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# A Review of Methods Employed to Identify Flicker Producing Sources

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***Abstract***

*Because of increasing requirements of the present consumers and industrial units utilizing sensitive loads, there is need of good power quality in order to retain the power quality standards. Nowadays the study of the voltage flicker is becoming essential part of power quality studies. The flicker is typically the effect of a rapidly changing load which is large with respect to the short circuit ability of an electrical supply system. The inferior effects of voltage flicker include malfunctioning of power electronic equipment. Also it causes annoying effects to human. Hence detection of the flicker source is an essential step in the power quality assessment process. This paper delivers a review about methods used to identify flicker producing loads in accordance with IEC 61000-4-15. Once the report related to the disturbance place is known, an investigation and corrective action can be accordingly carried out. Also a method based upon Discrete Wavelet Transform and Artificial Neural Network is proposed to detect initial instance of occurrence of flicker.*

***Keywords****: power quality, voltage flicker, flicker source, discrete wavelet transform, artificial neural network*



## 1. Introduction

The Voltage flicker has great significance in the field of power quality as it causes various problems in the power system network [1]. The voltage flicker can be defined as a noticeable change in brightness of a lamp due to speedy fluctuations in the voltage of the power supply [2]. It is also described as amplitude modulation of voltage whose frequency varies from 1 Hz to 20 Hz [2]. The root cause of flicker is weakness of power system relative to power requirement by load. There is considerable change in current over a short time of period if a system is not capable of supplying demand required by load, which results in voltage flicker [3]. The common sources of flicker are an elevator motor's starts and stops, manual spot welders, electric arc furnaces, reciprocating pumps and starting of a large motor [3].In some cases combination of interharmonics with supply voltage results in luminous flux and produce flicker [3]. The interharmonics are produced due to static frequency converters, cycloconverters, induction furnaces, sub synchronous converter cascades and arc furnaces [3]. The effect of voltage flicker includes reduction in operational efficiency of the electric arc furnaces, reduction in the life of the electrical motors, malfunctioning of the security system [3]. The apparatus such as computers and communication equipments suffer from deleterious effects.

Nowadays utilities as well as consumers have become more attentive to issue of voltage flicker. The detection of flicker is necessary in order to mitigate it. A soft computing method for identification of flicker source is presented in this paper. This method is based upon Discrete Wavelet Transform and Artificial Neural Network. The wavelet transform is used for extracting features of voltage signal with flicker. A multilayer feed forward neural network with back propagation algorithm is then trained with these features. The trained network is tested by applying a new input signal from a flicker source. The accuracy of proposed technique has been validated by performing simulation in MATLAB/Simulink environment.

This paper is structured in following manner. In section 2 the model of standard IEC flicker meter is described. The section 3 focuses on theory of flicker source detection and various methods of flicker source detection. The section 4 covers proposed approach and results. The paper is concluded in section 5.

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## 2. Model of Flicker Meter

The most appropriate method of flicker measurement is narrated in IEC 61000-4-15 [4]. Figure 1 shows block diagram of IEC flicker meter [4]. The description of each block is given below.

### 2.1. Normalization Block

The input flicker signal enters into this block. After that input voltage level is matched with electrical specifications of electronic components which are located at downward direction by reducing its magnitude with the help of a transformer. Also this block contains a signal generator to test the setting of flickermeter in the field. A circuit for normalizing the rms value of the input voltage with network frequency at the internal reference level is also included.

### 2.2. Demodulator with squaring multiplier

The behavior of the incandescent lamp is simulated in this block. The main function of this block is to split the main voltage signal (Carrier wave) with network frequency from the voltage fluctuation (ΔV) (modulating signal). This is done by using a square demodulator that squares the input.

### 2.3. Weighing Filters

In this block several filters are cascaded to serve the purpose of filtering out unwanted frequencies produced from the block 2 (demodulator). Another function of this block is weighing the input signal which helps to simulate the incandescent lamp eye-brain response.

### 2.4. Squaring and Smoothing

This block performs two functions with the help of a squaring multiplier and sliding mean filter. Firstly the squaring multiplier squares the voltage signal. This results into simulation of the nonlinear eye-brain response. The second function is to replicate the short term storage effect of the brain. This is done by using sliding mean filter which averages the signal. The output of this block is known as the instantaneous flicker level. If this level is 1 then the flicker is the perceptible flicker.

### 2.5. Statistical Evaluation

An arithmetical investigation of the instantaneous flicker level is carried out in this block. The output of block 4 is separated into appropriate classes to create a histogram. Then each class is used as an input to create a probability density function which is then used to form a cumulative distribution function. This data is then incorporated into the microprocessor to execute real time investigation of the flicker level. Hence direct calculations of the important estimation parameters are possible. The outputs of this block are flicker severity levels like short time flicker severity (Pst) and long term flicker severity (Plt).

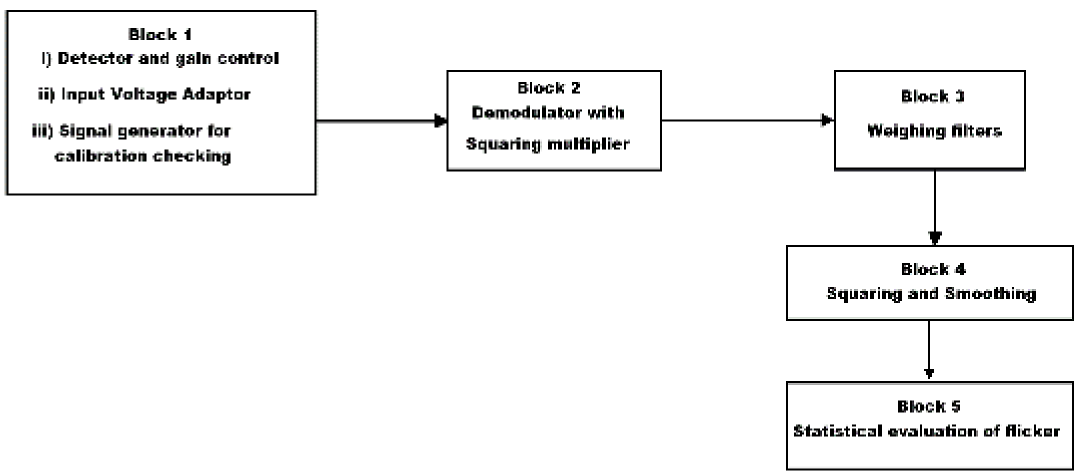


Figure 1. Block diagram of IEC flicker meter

Thus from block diagram of flicker meter it is clear that only voltage value is recognized to determine value of flicker level. Therefore it does not give any idea about detection flicker producing load. For detection of flicker source other parameters like power and current are required in addition to the voltage.

## 3. Flicker Source Detection Methods

The standards, short term flicker severity (Pst) and long term flicker severity (Plt) provide information regarding the flicker level except the flicker source direction [2].The recognition of the direction for the flicker source is of great importance for taking corrective action .This paper gives a review about methods developed so far to verify the flicker source direction. The direction is identified with regard to measuring point in the power systems. These methods are explained below.

### 3.1. Method based upon Interharmonics

In Dahai et al. 2005 [5] the correlation between interharmonics and flicker is analyzed. The analysis is explained below. The equation of flicker signal [5] is:

$$u(t) = A(1 + m\cos\omega_i t)\cos\omega t \quad (1)$$

Further the equation is simplified as

$$u(t) = A\cos\omega t + \frac{1}{2}Am[\cos(\omega + \omega_i)t + \cos(\omega - \omega_i)t] \quad (2)$$

The Equation (2) interprets that flicker signal comprises of interharmonic frequency components with frequencies.

Thus flicker causes interharmonics and vice versa. Hence detecting the interharmonics source is helpful to identify flicker source. Therefore flicker source identification is done by calculating the interharmonic power direction from a multiflicker source. The paper concludes that an interharmonic source with negative active power is the dominant source of flicker.

### 3.2. Slope method

A slope method has been given by Edwin et al. 2005 [6].This method utilizes the rms values of voltage and current flicker observed at monitoring point of power system located at the point of common coupling. The direction of active power flow is used to define type of event. When the fault due to an event is in the in the direction of active power then that event is downstream event or else it is upstream event. Once the direction of event is determined, slope method is used to detect flicker producing load. To calculate the slope the rms value of voltage flicker and current flicker is correlated with each other. The analytical method is explained by considering system shown in Figure 2 [6]. As shown a variable resistance $R_f$ is used as flicker producing load. For a downstream event the voltage at PCC is given by Equation (3) [6].

$$V = \sqrt{E_1^2 - 2E_1 Z\cos(\delta - \phi - \theta) + Z^2 I^2} \quad (3)$$

V and I are voltage and current at point of common coupling respectively.
$E_1$ and E2 are sending end and receiving end voltages respectively.
Z is source impedance, θ is angle for impedance Z, ϕ is an angle between V and I, and δ is an angle between $E_1$ and $E_2$.

For downstream event the change of voltage with respect to change in current which remains negative for actual system parameters is given by the Equation (4) while for upstream event, the positive change of voltage with respect to change in current is given by Equation (5) [6].

$$\frac{dV}{dI} = \frac{1}{2}\frac{2Z^2 I - 2E_1 Z\cos(\delta - \varphi - \theta)}{\sqrt{E_1^2 - 2E_1 Z\cos(\delta - \varphi - \theta) + Z^2 I^2}} \quad (4)$$

$$\frac{dV}{dI}=\frac{1}{2}\frac{2Z'^2I-2E_2Z'\cos(\varphi+\theta)}{\sqrt{Z'^2I^2-2E_2Z'I\cos(\varphi+\theta)+E_2^2}} \quad (5)$$

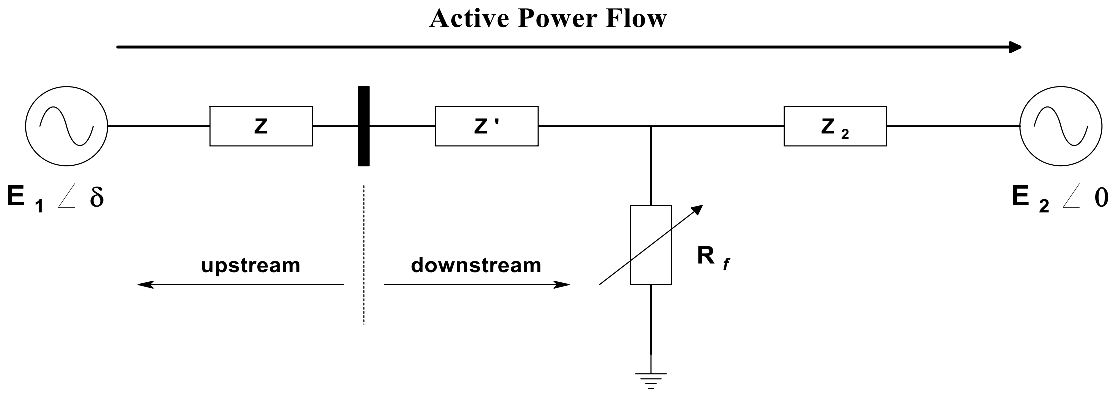


Figure 2. Equivalent Circuit for Analysis of Flicker Source Detection by Slope Method

It is concluded that if calculated slope is positive then the flicker source has upward direction and negative sign interprets that the flicker source has downward direction.

**3.3. Flicker Power measurement method**

Axelberg et al. 2006 [7] present a method based on flicker power measurement is used to detect flicker producing load. This method uses same technique as described in IEC 61000-4-15 to acquire low frequency signal (the envelope) of both voltage and current fluctuations. The amplitude modulation of these signals is used to compute instantaneous flicker power. This power is obtained by performing multiplication of both signals. This power is subsequently passed through a low pass filter to obtain so called flicker power. Figure 3 shows block diagram of this method [7]. Where, *u[n]* and *i[n]* are samples of voltage and current flicker signal respectively. The sign of flicker power is very useful to decide the location of flicker source with reference to monitoring point. If flicker power is positive (from generator to load) then the source is upstream that is above the monitoring point while negative (from load to generator) sign indicates that source is downstream that is below the monitoring point.

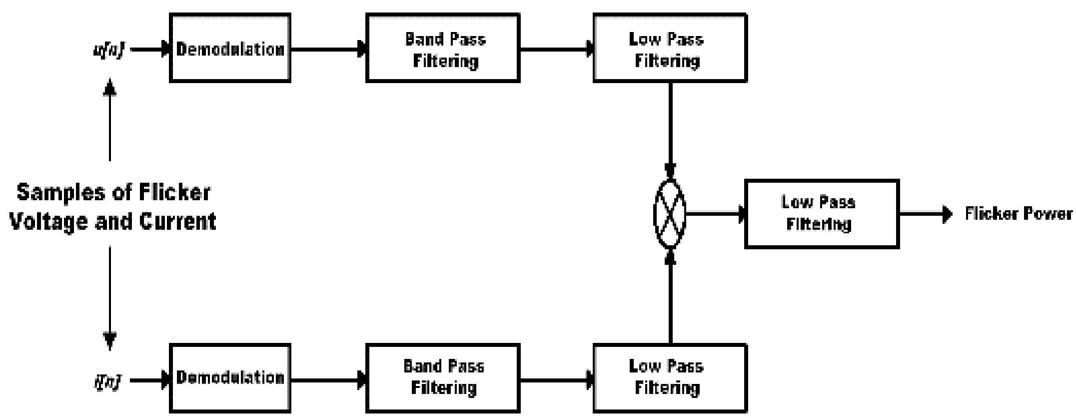


Figure 3. Block diagram to compute the flicker power

### 3.4. Flicker Energy measurement method

Payam et al. 2007 [8] introduced a method based upon calculation of flicker energy for determination of direction of flicker source. The flicker energy (E) is calculated by either Equation (6) or (7).

$$E(t) = \int_0^t m_u(t) m_i(t) dt \quad (6)$$

$$E = \sum_{j=1}^{n} m_{uj}(t) m_{ij}(t) \quad (7)$$

where $m_u(t)$ and $m_i(t)$ are amplitude modulated signals for flicker voltage and flicker current respectively. Figure 4 shows the block diagram for this method [8]. The summation of multiplication of discrete time sampled amplitude modulated voltage and current signals results in the energy signal. When the voltage envelope is in phase with current envelope then the flicker energy is positive whereas when they are out of phase with respect to each other the energy is negative. This sign is used to locate the flicker source. For a negative sign the source direction is downstream and a positive sign depicts upstream direction of the source.

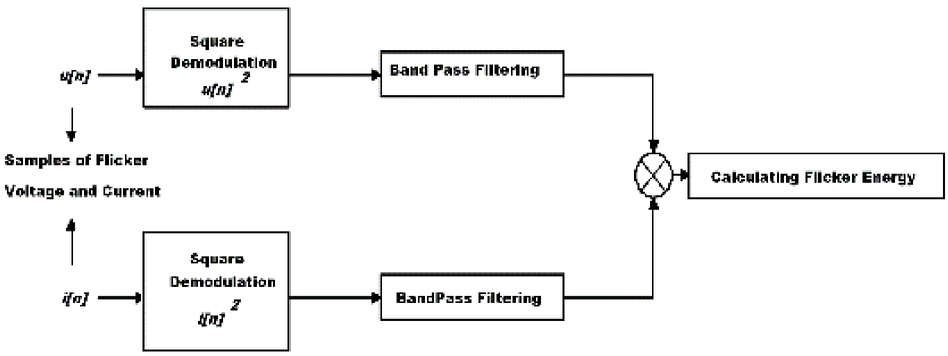


Figure 4. Block diagram for calculation of flicker energy

### 3.5. Correlation Method

Axelberg et al. 2008[9] presented an idea about identifying a predominant flicker source from a power system that contains multiple flicker sources. For upstream source, the envelopes of amplitude modulated voltage and current signals have same phase while for downstream source these are out of phase with respect to each other. For improving the demodulation process an envelope detector is used. Figure 5 shows block diagram for calculating the flicker power [9]. The calculation of flicker power is based upon the correlation between the envelopes of amplitude modulated voltage and current signals. If there is high correlation between these two, then the magnitude of flicker power is higher. On the other hand lower correlation results in lower flicker power. Therefore it is concluded that in a multiflicker source network, the outgoing line with higher flicker power is the dominant source of flicker.

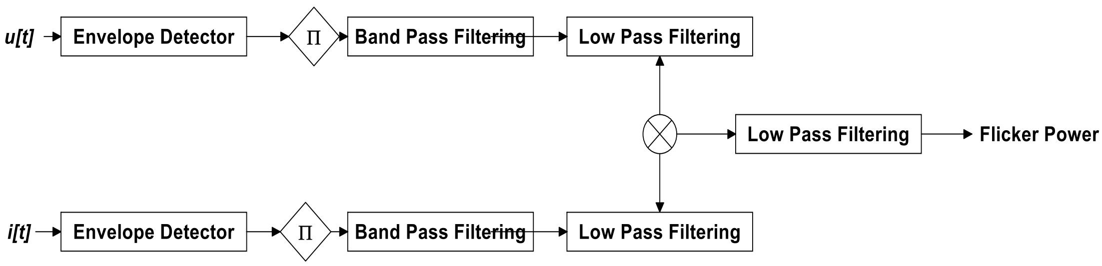


Figure 5. Block diagram to calculate flicker power

### 3.6. A Lookup Method

Moaddabi et al. 2008 [10] narrated about a methodical approach to locate the flicker source in an integrated network. Also an algorithm to decide least quantity of monitoring equipments is proposed. The number of monitoring equipments is found by selecting each bus as base bus one after another. Subsequently, it is checked whether the selected base bus is connected to flicker source or not. This is carried out by considering flicker power.

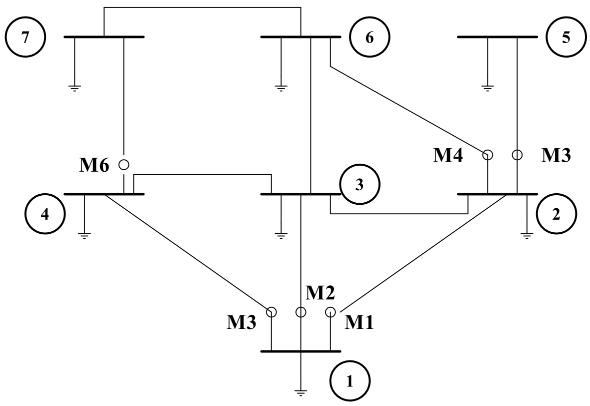


Figure 6. A network for preparation of matrix in look up method

Once the number of monitoring devices is known, the task is to optimize this number. For this minimum reactance of flicker source is obtained. A sign is assigned to each reactance. For upstream source reactance is positive while for downstream it is negative. A matrix is formed between all loads and monitoring points for a network shown in Figure 6 [10]. The matrix is shown in Figure 7 [10]. Let, monitoring equipments are denoted from M1 to M6 and L1 to L6 are flicker loads identifications. Similarly Xij+ (j=i=1to 6) is reactance of flicker source from upstream direction and Xij- (j=i=1to 6) is reactance of flicker source from downstream direction. Finally i and j is $i^{th}$ and $j^{th}$ bus respectively. The elements of this matrix are reactances. For each monitoring equipment and flicker load, two reactances are allocated. Once the matrix is completed, the minimization of the equipments number is done by monitoring equipment which observes minimum reactance.

| | M1 | M2 | M3 | M4 | M5 | M6 | |
|---|---|---|---|---|---|---|---|
| L1 | Min{$X_{11}$}+ Min{$X_{11}$}- | Min{$X_{12}$}+ Min{$X_{12}$}- | Min{$X_{13}$}+ Min{$X_{13}$}- | Min{$X_{14}$}+ Min{$X_{14}$}- | Min{$X_{15}$}+ Min{$X_{15}$}- | Min{$X_{16}$}+ Min{$X_{16}$}- | Min → $M_A$+ |
| L2 | Min{$X_{21}$}+ Min{$X_{21}$}- | Min{$X_{22}$}+ Min{$X_{22}$}- | Min{$X_{23}$}+ Min{$X_{23}$}- | Min{$X_{24}$}+ Min{$X_{24}$}- | Min{$X_{25}$}+ Min{$X_{25}$}- | Min{$X_{26}$}+ Min{$X_{26}$}- | Min → $M_B$+ |
| L3 | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | Min → $M_C$+ |
| L4 | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | → $M_A$- |
| L5 | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | → $M_B$- |
| L6 | Min{$X_{61}$}+ Min{$X_{61}$}- | Min{$X_{62}$}+ Min{$X_{62}$}- | Min{$X_{63}$}+ Min{$X_{63}$}- | Min{$X_{64}$}+ Min{$X_{64}$}- | Min{$X_{65}$}+ Min{$X_{65}$}- | Min{$X_{66}$}+ Min{$X_{66}$}- | → $M_B$- |

Figure 7. Monitoring equipment minimization matrix

The respective flicker load is assigned to the equipment with lowest reactance. This process is repetitive till the half of loads number is reached. For remaining of half flicker loads opposite signs are assigned. These signs depend upon path of flicker power flow. The smallest positive and negative reactance gives the information about identification of flicker source in upstream and downstream direction respectively.

### 3.7. Reactive current component method

The method in Altintas et al. 2010 [11] focused on individual flicker contribution of each load from a network containing multiple flicker sources. The flicker contribution of each load is defined as a measurement of IEC flickermeter when each load is solely acted upon the common bus which has constant source voltage. A unique flickermeter called flicker contribution meter is used to measure flicker contribution of each load. This meter uses the individual reactive current component. To carry out calculation, the phase angle between each load current and constant bus voltage is determined with the help of one cycle Discrete Fourier Transform (DFT) with sampling frequency equal to 3.2 kHz. Then multiplying sine of this phase angle by each load current gives each reactive component. This component is multiplied with constant source reactance to get reference voltage drop. Finally this drop is given to IEC flickermeter which gives value of flicker contribution of each load. This method serves purpose of decoupling the flicker effects of interconnected system and loads. This method is explained with the help an example as shown in Figure 8 [11]. In Figure 8, $i_n(t)$ is the phase current of plant *'n'*, ΔV is change in PCC voltage and $P_{st,n}$ is Individual Flicker Contribution of plant *'n'*.

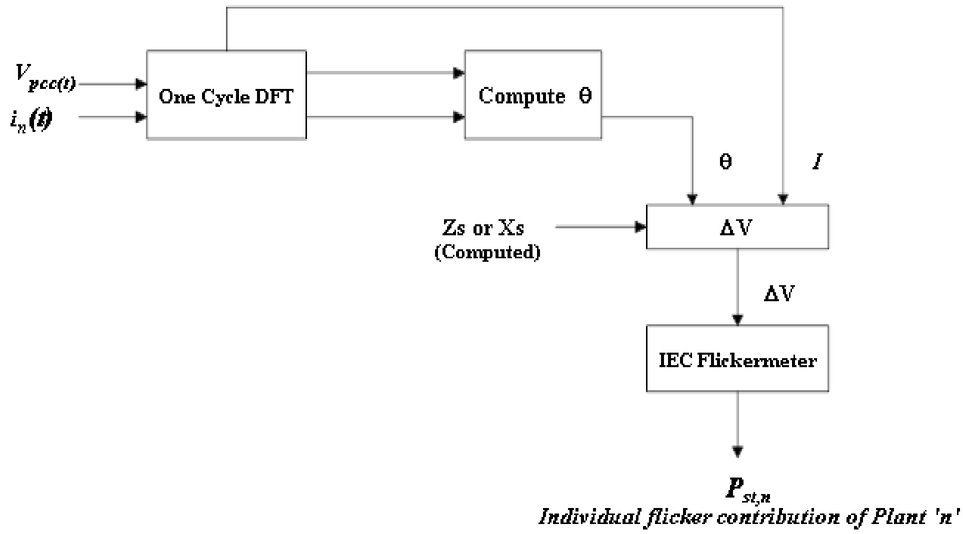


Figure 8. Block diagram of individual flicker contribution meter

### 3.8. Multi-resolution S-transform and ANN method

A technique to spot flicker source in distribution systems is given by Eghtedarpour et al. 2010 [12]. The block diagram is shown in Figure 9 [12]. The multi-resolution S-transform is used to extract the flicker index. Initially the bus voltages are measured and sampled. Then a magnitude–time plot of S-transform is used to identify flicker index which can be used to quantify the occurrence of flicker. The reason behind using the magnitude–time contour is that the counters of two signals with different frequency but with equal amplitude are not same and therefore their flicker indices will be different. After extracting the flicker indices of all voltage measurements, the maximum flicker index is identified. Artificial Neural Network (ANN) is used for source identification. The flicker indices, which are calculated by using S-transform, are inputs to the ANN. The output of the ANN is the indication of existence of flicker source in a particular bus. Further synthesis of output of ANN is done with the intention of identification the flicker source. If all output values not including the maximum are, less than 0.5 p.u. then the bus with the highest value is chosen as the flicker producing bus. On the other hand if there are more than one output values greater than 0.5 p.u., a zone which has buses with outputs greater than 0.5, is considered as flicker producing zone. The drawback of this method is that, it cannot be used for a large network to identify location of flicker source.

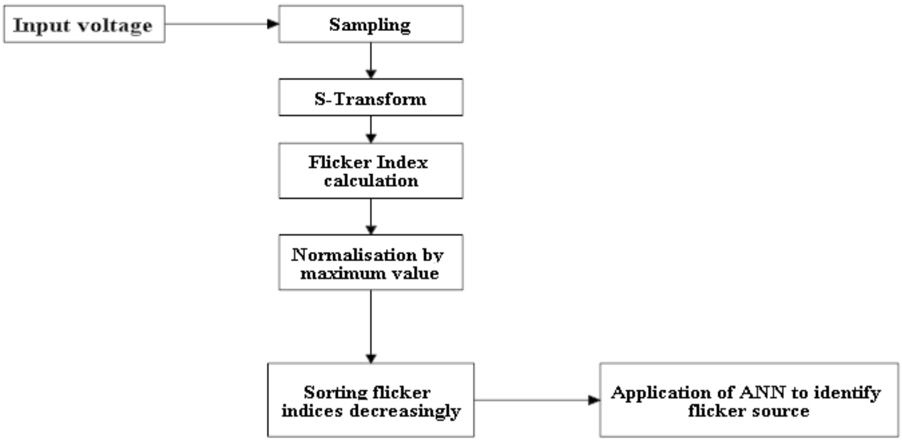


Figure 9. Block diagram for detection of flicker source by multi-resolution S-Transform and ANN method

### 3.9. Calculation of Flicker Power Using Coherent Detector

Poormonfaredazimi et al. 2012 [13] use same technique of flicker power to detect direction. But the algorithm used to calculate flicker power is different. For demodulation of voltage and current flicker signal a coherent detector is used. Figure 10 illustrates the block diagram for the method [13].

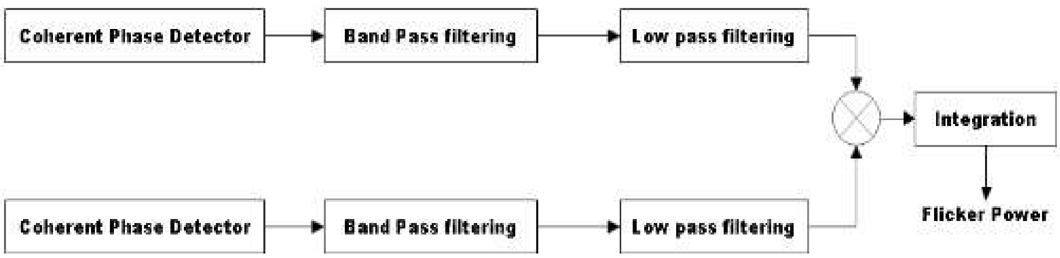


Figure 10. Block diagram of flicker power calculation by using coherent detector

In Figure 10 $m'_u(t)$ and $m'_i(t)$ are outputs of band pass filter for amplitude modulated voltage and current signal respectively. *FP(t)* is instantaneous flicker power. The advantage of this method is that, it does not generate extra small frequency component in flicker frequency range. The major drawback of this detector is that, it needs exact and detailed information of the frequency and phase angle of signal. In order to obtain frequency and phase angle wavelet transform is used. For analyzing different phenomenon of the power network various wavelet functions are used. This paper uses modulated Gaussian wavelet for frequency identification of carrier signal. A comparison is also given for calculation of flicker power based upon different modulators like square demodulator, envelope detector and coherent detector and wavelet transform. This comparison shows that the method employed in this paper gives good results.

### 3.10. State Estimation Method

A state estimation approach to detect various flicker sources in a non- radial power network is elaborated in Jalal Khodaparast et. al 2012 [14]. The benefit of implementing this method is that, it utilizes decreased number of measuring devices. As measurement of current is easy in non radial network as compared to voltage, hence instantaneous voltage is estimated with the use of current as state variable. After this estimated voltage and measured current is demodulated by using half wave rectifier in order to separate respective envelope. Then the flicker power is obtained by multiplying the Discrete Fourier Transformed envelopes of voltage and current. In order to detect the flicker source, the flicker power is tracked with respect to path of primary active power. For assigning the direction to the flicker source; sign of flicker power with respect to primary active power is checked. When flicker power is positive then flicker source is upstream relating to primary active power flow direction. The negative sign of flicker power shows that flicker source is in downward direction with regard to primary active power flow direction. This method correctly detects existence of several flicker sources but it doesn't give any idea about dominant flicker source. Figure 11 shows the block diagram of this method [14].

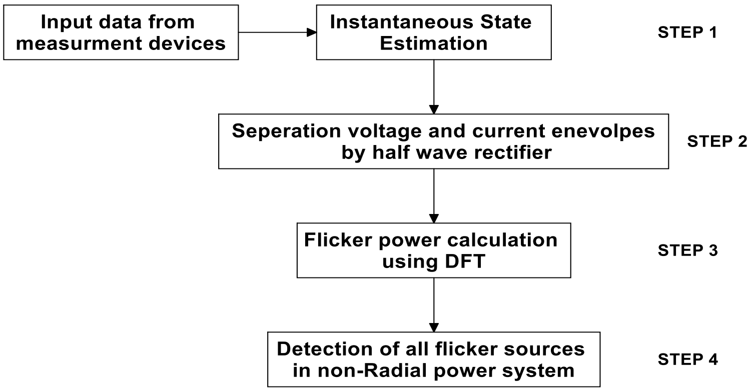


Figure 11. Block diagram of state estimation method

### 3.11. D-Q transformation method for flicker phase angle detection

Jalal Khodaparast et.al 2012 [15] present a technique to detect all flicker tones based upon estimation of phase angle of each flicker tone. Figure 12 shows block diagram of this method [15]. For detecting the direction of flicker source, flicker power sign is used. For calculating the flicker power accurately phase difference between flicker tones of voltage and current is required because the flicker power is directly proportional to cosine of this phase difference. The estimation of the phase difference between flicker tones of voltage and current is done with the use of half wave rectifier and d-q transformation. A half wave rectifier technique is used to track the flicker envelope. If main voltage is feeded to a half wave rectifier block then flicker envelope appears separately. The obtained flicker envelope then tracked by using series of low pass filters. This process is enhanced by d-q transformation. The matrix of d-q transformation is given in Equation (8).

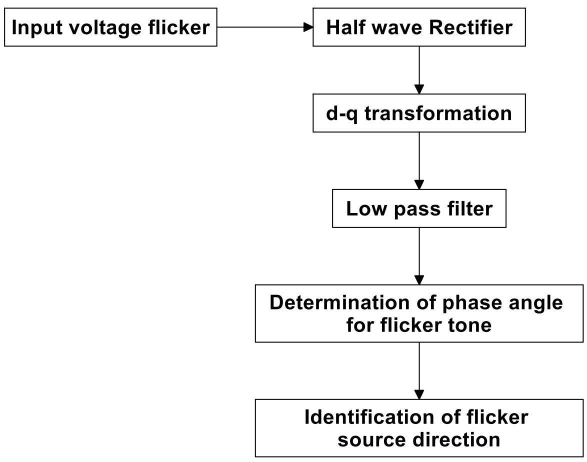


Figure 12. Block diagram of D-Q transformation method for flicker phase angle detection

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} sin\omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ cos\omega t & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (8)$$

Equation (8) illustrates that the utility input voltages is converted to DC quantities in the d-q reference frame. As a result any change in the utility input voltage will be reflected as change in d-q values. By comparing direction of fundamental power flow to direction of flicker power in each flicker tone, locations of all flicker sources are determined. If flicker power is positive then flicker source is upstream and if it is negative then flicker source is downstream with reference to fundamental power flow direction. The sign of flicker power depends on cosine of phase angle between voltage and current of flicker tones. For phase angle from $-\frac{\pi}{2}$ to $+\frac{\pi}{2}$ the flicker power is positive or else negative. Therefore for the specified range of phase angle the flicker source is upstream otherwise it is downstream.

### 3.12. D-Q transformation Method for Flicker Magnitude Calculation

J. Khodaparast et. al 2012 [16-18] use d-q transformation and half wave rectifier to identify all flicker tones that are present in utility voltage. But this paper focuses on calculation of amplitude of each flicker tone rather than phase. Figure 13 shows block diagram of this method [16].

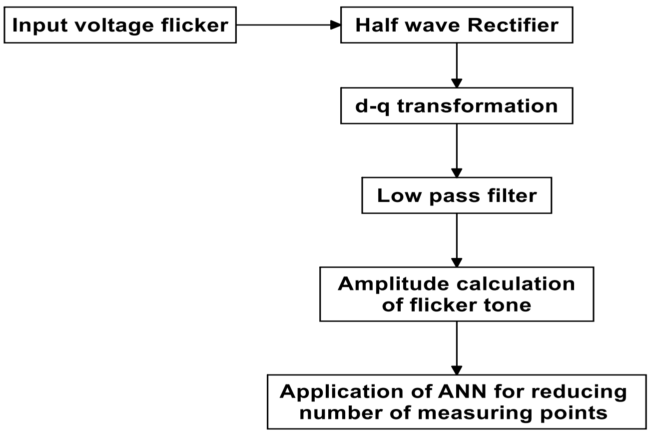


Figure 13. Block diagram of D-Q transformation method for magnitude calculation

A polluting bus will have the largest magnitude of flicker tone as compared with other buses. The amplitudes of flicker tones are considered as indices for detection of flicker sources. With the aim of reduction of count of measuring point neural network approach is used. The Neural Network is trained by using calculated amplitudes. The output of neural network is useful in identification of flicker source.

### 3.13. Method based upon FFT demodulation

Jamaludin et. al 2013, 2014 [19-20] suggest an algorithm based upon Fast Fourier Transform (FFT) to detect location of flicker source based upon flicker power as shown in Figure 14. In Figure 14, $m_{up}(t)$ is filtered voltage signal and $m_{ip}(t)$ is filtered current signal. *FP(t)* is instantaneous flicker power, u(n) and i(n) are input voltage and current signals. The process of calculation of flicker power involves multiplication of filtered voltage and current signals. The basic requirement is to extract voltage and current envelope. This is carried out by demodulating the sampled signal. Here for demodulation Fast Fourier Transform is used. The demodulated voltage and current signals are then passed through a band pass filter. The multiplication of $m_{up}(t)$ and $m_{ip}(t)$ is done to get *FP(t)*. Finally *FP(t)* is integrated over a period to get the Flicker Power. If the sign of calculated flicker power is negative then flicker source is downstream as for observing point. Furthermore, when sign is positive then flicker source is upstream. The ability of the FFT demodulation to demodulate flicker envelope without producing new considerable low frequency improves the effectiveness of calculation of flicker power. However this method does not give any trace about dominant flicker source.

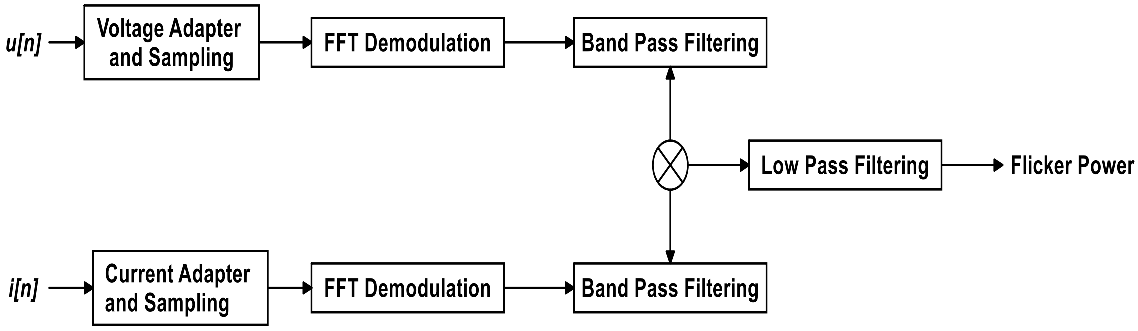


Figure 14. FFT demodulation algorithm for flicker power calculation

### 3.14. Enhanced Phase Locked Loop method

Focus on detection of flicker source as well as on identification of dominant flicker source is elaborated by Dejamkhooy et al. 2016 [21-23]. For detection of source flicker power sign is considered. The calculation of flicker power is done by extracting voltage and current envelope and then by integrating multiplication of envelopes over the period of flicker occurrence. The extraction of envelope is done by Enhanced Phase Locked Loop. Figure 15 shows block diagram for this technique [21]. Where u(t) and i(t) are voltage and current inputs, $m_v(t)$ and $m_i(t)$ are envelope signals of voltage and current signals and $f_p(t)$ is the instantaneous flicker power. The average value of instantaneous flicker power is called as flicker power. The detection of flicker source is done by considering sign of flicker power. If sign of flicker power is positive the flicker source is above and negative sign indicates flicker source is below with respect to monitoring point.

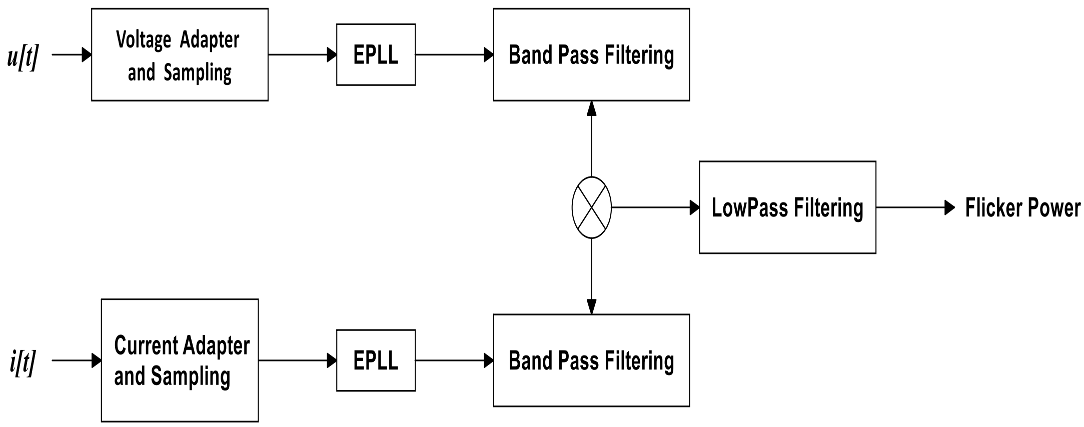


Figure 15. Block diagram of flicker detection by enhanced phase locked loop method

### 3.15. Jacobian Matrix Method

In Dejamkhooy et al. 2016 [21] the flicker power sign of flicker sources which are operated at the same time in a non radial network is identified by using Jacobian Matrix given by the Equation (9).

$$\begin{bmatrix} \Delta V \\ \Delta I_L \end{bmatrix} = [\,J\,][\,\Delta R\,] \tag{9}$$

where ΔV is voltage gradient and $\Delta I_L$ is current gradient for network under consideration. J is corresponding Jacobian matrix and ΔR is variation in load. For determining flicker power sign relative variation of load voltages and load currents are calculated to form Jacobian Matrix. It is concluded that flicker sources with same phase angles have negative flicker power. The detection of flicker source is done by considering this sign. It is shown that if flicker power is positive the flicker source is upstream as for observing point and if it is negative then flicker source is downstream regarding monitoring point. To identify dominant flicker source directed graph theory is introduced. A unique graph is introduced for this objective as shown in Figure 16 [21] and Figure 17 [21] for a two bus system. In both figures direction of arc indicates the flicker source. According to this theory power system buses act as vertices while transmission lines act as edges or arcs, for the directed graph.

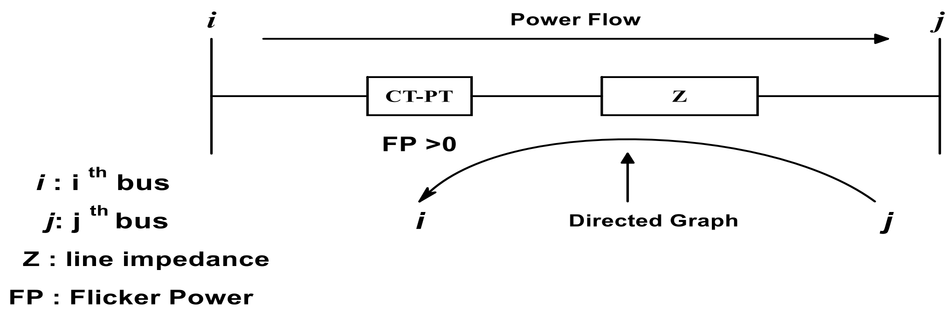


Figure 18. Directed graph of the arc between two vertices for positive flicker power

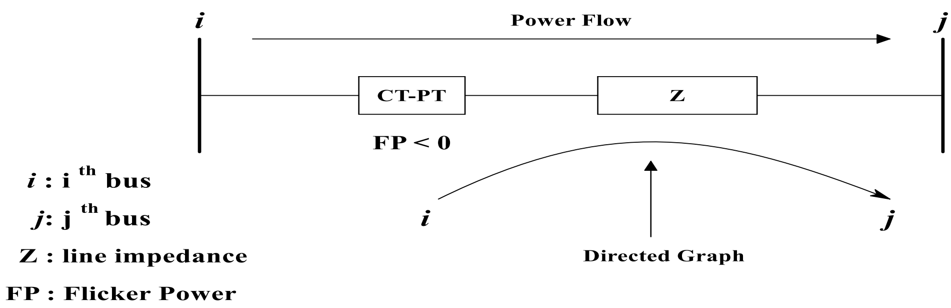


Figure 19. Directed graph of the arc between two vertices for negative flicker power

According to this theory a bus is said to be a dominant flicker source if every arc related to that bus indicates that this bus is a flicker source.

## 4. Identification Based on DWT and ANN

The identification of flicker is carried out by combining DWT and ANN. The DWT is basically used for extracting features of the signal while ANN is used for prediction of output in order to recognize the flicker [24-25]. The block diagram of the method is shown in Figure 20. Initially a voltage signal with flicker is given as input to first block. The DWT based feature extraction is carried out by Wavelet Tool in Matlab Simulink. The features like standard deviation, amplitude, mean absolute deviation, median absolute deviation and energy are obtained by multi signal analysis [25]. These features are extracted for 20 different signals with different magnitudes and frequencies. The signals considered for extracting features are within the standard range of magnitude and frequency for the flicker i.e. magnitude varies from 0.9 p.u. to 1.1 p.u. while frequency have range of 1 Hz to 30 Hz. These features are then passed to ANN with the target values. The target values are the values for a standard 50 Hz signal with unity magnitude.

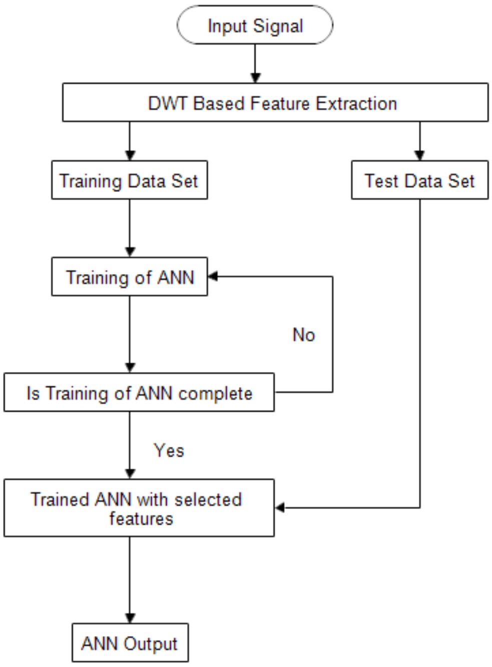


Figure 20. Block diagram of DWT-ANN method for identification

Actual extracted features are normalized to per unit values so that the ANN can work satisfactorily. Table 1 shows normalized values of the features extracted.

Table 1. Normalized Values for Extracted Features

| Input Signal with flicker (pu) | Amplitude (positive Peak) (pu) | Standard Deviation (pu) | Mean Absolute Deviation(pu) | Median Absolute Deviation(pu) | Energy (pu) |
|---|---|---|---|---|---|
| f1 | 0.9991 | 0.7108 | 0.6382 | 0.704 | 0.9882 |
| f2 | 0.9818 | 0.7095 | 0.6376 | 0.705 | 0.9475 |
| f3 | 0.9545 | 0.7082 | 0.6370 | 0.7068 | 0.9001 |
| f4 | 0.9727 | 0.7090 | 0.6374 | 0.7054 | 0.9346 |
| f5 | 0.9273 | 0.7074 | 0.6386 | 0.7071 | 0.8727 |
| f6 | 1.0000 | 0.7108 | 0.6382 | 0.705 | 0.9582 |
| f7 | 0.9818 | 0.7095 | 0.6376 | 0.705 | 0.9157 |
| f8 | 0.9545 | 0.7082 | 0.6370 | 0.7038 | 0.8750 |
| f9 | 0.9727 | 0.7090 | 0.6374 | 0.7049 | 0.8910 |
| f10 | 0.9909 | 0.7101 | 0.6379 | 0.7049 | 1.0000 |
| f11 | 0.9455 | 0.7079 | 0.6368 | 0.7026 | 0.9058 |
| f12 | 0.9545 | 0.7082 | 0.6370 | 0.7067 | 0.9202 |
| f13 | 0.9627 | 0.7086 | 0.6372 | 0.7051 | 0.9361 |
| f14 | 0.9727 | 0.7090 | 0.6374 | 0.7036 | 0.9356 |
| f15 | 0.9782 | 0.7095 | 0.6376 | 0.7058 | 0.9499 |
| f16 | 0.9900 | 0.7101 | 0.6379 | 0.7039 | 0.9521 |
| f17 | 1.0000 | 0.7108 | 0.6382 | 0.7043 | 0.7580 |
| f18 | 0.9900 | 0.7101 | 0.6379 | 0.7034 | 0.7658 |
| f19 | 0.9809 | 0.7095 | 0.6376 | 0.7080 | 0.7742 |
| f20 | 0.9827 | 0.7108 | 0.6382 | 0.7035 | 0.9695 |
| Target | 0.9091 | 0.7073 | 0.6366 | 0.7073 | 0.8636 |

### 4.1. Validation of Proposed Method

The validity of proposed method is checked by using test data. For obtaining the test data the flicker producing load selected is an arc furnace. The arc furnace model is simulated using mathematical equations given in [26]. Figure 21 shows the diagram of the network with load.

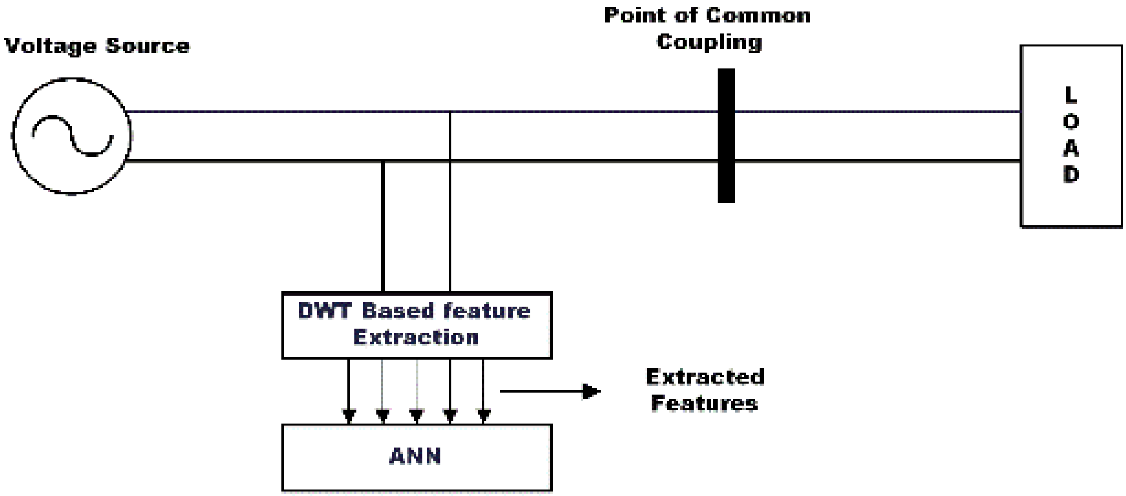


Figure 21. Simplified diagram of a network with load

The proposed algorithm is applied to the output for single phase. The similar features are extracted. These features are the new inputs to the trained ANN. Table 2 shows the results obtained.

Table 2. Results Obtained from Arc Furnace Model

| Type of Data | Amplitude (positive Peak) (pu) | Standard Deviation (pu) | Mean Absolute Deviation (pu) | Median Absolute Deviation (pu) | Energy (pu) |
|---|---|---|---|---|---|
| Input | 0.9273 | 0.627 | 0.494 | 0.747 | 1.3118 |
| Output | 0.9118 | 0.6366 | 0.6366 | 0.9079 | 0.9118 |

From Table 1 and Table 2, it is observed that the outputs with new data are well matched with the targets. Therefore it is noteworthy to say that the new input to ANN has same features as that of original training inputs which are flicker signals. Hence it can be said that the test input resembles to the flicker signal.

## 5. Conclusion

A study regarding methods studied to identify flicker producing loads in accordance with IEC 61000-4-15 has been presented in this paper**.** Various methods such as interharmonic power direction method, slope method, reactive current component method, energy method and flicker power method are used to detect direction of flicker source. Among these methods interharmonic power direction method and flicker power method use sign of power to identify flicker source. The negative sign indicated that the source location is downstream with respect to measurement point while positive sign is for the source which is situated at upstream direction. The slope method uses sign of slope characteristic. If slope has positive sign then flicker source is from upstream while negative sign indicates flicker source is from downstream. In energy method the positive sign of energy indicates upstream direction of source and for negative sign source direction is downstream. Other methods use techniques like FFT, d-q transformation and neural network to determine direction of flicker power. Also a technique for detection of the flicker source has been proposed. The strategy used is a combination of the discrete wavelet transform and the feed forward back propagation neural network. The DWT is used primarily for extracting features of contaminated source voltage due to presence of the voltage flicker. The ANN serves purpose of identification of the flicker source which causes the distortion of the source voltage. The validation of the methodology presented is done in MATLAB/Simulink environment. From the simulation results it is clear that the anticipated output parameters are well converged with target assigned to ANN. Therefore the test signal is a flicker signal and the source from which it is coming is a flicker source.

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