Chapter 8
Analysis of Voltage Sag and Swell Problems Using Fuzzy Logic for Power Quality Progress in Reliable Power System

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1 Introduction

The electricity generation from conventional and non-conventional sources, its transmission from DC or AC system, its distribution to domestic and commercial consumers, and its utilization from human being and for industrial requirements makes a power system network. In a smart power system, the difficulties during this complete process are solved in a smart manner. Such type of disturbances includes mainly VAR controlling and power quality issues. Managerial controlling from load dispatch centers makes a power system better. Additionally, the fuzzy-based expert systems can be implemented so as to make the existing system smarter with higher accuracy.

The problems due to power quality and problems arising are penalty of more utilization of solid-state switching devices, nonlinear load, electronic load, and switching load. The arrival of high rating semiconductor switches in distribution and transfer leaves current to be non-sinusoidal [1]. Electronic load causes voltage distortion and harmonic distortion. Power quality problems create onset of systems, sensitive equipment, data loss in the commuter, and MAL functioning in the memory, like computers, programmable logic controller, the protective and relay apparatus [1].

A voltages sag or voltage dip is a short duration decrease in rms voltage. It is caused by short circuit phenomena, overload, and starting of electric motors. If the value of RMS voltage reduces from 10 to 90 percent of the nominal voltage for a cycle to a minute duration, then phenomena of voltage sag is produced. Voltage sag is termed as sustained sag if this low voltage remains in the system for a longer duration up to a minute. Voltage swell is the contradictory of voltage sag. It is the phenomena of an increase in the level of voltage which occurs due to turn off of a

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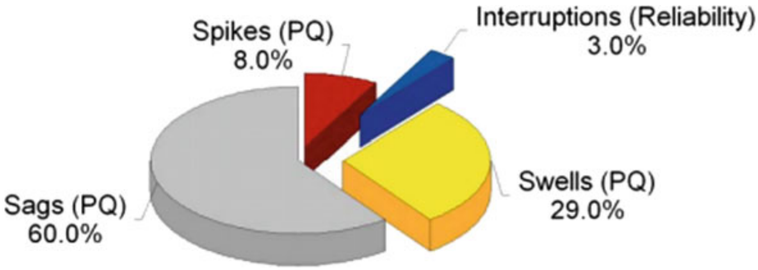
heavy load in an electrical power system. Similar to sag, swell happens for a very short duration, and if it is of longer duration, then termed as sustained swell.

Voltage sag mainly increases the problems of power quality. It affects the electricity distribution system and various industries which causes very high loss of power. Short duration voltage dips can cause the whole industry out from their normal operating condition. Generally, it is considered that the voltage dip as a source 10–90%. The main reasons include short circuit condition and breakdown voltage dips, lightning phenomena, and power surges. In overhead transmission and distribution systems, lightning phenomena is the main reason for producing voltage sag, with an approximate occurrence of 50% of total cases [2]. The following pie chart shows the main reasons for poor power quality and their approximate percentage.



To minimize conflict of power quality in electrical devices, some well-organized detection and categorization techniques are necessary in the electrical power systems. Types of power quality disturbances which are based on visual check of waveforms by human being operators is a time consuming and laborious task. Also, it's not always necessary that we can remove some important information from simple visual inspection [2]. The categorization of Power quality disturbances in an electrical power system has now become a very important job for proper development and design of preventive and corrective actions.

In the mid of 1950s, artificial intelligence has emerged as a new stream of computer science engineering. There are many powerful tools produced by artificial intelligence, which are used practically in different engineering streams so as to resolve those complex engineering problems which require human intelligence. In this paper, fuzzy logic tool is used for the analysis of disturbances like voltage sag and swell [2, 3].

Fuzzy Controller

Fuzzy controllers are very simple and it is a new addition to control theory. They consist of an input stage, a processing stage, and an output stage. Its design philosophy differs from all previous methods by containing dexterous knowledge in controller design. These FLCs are attractive choices where specific mathematical modeling formulas are not possible. It has good control robustness as compared to traditional control scheme. It modifies a dexterous knowledge-based control strategy into automatic control strategy in essence [3].

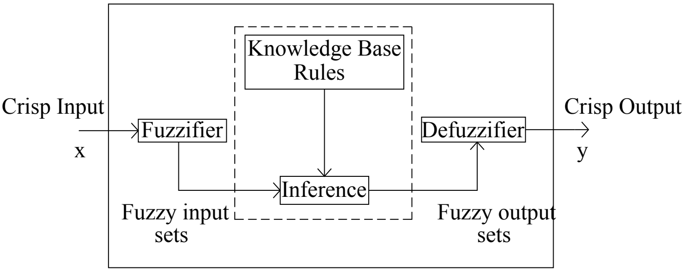


Fig. 1 Architecture of a Fuzzy Controller

A Mamdani-based fuzzy controller is used with maximum-minimum interference method. It performs the function in the following 4 stages which is shown in the following Fig. 1.

(1) Fuzzification process
(2) Rule base
(3) Inference
(4) Defuzzification process.

Fuzzification is the procedure of changing real scalar value into a fuzzy value which is achieved with the different types of fuzzifiers. (Membership functions).

Rule base scheme is used as a way to store and manipulate knowledge to understand the information in a useful manner. They are used in AI.

FIS is a system that uses the theory of fuzzy set for mapping of inputs. The input is features while the output is classes of fuzzy classification.

Defuzzification is the process of getting a scientific result in the Crisp logic, available fuzzy sets, and related membership degrees. So, the process of mapping of fuzzy to crisp set is called as Defuzzification.

The planned fuzzy-based expert system is developed to classify short voltage disturbances which can be defined as instantaneous and temporary sag, swell, and interruption, which are 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.

To process the raw disturbance data so as to remove 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].

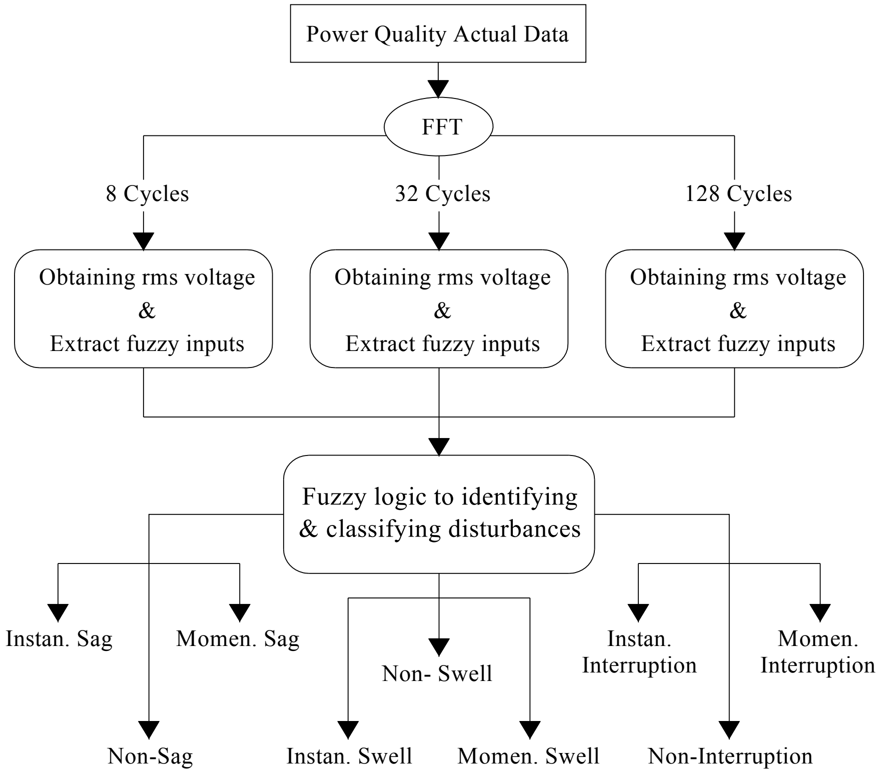


Fig. 2 Design of the proposed fuzzy-expert system

2 Fuzzy Logic Inputs and Outputs

The Mamdani-type fuzzy 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 (Sag Durat), swell duration in second (Swell Durat), transient duration in second (Tran Durat), 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].

3 Membership Functions

The input and output variables are represented by the most common shape of membership functions which are either in trapezoidal or triangular forms and bell curves are also used but the shape is less important than no. of curves. The range of input variables and thresholds are chosen in accordance with the respective disturbance definition as defined in the IEEE Std. 1159-1995. The following Tables 1 and 2 represent fuzzy sets for Input and Output Variables [7, 8].

The membership functions defined for the five input variables are as shown in Figs. 3, 4, 5, 6, and 7. The output variables are defined by three membership functions as shown in Figs. 8, 9 and 10.

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.

Table 1 Fuzzy sets defined for the input variables

Membership Function	Input 1: Maximum voltage (p.u.)	Input 2: Sag duration (s)	Input 3: Swell Duration (s)	Input 4: Transient Duration (s)	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

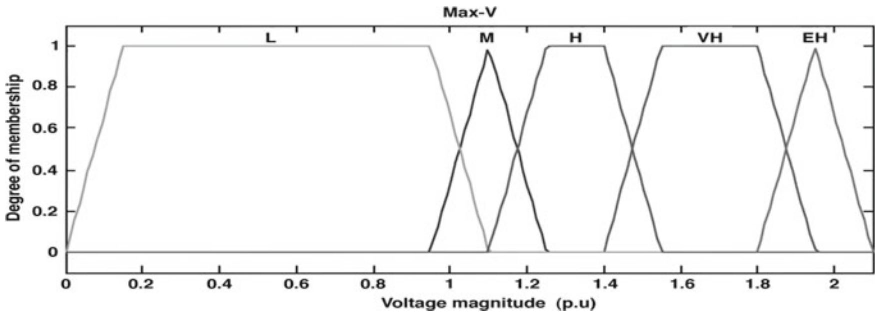


Fig. 3 Maximum voltage input membership function

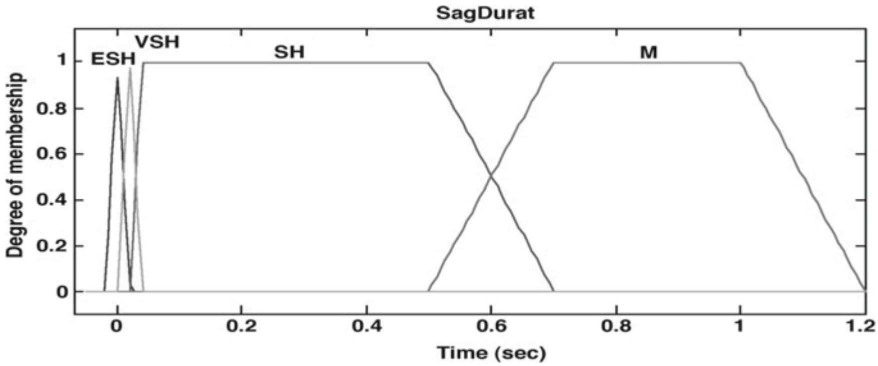


Fig. 4 Sag duration input membership function

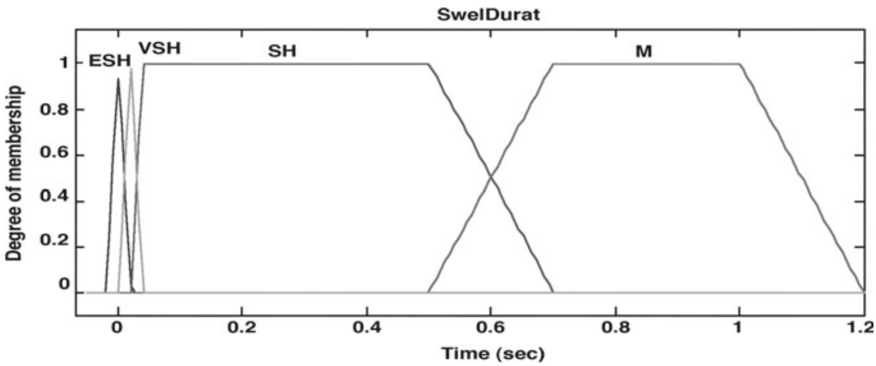


Fig. 5 Swell duration input membership functions

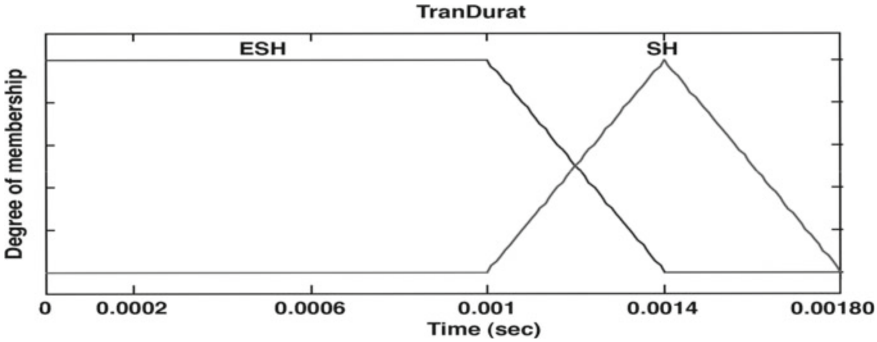


Fig. 6 Transient duration input membership functions

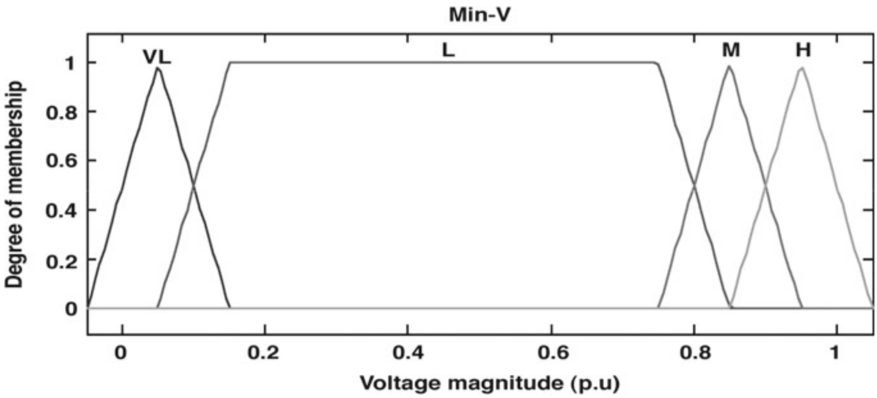


Fig. 7 Absolute minimum voltage input membership function

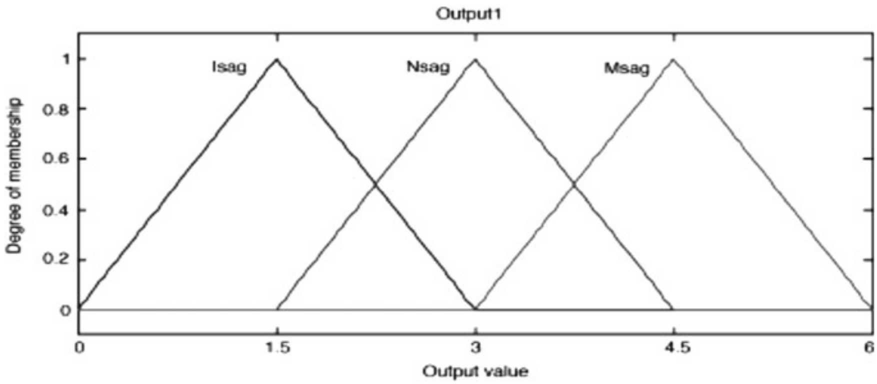


Fig. 8 Output1 membership function

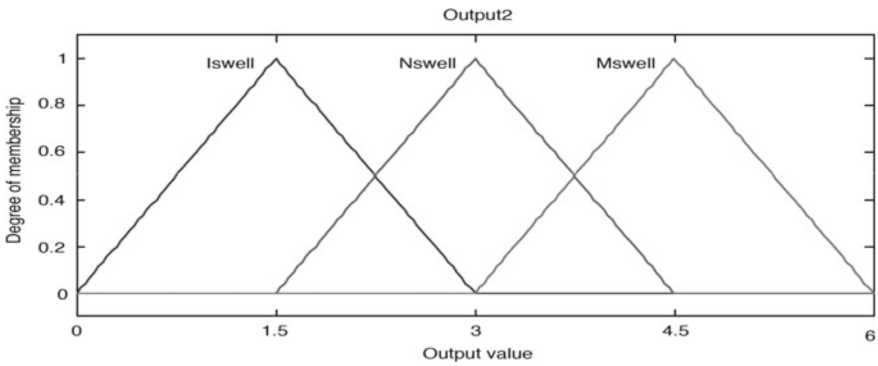


Fig. 9 Output2 membership function

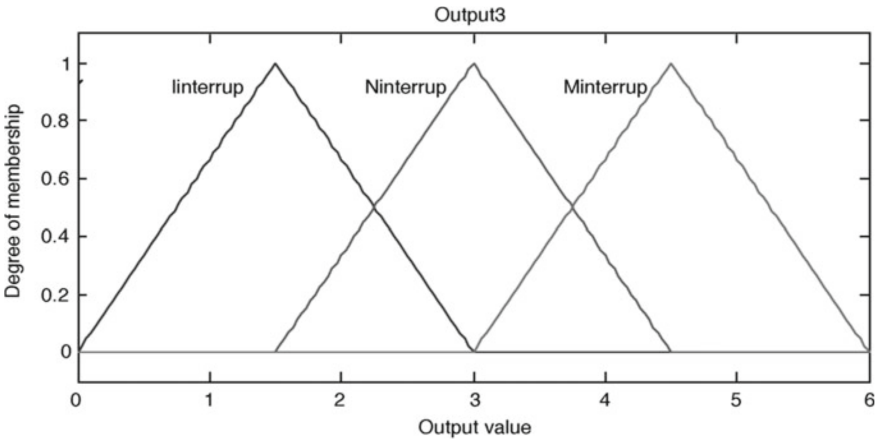


Fig. 10 Output3 membership function

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 (Swell 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 interrupt). etc.

4 Conclusion

During the contingency analysis of an electrical power system, the variation in the level of voltage and current are the two important issues that affects the reliability a lot. In this paper, a fuzzy logic-based system is developed so as to analyze such types of disturbances like sag, swell, transient signal, etc. If such types of disturbances are detected and corrected, the reliability of existing power system network will increase automatically. Five fuzzy inputs and three outputs are used with If-Then rules in the fuzzy inference system (FIS). In this, a technique based on FFT with RMS average method is used to describe the features of many kinds of disturbances. The disturbances in the voltage are applied to the proposed fuzzy system to test the accuracy, sag, swell, and other disturbances. Hence, better results are obtained with the proposed fuzzy-based expert system that confirms the power quality progress and makes the power system reliable.

References

1. “Power quality issues standards &guide lines”, IEEE, Vol 32, May 96
2. Ebron S, Lubkeman D, White M (1990) A neural network power distribution feeders. IEEE Trans Power Deliver 5(2):905–914
3. Sultan AF, Swift GW, Fedirchu DJ (1992) Detection of high impedance arcing faults using a multi-layer perceptron. IEEE Trans Power Delivery 7(4):1871–1877
4. Amouzad Mahdiraji, G, Mohamed A (2006) A fuzzy-expert system for classification of Short duration voltage disturbances, Jurnal Teknologi, 45(D) Dis. 2006: 41–57, © Universiti Teknologi Malaysia
5. Liao Y, Lee JB (2004) A Fuzzy-expert system for classifying power quality disturbances. J Elect Power Energy Syst 26:199–205
6. Classification of Power Disturbances using Fuzzy LogicBoris Bizjak, Peter Planins University of Maribor - FERI, Smetanova 17, Maribor, SI - 2000, Slovenia Giang Z.L., 2004
7. Gaouda AM, Kanoun SH, Salama MMA, Chikhani AY (2002) Pattern recognition application for power system disturbance classification. IEEE Trans Power Deliver 17:677–683
8. Dash PK, Mishra S, Salama MMA, Liew AC (2000) Classification of power system disturbances using a fuzzy expert system and a Fourier linear combiner. IEEE Trans Power Deliver 15:472–477