# Detection of Several Flicker Sources in a Non-radial Power System

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**Abstract.** Detection of flicker sources is the first step to mitigate the effect of flicker in power system. In this paper, in order to reduce the number of measurement devices, instantaneous voltages are estimated by using state estimation methods and then root mean square of the voltages and currents variation are detected and then sign of flicker powers is obtained in selected branches. By comparing the sign of flicker power with direction of fundamental active power, the places of flicker sources are obtained. For validation, the 6-bus non-radial network is simulated and algorithm for flicker sources detection is tested in this paper. The simulations results show that by using the proposed algorithm, all flicker sources in a non-radial network can be detected correctly.

**Keywords:** Flicker Power, Flicker Sources, Non radial Network, Power Quality.

## 1 Introduction

In recentyears, 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. Detection of flicker source's place is the first step to mitigate flicker in power system. Since now, many different methods for detection of place of flicker sources have been presented. In one of them, the slop of V-I characteristic is used [1]. Another method proposed flicker power [2]. Detection of flicker source in multi side supplied network has been considered in [3], and intelligent identification of flicker source is proposed by using S-transform and neural network in [4]. Generally in these methods only dominate flicker source is considered, while existence of multiple flicker sources in a power system is more realistic than single source.In this paper, by modifying the definition of upstream and downstream, they are generalized to non-radial network.State estimation is used to generate the best estimationof the state variables from limited measurements that are companied with measurement noise [5]. Due to the fact that in practice in a network, measurement of currents is easier than measurement of voltage [5], all bus voltages have been estimated by using state estimation. To detect multiple flicker sources in a non-radial power system, first bus voltages are estimated by using state estimation. Then envelop of voltages and currents are extracted and flicker power is calculated by

V.V. Das, E. Ariwa, and S.B. Rahayu (Eds.): SPIT 2011, LNICST 62, pp. 56–60, 2012.

using Discrete Fourier Transform (DFT).In the next step sign of flickerpower in every lineis specified and by using them,the places of flicker source are detected.

## 2 Instantaneous State Estimation

For determination of the place of flicker sources in N-bus power network, minimum number of measurements is necessary that cause network become observable. There are N lines that flicker power should be analyzed in them and two possible choices are available. The first one is using power quality meter (PQ meter) in any selected line which is expensive and impractical for a large system. The second choice is using available measurement devices in network which is available in thecontrol center. So in general, N currents and N voltages are needed. In real network, by using current measurements and relationships which exist in network, voltages can becalculated. If line current and some bus voltages are chosen as measurements (z), the main equation of state estimation is given as:

$$z = Hx + \varepsilon \tag{1}$$

If branch model is considered as PI model,Arrays of H are determined as follow:

$$H(k,i) = \frac{2C_{ij}}{\Delta t(1+\alpha)} + \frac{1+\alpha}{\frac{2L_{ij}}{\Delta t} + (1+\alpha)R_{ij}} \tag{2}$$

$$H(k,j) = -\frac{1+\alpha}{\frac{2L_{ij}}{\Delta t} + (1+\alpha)R_{ij}} \tag{3}$$

whereα is a constant between 0 and 1, referred to as the compensating factor. $R_{ij}$, $L_{ij}$and $C_{ij}$ are resistance, inductance and capacitance of branch *K* respectively, which is locatedbetween buses i and j, and Δt is sampling time [5]. Instantaneous bus voltages are then calculated as (4). Where R is diagonal matrix and its arrows are the measurements errors.

$$x_{est} = [H^T R^{-1} H]^{-1} H^T R^{-1} z_{meas} \tag{4}$$

## 3 Envelope Separation

Modulated voltage and current signals are as follow:

$$u_{AM}(t) = (U_c + m_u(t))\cos(2\pi f_c t) \tag{5}$$

$$i_{AM}(t) = (I_c + m_i(t))\cos(2\pi f_c t) \tag{6}$$

where $m_u(t)$ and $m_i(t)$ are low frequency fluctuation generating from flicker source and $f_c$ is fundamental carrier signals (50 Hz/60 Hz). The complete demodulation process which is shown in Fig. 1,is used in this paper [2].

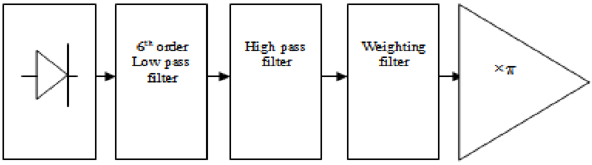

**Fig. 1.** Method of envelop separation

## 4 Proposed Method for Detection of Flicker Sources

The main purpose of this paperis the detection of flicker sources in a non-radial power network.In radial network, recognition of upstream and downstream is easy. Upstream is toward utility and downstream is toward load. But in non radial system it is hard to recognize as each feeder is supplied from more than one side. In this case fundamental power flow direction in any line under study should be determined and then upstream is in the opposite direction from fundamental power flow and downstream is in the same direction as fundamental power flow. Due to the presence of some sub-harmonic, DFT has been applied to voltages and currents envelopes to calculate power flicker and then all of flicker sources could bedetected. Measured values of currents and base voltage in form of discrete data, which is created from simulated power system in PSCAD, have been used as input.The proposed method has four parts and MATLAB has been used for simulation for these parts.

### 4.1 First Part: State Estimation

In an N-bus power system, N measured current and one measured voltage (base voltage), is used as input for state estimation. The complete process of this part is given in section 2.

### 4.2 Second Part: Envelope Separation

In this part, as it is possible to have more than one sub-harmonic, a demodulation method, as shown in Fig. 1, has been used. Inputs of this stage are measured currents and estimated voltages extracted from first part and outputs of this stage are voltages and currents envelopes.

### 4.3 Third Part: Flicker Power Calculation Using DFT

In this part, tracked envelopes of voltages and currents extracted in previous stage pass to DFT and then by multiplying DFT of current envelope and DFT of voltage envelope, flicker power is calculated in any sub-harmonic.

$$U = [|U_1| \angle\beta_1, |U_2| \angle\beta_2, \ldots |U_N| \angle\beta_N] \tag{7}$$

$$I = [|I_1| \angle \alpha_1, |I_2| \angle \alpha_2, \ldots |I_N| \angle \alpha_N] \tag{8}$$

In (7) and (8), U and I are array of complex values showing the DFT of voltage and current envelopes. $U_K$ and $I_K$' whereK=1, 2,…, N are the orders of frequency derived by DFT analysis, are the voltage and current phasors of the sub-harmonics respectively. Therefore flickers power in any sub-harmonic can be expressed as:

$$\begin{aligned} S_k &= U_k . I_k^* = P_k + jQ_k \\ P_k &= real\{S_k\} \end{aligned} \tag{9}$$

### 4.4 Fourth Part: Detection of All Flicker Sources in Non-radial Power System

In non-radial power system, upstream and downstream are defined with respect to fundamental power flow direction in any line. Fundamental power flow directions in each line are calculated using by measured currents and estimated voltages. With comparing fundamental power flow direction with power flickers in any sub-harmonic, 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.

## 5 Simulation Results

In this section, simulations have been carried out to verify the effectiveness of the proposed algorithm in detecting the multiple flicker sources in non-radial network. The PSCAD software has been used to capture the instantaneous waveforms of the voltages and currents in test cases. Then these results have been used as input for MATLAB simulations to conduct. Arc furnaces are used as flicker loads in simulations. A simulation based on 6-bus test system is used to demonstrate the proposed approach. Fig. 2 shows a 220 KV power network which is supplied by two 11 KV generators [6]. In this study, a network with two flicker sources has been considered. First arc furnace is connected to bus 2 with envelope frequency of 10 Hz and amplitude modulation of 0.1 PU and the second arc furnace is connected to bus 5 with envelope frequency of 5 Hz and amplitude modulation of 0.07PU. Flicker powers (FP) and fundamental active powers are given in Table 1. Sign of flicker power is used to decide whether flicker source is downstream or upstream with respect to point of study. Based on the values of the powers shown in Table 1, direction of fundamental and flicker power flows are shown in Fig. 2. In this figure, long curved arrow represents flicker power of 5 Hz and short curved arrow represents flicker power of 10 Hz, also dashed arrow are presented direction of fundamental power flow. By following the long curved arrow, bus 2 which is the place of arc furnace producing 10 Hz sub-harmonic, is achieved. In the same way by following short limber arrow, bus 5 which is the place of other arc furnace is determined.

**Table 1.** Simulation Result Of The Second Case

| Branch No. | Fundamental power (MWatt) | FP (MWatt) At $f_1$(10 Hz) | Sign of FP at $f_1$(10 Hz) | FP (MWatt) At $f_2$(5 Hz) | Sign of Fp at $f_2$(5 Hz) |
|---|---|---|---|---|---|
| 1 | 92.11 | -0.765 | negative | +0.031 | positive |
| 2 | 58.82 | +0.077 | positive | -0.060 | negative |
| 3 | 58.62 | +0.076 | positive | -0.061 | negative |
| 4 | 58.41 | +0.076 | positive | -0.061 | negative |
| 5 | 142 | +0.212 | positive | -0.152 | negative |
| 6 | 62.61 | -0.537 | negative | +0.057 | positive |

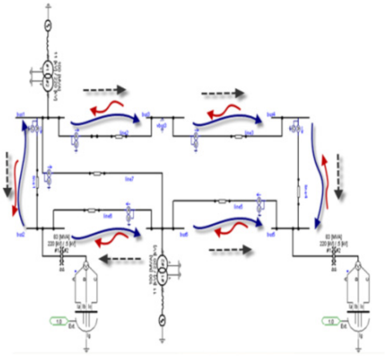

**Fig. 2.** Graphical simulation result of the second case

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