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Fuzzy Based Power Quality Disturbances Identification in Power Systems

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ABSTRACT

Recognition and classification of different power quality events is of great importance in power systems which should be done on line. For this purpose, different methods are presented which each has advantages and disadvantages. In this paper, recognition way is presented for power quality disturbances such as sag, swell, outage, surge and normal based on fuzzy systems. In this method, voltage or current signal is decomposed on line using Fourier linear combiner (FLC) and amplitude and phase for each component of voltage or current signals are obtained. Then, a fuzzy controller is designed which its inputs are signal fundamental component amplitude and its slope variation. Fuzzy controller recognizes event type by these inputs and fuzzy rules obtained experimentally and then it classifies them. Eventually, mentioned strategy is implemented using tool box of fuzzy logic in MATLAB software and obtained results verify efficiency and usefulness of proposed method.

KEY WORDS: Power Quality Event, Fuzzy Controller, Fourier Linear Combiner, and Power System Disturbances.

I. INTRODUCTION

Power quality issue has been in attention of electrical engineers for ages. But by adventure of new electronical devices and their sensitivity to electrical energy, this issue is becoming one of the main concerns of electricity companies and their consumers. Low voltage networks are susceptible to different disturbances such as harmonics, voltage variations (swell and sag), transient ripple, frequency variations, DC offset and so on. In power systems, voltage and current disturbances (harmonics, sag, flicker, outage and etc) can lead to false operation of different kinds of protective relays and system reliability reduction. Moreover, it can cause energy measurement errors. Regarding problems created by power quality disturbances in networks, their recognizing and classifying is of great importance.

In the literatures, various methods based on wavelet transform, fuzzy logic, neural network and genetic algorithm have been proposed and implemented for PQ recognition and classification. References [1–9] present different approaches based on wavelet transform and wavelet packet for PQ events recognition. In [10] a hybrid scheme using a Fourier Linear Combiner and a fuzzy expert system is presented for the classification of transient disturbance waveforms in a power system. Neural network detection schemes have also been carried out in some methods [11]. Hybrid schemes using neural networks and wavelet transform are suggested in [12, 13].

Other techniques based on fuzzy reasoning and wavelet transform have been presented in [14, 15]. A novel approach for detection and classification of power quality (PQ) disturbances is proposed in [16]. The distorted waveforms (PQ events) are generated based on the IEEE 1159 standard, captured with a sampling rate of 20 kHz and de-noised using discrete wavelet transform (DWT) to obtain signals with higher signal-to-noise ratio. Reference [17], presents a method based on S-transform and artificial neural network to detect and classify power quality disturbances. The input features of the neural network are extracted using S-transform.

In this study, a fuzzy expert system is used to detect disturbances. This method has following advantages such as real-time, simple, less calculation .In this technique, voltage or current signals are measured on line and they are decomposed using Fourier linear combiner. Then, amplitude and phase of each component of signal are obtained. After that, a fuzzy system is designed which can distinguish event type using these inputs and fuzzy rules are experimentally obtained as well. Eventually, mentioned strategy is implemented using tool box of fuzzy logic in MATLAB software.

II. INTRODUCING FLC METHOD[10]

Network voltage or current in k^{th} sample can be written as:

$$y(k) = s(k) + v(k) \tag{1}$$

Where;

$$s(k) = \sum_{i=1}^{N}\left(a_i \cos i\omega k\Delta T + b_i \sin i\omega k\Delta T\right) \tag{2}$$

Where ω is fundamental component frequency and N is the highest harmonic order and T is sampling time. In (1), v *(k)* is white Gaussian noise with Gaussian distribution and σ_v^2 is variance. A DC reductive component can be added to (2).

To obtain Fourier coefficient a_i and b_i related to signals, an adaptive estimator in linear combination of Fourier coefficient can be used. Input array is as follow:

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$$X(k) = \cos k\omega\Delta T,\ \sin k\omega\Delta T,\ \ldots,\ \cos k\omega N\Delta T, \sin k\omega N\Delta T \tag{3}$$

Input coefficient array W_i is composed of a_i and b_i which are Fourier coefficient signals. To obtain a_i and b_i parameters, an operational index in form of $J(k) = E\left(\left|e(k)^p\right|\right)$ should be minimized. Where E is expected value and $e\ (k)$ is error between desired value and estimated signal. P is an index which is varied between 1 and 5. Weight array W_i in each sample can be written as:

$$W_i(k+1) = \begin{cases} W_i + \mu e^{p-1}(k) x_i(k) & \text{p is even} \\ \\ W_i + \mu \operatorname{sgn}(e(k)) e^{p-1}(k) x_i(k) & \text{p is odd} \end{cases} \tag{4}$$

Where in this equation:

$$i = 1,2,\ldots,N \tag{5}$$

$$x_i(k) = [\cos i\omega k\Delta T \ \ \sin i\omega k\Delta T]^T \tag{6}$$

$$W_i = [a_i(k) \ \ b_i(k)]^T \tag{7}$$

Equation (4) for $p=3$ changes to:

$$W_i(k+1) = W_i + \mu e^2(k) \operatorname{sgn}\{e(k) x_i(k)\} \tag{8}$$

Algorithm for values of p>5 does not present appropriate answer and causes signals to be estimated wrongly. To access desired results, coefficient value of μ can be variable. Suitable values of μ is 0.2<μ <2. Maximum amplitude and fundamental component phase are respectively obtained as:

$$A = \sqrt{a_1^2 + b_1^2} \tag{9}$$

$$\angle\Phi_1 = \tan^{-1}\left(\frac{b_1}{a_1}\right) \tag{10}$$

III. Fuzzy System Designing to Recognize Different Events

In this part, a fuzzy system is designed to recognize power quality disturbances. Maximum amplitude of fundamental component and its phase are inputs for this fuzzy system. Maximum amplitude input has five fuzzy levels which are:

- Large Negative(LN)
- Small Negative(SN)
- Zero(Z)
- Small Positive(SP)
- Large Positive(LP)

This fuzzy set is shown in Fig. 1. Also, signal slope variation includes three levels of:

- Negative (SN)
- Zero (SZ)
- Positive (SP)

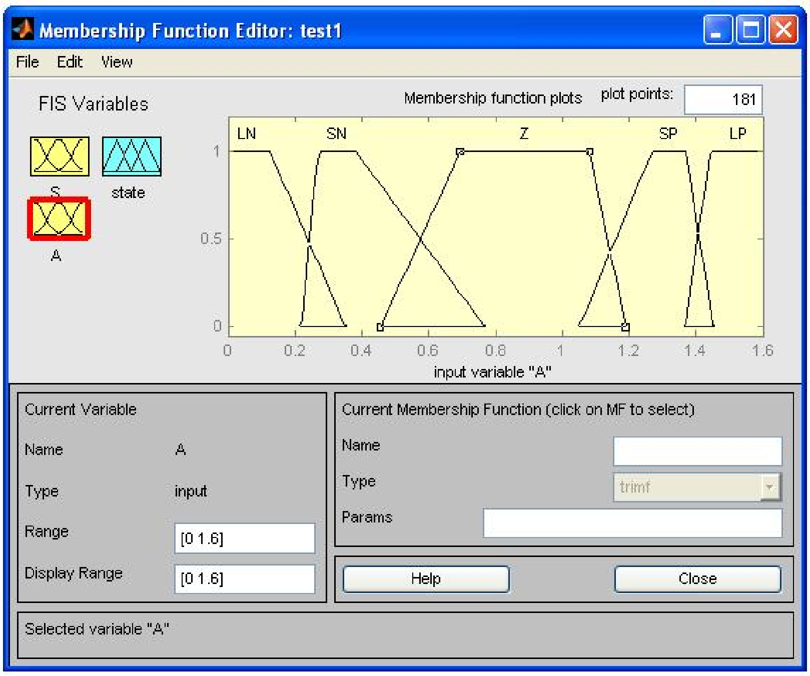

Fig.1: Membership function for fundamental component

For this input, fuzzy set figure is plotted in Fig. 2. Regarding Fig. 3, fuzzy output has five fuzzy sets which are:

- outage
- sag
- normal
- swell
- surge

Slope variations amplitude of fundamental component in each sample is defined as:

$$S(k) = \frac{A(k) - A(k-1)}{\Delta T} \tag{11}$$

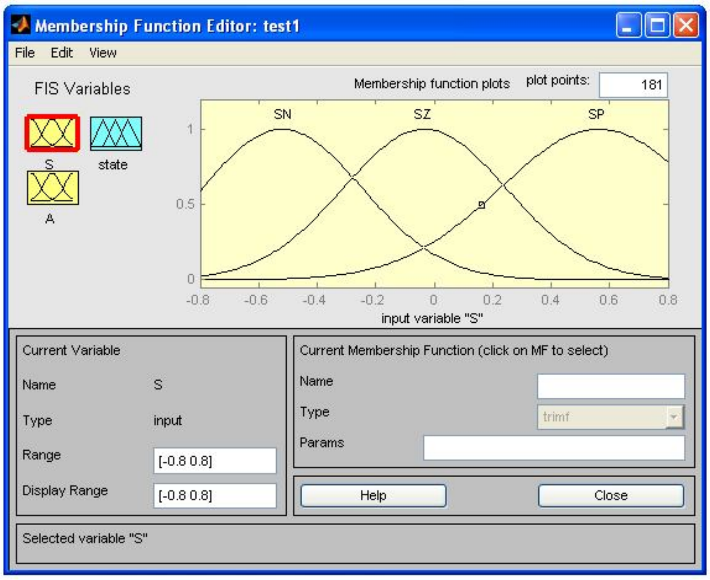

Fig.2: Membership function for slop of fundamental component

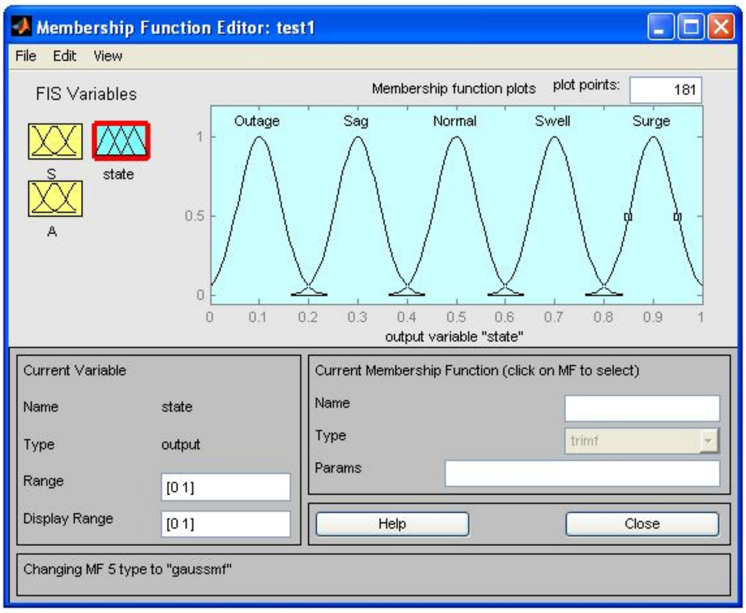

Fig.3: Membership function for output

Where ΔT is sampling period and k is repeating times. Fuzzy rules are listed in Table. 1.

Table. 1: Fuzzy rules [10]

Branch Number	SN	SZ	SP
LN	Surge	Outage	Outage
SN	Sag	-	-
Z	-	Normal	-
SP	-	Swell	Swell
LP	-	Sag	Surge

IV. FUZZY CONTROLLER IMPLEMENTATION

First of all, waveform enters FLC part and amplitudes of fundamental component and other components are obtained. Then, slope variations of fundamental component amplitude are calculated using (11). This fundamental component amplitude is imported to fuzzy part as inputs. A program written in MATLAB runs SIMULINK each time which is indicated in Fig. 4.

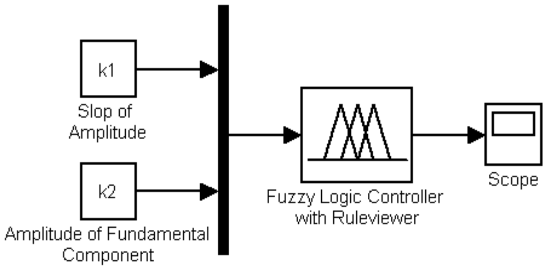

Fig. 4: Importing amplitude and slop of amplitude to fuzzy system for each sample

In Fig. 5, the implemented fuzzy rule in MATLAB is presented. In this figure, the values of fundamental component and its slop are considered equal to 0.589 and 0.235 respectively and the output value is equal to 0.3 which means in this condition, the event is Sag.

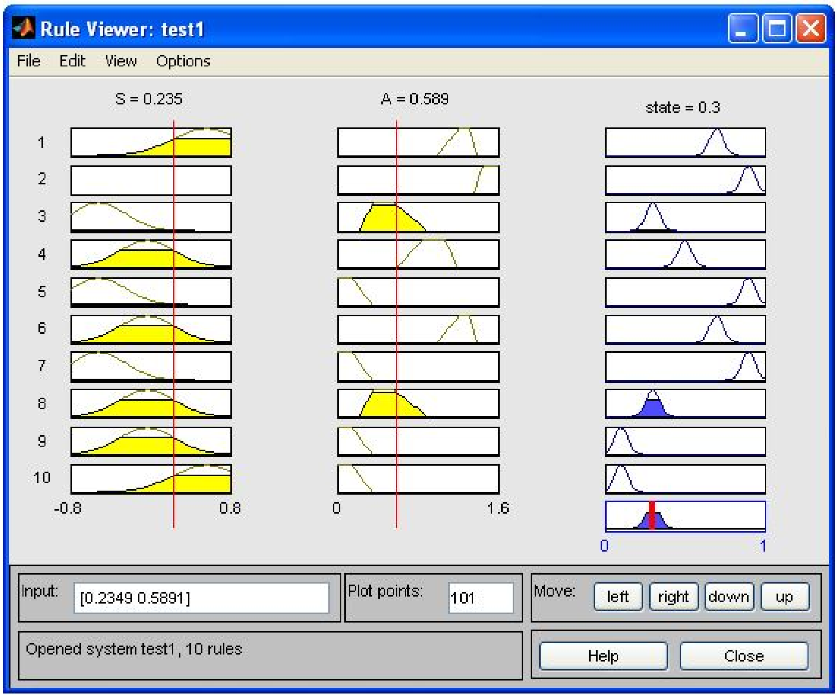

Fig. 5: Implemented fuzzy rule in MATLAB

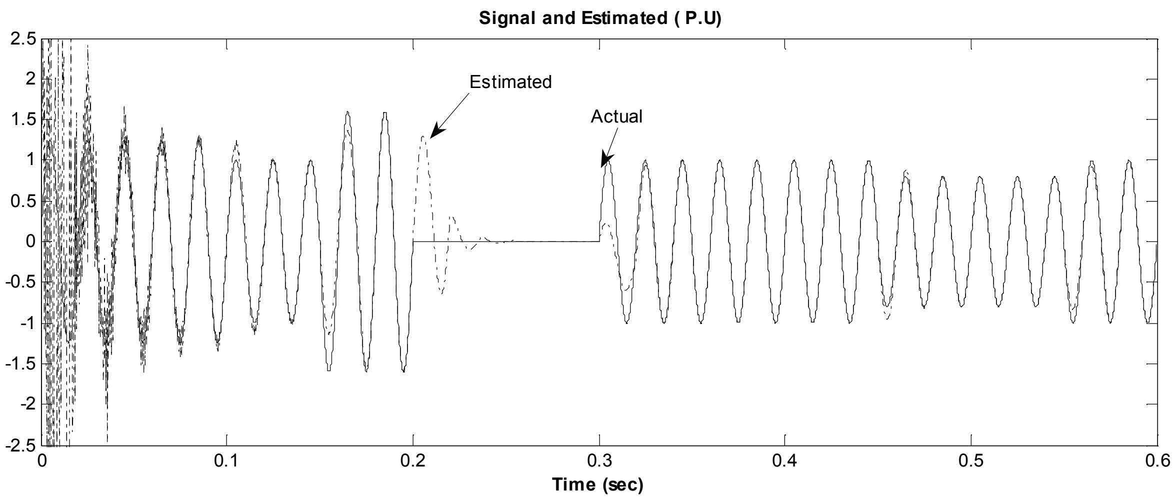

Fig. 6: Estimated and real time signal

After that, for different inputs, output is calculated each time. According to Fig. 3, occurring events for various fuzzy output values are as follow:

if $0 \le \text{state} \le 0.2$ then event is Outage

if $0.2 \le \text{state} \le 0.4$ then event is Sag

if $0.4 \le state \le 0.2$ *then event is Outage*

if $0 \le \text{state} \le 0.2$ then event is Outage

if $0 \le \text{state} \le 0.2$ then event is Outage

In this section, to show proposed method capability, an example is proposed according to following expression.

$$V(t) = \begin{cases} 1.25\sin(\omega t) & 0 \le \omega t \le 0.1 \quad \textit{Swell} \\ \sin(\omega t) & 0.1 \le \omega t \le 0.15 \quad \textit{Normal} \\ 1.6\sin(\omega t) & 0.15 \le \omega t \le 0.2 \quad \textit{Surge} \\ 0.6\sin(\omega t) & 0.2 \le \omega t \le 0.3 \quad \textit{Outage} \\ \sin(\omega t) & 0.3 \le \omega t \le 0.45 \quad \textit{Normal} \\ 0.4\sin(\omega t) & 0.45 \le \omega t \le 0.55 \quad \textit{Sag} \\ \sin(\omega t) & 0.55 \le \omega t \le 0.6 \quad \textit{Normal} \end{cases}$$

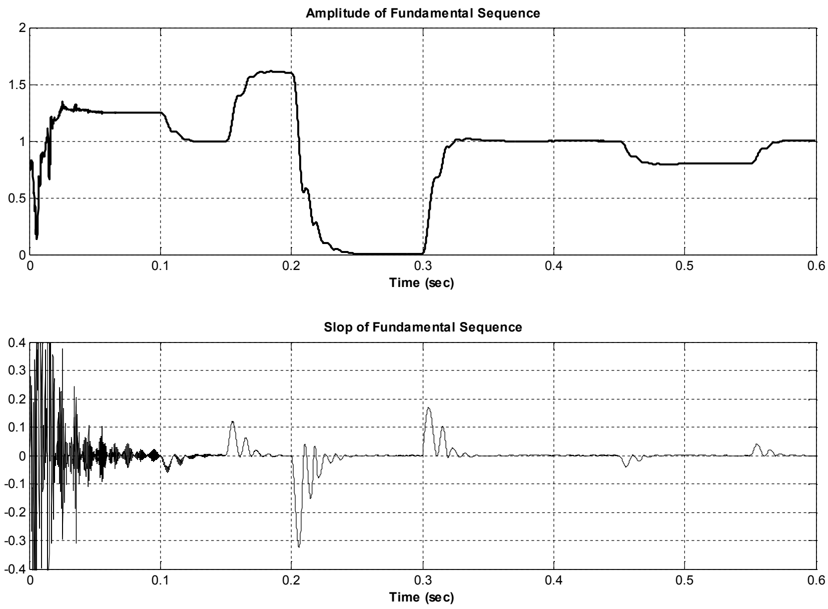

Fig. 7: Amplitude of fundamental component and its variation obtained using FLC

This waveform includes several events for instance, outage, swell, sag and surge which are specified in Fig. 7. In this figure, estimated signal values (sum of estimated sinusoidal components) are shown as well. This figure shows the precise of estimated signal by this method. Only in significant variations such as from surge to outage case, estimation dynamic is relatively slow. Nevertheless, in other cases, real time waveform is obtained quite fast. In Fig .7, fundamental component amplitude value and its variation have been shown. These waveforms are outputs of FLC section which are considered as fuzzy section inputs. Fuzzy system recognizes event type regarding input value which is plotted in Fig. 8.

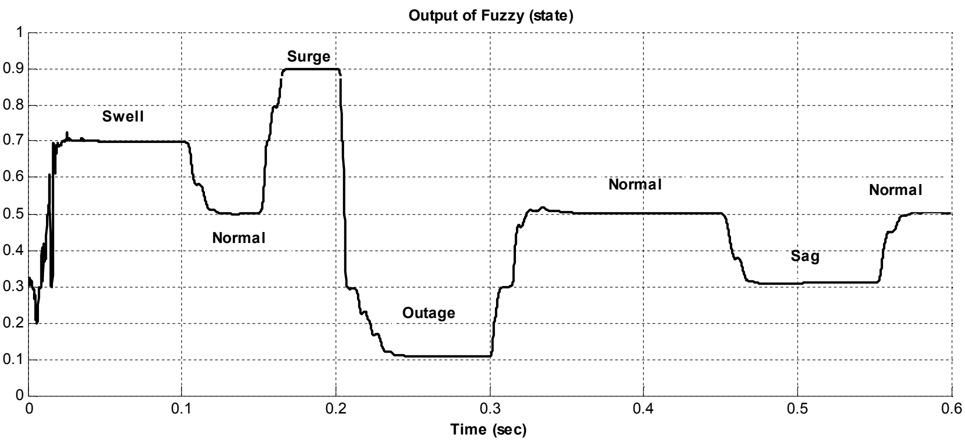

Fig. 8: output of fuzzy section and identification of power quality disturbances

V. CONCLUSION

In this paper, recognition and classification of different power quality disturbances have been investigated. In this method, sampled signal has been imported to recommended algorithm on line. This signal has been decomposed using Fourier linear combiner (FLC). Then, amplitude and phase for each component of voltage or current signal have been obtained. Moreover, a fuzzy system has been designed which its inputs were component amplitude and slope variations and its output was disturbance type. Furthermore, several rules have been considered by which disturbance types can be easily recognized and then be classified. Finally, to verify efficiency of mentioned method, a waveform with different events has been imported to fuzzy system. Obtained results have been evaluated and they have proved that not only power quality disturbances were recognized and classified but also it required relatively less calculation.

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