmonics active filters and Thermostat controlled loads.
- System faults in electrical supply system can cause temporary voltage fluctuations. These kinds of events

may cause very high flicker levels but are not frequent.

#### C. Flicker Mitigation

Flicker occurs due to two reasons: network impedance and fluctuated load current. To minimize flicker, the magnitude of voltage fluctuations must be reduced. To achieve this, two strategies can be used: a) Reduce the network impedance. b) Reduce the load current fluctuation.

The power utility is responsible for the first option. This can be achieved through two approaches:

1. Network Reinforcement:

Reducing network impedance means increasing the short circuit power at the load bus. This is achieved by reducing the impedances between the load and the supply through network reinforcement. Unfortunately, this solution is economically not justifiable.

2. System Reconfiguration:

A cheaper solution could be to increase the short circuit power at the PCC with the existing system infrastructure.

On the other hand, reducing the current fluctuation of the load should be done by the load (network customer). This can be achieved through reactive compensation. The voltage drop caused by a variable/fluctuating load can be decomposed into two components: reactive component and active component. The reactive load component is dominant due to high X/R ratio. There are different options for reactive compensation: Shunt Capacitors, Synchronous Condenser, Static Var Compensation (SVC), and Static synchronous compensation (STATCOM).

# 3. Flicker Indices and Limits

A. Flicker Indices

The flicker assessment is basically based on human perception of voltage fluctuations with certain outward shapes and various repetition rates (frequencies). The international Electrotechnical Commission standard IEC 61000 4-15 describes the flicker measuring methodology[8]. Two indicators are used to assess the flicker severity [8, 9].

- Pst (P for Perceptibility) is the short term flicker severity index evaluated over a short period. The standardization bodies specify the time over which the Pst is calculated to be 10 minutes [2, 8, 9].
- Plt is the long term flicker severity index evaluated over a long period. It calculated for 2 hours of the observation period using 12 pieces of successive 10 minutes Pst values [2, 8, 9].

$$P_{lt} = \sqrt[3]{\frac{1}{12}\sum_{j=1}^{12} P_{st}^{3}}$$
(1)

When there are more than one flicker source, the total flicker severity can be determined by adding the annoying factors caused by individual sources.

$$P_{st} = \sqrt[3]{\sum_{i} P_{st_i}^3} \tag{2}$$

At Pst =1 p.u flicker severity, 50% of the people exposed to flicker will feel unpleasant or irritable. This flicker level is called "the threshold of irritability". The international standardization bodies (IEC & IEEE) provide tables and curves showing Pst=1 as a function of the percentage relative voltage change and the frequency of the voltage changes [9].

The international standardization bodies (IEC & IEEE) provide tables and curves showing Pst=1 as a function of the percentage relative voltage change and the frequency of the voltage changes [9]. An example is shown in the following figure.



Fig. 2. Pst = 1 test points for rectangular voltage fluctuations [9]

Figure 2 shows the Pst =1 curve of a 60W (230V and 120V) incandescent lamp for a rectangular voltage change according to IEC and IEEE [9]. It can be seen that the Pst=1 curve have a minimum relative voltage changes value of 0.29% at 1052 changes per minute i.e. 8.8Hz. Note that 1Hz voltage fluctuation means 120 voltage changes per minute.

The relative voltage change should be always in the area below the Pst=1 curve to be admissible. However, at low changing rates below 0.6 changes per minute, the threshold level of Pst=1 is not valid as a voltage fluctuations limit because the corresponding (d %) is too high. An example for this case is an occasional large voltage change. This voltage change has small effect on the Pst value but it will be very disturbing to other loads connected to the same point of common coupling (PCC). This example could be an appliance that draws a very large inrush current from the supply when it is first switched on, especially if the input has no inrush current limiting circuitry. The inrush current may cause a substantial deviation in the supply voltage causing disturbance to sensitive loads connected to the same PCC.

## B. Flicker Limits

IEC 61000 3-7 provides guidance to system operators, owners and engineers that are responsible for providing electrical service to loads that cause voltage fluctuations. The relevant IEC standard has been recently adopted by IEEE [10, 11]. It is worth mentioning that compatibility levels are not defined by IEC 61000 3-7 for MV, HV and

EHV systems. However, indicative values of planning levels are presented as shown in the following table.

Table I IEC indicative values of planning levels for flicker [11]

Indicator	$MV \\ 1 kV < U \le 35 kV$	HV & EHV U> 35 kV
P <sub>st</sub>	0.9	0.8
P <sub>lt</sub>	0.7	0.6

According to the national grid code [12], "the level of voltage fluctuations at a Connection Point shall be within the limits defined in IEC 61000-3-7, with a Flicker Severity (Short Term) of 0.8 Unit and Flicker Severity (Long Term) of 0.6 Unit."

## 4. Measurement Results and Discussion

There are three main industrial areas in the MIS of Oman: Rusail area in Muscat, Sohar Industrial Area and Nizwa industrial area. Data of relevant grid station are listed in Table II.

Grid Station	Number of Tx	Rating of each Tx	Max short circuit level on 132 kV side (kA)
Rusail	4 ×132/33 kV	75 MVA	17.76
Sohar SIA	2 × 220/132 kV	500 MAV	16.77
Nizwa	2 ×132/33 kV	125 MVA	14.05

Table II Grid stations data [1]

Measurements were conducted using Hioki 3196 Power Quality Analyzer Meter [13]. 10-minute average values were recoded over a period of 1 week in each location.

## A. Rusail Grid Station

A summary of flicker measurements at Rusail grid station is presented in Figure 3. A and B in the figure show the start and the end of the measurement period.

As seen from Figure 3, the average value of the short term flicker severity index (Pst) ranges between 0.262 and 0.463. The maximum value of Pst is 0.811. This value is slightly higher than the limit specified by the grid code (0.8).

For the long term flicker severity index (Plt), the average value ranges between 0.265 and 0.464. The maximum value of Plt reaches 0.522, which is lower than the limit specified by the grid code (0.6). A sample of the chronological variation of flicker level at Rusail grid station is shown in Figure 4.

For the long term flicker severity index (Plt), the average value ranges between 0.265 and 0.464. The maximum value of Plt reaches 0.522, which is lower than the limit specified by the grid code (0.6). A sample of the chronological variation of flicker level at Rusail grid station is shown in Figure 4.

IEC Flicker CH1				
		Pst Pl	t	
А	01/24 11:41:00	0.424	0.485	
B	01/17 11:51:00	0.502	0.502	
	- 7 00:00:00	0.078	0.017	
	MAX values	0.811	0.522	
	AVE values	0.463	0.464	
	MIN values	0.407	0.418	
		IEC Flicker CH2	2	
		Pst Pl	t	
А	01/24 11:41:00	0.230	0.324	
В	01/17 11:51:00	0.270	0.270	
	- 7 00:00:00	0.039	- 0.054	
	MAX values	0.642	0.324	
	AVE values	0.282	0.283	
	MIN values	0.219	0.229	
		IEC Flicker CH3	}	
		Pst Pl	t	
А	01/24 11:41:00	0.199	0.207	
В	01/17 11:51:00	0.235	0.235	
	- 7 00:00:00	0.035	0.027	
	MAX values	0.652	0.368	
	AVE values	0.262	0.265	
	MIN values	0.185	0.199	

Fig. 3. Summary of Flicker measurements at Rusail grid station



Fig. 4. Flicker measurements at Rusail grid station.

#### B. Sohar SIA Grid Station

The power quality analyzer was set to record required data for a period of one week starting from 28th of January 2012. A summary of flicker measurements at Sohar SIA grid station is presented in Figure 5.

The average value of the short term flicker severity index (Pst) are 0.737, 0.839 and 0.835. The last two average values are higher than the limit specified by the grid code (0.8). The highest recorded Pst value is 2.148.

For the long term flicker severity index (Plt), the recorded values range between 0.191 and 1.193. All average values are higher than the 0.6 limit specified by the grid code.

IEC Flicker CH1 Pst Plt				
A B	02/04 13:04:00 01/28 13:14:00	0.651 1.025	0.947 1.025	
	- 7 00:00:00	0.374	0.078	
	MAX values AVE values MIN values	2.148 0.835 0.400	1.193 0.874 0.407	
		IEC Flicker CH	2	
		Pst P	lt	
A B	02/04 13:04:00 01/28 13:14:00	0.450 0.945	0.887 0.945	
	- 7 00:00:00	0.495	0.058	
	MAX values AVE values MIN values	2.085 0.737 0.205	1.123 0.812 0.213	
		IEC Flicker CH	3	
		Pst P	lt	
A B	02/04 13:04:00 01/28 13:14:00	0.531 1.144	1.014 1.144	
	- 7 00:00:00	0.612	0.130	
	MAX values AVE values MIN values	1.878 0.839 0.182	1.189 0.928 0.191	



A sample of the chronological variation of flicker level at Sohar SIA grid station is shown in Figure 6.



Fig. 6. Flicker measurements at Sohar SIA grid station

This high level of flicker distortion is attributable to the operation of arc furnaces. A simultaneous measurement of the current in the 132 kV feeder supplying the arc furnace demonstrates the relationship between the operation of arc furnaces and the high level of flicker as demonstrated in Figure 7.



Fig. 7. Current measurements of the 132kV feeder connected to an arc furnace at Sohar SIA grid station

#### C. Nizwa Grid Station

In Nizwa grid station, the analyzer was set to record required data for a period of one week starting from 29th of February 2012. As demonstrated in Figure 8, the average values of the short term flicker severity index for the three phases are 0.661, 0.621 and 0.6. The highest recorded Pst value is 2.695.

IEC Flicker CH1			
		Pst Plt	
	A 03/0712:11:00	0.612	0.605
	B 02/2912:21:00	0.774	0.774
	- 7 00:00:00	0.161	0.169
	MAX values	2.695	1.250
	AVE values	0.661	0.667
	MIN values	0.560	0.584
		IEC Flicker CH2	
		Pst Plt	
	A 03/07 12:11:00	0.569	0.564
	B 02/29 12:21:00	0.709	0.709
	- 7 00:00:00	0.140	0.145
	MAX values	1.839	0.890
	AVE values	0.611	0.617
	MIN values	0.532	0.545
		IEC Flicker CH3	
		Pst Plt	
	A 03/07 12:11:00	0.576	0.574
	B 02/29 12:21:00	0.722	0.722
	- 7 00:00:00	0.146	0.149
	MAX values	1.797	0.881
	AVE values	0.621	0.625
	MIN values	0.537	0.558

Fig. 8. Summary of Flicker measurements at Nizwa grid station

It is worth mentioning that the Pst value is lower than the limit specified by the grid code (0.8) most of the time. However, this is not the case for the recorded Plt values. In most of the cases, the Plt values were higher than the 0.6 limit specified by the grid code. The recorded values range between 0.545 and 1.25. All average recorded values are higher than the 0.6 limit.

A sample of the chronological variation of flicker level at Nizwa grid station is shown in Figure 9.

Spikes in the flicker measurements might be attributable to the unstable 132kV single circuit connection with Petroleum Development Oman (PDO) power network. The tripping of this connection causes voltage spikes as seen in Figure 10.



Fig. 9. Flicker measurements at Sohar SIA grid station



Fig. 10. Voltage measurements at the 132kV side of Nizwa grid station

## 5. Conclusions

This paper presents a review of flicker causes, impacts, mitigation techniques, indices and limits. Moreover, a case study about flicker measurements at three grid stations feeding industrial areas in the main interconnected system of Oman is presented. The measured flicker levels in two of the three grid stations violate the limits specified by the national grid code. It is worth mentioning that Sohar SIA grid station has the highest flicker distortion level due to the operation of arc furnaces. It is recommended to include limits on flicker levels emitted from a single industrial customer in the grid code. As heavy industry loads are expanding in the country, it is expected that power quality distortion levels will increase. Therefore, continuous monitoring of power quality distortion levels is important.

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