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DESIGN AND CONSTRUCTION OF AN OBJECTIVE FLICKER METER

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ABSTRACT

Furthermore, modern electric power customers require better quality power supply for their sensitive facilities. Hence, voltage flicker is considered as one of the major electric power quality problems. In this paper, we have been explained design and construction of a digital flicker meter that we use it in power quality control of Turkish Electrical Transmission System to measure voltage flickers of different points under different load conditions. The given digital flicker meter is compatible with the functional and design specifications given in IEC 61000-4-15 standards is realized by the use of Labview software.

Keywords: Electric power quality; Voltage flicker; Flicker meter

1. INTRODUCTION

Voltage Flicker occurs when heavy loads, such as reciprocating machines or electric arc furnaces (EAFs), operate periodically in a weak power distribution system. During the steel making procedures, load currents change extremely. If the system short circuit capacity is not enough, voltage fluctuation from 0.5 to 30 Hz would occur at the PCC bus and influence the power supplying area. Many papers have reported that a small voltage fluctuation from 0.3% to 0.5% in the frequency range of 6-10 Hz will cause visible incandescent lamp flickering. This visible lighting flicker will cause uncomfortableness to eyes [1]. When a voltage waveform contains interharmonics, the RMS and peak magnitudes of the waveform will fluctuate. This is because the periods of the interharmonic components are not synchronous with the fundamental frequency cycle. This fluctuating magnitude is essentially a form of voltage flicker. If the magnitude is sufficiently large and the fluctuating frequency is in a range perceptible by human eyes, a light flicker will occur. As a result, devices that produce interharmonics have been considered as a major source of light flicker [2].

According to International Electrotechnical Committee (IEC) standard 61000-4-15, voltage flickers shall be measured and quantified using the IEC flicker meter [3]. The IEC flicker meter is essentially a signal-processing unit that takes raw voltage signals as inputs and outputs flicker severity indices P_{st} and P_{lt}.

The structure of the IEC flicker meter is shown in Fig. 1. In recent years, the IEC flicker has gained international acceptance. For example, Institute of Electrical and Electronics Engineers (IEEE) Task Force on voltage flicker recommends adopting the flicker meter concept and algorithm in to the IEEE standards [4].

In this paper, we will explain an objective flicker meter that has been designed and constructed according to IEC standard 61000-4-15, for measuring voltage flicker effects in Turkish Electrical Transmission System.

2. FLICKER MEASUREMENT TECHNIQUE

The flicker meter proposed by IEC is designed for analog applications and mainly divided to two parts. First part resembles lamp-eye-brain response and second part analyzes the flicker signal statistically [5]. Function and design properties of flicker meter is given at IEC 61000-4-15 standard.

Figure 1 shows a block diagram for the complete flicker meter instrument described in the IEC standards. The voltage adaptor at the first block normalizes the signal to the voltage RMS value. The demodulator in the second block squares the output of the first block and resembles the lamp response. The filters on the third block eliminate the ripples with twice the line frequency caused by the squaring operation and weight the signal to simulate the lamp-eye response. The squaring multiplier at the fourth block squares the weighted signal and imitates the non linear eye-brain response and the sliding mean filter resembles the storage of the brain. Finally, at the last block flicker signal is analyzed statistically. Since digital data acquisition has been widely used recently, a digital flicker meter is designed to measure the voltage flicker.

For data acquisition, National Instruments SC2040 with eight- channel sample & hold card and 16 bit, 200 kS/s 6036E data acquisition card are used. For each channel, 3200 samples per second are collected. Voltage signals converted to digital by means of this way are transferred to laptop computers.

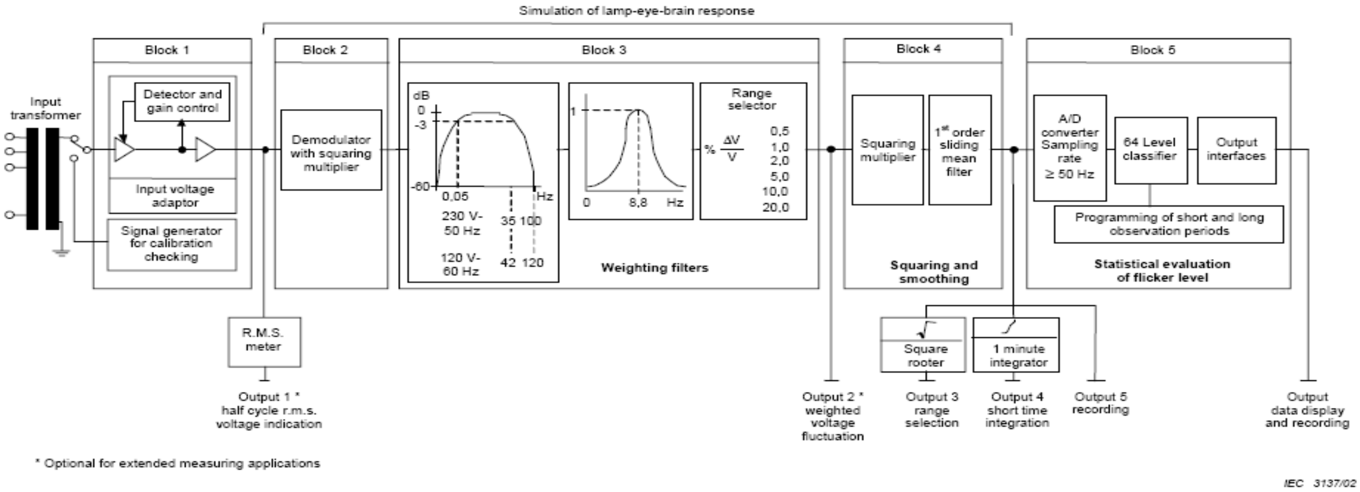


Fig. 1: Functional diagram of IEC flicker meter [3]

The IEC flicker meter is in time domain and mainly uses blocks given in the IEC standards. However, since in the given flicker meter, data signals are digitally collected, transfer functions of continuous time filters described in the related IEC standards are transformed to discrete time filter transfer functions. The block diagram of the flicker meter is illustrated in Fig. 2.

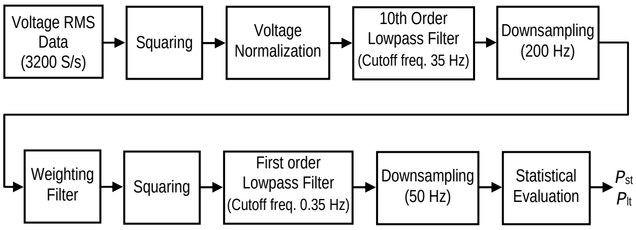


Fig. 2: Block diagram of flicker meter

Voltage rms value is squared and divided to 10 minute mean value of voltage so that it can be normalized. In the design of digital flicker meter a 10^{th} degree Butterworth low pass filter is recommended. Unlike the analog application, the low frequency response of the band pass filter in the range 0.05-35 Hz is realized in the weighting filter.

By filtering out the high frequency components step by step, processing with lower sampling rates has become possible and therefore down sampling is also made step by step. As the weighting filter an IIR (infinite impulse response) filter is used. The coefficients used in the filter are given in Table 1.

Table 1: Discrete time weighting filter coefficients

Order	Numerator Coefficient	Denominator Coefficient
z^0	9.487215×10^{-2}	1.00000
z^{-1}	-1.582865×10^{-1}	-3.167151
z^{-2}	4.023729×10^{-2}	3.752054
z^{-3}	2.317702×10^{-2}	-1.958255
z^{-4}		3.747149×10^{-2}

The sliding mean filter following the squaring block is modeled by a first order Butterworth low pass filter with the cut off frequency 0.53 Hz. After this block, the statistical analysis of instantaneous flicker signals is done. Assessment is done according to the methods described in the IEC standard. In evaluating the short term flicker severity 10-minute time intervals are considered. On the other hand, long term flicker severity is evaluated with two hours time intervals are used. 10 minute short term flicker is evaluated with the formula given below which is given in IEC standard.

$$P_{st} = (0.0314\, P_{0.1} + 0.0525\, P_{1s} + 0.0657\, P_{3s} + 0.28\, P_{10s} + 0.08 P_{50s})^{1/2} \qquad (1)$$

Multipliers $P_{0.1}$, P_{1s}, P_{3s}, P_{10s}, P_{50s} given in the equation above are the levels of instantaneous flicker severity that is exceeded in 0.1%, 1%, 3%, 10%, 50% time of the observation time respectively. These smoothed multipliers are obtained by the following equations.

$$P_{1s} = (P_{0.7} + P_1 + P_{1.5}) / 3 \qquad (2)$$

$$P_{3s} = (P_{2.2} + P_3 + P_4) / 3 \qquad (3)$$

$$P_{10s} = (P_6 + P_8 + P_{10} + P_{13} + P_{17}) / 5 \qquad (4)$$

$$P_{50s} = (P_{30} + P_{50} + P_{80}) / 3 \qquad (5)$$

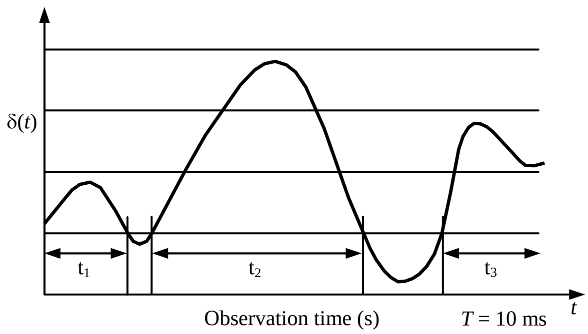


Fig. 3: Time variations of instantaneous flicker signal

Long term flicker severity is calculated from the short term values with the following formula.

$$P_{lt} = \sqrt[3]{\frac{\sum_{i=1}^{12} P^{3}_{sti}}{12}} \tag{6}$$

P_{sti}: Consecutive short term flicker severity values during two hours.

In the related IEC standard [3], normalized values whose flicker severity must be equal to one for sinusoidal and rectangular voltage fluctuations, are given with the title of "4.1 Analog Response". Accuracy of the flicker meter is tested with respect to these values. It is calibrated such that the error is in the limit of ± %5 for all cases.

3. MOBILE POWER QUALITY MONITOR AND FLICKER MEASUREMENT RESULTS

The mobile power quality monitors that has been shown in Fig. 4 are established to take the nationwide power quality snapshots of Turkey Electricity Transmission System as a subproject of the National Power Quality Project carried out by The Scientific & Technological Council of Turkey (TUBITAK).

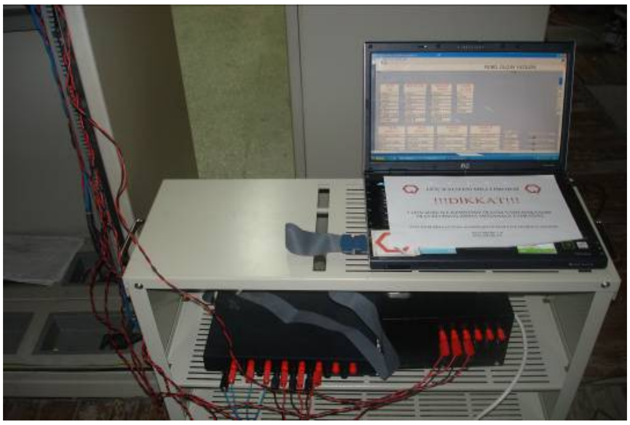


Fig. 4: The Mobile Power Quality Monitor

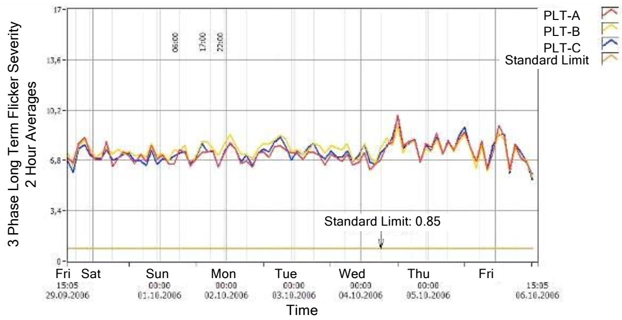
Measurements are performed by sampling, digitalizing and analyzing voltage and current waveforms taken from conventional voltage and current transformers that belongs to Turkish Electricity Transmission Company (TEIAS). The methods and measurement periods given in IEC 61000-4-30 are used in all measurements [5]. Flicker meter software is a part of the mobile power quality monitoring software that analyzes other quality parameters.

PQ measurements have been carried out at 59 transformer substations, 205 incoming and outgoing feeders. All measurement points are classified in Table 2 on the basis of the load types (heavy industry, industry + urban, urban only), and operating voltage level (medium, high, and extra-high voltages).

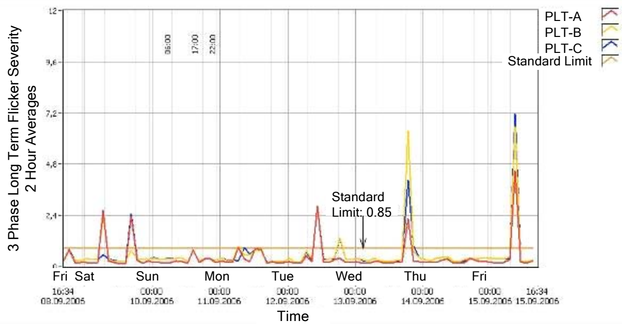
Table 2: The Number of measurement point
NB: Number of busbars, NF: Number of feeders

Number of Measurement Points								
Voltage Levels	Load Type							
	Heavy Industry		Industry + Urban		Urban Only		TOTAL	
	NB	NF	NB	NF	NB	NF	NB	NF
33 kV	11	19	56	89	20	24	87	132
154 kV	4	6	31	39	10	11	45	56
380 kV	2	2	9	14	1	1	12	17
TOTAL	17	27	96	142	31	36	144	205

According to measured voltage flicker values during one week, 2 hours average values of 3 phase long term flicker severity of different loads is shown in Fig. 5, separately.



(a)



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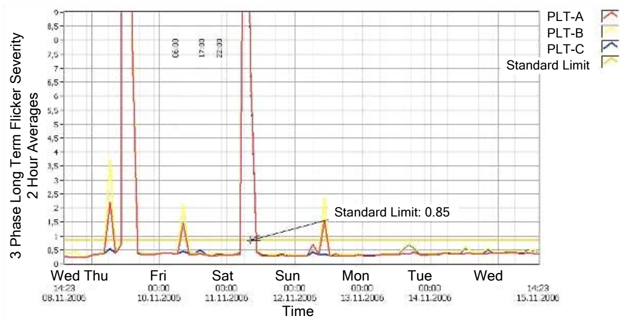

(c)

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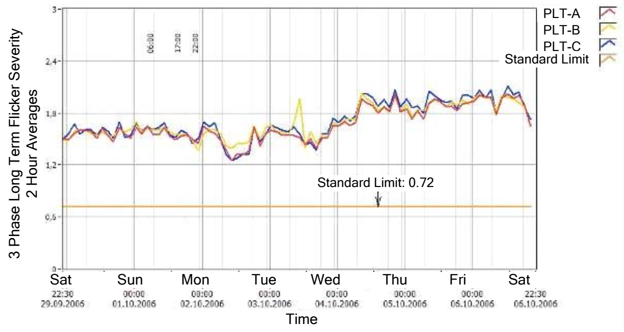

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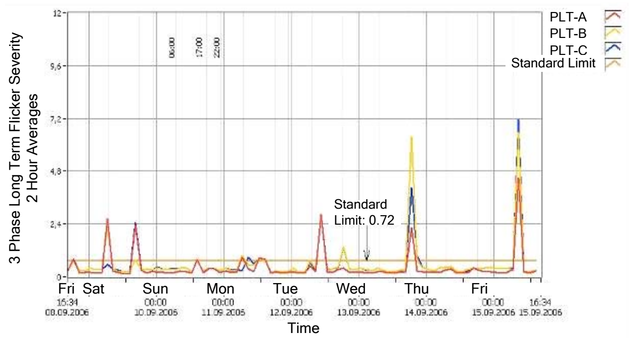

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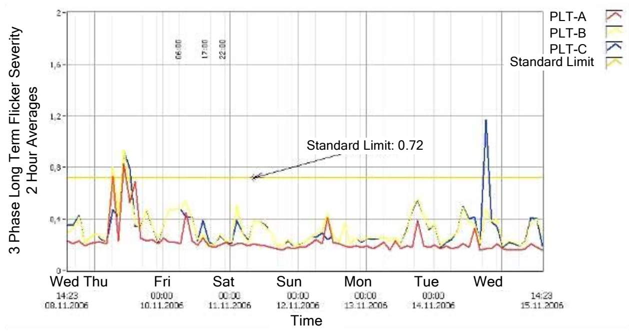

(f)

Fig. 5: (a) Medium voltage (heavy industry) voltage flicker; (b) Medium voltage (urban) voltage flicker; (c) Medium voltage (urban + industry) voltage flicker; (d) High voltage (heavy industry) voltage flicker; (e) High voltage (urban) voltage flicker; (f) High voltage (urban + industry) voltage flicker

The limits of the flicker severity are specified by "Electricity Market Network Regulation" in Turkey. In IEC 61000-4-30, under the heading A.6.2.3 "99% (or other percentage) probability weekly values for P_{st}, or 95 % (or other percentage) probability weekly value for P_{lt}, might be compared to contractual values" is suggested. From this viewpoint, for all measurement points a statistical work is done about which points and phases exceed the limit longer than the suggested time periods. The points at which the long term flicker severity exceeds the limits more than 5% of the week are assessed as problematic. Some results obtained by this evaluation are shown in Table 3, Fig. 6 and Fig 7.

Table 3: Long term flicker severity and busbar average short circuit MVAs of different measurement points at 154 kV voltage

154 kV Voltage Level Long Term Flicker Severity (P_{lt})			
Transformer Station (TS)	Limit (0.72) Exceeding Percentage (%)	Short Circuit (MVA)	
		TS	Average
TS 1*	100.0	5634	5320.5
TS 2*	98.8	5148	
TS 3*	98.8	5171	
TS 4*	98.7	5329	
TS 5**	30.1	334	963.79
TS 6**	13.25	325	
TS 7**	13.04	923	
TS 8**	12.6	1119	
TS 9**	12.04	814	
TS 10**	10.84	1318	
TS 11**	8.43	1518	
TS 12**	7.2	1143	
TS 13**	6.02	455	
TS 14**	6.02	1689	
TS 15	4.81	1668	2046.5
TS 16	4.81	1060	
TS 17	4.8	1868	
TS 18	4.8	3828	
TS 19	4.6	854	
TS 20	3.2	2746	
TS 21	2.2	4183	
TS 22	1.2	1871	
TS 23	1.2	2387	

* Heavy industry and above IEC suggested limit 5%

** Above IEC suggested limit 5%

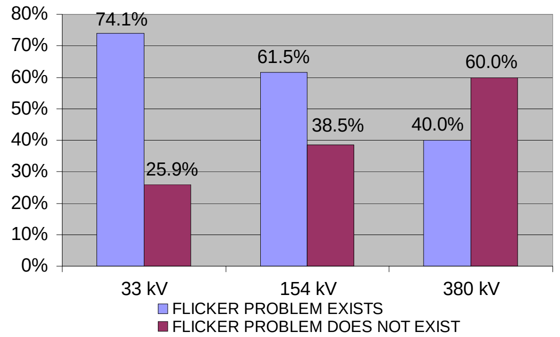

Fig. 6: Flicker problem percentages for different voltage levels

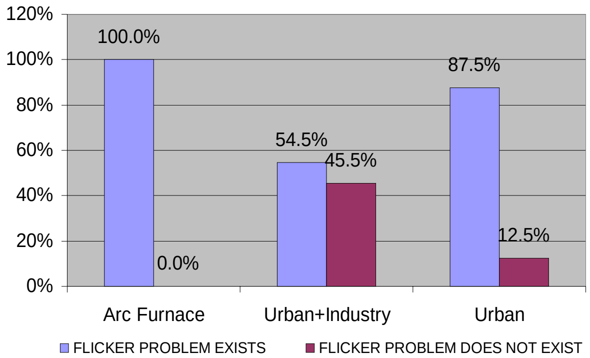

Fig. 7: Flicker problem percentages for different load profiles

4. CONCLUSION

In this paper under national power quality project of Turkey, design and construction of an objective flicker meter and real time measurement techniques of voltage flickers in mobile power quality monitoring system of the Turkish Electricity Transmission System have been explained. According to the two hours average values of three phase long term flicker severity of different loads, Long term flicker severity values of heavy industry loads always exceeds the given standard limits during one week measurements with respect to urban + industry and urban loads. With decreasing voltage level of the electrical transmission system, percentage of flicker occurrence has been increased. According to voltage flicker measurement results of heavy industrial loads (arc furnaces), approximately 100 percents of that loads have flicker problems, so one of the important aim of this project is to monitoring the behavior of heavy industry loads like arc furnaces and etc, in the Turkish Electricity Transmission System and impose some external power electronics circuits to solve that problems simultaneously.

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