Enhancing Power Quality and Grid Control with Real-Time Monitoring Sensors

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Abstract: Monitoring and controlling power quality is become crucial to ensure the power system runs steadily as smart grids have developed quickly. Issues related to conventional power quality monitoring techniques include insufficient real-time performance and limited monitoring accuracy. In order to increase real-time monitoring accuracy, this paper suggests smart grid reliability tracking and modification technique that employs photoelectric sensors combined optical systems signal treatment. In this article, the power grid's power quality is continuously monitored using photoelectric sensors, which then send information about the monitoring to an optical system. Key power quality metrics are extracted via signal processing of information collected via optical devices. Finally, the control and improvement of the quality of power can be achieved by making changes to the smart grid's important equipment. The tests show that using photoelectric sensors along with optical system processing to observe and change the power quality in a smart grid can make tracking more accurate and improve real-time performance. The power grid is much more stable and reliable now that it could be checked and managed at real time for changes in power quality.

Keywords: Smart Grid, Photoelectric Sensors, Optical System, Performance.

1. Introduction

Monitoring and managing power quality is a crucial criterion for developing a smart grid. The electricity system's operational condition and other indicator metrics must be continuously monitored to make use of smart grid technology [1 -5]. The rapid identification and resolution of issues with power quality can guarantee that power quality is in excellent condition because of wireless communication and automated control technologies [6-9]. Many sensors and monitoring tools are often employed in smart grids to track on different power system indications in real time. Such characteristics like voltage, current, frequency, along with power factor may be monitored by these devices, which can then send the monitoring data into a central server for processing and analysis [10-15]. The degree of power quality may be precisely assessed and relevant issues can be promptly identified by examining monitoring data. Automatic control technology allows the smart grid system to be modified and managed after power quality problems have been identified. If the voltage or frequencies exceeds beyond the typical range, for instance, a smart grid system may modify the generator's output or the transformer's transformation ratio to keep the power quality stable [16-20]. The smart grid method is capable of getting rid of power system congestion and make the power better by managing the entry and exit of complex loads [20-25].

According to current research, this paper suggests the use of optical signal processing technologies and photoelectric sensors as the foundation for a smart grid information monitoring system. This technology enables real-time monitoring quality of power & manage the smart grid, guaranteeing the power system's steady functioning. The power grid now includes communication capabilities in addition to a dependable power source when the smart grid's development is completed. In distant locations, this makes up for the limitations of wireless connection, enabling the provision of high-quality communication services. The electricity network may act as a platform for data transfer in cities with advanced communications systems, facilitating the informatisation of the gas, water, and streaming television sectors. This approach of using the electricity network for information transmission may help the information sector expand while simultaneously increasing the effectiveness and dependability of information transfer.

2. Developing Photoelectric Sensors for Smart Grids

2.1. Photosensor Design Concepts

If linearly polarised light propagates in a magnetooptical medium, the deflection angle from the polarisation plane is seen, allowing the magneto-optic outcome to measure the magnetic field intensity & current indirectly. Information about strength of magnetic field and the size of the current may be inferred indirectly by monitoring the variations at polarisation angle for light that is linearly polarised. The Jones matrix, a matrix form which illustrates how optical components affect light, may be used to show that linearly polarised light is transmitted and transformed. Two vertically polarised lights together may be used to approximate any linearly polarised light. Given the assumption that a linearly polarised light is indicated by combining 2 vertically polarised lights. The Jones matrix theory states that all linearly polarised light might be indicated through a matrix having 1 column and 2 rows as shown in equation (1):

$$\mathrm{D} = \begin{pmatrix} \mathrm{D_x} \\ \mathrm{D_y} \end{pmatrix} = \begin{pmatrix} \mathrm{a_1 exp\ (i} \propto_1) \\ \mathrm{a_1 exp\ (i} \propto_2) \end{pmatrix} \qquad (1)$$

Researchers may discover more about the way magnetic field strength & current amount affect magneto-optical media by looking at Jones matrix at fibre optic current sensors. This helps them figure out how the polarisation phase of polarised light changes at the transmission. To make fibre optic current sensor to measure and keep track of current accurately, the Jones matrix theory can be used in this way.

2.2. Techniques for Signal Denoising

Both hardware devices or software methods is utilized to eliminate noise of signal. Addition of filters with hardware circuit mostly gets rid of input noise, while the Fourier transform, wavelet transform, EMD, as well as digital filters are used by the software program to process the signal. Most of the time, hardware FIR filters are used to capture low-frequency signals because they simplify computations and filter orders by losing phase accuracy. There are some limits to hardware filters. To meet the needs of a specific application, the minimum frequency cannot be altered. While electronic filters generally have rectangular factors that lack perfection and accuracy, this can change the way the filter works. Which means that hardware FIR filters might not work for I-V testing systems that need to be accurate when checking photoelectric sensors. Soft-ware methods can be used to get rid of noise in signals to solve these problems. Instead of being rigid, software methods are more adaptable and can be improved and altered according to particular requirements. Time-frequency analysis and standard signal processing methods can be employed together by ML along with DL to predict signals or data. Instead of handling things in real time, these algorithms are more interested in making predictions or performing tasks subsequently.

The objective of this research paper is to utilize software techniques for processing the data, since this paper is primarily concerned with the real-time processing for signals at I-V evaluation for photoelectric sensors. Modern versions of the classic filtering algorithms sometimes include enhancements like median, arithmetic average, moving average, and finite amplitude filtering. The median filtering method is mostly used in the processing of testing data for this paper. The domain of signal processing makes extensive use of the median filtering method. Using the median as a filter, it eliminates outlier or noise contamination.

Performing filtering operations by adjusting a window's width (z) is the fundamental idea behind the median filtering method. The median filtering procedure requires removing the highest value X_{max} as well as minimum value X_{min} inside the window along with data sorting by window width w. The remaining data must then be averaged to provide the value of median as illustrated at equation 2.

$$\overline{X_k} = \frac{1}{w-2}\left(\left[\sum_{i=n-z+1}^{n} X_i\right] - X_{imax} - X_{imin}\right), n = w, w+1, \ldots. \qquad (2)$$

2.3. Photoelectric sensor Application Testing in Visible Light

As part of the experiment, the photoelectric sensor was tested using a Raman laser source. The objective is to examine the properties of sensors under varying conditions, including voltage application and various wavelengths and powers. As incident light sources, researchers selected a number of common visible light wavelengths. The photoelectric sensor's reaction for varying light intensities were monitored by adjusting the laser power. Researcher optimised the photoelectric sensor's working parameters and examined the variations with respect to current upon adding voltage to gate. The voltage influence of gate in sensor is also evaluated.

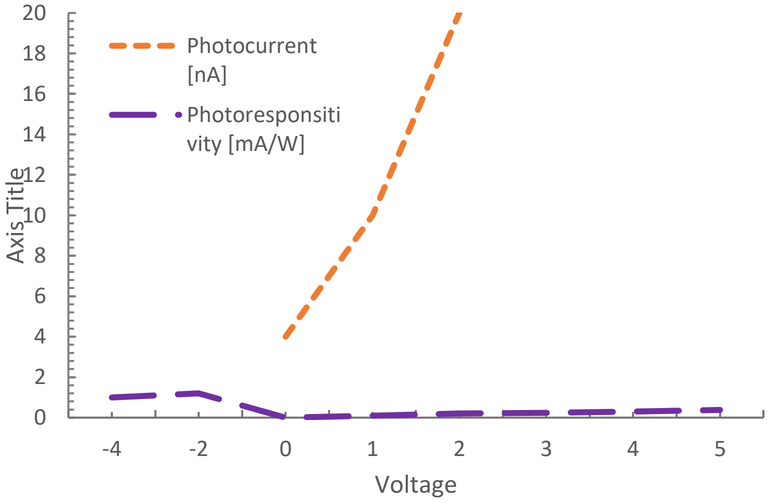

Figure 1 Power Function of Photoelectric Sensors uses 514nm Light as Response Current and Gate Voltage.

Figure 1 displays the change in the photoelectric sensor's reaction current to 514 nm light at various light intensities. The photoelectric sensor's reaction current headed up as the power of the incident light went up. That means the photoelectric sensor can successfully turn 514 nm light into electrical data and is sensitive to it. Figure 1 shows that the if incident power of light goes up, so does the reaction current of the photoelectric sensor. The sensor responds linearly towards 514 nanometer light, which means it could turn light energy into electrical data.

By applying various gate voltages towards gates of photoelectric sensor, the response current may be observed. As shown in Figure 1, the response current was measured and displayed at various gate voltages. Figure 1 shows that the photoelectric sensor's response current may be amplified by positive as well as negative pressure. Using a negative voltage, on the other hand, produces a stronger amplifier. Thus, in real-life situations, a suitable negative voltage may further enhance the sensitivity and responsiveness of photoelectric sensors.

2.4. Evaluating Smart Grid Photoelectric Sensors

Statistical evaluation was executed based on measurement findings acquired from several measurements taken on the two sensor heads. Tabulated in Figure 2 are the mean as well as the SD for the readings from each of the sensor heads. All of the sensing heads' average response currents may be found by averaging the observed values.

Figure 2 reveals that sensor head 1 has a much greater signal strength than sensor head 2 at 600 A. The increase in signal intensity was attributed to sensor head one having more rotations than sensor head two. However, sensor head 2 has greater measurement accuracy than sensor head 1, resulting in lower jitter and SD. Adding winding coils to the detecting head boosts signal intensity and sensor sensitivity. However, sensor precision and stability must be considered while measuring signal strength to yield accurate results.

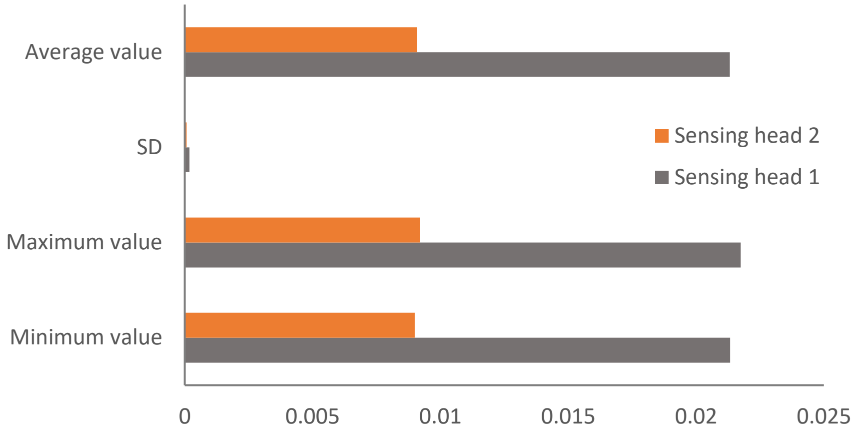

Figure 2 First and Second Sensor Heads Values of Current Measurement

The measurement outcomes were examined by employing the information in Figure 3, and the average measurement error was used to find the average difference of the measurement outcomes from the true number. To further understand and use measurement data, these statistics can be used to judge the accuracy, stability, and consistency of the outcomes.

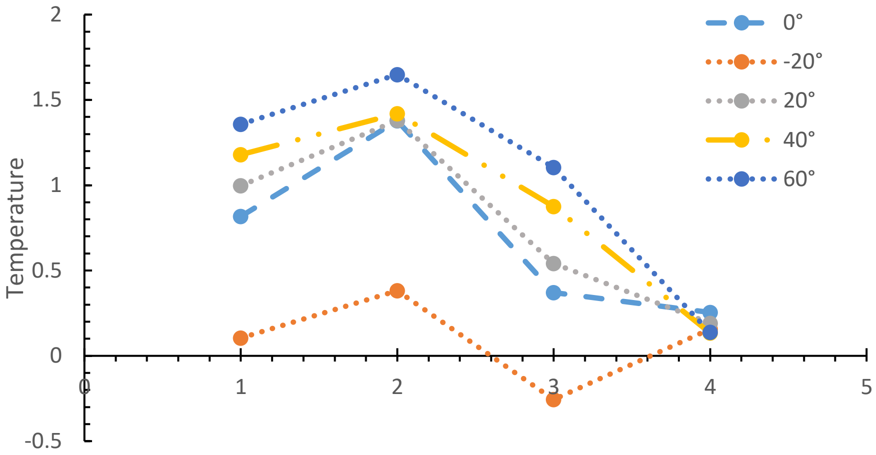

Figure 3 600A Current Temperature Analysis.

3. Processing Optical Signals and Measuring Power Quality

3.1. Two-wave Coupled Optical Amplification

The incident light must satisfy Bragg diffraction conditions in photorefractive crystals in order for the refractive index volumetric phase grating to produce Bragg diffraction impact on the incident beam. The volumetric phase grating for the crystal will cause incoming light to undergo Bragg diffraction, and the grating distribution will influence strength and direction of the diffracted beam. The readout light is seen as the mixture of several sub beams at the refractive index volumetric phase grating. An optical path discrepancy will exist between the diffraction beams of subbeams 1 and 2 when they are subjected to volume phase grating diffraction. The difference in optical paths may be expressed using formula (3):

$$\Delta = 2n\Delta\sin\theta \qquad (3)$$

Through a refractive index of bulk phases grating, the angle among readout light & angle of bulk phase grating is indicated by θ, and refractive index for readout light at crystal is indicated by n. Since just minor amount of readout light is diffracted by every refractive index plane & every of sub-diffracted wave's merge for generating output diffracted from volume phase grating, this diffraction method is comparable to optical reflection. These sub-diffracted waves is now interfere with one another in phase during the superposition process. Formula (4) may be used to illustrate the circumstances for this interference:

$$2n\Delta\sin\theta = p\lambda[p = 1,2,3,\ldots] \qquad (4)$$

Phase length interference for sub-diffracted waves is described by formula (4). An output diffracted beams will be created when the sub diffracted wave interacts with one another, fulfilling this requirement.

The diffraction phenomena in bulk phase gratings may be described by the Bragg diffraction criterion when the crystal thickness is much larger compared to grating spacing d. The requirement of Bragg diffraction states that there can be no more than one order of diffraction, with m being the maximum possible value.

The condition of Bragg diffraction could be used to define the diffraction effect in majority phase gratings if the crystal's width is higher than the distance of grating. The number of diffraction order is set to 1, that means there can only be first order of diffraction and the equation 5 is represented as,

$$\frac{\lambda}{n\sin\theta} = \frac{\lambda_0}{n_0\sin\theta_0} \qquad (5)$$

The reflected wave interfering with the diffracted wave is known as Bragg angle. In 2 wave coupling, the 2 coherent light beams serve as both the writing and reading lights for fractal index-volume phase grating, which is formed when two beams of light impinge symmetrically on a crystal and write into it via crystal photorefractive effect. The Bragg diffraction requirement must be met all the way through the operation, & the difference among the wave vectors for the scattered light and the volume of the phase grating must be equal to one. Furthermore, every light beam's diffraction direction is identical to another beam's incidence direction.

In cases where (x,y) has a very modest amplitude (<1), formula(6) indicated as:

$$\tau[x,y] = A\left[1 + i_{\varphi}(x,y) - \frac{\varphi^2(x,y)}{2} + \cdots\right] \tag{6}$$

3.2. Techniques for Processing Optical Signals

Image data from wavefront sensors (WFS) is usually made up of 3 parts: the target signal, the background signal, as well as detection noise. These parts are affected by things like background noise, CCDreadout noise, and background dark current. The greyscale signal of the picture that was obtained by WFS can be written as (7):

$$I[x,y] = I_s[x,y] + I_n[x,y] + I_B[x,y] \tag{7}$$

Noise may negatively affect slope extraction accuracy; hence it is vital to reduce noise in wavefront sensors (WFS) picture signals. Threshold technique is the noise suppression approach used to minimise WFS detection inaccuracy.

During threshold processing for WFS consisting of a detector target surface of pxp, each pixel requires threshold judgement and sop-subtraction operations. Threshold processing is only possible within the subaperture to decrease computing complexity. If there are no subapertures in the wavefront detection system, each subaperture is L-sized. Perform subtraction procedures for each aperture to finish threshold processing. Therefore, the overall computing complexity for the complete wavefront detection system is:

$$N_T = nkl \tag{8}$$

3.3. Parameters for Power Quality Monitoring

Variance among voltage as well as system normal voltage when everything is functioning normally is called voltage deviation. The most important one that affects voltage variation is reactive power. When power system is running, variation at distribution for reactive power might lead to changes in voltage, which can raise the cost of gearbox and power supply and shorten the life of certain lines and equipment. To figure out voltage deviation, use formula (9).

$$u_{\Delta} = \frac{u_r - u_N}{u_N} * 100 \tag{9}$$

The permitted voltage variation is plus or it might be minus 8% with respect to the nominal voltage when it is less than or equal to ten kilovolts. For power supply having single phase operating at standard voltage, the permitted voltage variation range is between positive 7% and negative 10%. To assess constancy & compliance for voltage, percentage variation among observed voltage & normal voltage may be computed using formula (9).

The step for determining the overall harmonic distortion of voltage & current is provided by formulas (10 and 11).

$$Th_u = \frac{U_H}{U_1} * 100\% = \frac{\sqrt{\sum_{h=2}^{\infty} {U_h}^2}}{U} * 100 \tag{10}$$

$$Th_u = \frac{I_H}{I_1} * 100\% = \frac{\sqrt{\sum_{h=2}^{\infty} {I_h}^2}}{U} * 100 \tag{11}$$

Common failures in power systems include voltage sag and interruptions, both of which may severely damage equipment and the economy. A voltage drop is the rapid and complete loss of electrical current followed by its rapid and complete restoration to its original source voltage. When the actual voltage acquired is below than 1% of the rated voltage and the user is fixed in condition of voltage loss to an extended period of time, this is called voltage interruption. Voltage sag and interruption can be calculated using formula (12).

$$u_1 = \frac{u_r}{u_N} * 100\% \qquad (12)$$

In Formula (12), u_1 indicates voltage at voltage sag, u_r depicts real voltage, and u_N indicated rated voltage. Based on equartion (12), voltagesag is calculated when real voltage is below 91% of μ_N. A voltage interruption occurs if the actual voltage is below than 1% to the rated voltage as N. The voltage judgement criteria for sag and interruption are based on the difference between real and rated voltage. In the event of a voltage interruption, the real voltage is much less than the μ_N. The fault levels may be determined by its differential value.

4. An approach for Monitoring and Regulating Smart Grid Power Quality using Similar Technologies

4.1. Develop a Comprehensive System for Monitoring Smart Grid Information

The unified modelling of enormous data is provided at the smart grid, may successfully accomplish the incorporation & exchange of smartgrid data, enhance power grid's operational efficacy, & increase its level of control.

The entire set system works by following this rule: In a power system, a voltage/current transformer lowers the voltage & current of a strong current signal. This signal is then handled through a filtering circuit. Nyquist sampling is used to turn the current and voltage data into separate patterns. The processed signal then goes into the A/D converter. This is followed by the discrete series going to the digital signal processor (DSP) over FFT. Isolated voltage & current cycles could be broken to many harmonic elements for statistical computations using FFT. The calculations of indicators like voltage, current, power, frequency, & harmonics could be found during the measurement process. If a 4G connection modem is added to the SCI USB port, these calculations can be shown on the screen or sent to the tracking centre. This system lets different power system data be sent to the tracking centre in real time for research and maintenance.

4.2. Module for Monitoring Power Quality

Figure 4 illustrates the general principle behind the overall power quality monitoring terminal system. The voltage/current transformer step-down/current lowering process is applied to power system's high current signal. The signal undergoes processing through the conditioning circuit before being converted into a discrete sequence by the analogue to digital converter for Nyquist sampling. Next, using DSP and the Fast Fourier transform, the discrete series is divided down into harmonic components. The results of calculating indicators like current, voltage, power, frequency, & harmonics may be achieved using mathematical calculations. By connecting 4G connection unit with SCI serial port, these computation results may be transmitted to the monitoring centre or shown on the display screen. Through a number of computations and processing steps, the whole system keeps track on and evaluates the power system.

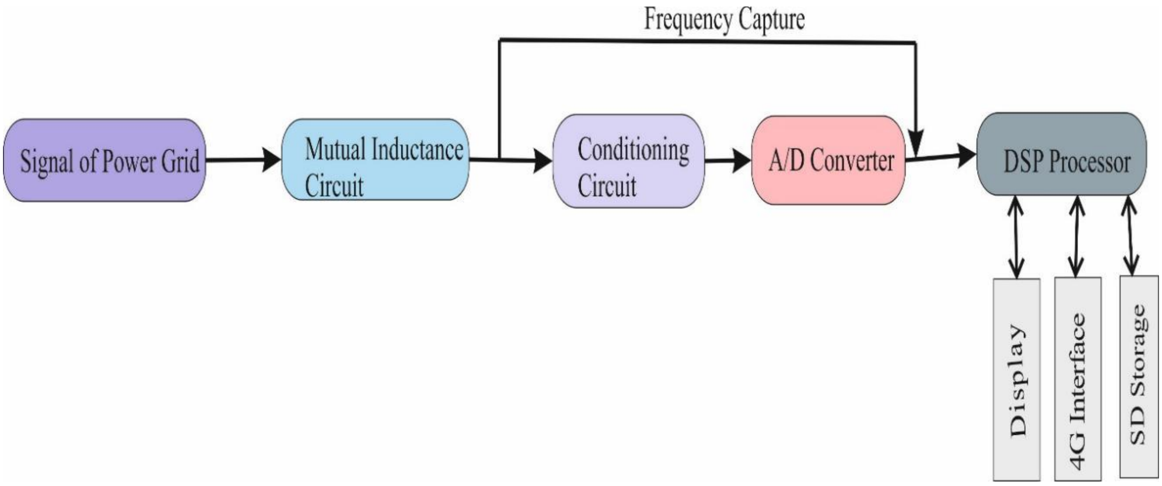

Figure 4 Power Quality Detection Terminal's Framework.

5. Evaluation of Smart Grid Power Quality Regulating Impact

Comparing the measurements of the useful AC voltage on 51 Hz with FLUKE is shown in Figure 5. With FLUKE testing tools set to 51 Hz, Figure 5 shows the actual values of AC voltage.

Researcher measured the useful value of the AC current in 51 Hz employing FLUKE and outcome are illustrated in Figure 6. Depending on FLUKE testing tools at 51 Hz, Figure 6 shows the actual amounts of AC current.

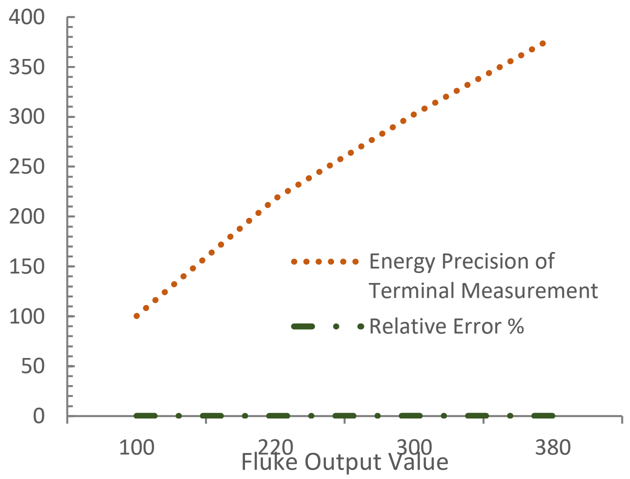

Figure 5 Comparison of Measurement Results for Voltage RMSM.

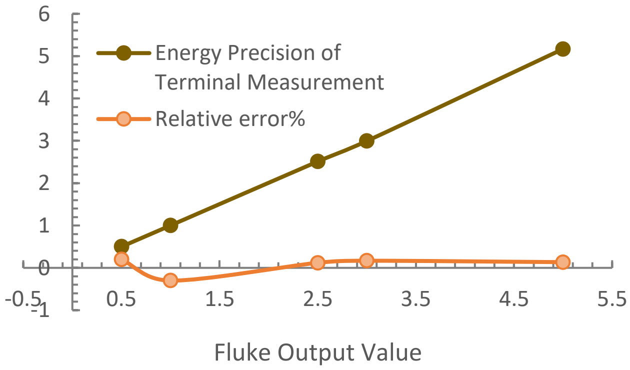

Figure 6 Current Effective Value Measurement Results

Four DROK 90331 power supply fluctuation voltages with varying flicker frequencies are tested in Figure 7. The conventional power supply configuration & terminal measurements at various frequencies are compared in Figure 7. The relative rates of error are the terminal's measurement value minus normal setting of power supply. The terminal's detection findings as well as the typical power supply settings values have a relative error rate of 6%, meeting accuracy standards.

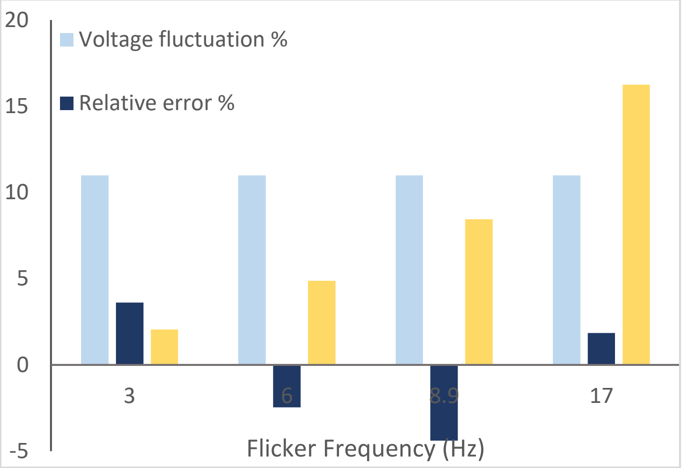

Figure 7 Assessments of Voltage Flicker Evaluation

6. Conclusion

Incorporating photonic devices as well as optical system signal processing technology, the smart grid information tracking system as a whole makes it easier to assign resources. Through this method, energy can be sent exactly where it's needed, based on demand. This makes sure that power supplies are better distributed. Optoelectronic devices as well as optical system signal processing systems are used in the intelligent power grid data tracking system as a whole. This can keep track on information in the power grid really quickly. This system can correctly find out the amount of power is needed as well as how much is available by collecting and processing data. In order to accomplish exact management and allocation of energy, the system may additionally implement power resources, analyse information from the power grid, and estimate the pattern for variations in power demand. To satisfy people's requirements for living and working, rural as well as urban areas may benefit from a steady, clean, and safe supply of energy.

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