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Analysis of Voltage Sag and Swell Using Modern Technique

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Abstract— **The power quality (PQ) requirement is one of the most important issues for power companies and their customers. The power quality disturbances like voltage sag, swell, notch, spike and transients are analyzed using various techniques. One of the important aspects in power quality assessment is automated detection and classification of power quality disturbances which requires the use of artificial intelligent techniques. This paper presents the application of fuzzy-expert system for classification of short duration voltage disturbances which include voltage sag, swell and interruption. A fuzzy-expert system has been developed to set the fuzzy rules with inputs and outputs. The system is designed for detecting and classifying the three types of short duration voltage disturbances.**

Index Terms — **Power Quality, Fuzzy Controller, Fuzzy Expert System, Extraction of Features, Membership Functions.**

I. INTRODUCTION

Power supply quality issues and resulting problems are consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, electronic type loads .The advent and wide spread of high power semiconductor switches at utilization, distribution and transmission leaves have non sinusoidal currents [1]. The electronic type load causes voltage distortions, harmonics and distortion. Power quality problems can cause system equipment mal function, computer data loss and memory mal function of the sensitive equipment such as computer, programmable logic devices [PLC] controls, and protection and relaying equipment [1].
Voltage sags are most wide spread power quality issue affecting distribution systems, especially industries, where involved losses can reach very high values.
Emerging power systems. Classification of power quality disturbances based on the visual inspection of waveforms by human operators is laborious and time consuming.
Moreover, it is not always possible to extract important information from simple visual inspection [2]. The classification of PQ disturbances in electric power systems has become an important task for proper developing and designing the preventive and corrective measures.

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Artificial intelligence emerged as a computer science discipline in the mid 1950s. Since then, it has produced a number of powerful tools, many of which are of practical use in engineering to solve difficult problems normally requiring human intelligence. In this paper we have used Fuzzy Logic Systems to classify Voltage Sag, Swell, and Interruption [2] [3].

II. FUZZY CONTROLLER

FLC is a new addition to control theory. Its design philosophy deviates from all previous methods by accommodating expert knowledge in controller design. These FLC are attractive choice where precise mathematical modeling formulas are not possible. It has good control robustness compared with traditional control scheme. It changes an expert knowledge based control strategy into automatic control strategy in essence [3]. A mamdani type Fuzzy Logic Controller is used in this study with max-min interference method which performs the function in four stages as shown in Fig. 1.
(1) Fuzzification
(2) Rule Base
(3) Inference Mechanism
(4) Defuzzification

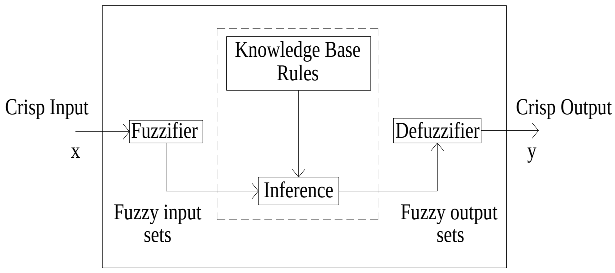

Fig. 1 Fuzzy Controller Architecture

III. THE PROPOSED FUZZY EXPERT SYSTEM, PREPROCESSING AND EXTRACTION OF FEATURES

The proposed fuzzy-expert system is designed to classify short duration voltage disturbances defined as instantaneous and momentary sag, swell and interruption, as shown in Fig.2 [3]. In the study, the disturbance data are obtained from PQ monitoring in which the monitoring software by default has three different sampling frequencies of 0.4 kHz (128 cycle), 1.6 kHz (32 cycle) and 6.4 kHz (8 cycles) and each frame has 1024 samples.

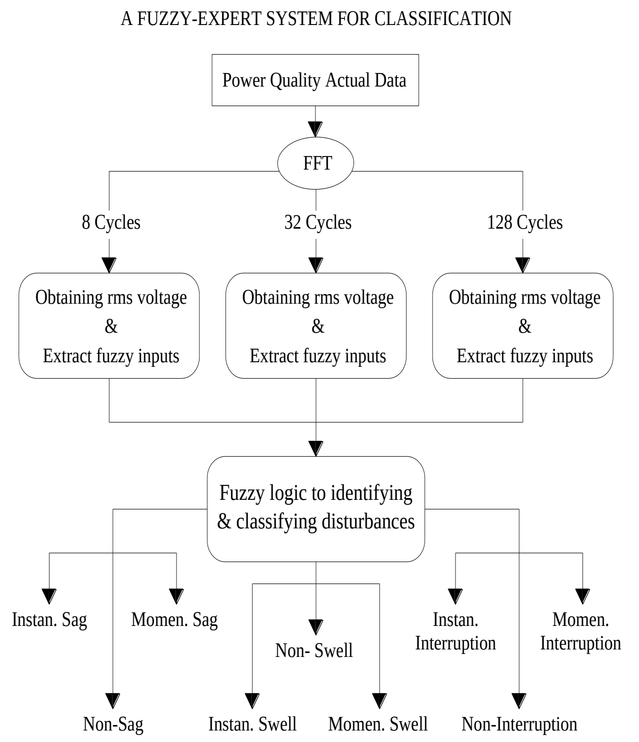

Fig. 2 Design of the proposed fuzzy-expert system

To process the raw disturbance data so as to extract features of the various disturbances, preprocessing of the disturbance signals is required. Initially, fast Fourier transform analysis is used to separate the 8, 32 and 128 cycle waveforms. Then root mean square (rms) method is applied by first approximating the fundamental frequency profile of actual voltage waveform and determining the maximum and minimum voltage magnitudes. An advantage of this method is its simplicity, fast calculation and less requirement of memory because rms voltage can be stored periodically instead of per sample [4].

IV. FUZZY LOGIC INPUTS AND OUTPUTS

The Mamdani-type fuzzy inference system with five inputs and three outputs has been considered in the proposed fuzzy-expert system. The five inputs include maximum voltage in p.u (Max-V), sag duration in second (SagDurat), swell duration in second (SwellDurat), transient duration in second (TranDurat) and minimum voltage in p.u (Min-V) [5]. The maximum voltage has been chosen as a fuzzy input variable so as to classify instantaneous and momentary swell whereas the minimum voltage is for differentiating between interruption and voltage sag.

The sag duration is used as an input variable for classifying instantaneous and momentary sag whereas the swell duration is used to classify swell disturbance to instantaneous and momentary swell. The transient duration is chosen as a fuzzy input for distinguishing between instantaneous swell and impulsive transient disturbance [5]. The three FL outputs are Output1, Output2 and Output3 in which Output1 is designated for classifying instantaneous sag, non-sag and momentary sag, Output2 for classifying instantaneous swell, non-swell and momentary swell, and Output3 for classifying instantaneous interruption, non-interruption and momentary interruption [6].

V. MEMBERSHIP FUNCTIONS

The input and output variables are represented by some membership functions which are either in trapezoidal or triangular forms. The range of input variables and thresholds are chosen in accordance with the respective disturbance definition as defined in the IEEE Std. 1159-1995. Table 1 and 2 shows the fuzzy sets for input, output variable [7] [8].

TABLE 1: FUZZY SETS DEFINED FOR THE INPUT VARIABLES

Membership function	Input 1: Maximum voltage (p.u.)	Input 2: Sag duration (sec)	Input 3: Swell Duration (sec)	Input 4: Transient Duration (sec)	Input 5: Absolute Minimum voltage (p.u.)
1.	L Low	ESH Extremely short	ESH Extremely short	ESH Extremely short	VL Very Low
2.	M Medium	VSH Very Short	VSH Very Short	SH Short	L Low
3.	H High	SH Short	SH Short	SH Short	M Medium
4.	VH Very High	M Medium	M Medium	-	H High
5.	EH Extremely High	-	-	-	-

TABLE 2: FUZZY SETS DEFINED FOR THE OUTPUT VARIABLES

Membership function	Output 1	Output 2	Output 3
1	I sag Instantaneous sag	I swell Instantaneous swell	I interrupt Instantaneous interruption
2	N sag Non sag	N swell Non swell	N interrupt Non interruption
3	M sag Momentary sag	M swell Momentary swell	M interrupt Momentary interruption

The membership functions defined for the five input variables are as shown in fig. 3 to 7. The output variables are defined by three membership functions as shown in fig. 8 to 10.

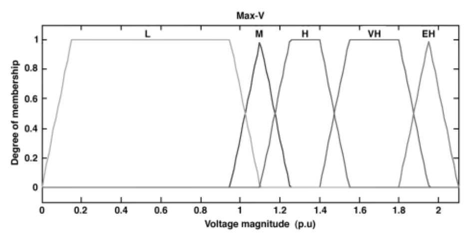

Fig. 3 Maximum voltage input membership function

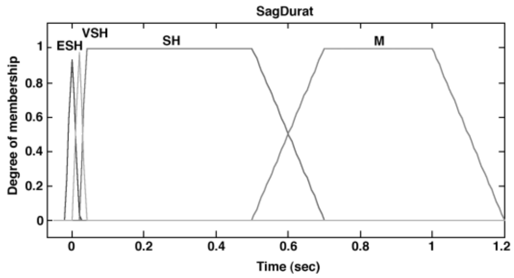

Fig. 4 Sag duration input membership function

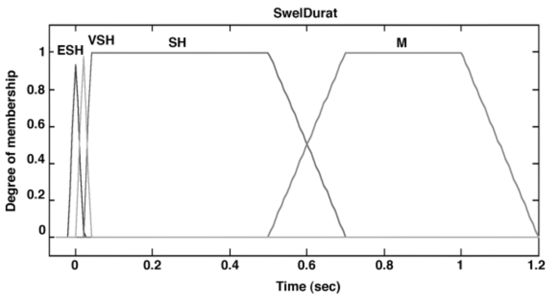

Fig. 5 Swell duration input membership functions

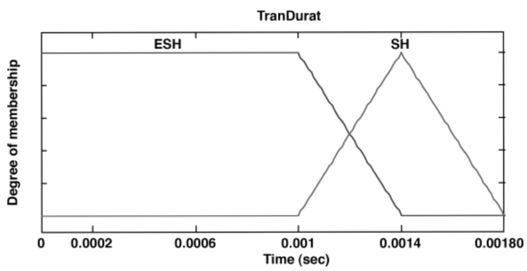

Fig. 6 Transient duration input membership functions

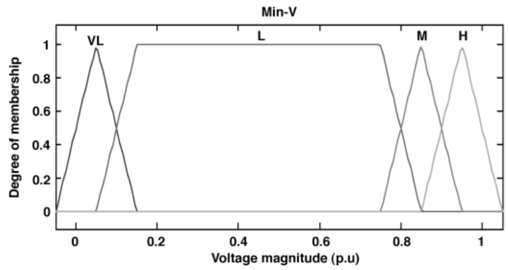

Fig. 7 Absolute minimum voltage input membership function

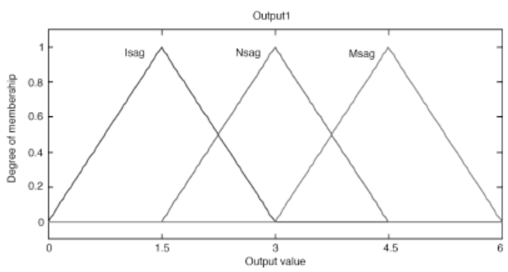

Fig. 8 Output1 membership function

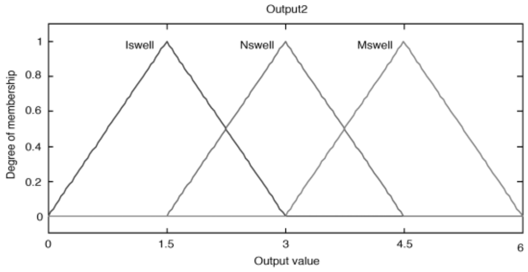

Fig. 9 Output2 membership function

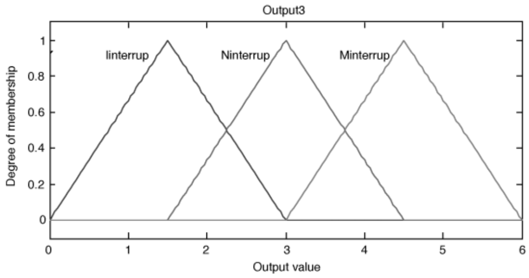

Fig. 10 Output3 membership function

If-Then rules (30) have been generated for classifying sag, swell and interruption disturbances. These rules are represented in the following form:

IF premise THEN consequent Example of the generated rules for identifying sag, swell and interruption and classifying them to instantaneous, momentary and non sag, swell and interruption are given as follows:

(1) If (Max-V is L) and (Sag Durat is SH) and (Swel Durat is ESH) and (Tran Durat is ESH) and (Min-V is L) then (Output1 is I sag) (Output2 is N swell) (Output3 is N interrup). etc. To illustrate the classification results of the proposed fuzzy-expert system, 30 case examples were considered and analyzed.

VI. CONCLUSION

Identification and classification of voltage and current disturbances in power systems is an important task in power system monitoring and protection. A fuzzy-expert system has been developed for detecting and classifying short duration voltage disturbances, namely, instantaneous, momentary and non sag, swell and interruption from the 8, 32 and 128 cycles waveforms. For the fuzzy inference system, fuzzy If-Then rules has been created based on five fuzzy inputs and three fuzzy outputs. Prior to the fuzzy implementation, a simple signal processing technique based on FFT and rms averaging technique have been used to derive the features of various disturbances. The proposed fuzzy-expert system has been tested with various types of real voltage disturbances so as to verify its accuracy in classifying sag, swell and interruption. The test results reveal that the proposed system has accurately identified and classified 98.4% of the tested voltage disturbances.

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