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Detection of Several Flicker Sources Using d-q Algorithm and Flicker Power

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ABSTRACT

Detection of flicker sources is the first step to mitigate the effect of flicker in power system. In this literature, existence of several flicker sources is studied and proposes a technique for detecting all existing tones in voltage and current envelope. Half wave rectifier demodulation is improved by using d-q transformation, to calculate phase difference between voltage flicker tones and current flicker tone. These phase differences are considered as index of flicker sources detection. By using phase difference between voltage flicker tones and current flicker tones, signs of flicker power are obtained in selected branches. By comparing the sign of flicker power with direction of fundamental active power, the place of flicker source is obtained. For validation, the 6-bus network is simulated and algorithm for flicker sources detection is tested. The simulations results show that by using the proposed algorithm, all flicker sources in a power system can be detected correctly.
KEYWORDS: d-q Algorithm, Flicker power, Flicker sources, Flicker tones, Improved half wave rectifier, Power quality.

1. INTRODUCTION

In recent years, by Proliferation of non linear load in power network, power quality became of great importance for both consumers and utilities. One of the most important power quality events is flicker. Flicker defined as perception of the human eyes to the light flux of lamps which depend on voltage RMS value. So flicker is defined as root mean square (RMS) voltage variation with low frequency. Due to competition in power market, it is necessary to eliminate or reduce negative effects of flicker. Detection of flicker source's place is the first step to mitigate flicker in power system. After this stage by using the appropriate instrument or improving the network structure, flicker is mitigated.

Since now, many different methods for detection of place of flicker sources have been presented. In one of them, with determining the slop of V-I characteristic, the place of flicker source is determined in observation point [1]. Another method is proposed for determining the direction of a flicker source by calculating the sign of the flicker power [2], [3]. Detection of flicker source in multi side supplied network has been considered in [4], and intelligent identification of flicker source is proposed by using S-transform and neural network in [5].

The first step of flicker sources detection is separation of voltage and current envelope. There are many methods for detection of envelope. Square method (Square demodulation) is one of these techniques [6], but disadvantage of this method is its low accuracy as it generates additional low frequency components because square method is not linear [3]. The Fast Fourier Transformation (FFT) is another method which is used to detect the flicker tones included in voltage envelope [7]. However, the accuracy of the FFT is affected by the leakage effect [8] and it increases when system frequency deviates from nominal value. Another method is Phase Shifting method [9]. However in this method there would be a small phase shift in flicker tones when main signal is fed to phase shifter so it decreases accuracy. Another technique is Hilbert Transform [10]. However this method has a high mathematical burden, because impulse response of the filter corresponded to Hilbert Transformation is infinite and so it needs to know all the samples of a signal [9]. Wavelet Transform can separate a signal into different bandwidth and then reconstructs special bandwidth, so it is introduced as tool for envelope tracking [11]. But drawback of this technique is difficulty of interpretation of its returns

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results [12]. Kalman Filter is optimal recursive estimators which estimate the magnitude and frequency of voltage variation and is used to track flicker envelope [13]. However, its computational burden is high [8].

d-q Transformation has been applied for detection and classification of power quality disturbances [12], [14]. By using this method, a three phase signal can be converted into a two dimensional frame (d-q) which direct axis (d) is at angle of 90^0 to quadrature axis (q) and this frame is rotating with angular velocity. By combining abc-dqo Transformation algorithm and 90^0 phase shift algorithm, a fast and accurate algorithm to recognize all voltage disturbances and faults characteristics have been presented in [12]. The utility input voltages are sensed and then converted to DC quantities in the d-q reference frame. Thus any disturbances at the utility input voltage will be reflected as disturbance in d-q values. Using these disturbed values, it is possible to detect the power quality events like sag, swell, flicker and so on [12], [14]. In this paper, a method is proposed for calculating all flicker tones phases in voltage and current envelope using d-q transformation and half wave rectifier. The places of flicker sources are determined by using sign of flicker powers in selected branches. And sign of flicker power is determined by using phase difference between voltage flicker tone and current flicker tone which is obtained by d-q transformation and half wave rectifier.

2. DQ TRANSFORM

The d-q transformation is a transform that maps balanced three phase voltages to a synchronous rotating frame in order to extract a set of three-phase voltages with special frequency and to represent them as a DC component. The d-q Transformation is defined as follows [15]:

$$\begin{bmatrix} v_d(t) \\ v_q(t) \end{bmatrix} = (2/3) \begin{bmatrix} \sin(\omega t) & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos(\omega t) & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \tag{1}$$

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

And also inverse of d-q transformation is defined as (2), where ω is d-q Transformation frequency, v_d and v_q are synchronous rotating frame parameters, v_a , v_b , and v_c are abc parameters coordinate system. If d-q Transformation frequency (ω) is equal to frequency of the phase voltage (ω_c), d-q synchronous rotating frame lock to abc synchronous rotating frame. Under this condition, relation between balanced three phase voltages as given in (3) and d-q synchronous rotating frame parameters has been defined as (4).

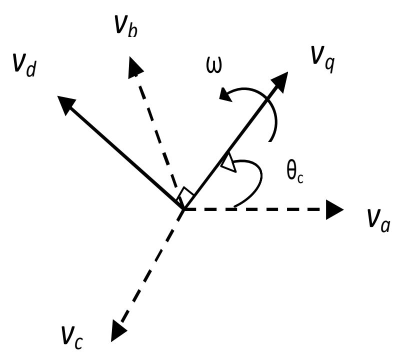

Fig. 1. abc-dq Transform

$$\begin{cases} v_a(t) = V_c \cos(\omega_c t + \theta_c) \\ v_b(t) = V_c \cos(\omega_c t + \theta_c - \frac{2\pi}{3}) \\ v_c(t) = V_c \cos(\omega_c t + \theta_c + \frac{2\pi}{3}) \end{cases} \tag{3}$$

$$\begin{cases} v_d(t) = -V_c \sin(\theta_c) \\ v_q(t) = V_c \cos(\theta_c) \\ V_c = \sqrt{v_d^{\,2}(t) + v_q^{\,2}(t)} \\ \theta_c = -\arctan(\frac{v_d(t)}{v_q(t)}) \end{cases} \tag{4}$$

where V_c, ω_c, θ_c are amplitude, frequency, phase angle of the phase voltage. Concept of d-q transformation is shown in Fig. 1.

3. PROPOSED METHOD FOR FLICKER TONES DETECTION

In a power system, due to the presence of different flicker sources, usually more than one tone is presented in voltage envelope. In this paper a new method has been proposed for frequency identification. In general, consider voltage of phase ''a'' with N flicker tones in its voltage envelope as given in (5):

$$v_a(t) = V_c\left(1 + \sum_{k=1}^{k=N} V_{mk}\cos(\omega_{mk}t + \theta_{mk})\right)\cos(\omega_c t + \theta_c) \tag{5}$$

where V_{mk}, ω_{mk}, θ_{mk} are amplitude, frequency and phase angle of the kth voltage flicker tone respectively. So there is more than one flicker tone in voltage waveform and the aim is to separate all flicker tones. First of all, it is necessary to identify frequencies of these tones existed in envelope. According to (5), at AM (amplitude modulation), each flicker tone produces one sub-harmonic in (f_c–f_{mk}) and one inter-harmonic in (f_c+f_{mk}) as follow:

$$v_a(t) = \begin{bmatrix} V_c\cos\left[2\pi(f_c)t + \theta_c\right] + \\ \frac{1}{2}\sum_{k=1}^{k=N} V_c V_{mk}\cos\left[2\pi(f_c - f_{mk})t + \theta_c - \theta_{mk}\right] + \\ \frac{1}{2}\sum_{k=1}^{k=N} V_c V_{mk}\cos\left[2\pi(f_c + f_{mk})t + \theta_c + \theta_{mk}\right] \end{bmatrix} \tag{6}$$

So according to this concept, frequencies of flicker tones are determined. By multiplying (5) and $cos(2\pi f_v t)$, the result is:

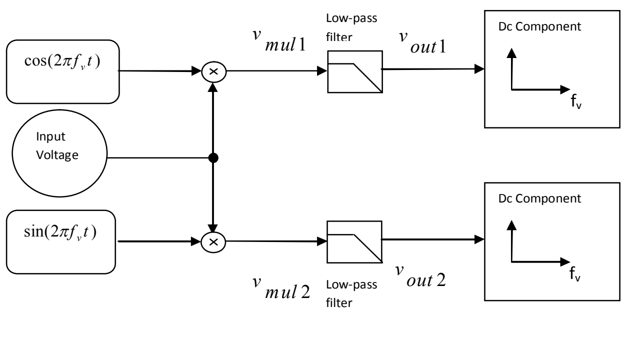

Fig. 2. Detection of signal frequencies

$$v_{mul1}(t)=\cos(2\pi f_v t)v_a(t)=\frac{1}{2}V_c\cdot\left[\begin{array}{l}\cos[2\pi(f_v+f_c)t+\theta_c]+\cos[2\pi(f_v-f_c)t-\theta_c]+\\ \frac{1}{2}V_{mk}\left(\sum_{k=1}^{k=N}V_{mk}\cos[2\pi(f_v+f_c-f_{mk})t+\theta_c-\theta_{mk}]+\sum_{k=1}^{k=N}\cos[2\pi(f_v-f_c+f_{mk})t-\theta_c+\theta_{mk}]\right)+\\ \frac{1}{2}V_{mk}\left(\sum_{k=1}^{k=N}\cos[2\pi(f_v+f_c+f_{mk})t+\theta_c+\theta_{mk}]+\sum_{k=1}^{k=N}\cos[2\pi(f_v-f_c-f_{mk})t-\theta_c-\theta_{mk}]\right)\end{array}\right. \tag{7}$$

where f_v is variable frequency in proposed algorithm. Then, this output is passed to a low-pass filter to give out DC components at each available frequency. Since flicker is a slow change in the voltage magnitude with frequencies between 0.5 to 30 Hz [16], by changing f_v from 0 to $2f_c$ ($fc=50$ or 60 Hz), there will be a DC component in (7). The output is given as (8) when f_v changes from 0 to $2f_c$.

$$\begin{cases} v_{out1}(f_v)=\frac{V_c}{2}\cos(-\theta_c)\ \forall\ (f_v=f_c)\\ v_{out1}(f_v)=\frac{V_cV_{mk}}{4}\cos(-\theta_c+\theta_{mk})\ \forall\ (f_v=f_c-f_{mk})\\ v_{out1}(f_v)=\frac{V_cV_{mk}}{4}\cos(-\theta_c-\theta_{mk})\ \forall\ (f_v=f_c+f_{mk})\end{cases} \tag{8}$$

So the argument of *cos* is zero at frequencies of (f_c–f_m) and (f_c+f_m), and thereby there will be DC component in the output. In general, (8) can identify flicker frequencies but there are some special conditions, in which the argument of *cos* would be 90^o, and thereby output would be zero, so voltage of phase ''a'' is multiplied to *sin (2πf$_v$t)* to solve this problem and this proposed algorithm would be generalized method. So after multiplying to *sin* $(2\pi f_v t)$ and then passed to a low-pass filter, output is obtained as (10) by changing f_v from 0 to$2f_c$.

$$v_{mul2}(t)=\sin(2\pi f_v t)v_a(t) \tag{9}$$

$$\begin{cases} v_{out1}(f_v)=\frac{V_c}{2}\sin(-\theta_c)\ \forall\ (f_v=f_c)\\ v_{out2}(f_v)=\frac{V_cV_{mk}}{4}\sin(-\theta_c+\theta_{mk})\ \forall\ (f_v=f_c-f_{mk})\\ v_{out2}(f_v)=\frac{V_cV_{mk}}{4}\sin(-\theta_c-\theta_{mk})\ \forall\ (f_v=f_c+f_{mk})\end{cases} \tag{10}$$

Block diagram of proposed algorithm for detection of flicker tones frequencies is depicted in Fig. 2. Now there are two frequency spectrums which should be analyzed. According to amplitude modulated, each flicker tone produces one sub-harmonic in (f_c–f_m) and one inter-harmonic in (f_c+f_m).

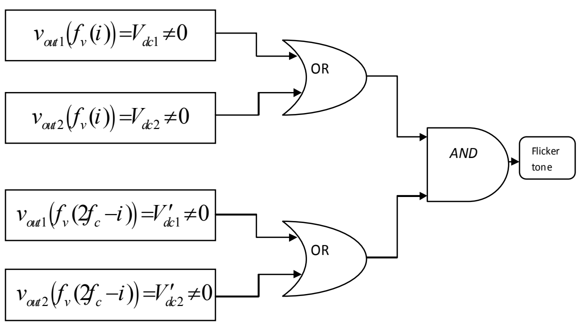

Fig. 3. Block diagram of recognizer unit

The next step is designing a recognizer unit to separate frequencies of flicker tones. Block diagram of proposed algorithm is shown in Fig. 3. This block diagram includes four conditional statements. Two of them verify output of first and second spectrum in $f_v\,(i)$ and another two of them verify outputs of spectrums in $f_v\,(2f_c\text{-}i)$. If there are DC components in (f_c–f_m) and (f_c+f_m) in both spectrums, recognizer unit would give out this frequency as flicker tone. So four conditions are examined at a moment and if output of AND logical gate is one, that frequency will be flicker tone. Also this algorithm can identify system frequency however power system frequency is usually 50 or 60 Hz. If system frequency and frequencies of flicker tones are constant during the time, they should be detected once in time but if they are not fixed, they should be detected any time for using the d-q transformation correctly. Outputs of the recognizer unit are sent to next part which will be explained in section IV.

4. PROPOSED METHOD FOR DETECTION OF FLICKER SOURCES PLACES

Flicker power method is a method in flicker source detection issue. If there are several flicker source in power system, Flicker power is obtained as follow:

$$\begin{aligned} FP &= \frac{1}{T}\int_0^T fp(t)dt = \\ &\frac{1}{T}\int_0^T \left(\sum\nolimits_{k=1}^{N} V_{mk}\cos(\omega_{mk}t+\theta_{mk})\right).\left(\sum\nolimits_{k=1}^{N} I_{mk}\cos(\omega_{mk}t+\alpha_{mk})\right)dt \\ &= \sum\nolimits_{k=1}^{N}\frac{V_{mk}I_{mk}}{2}\cos(\theta_{mk}-\alpha_{mk}) = \sum\nolimits_{k=1}^{N}\frac{V_{mk}I_{mk}}{2}\cos(\phi_{mk}) \end{aligned} \tag{11}$$

where I_{mk}, ω_{mk}, α_{mk} are amplitude, frequency and phase angle of the kth current flicker tone respectively. φ_{mk} is phase difference between voltage flicker tones and current flicker tone. fp(t) is instantaneous flicker power and FP is flicker power. This quantity is calculated from the low frequency amplitude variations of the voltage and current. With comparing fundamental power flow direction with direction of power flickers in each flicker tone, places of all flicker sources are determined. If flicker power was positive, it implies that flicker source is upstream with respect to fundamental power flow direction and if flicker power was negative, it implies that flicker source is downstream with respect to fundamental power flow direction. According to (11), depending on if sign of *cos* is negative or positive, sign of flicker power is negative or positive thereby sign of flicker power is determined by using phase difference between voltage flicker tones and current flicker tone. As you know, if argument of *cos* is between –π/2 and +π/2, sign of *cos* is positive.

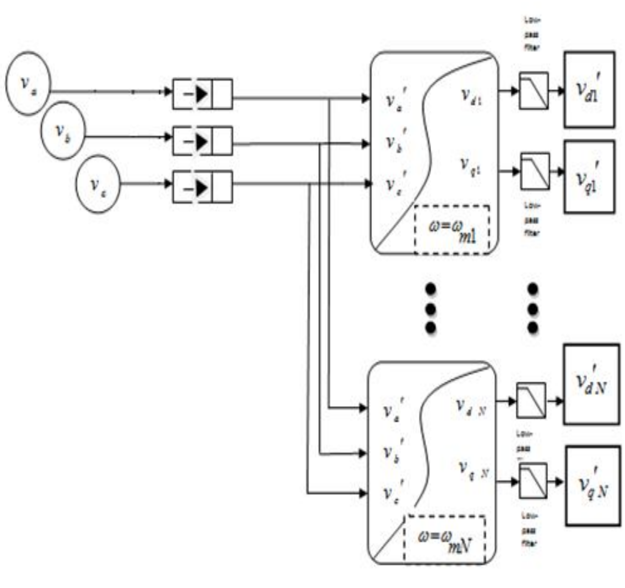

Fig. 4. Improvement of half wave rectifier method

For calculating of phase difference between voltage flicker tones and current flicker tone, a method based on half wave rectifier and d-q transformation is proposed in this paper, to be able to extract phases of all flicker tones. Half wave rectifier is a method which has been used for tracking flicker envelope [3]. In half wave rectifier method, by feeding main voltage to a half wave rectifier block, flicker envelope is appeared independently. Then flicker envelope can be tracked by using filter chain. In this paper, this method is improved by d-q transformation. Proposed method flowchart is shown in Fig. 4. Assume three phase voltages that have N tone as (12).

$$\begin{cases} v_a(t)=V_c\left(1+\sum_{k=1}^{k=N}V_{mk}\cos(\omega_{mk}t+\theta_{mk})\right)\cos(\omega_c t+\theta_c) \\ v_b(t)=V_c\left(1+\sum_{k=1}^{k=N}V_{mk}\cos(\omega_{mk}t+\theta_{mk}-\frac{2\pi}{3})\right)\cos(\omega_c t+\theta_c-\frac{2\pi}{3}) \\ v_c(t)=V_c\left(1+\sum_{k=1}^{k=N}V_{mk}\cos(\omega_{mk}t+\theta_{mk}+\frac{2\pi}{3})\right)\cos(\omega_c t+\theta_c+\frac{2\pi}{3}) \end{cases} \tag{12}$$

Flicker tones are obtained according to Fig. 5. Consider (13) as a voltage of phase ''a'' with N flicker tones. After passing half wave rectifier, (14) is obtained as [3]:

$$v_a(t)=V_c\left(1+\sum_{k=1}^{k=N}V_{mk}\cos(\omega_{mk}t+\theta_{mk})\right)\cos(\omega_c t+\theta_c)=V_c\left(1+\sum_{k=1}^{k=N}v_{mk}\right)\cos(\omega_c t+\theta_c) \tag{13}$$

$$v_a^{'}(t)=V_c\left(1+\sum_{k=1}^{k=N}v_{mk}\right)\cos(\omega_c t)\big|_{1/2waverect}=V_c\left(1+\sum_{k=1}^{k=N}v_{mk}\right)\cdot\left(\frac{1}{\pi}+\frac{1}{2}\cos(w_c t_c)-\frac{2}{\pi}\cdot\left(\begin{matrix}\frac{1}{1.3}\cos(2w_c t)+\frac{1}{3.5}\cos(4w_c t)\\+\frac{1}{5.7}\cos(6w_c t)+\ldots\end{matrix}\right)\right) \tag{14}$$

It can be seen that many different frequencies are produced. Outputs of the d-q transformation ($\omega=\omega_{m1}$) for tracking of the first tone are obtained as (15):

$$\begin{cases} v_{d1}(t)=-\frac{V_cV_{m1}}{\pi}\sin(\theta_{m1})+AC_{d1(rectifier)}(t) \\ v_{q1}(t)=\frac{V_cV_{m1}}{\pi}\cos(\theta_{m1})+AC_{q1(rectifier)}(t) \end{cases} \tag{15}$$

where $AC_{d1}(rectifier)$ and $AC_{q1}(rectifier)$ refer to alternating components after passing d-q transformation in rectifier method. Then, by using low-pass filter v'_{d1} and v'_{q1} are:

$$\begin{cases} v_{d1}'(t)=-\frac{V_cV_{m1}}{\pi}\sin(\theta_{m1}) \\ v_{q1}'(t)=\frac{V_cV_{m1}}{\pi}\cos(\theta_{m1}) \end{cases} \tag{16}$$

So, phase of the first voltage flicker tone is obtained as follow:

$$\theta_{m1}=-\arctan(\frac{v_{d1}'(t)}{v_{q1}'(t)}) \tag{17}$$

So, phase of the all voltage flicker tones are obtained. For example, kth flicker tone is obtained as:

$$\theta_{mk}=-\arctan(\frac{v_{dk}'(t)}{v_{qk}'(t)}) \tag{18}$$

Also the same procedure should be applied for current. Assume three phase currents that have N tone as (19).

$$\begin{cases} i_a(t) = I_c\left(1+\sum_{k=1}^{k=N} I_{mk}\cos(\omega_{mk}t+\alpha_{mk})\right)\cos(\omega_c t+\beta_c) \\ i_b(t) = I_c\left(1+\sum_{k=1}^{k=N} I_{mk}\cos(\omega_{mk}t+\alpha_{mk}-\frac{2\pi}{3})\right)\cos(\omega_c t+\beta_c-\frac{2\pi}{3}) \\ i_c(t) = I_c\left(1+\sum_{k=1}^{k=N} I_{mk}\cos(\omega_{mk}t+\alpha_{mk}+\frac{2\pi}{3})\right)\cos(\omega_c t+\beta_c+\frac{2\pi}{3}) \end{cases} \quad (19)$$

So, phase of the all current flicker tones are obtained. For example, kth flicker tone is obtained as:

$$\alpha_{mk} = -\arctan(\frac{i_{dk}'(t)}{i_{qk}'(t)}) \quad (20)$$

So phase difference between voltage flicker tone and current flicker tone in each line for kth flicker tone is calculated as:

$$\phi_{mk} = \theta_{mk} - \alpha_{mk} \quad (21)$$

This algorithm can detect more than one flicker source because this proposed algorithm can calculate phase of all flicker tones separately.

5. SIMULATION RESULT

In this section simulations for two cases have been carried out to verify the effectiveness of the proposed algorithms in detecting several flicker sources in power network. Spot welders are one of the main loads which can produce flicker in the power network. There are some methods to simulate the spot welder. The performance of a spot welder can be simulated by variable resistor shown in Fig. 5.

The resistor *(R)* connected with an ideal switch which is controlled by pulse generator are treat as variable resistor. Current of a single phase spot welder with envelop frequency 10 Hz is shown in Fig. 6. A simulation based on 6-bus test system is used to demonstrate the proposed approach. Fig. 7 shows a 230 KV power network which is supplied by three generators and its data is given in APPEDIX [17]. In this study, two different cases are considered and analyzed; one flicker source, two flicker sources. First of all, some lines should be selected to analyze, so two lines ended to each bus are selected. Line between bus 1 and 2, line between bus 2 and 3, Line between bus 3 and 6, Line between bus 5 and 6, Line between bus 4 and 5 and Line between bus 1 and 4 are six considered lines for power system shown in Fig. 7.

5.1. Case one (one flicker source)

In the first case, the applicability of the proposed method for network with only one flicker source has been examined. In this section, only one spot welder in power network connected to bus 3 has been considered. Envelope frequency is 5 Hz and resistance(*R*) is 70 Ω. Phase difference between voltage flicker tone and current flicker tone in each selected line is calculated using proposed algorithm shown in Fig. 4. Simulation results are presented in table I. Based on the signs of the powers shown in Table I, direction of fundamental and flicker power flows are shown in Fig. 8. In order to improve the visualization of simulation results, only six selected lines are shown in Fig. 8. In Fig. 8, dashed arrows represent positive direction of fundamental power flow and bold arrow represent flicker power. By following the direction of flicker power (bold arrow with head number 5), the place of flicker source can be found. Thus, the load connected at bus 3 is a flicker source.

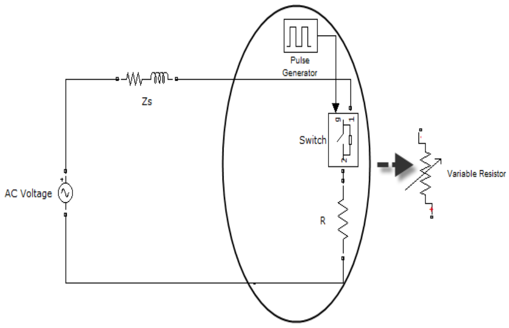

Fig. 5. Modeling of spot welder as variable resistor

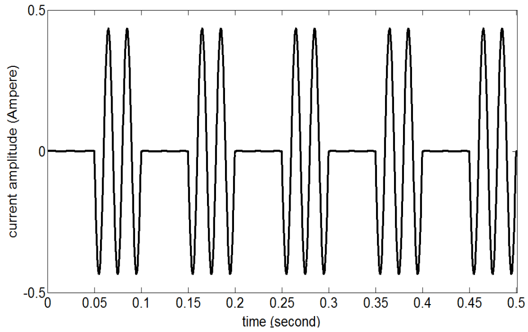

Fig. 6. Single phase spot welder current

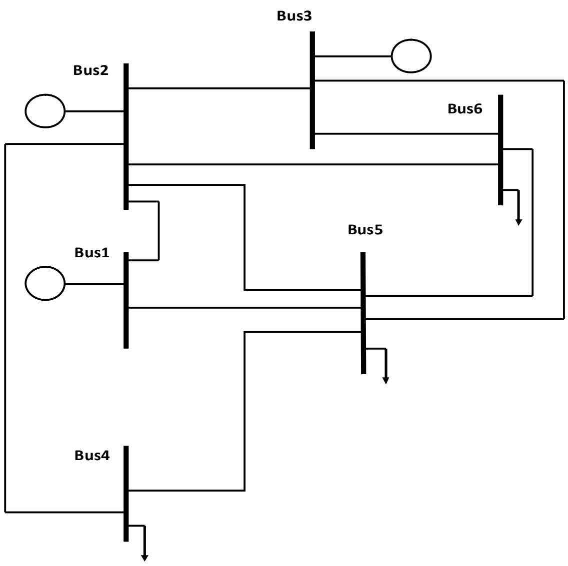

Fig. 7. Power network

5.2. Case two (two flicker sources)

In the second case, the applicability of the proposed method for network with two flicker sources has been examined. In this section, first spot welder is connected to bus 3 with envelope frequency of 5 Hz and resistance is 70 Ω and the second spot welder is connected to bus 4 with envelope frequency of 10 Hz and resistance is 100 Ω. Simulation results are presented in table II and table III. Based on the signs of the powers, direction of fundamental and flicker power flows are shown in Fig. 9. In Fig. 9, dashed arrows represent positive direction of fundamental power flow and bold arrow with head number 5 represent flicker power of 5Hz and bold arrow with head number 10 represent flicker power of 10Hz and . By following the arrows with head number 5, the place of flicker sources with envelope frequency 5 Hz can be found and by following the arrows with head number 10, the place of flicker sources with envelope frequency 10 Hz can be found. Furthermore, this method is implied for more sources too but because of space limitation, they were not presented.

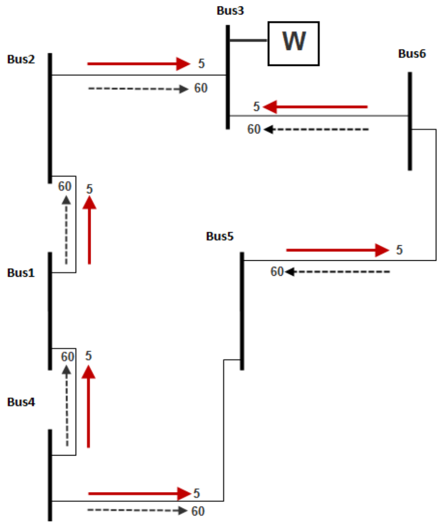

Fig. 8. Graphical simulation result of the first case

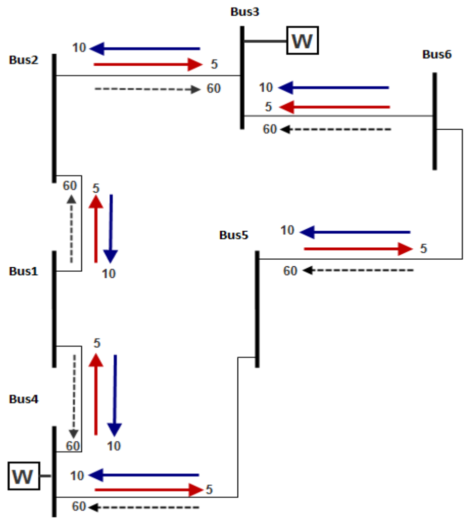

Fig. 9. Graphical simulation result of the second case

6. CONCLUSION

Identification of the flicker sources is the first step in the process of improving power quality. In this paper, a method is proposed for calculating all flicker tones in voltage and current envelope using d-q transformation and half wave rectifier. The proposed method is capable of getting more than one tone in envelope. Then phase difference between voltage flicker tone and current flicker tone is obtained and so sign of flicker power is determined. The places of flicker sources are determined by using signs of flicker powers in selected branches. Simulation has been carried out which results show accurate detecting of the flicker sources places.

APPENDIX

Table IV presents Generators and loads data of power system and table V presents lines data.

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Table. I. Simulation result of first case

from	to	Fundamental Power(MW)	Phase difference	Sign of flicker power
1	2	+121	-151.18	Negative
2	3	+9.3	+186.70	Negative
3	6	-3.55	+194.66	Negative
5	6	-4.77	+10.74	Positive
4	5	+0.98	+189.78	Negative
1	4	-9.55	-119.57	Negative

Table. II. Simulation result of second case (5Hz)

from	to	Fundamental Power(MW)	Phase difference	Sign of flicker power
1	2	+116	-127.15	Negative
2	3	+6	+194.77	Negative
3	6	+0.15	+229.18	Negative
5	6	-5.77	+11.53	Positive
4	5	-3.92	-9.23	Positive
1	4	+3.75	+18.95	Positive

Table. III. Simulation result of second case (10Hz)

from	to	Fundamental Power(MW)	Phase difference	Sign of flicker power
1	2	+116	-0.2000	Positive
2	3	+6	-23.59	Positive
3	6	+0.15	+230.72	Negative
5	6	-5.77	+187.77	Negative
4	5	-3.92	+191.86	Negative
1	4	+3.75	+181.38	Negative

Table. IV. Generators and loads data

Bus number	GEN (pu) (S=100 MW)	voltage (pu)	P load (pu)	Q load (pu)
1	0.00	1.050	0.00	0.00
2	0.50	1.050	0.00	0.00
3	0.60	1.070	0.00	0.00
4	0.00	1.000	0.70	0.70
5	0.00	1.000	0.70	0.70
6	0.00	1.000	0.70	0.70

Table. V. lines data

From	To	R(pu)	X(pu)	BCAP(pu)
1	2	0.1000	0.2000	0.0200
1	4	0.0500	0.2000	0.0200
1	5	0.0800	0.3000	0.0300
2	3	0.0500	0.2500	0.0300
2	4	0.0500	0.1000	0.0100
2	5	0.1000	0.3000	0.0200
2	6	0.0700	0.2000	0.0250
3	5	0.1200	0.2600	0.0250
3	6	0.0200	0.1000	0.0100
4	5	0.2000	0.4000	0.0400
5	6	0.1000	0.3000	0.0300