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Conventional Energy Signature Analysis of Power System Condition

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Abstract—ConventionalPower system condition is a complex research issue from the point of view of connectivity and multi parameter effect. Events in power system have peculiar signature in terms of one or more transforms. Hybrid approach of analyzing are modernized efforts to have more concrete decision making as far as intelligent tripping is concerned. Features of Fuzzy Logic when augmented by wavelet prove more beneficial to analyse composite events and clarity. Human rules, linguistic sense make it easy to design and formulate various conditions observed in power system. This paper highlights integrated signature analysis of voltage and current with the help of hybrid fuzzy wavelet based diagnostic technique.Regular monitoring of wavelet coefficients of current, voltage and power signatures along with their degree of severity reveal advanced health of interconnected power system. This paper proposes Integrated approach of Signature analysis of current for determination of health of power system. This method is popular for transformer, motors but rarely cited for power system due to variability of connection and no unified approach. Results obtained are good estimate for selective discrimination between degree of voltage and current unbalances existing in power system.

***Keywords*—**CSA (current Signature Analysis), FIS (Fuzzy Inference System), DWT (Discrete Wavelet Transform), CWT (Continuous Wavelet Transform).

I INTRODUCTION

FAULT classification in power system is a topic of interest for several years and as a result of this a number of hybrid and individual fault classification techniques have been developed by different researchers from time to time. Some of the important fault classification techniques are: (i) wavelet transform based techniques [1–6], (ii) neural network based techniques [7–14] and (iii) fuzzy and fuzzy-neural network based techniques [15–18]. These intelligent techniques are effective over wide variations in the operating conditions and hence are widely accepted for condition monitoring of power system. The techniques based on wavelet transform are computationally complicated and the techniques based on neural network involve a tedious training process. The fuzzy logic based fault classification approaches involve some linguistic rules only [19] and as such are simpler than the wavelet transform based techniques or the neural network based techniques.

Ferrero et al. [15] proposed a fuzzy logic based approach for identifying the type of fault (whether l-g or l-l-g). Wang et al. [16] proposed an improved method based on fuzzy-neural network approach to determine whether the fault is of l-g, l-l or l-l-g type. As a further improvement, Dash et al. [17] proposed a fuzzy-neural network based method and Das et al. [18] proposed a fuzzy logic based method for fault classification. Both of these approaches can identify all ten types of short circuit faults.

In this paper, an alternative fuzzy wavelet based integrated signature based fault classification approach for transmission line protection has been proposed. Samples of three phase currents at one end of transmission line are required to be considered for fault classification by the proposed approach.

To validate the proposed approach, extensive simulation studies have been carried out using Fuzzy Rules and MATLAB Simulink Models for different types of fault considering wide variations in fault location, fault inception angle, load angle and fault resistance.

In recent years, researchers have developed powerful wavelettechniques for the multi-scale representation and analysis ofsignals. Wavelets localize the information in the time-frequencyplane. One of the areas where these properties have been appliedis power engineering. Due to the wide variety of signals andproblems encountered in power engineering, there are variousapplications of wavelet transform. Another important aspect ofpower disturbance signals is the fact that the information ofinterest is often a combination of features that are well localizedtemporally or spatially such as power system transients. This requires the use of analysis methods sufficiently, which are versatile to handle signals in terms of their time-frequency localization. The power system transients caused by disturbances have vital information embedded.

The main advantage of WT over STFT (Short Time-Fourier Transform) is that the size of analysis window varies in proportion to the frequency. Fourier techniques cannot simultaneously achievegood localization in both time and frequency for a signal. Mostpower signals of interest include a combination of impulse-likeevents such as spikes and transients for which STFT and other conventional time-frequency methods are much less suited for analysis.

WT can hence offer a better compromise in terms oflocalization.The wavelet transform decomposes transients into a series ofwaveletsubcomponents, each of which corresponds to a specific timedomain signal that covers a specific octave frequency bandcontaining more detailed information. Such wavelet componentsappear to be useful for detecting, discrimination and classifying thesources of transients. Therefore the wavelet transform is feasibleand practical for analyzing power system transients.

Fuzzy logic technology has achieved impressive success in diverse engineering applications ranging from mass market consumer products to sophisticated decision and control problems [22]. Applications within power systems are

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extensive with more than 100 archival publications in a recent survey [23,24].
Several of these applications have found their way into practice and fuzzy logic methods are becoming another important approach for practicing engineers to consider.
In 1965, L.A. Zadeh laid the foundations of fuzzy set theory [25] as a method to deal withpractical systems. Bellman and Zadeh write: "Much of the decision-making in the real world takes place in an environment in which goals, constraints and the consequences of possible actions are not known correctly" [26]. This is the core of fuzzy sets or fuzzy logic applications. Fuzzy sets were formulated as a generalization of conventional set theory. Partially as result of this fact, fuzzy logic remained the purview of highly specialized and mathematical technical journals for many years. This changed abruptly with the highly visible success of several control applications in the late 1980s.

Fuzzy logic has two different meanings. In a narrow sense, it is a logical system, which is an extension of multi valued logic. However, in a wider sense it is almost synonymous with the theory of fuzzy sets, a theory which relates to object classes with not so sharp boundaries in which membership is a matter of degree. Hence, fuzzy logic in this sense is a branch of FL. Even in its more precise definition, fuzzy logic differs both in concept and substance from traditional multi valued logical systems.

II POWER SYSTEM TRANSIENTS

Electric utilities often face the problem of finding the exact location of a fault in a power system. These faults often occur at the worst possible time and cause the maximum amount of inconvenience to the utility's customers. Most fault identification or location techniques today require the judgment of skilled operators can also produce less than desired results for rapid fault location and thus may inflict additional damage to the cable. When a fault occurs in a power system, there are specific relationships between fault voltage, fault current, the resulting fault impedance and location. Thus, fuzzy logic which is an effective way to map an input space to an output space and it can be employed in fault location as an efficient, economic and adaptable method (compared with other artificial intelligence systems) by simply representing the aforementioned specific relationships as 'if-then' rules combined with a set of common-sense rules. This paper highlights the results of investigations into a new fault location technique using advanced signal processing technique based on wavelet technology to extract useful information and this is then applied to fuzzy logic in order to identify and locate the disturbances in a power system comprising of several fault conditions, through pattern recognition.

Health of Power System depends on at least a dozen key features of the electrical supply including frequency and voltage variations, but the most crucial factor is waveform distortion or harmonic content. Harmonic in voltages can cause malfunctions in critical equipment, such as the sensing circuits of circuit breakers and UPS, while harmonic current can result in overheating of conductors, transformers, motors coils and capacitors. These are potentially disastrous and cases of building supply failure and supply related fires are increasing.

Switching phenomena in Power Systems are over-voltages, over-currents and electrical fields, which haven't to neglect.

Over-voltages are one the most significant problems in thepower distribution system. Lightning over-voltages are one of the most probable over-voltages that are caused due to the direct strike of the lightning to the overhead contact system. Switching over-voltages due to the switching phenomena in the substations are also another major source of overvoltage generation in these systems. These over-voltages can be dangerous for the electrical equipment of the power system if not controlled and reduced effectively. Faults, energisation, auto-reclosure, power swings and many more is endless list of disturbance or transients in power system each with peculiar feature in terms of time or frequency.

IIIANALYSIS OF TRANSIENTS BYFUZZY LOGIC BASED RULES

When Aristotle and his predecessors devised their theories of logic and mathematics, they introduced Law of the Excluded Middle, which says that every proposition must either be true or false. For instance, grass is either green or not green; it clearly cannot be both green and not green. But not everyone agreed, and further Plato indicated there was a third region, beyond true and false, where these opposites "tumbledabout."
In the Aristotelian world view, logic dealt with two values. In the 19th century, George Boole formulated a system of algebra and set theory that could deal mathematically with such two-valued logic, true and false to 1 and 0, respectively. Then in early 20th century, Jan Lukasiewicz came with a three-valued logic (true, possible, false), which never gained wide acceptance. In 1965, Lotfi A. Zadeh of the University of California at Berkeley published "Fuzzy Sets," which laid out the mathematics of fuzzy set theory and, by extension, fuzzy logic. He observed that conventional computer logic couldn't manipulate data that represented subjective or vague ideas, so he created fuzzy logic to allow computers to determine the difference among data with different shades of gray.
Although, the technology was from U.S., U.S. and European scientist largely ignored it for years, perhaps because of its vague unconventional name. They refused to take it seriously something that sounded so childlike. Some researchers argued that fuzzy logic was merely probability in disguise. But fuzzy logic is widely accepted in countries like China, Japan.
Fuzzy logic has also been used to diagnose the health of a power system and foresee any developing failures. Fuzzy logic has been used to smooth out some of the problems that can appear when using the cut and dry rules of expert system knowledge. By forming fuzzy membership functions for the different measurements, it is possible to overlap the individual membership functions into one large fuzzy matrix that can be used for diagnosis. From the point of view of human–machine cooperation, it is desirable that faults classification process would be

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Interpretable by humans in such a way that expert could be able to evaluate easily the classifier solution. Another interest of an intelligent interface lies in the implementation of such a system in a control room. Operators have to be informed very quickly if a fault is occurring. They have to understand what exactly the process situation is, in order to make the right counteraction if possible or to stop the system if necessary.

A. Fuzzy based Membership Function

The membership function of a fuzzy set is a generalization of the degree of certainty in sets. In fuzzy logic, they represent the degree of truth as an extension of valuation of a variable. Degrees of truth are often confused with the concept of probability, although they are conceptually distinct, because fuzzy truth represents membership in confusing/vaguely defined sets. Membership functions were introduced by Zadeh in the paper on fuzzy sets (1965). A linguistic variable represents fuzzy space which is essentially a fuzzy set derived from the evaluation of the linguistic variable. A linguistic variable has the properties of approximate or imprecise concepts in a systematic and computationally useful way.

B. Fuzzy based Rules

Following are certain rules used for simulation. The fault protection according to power system condition computes a delay time corresponding to different fault types and fault strengths. This delay time can be given to the relay to mechanically adjust the tripping time of the relay.

I TABLE: Rule Base

RULE BASE 2

S. no.	Voltage Unbalance	Low Voltage	Current Unbalance	Out
1	VUL	LVH	CUL	VS
2	VUL	LVL	CUM	VL
3	VUM	LVM	CUL	N
4	VUL	-	CUL	VL
5	VUL	-	CUM	LN
6	VUH	LVM	-	S
7	VUEH	LVEH	CUEH	EL
8	VUEH	-	-	EL
9	-	LVEH	-	EL

VUL Voltage Unbalance Low
VUM Voltage Unbalance Medium
VUH Voltage Unbalance High
VUEH Voltage Unbalance Extremely High
LVH Low Voltage High
LVL Low Voltage Low
LVM Low Voltage Medium
LVEH Low Voltage Extremely High
CUL Current Unbalance Low
CUM Current Unbalance Medium
CUEHCurrent Unbalance Extremely High
VS Very Short
VL Very Long
N Normal
LN Long
S Short
EL Extremely Low

IV SYSTEM STUDY AND RESULTS

A simple power system network, shown in Fig.4 consisting of a generator 13.8 kV, 100 MW, a local load of 10 MW and remote load of 80 MW along with 10 km and 90 km line sections along with 13.8 kV/ 400 kV step up and step down transformer was used for the simulation purpose.

The transient disturbance generated due to fault is decomposed by wavelet transform into Approximate and Detail Coefficients. The decomposition of the signal into these detail coefficients and approximations are carried out until the fundamental frequency signal (50Hz) is obtained as the approximation at that level. The detail coefficient obtained at the final level is characteristic for each type of simple power system fault.

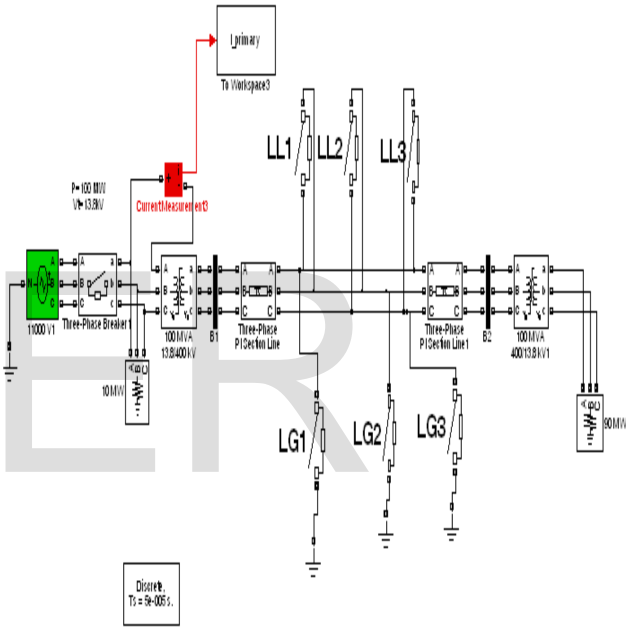

Figure 1.A simple power system MATLAB SIMULINK SIMPOWERSYSTEM MODEL considered for analysis

Faults were created at a distance of 10kms from both the buses. Different types of faults were simulated using MATLAB package. Different types of faults were created and the transients were recorded for analysis. Simulation is carried out for eleven types of Faults i.e. AG, BG, CG, AB, BC, CA, ABG, BCG, CAG, ABCG, ABC. Only SIGNATURE of Phase-A current was tracked and its wavelet coefficients along with energy were computed and fed to following Rule Based System. The tabulated Results and Graph are as follows.

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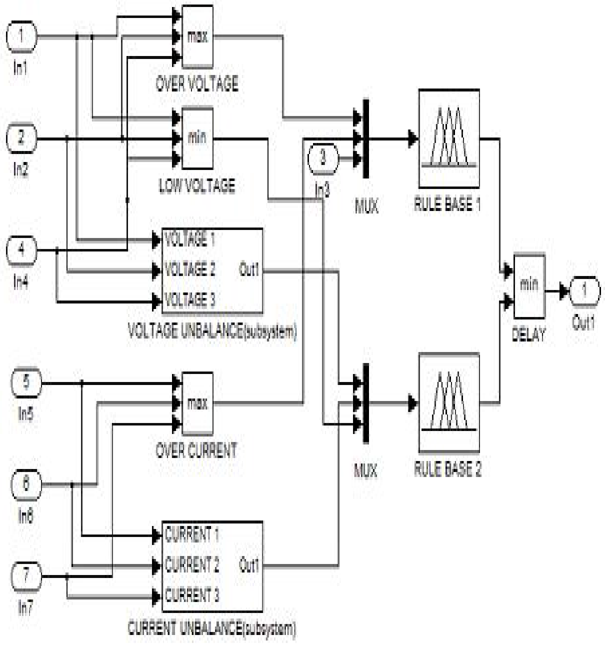

Name	***Signal Type***
In1	***DWT Coefficients for Phase A Voltage***
In2	***DWT Coefficients for Phase B Voltage***
In3	***Threshold Value Set by user***
In4	***DWT Coefficients for Phase C Voltage***
In5	***DWT Coefficients for Phase A Current***
In6	***DWT Coefficients for Phase B Current***
In7	***DWT Coefficients for Phase C Current***

Figure 2.FuzzyWavelet based diagnosis of power system of voltage and current related conditions

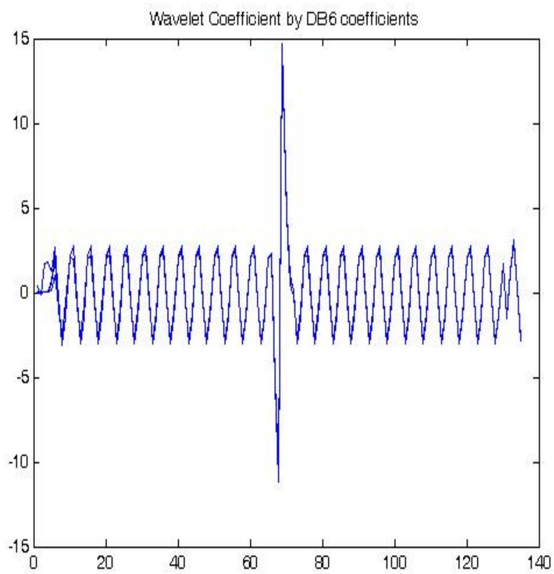

Figure 3.AG(Type) Low(Fuzzy Linguistic) Current Coefficients(Wavelet**)**

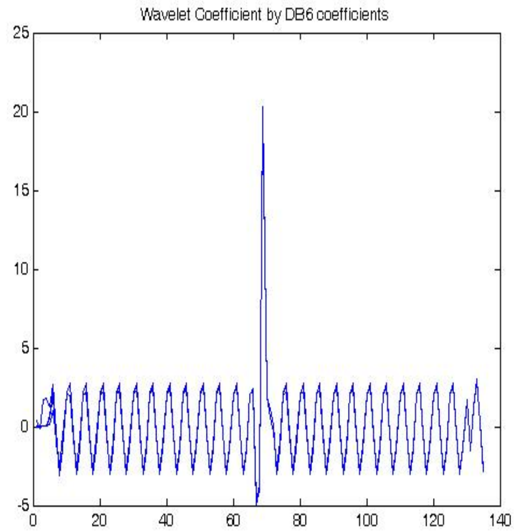

Figure 4**.**AG(Type) Medium(Fuzzy Linguistic) Current Coefficients(Wavelet)

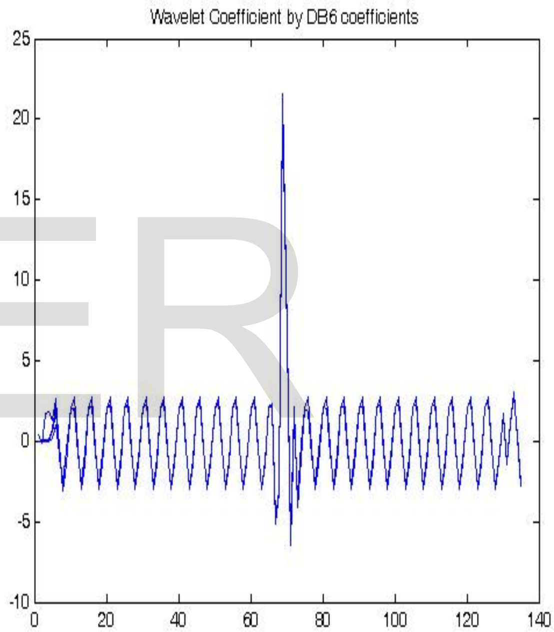

Figure 5.AG(Type) High(Fuzzy Linguistic) Current Coefficients(Wavelet)

These results show sudden change in the values of detail coefficients at the time of fault or disturbance and the severity by their peak value as well. Combined Fuzzy-Wavelet have strong discriminative power for different disturbances or faults. This is evident from collected signatures. The timing and severity helps in diagnosing the fault type. In case of similar coefficients for different fault events, work is extended to multi level feature extraction as well.

A single methodology of all possible signature is sufficient to widely cover transient, dynamic performance of various current situations. Switching surges and lightning surges also can be selectively discriminated by this method.

Due to lack of "time" related information in other feature extraction transforms, wavelet has sufficiently proven to be the best for the instant of disturbance till date. If backed with fuzzy it becomes more robust to analyse different conditions of power system.

VCONCLUSION AND FUTURE SCOPE

The application of integrated fuzzy-wavelet domain to determine the integrated power system signature is investigated here. Fuzzy rules can discriminate between different conditions of power system under ambiguity, while wavelet domain can detect time-frequency aspect. For multiple faults, composite faults hybrid application of both domains will be more useful and will be a double layer analysis of power system condition.

In the past ten years, wavelet theory and applications have made great strides in fields outside thepower engineering area, such as signal and image processing also fuzzy has been successful in revealing ambiguous state of power system. Hence firm decision during confusing condition of power system is a challenging task. The effort in this combined way is very recent and seems to be moving in two main directions. One is concerned with theaccurate identification and classification of transients. The other is more concerned with theoverlapping states of power system well understood by fuzzy logic.

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