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Fault detection and localization of symmetrical fault using PCA and WT

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Abstract: Power system is one of the most complicated interconnected systems from the generation to the distribution ends due to its multi-constraint operation and control. Maintaining the integrity of power system is imperative for the effective operation of interconnected power systems. Power system is always risk to get subjected to major and minor perturbations due to unavoidable situations and their impact on the system depends significantly on the nature of disturbance and its localization. Although, conventional protective devices interrupt the faulty section of the power system but are not efficient in detecting the exact location of the fault, especially in the case of transmission lines. Consequently, it requires a long time in manual identification of the fault location. Smart protection schemes based on efficient algorithms for the identification of the faulted bus and its time localization can curtail the supply storage time of the faulted section effectively. In this paper, one of the severe disturbance i.e. three phase bolted fault is applied on different buses of standard IEEE 39 bus system to acquire the bus voltage data. "Principal Component Analysis" (PCA) & "Wavelet Transform" (WT) techniques are applied on the stored data for the detection of faulted bus and to highlight the instant of fault occurrence respectively. The results of the analysis show that these techniques serve as useful tools in detecting the abnormalities in the operation of power system and to morph the existing protection schemes into an intelligent and smart protection scheme.

Keywords: Principal Component Analysis, Wavelet Transform, Bolted bus fault.

I. INTRODUCTION

Power System is one of the most complex man made system. It has emerged revolutionary with the passage of time but has raised many questions and challenges to the power system engineers and analysts. Operating the power system in desirable limits is the major challenge for them. There are many dimensions which act as challenge such as growth in electricity demand, overloading of transformers and transmission lines, the aging of utility infrastructure, integration of renewable energy sources via different technologies, high voltage interconnections between AC and DC networks for bulk power supply, stability and others[1-3].

Many contingencies that occurred in the past have brought the attention of the engineers and scientist to find out better solutions to tackle such problems. In order to identify the problems quickly, smart gadgets and devices have been introduced and fast protection algorithms have been developed like SCADA, PMU and others which make use of effective real time data[4]. Importance and effectiveness of fast algorithms in instantaneous detection and decision making can be in reference[5, 6]. Modern tools in technology have helped the system to become more reliable and efficient. Dedicated relays have been developed in the domain of power system protection which can work effectively in detecting different scenarios of power system.

In monitoring the Power System there will be huge amount of data in multiple dimensions. There are various signals that can be obtained from various locations in the network including voltages, currents, frequency and others. With the careful monitoring and analysis of data of above mentioned parameters we can refer the state of the system.

A new fault detection algorithm based on two techniques i.e. PCA and DWT is proposed in this paper. The idea behind this algorithm is to utilize statistical tool "Principal Component Analysis" and frequency localization tool "Wavelet Transform" in the detection of fault and finding the instant of the three phase bolted fault at bus. These techniques can serve as efficient tool on handling sampled data of various parameters of power system. The standard IEEE 39 bus system (as shown in Fig. 1) is used as the analysis network at PSSE and test results of above mentioned tools on various buses have been presented in this paper.

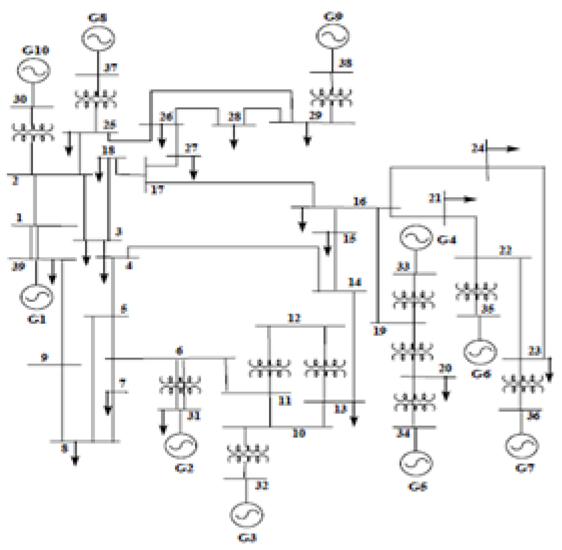

Figure 1: IEEE 39 bus system single line diagram

The summary of the work presented in this paper is:

1. Three phase fault creation at various buses to obtain 39 buses voltage data in matrix form.
2. Detection of faulty bus using PCA.
3. Time localization of the fault on faulty bus using WT.

II. LITERATURE REVIEW

Power system bus faults are usually detected by means of differential voltage and current schemes which makes use of current imbalance technique in general. This method usually suffers when connected CTs step into the saturation mode and produce erroneous results. Voltage as the detection parameter provides better solution to the problem and makes use of linear couplers[7]. Today power systems have become more digitalized and use of discrete signals has become important part from communication to the relay coordination and fault detections. Wavelets provide significant and potential methodologies for the fault detection in power system in both continuous and discrete form of signals and have been discussed in [8, 9] and in many others. Different intelligent techniques including PNN, Fuzzy logic and estimation tools have provided effective support to the wavelet applications in power system[7, 10]. Uses of variety of mother wavelets on real time data have been presented in different articles depending upon the transient nature. This algorithm in this paper provides rapid algorithm for offline detection of fault in a large power system and make use of Principal Component Analysis and Wavelet Transform.

A. Principal Component Analysis

PCA is a statistical technique that is used in many research areas. It resembles to the regression analysis which finds the line of best fit for the given data by minimizing the sum of squared distances but here the distances calculated are perpendicular to the obtained lines[11]. The purpose of using this technique is to analyze the data in terms of less number of variables than the one present in the original set of data. Thus, it makes the data analysis efficient. It may happen in the data collected for variety of features that they are separately representing the same information present in the data. In this way, by combinely representing them into new dimension will be an effective representation and it will be easy to analyze and interpretable. Purpose of principal component analysis is to find the variation in the data. And for the analyst it is important to find those variables in which the more information patterned is stored rather to keep working with the redundant variables[12].

If the data has the ‘x’ number of original variables which are highly correlated then we can reduce them into ‘y’ numbers of independent and uncorrelated variables where (y<x). This shows that the data dimensions will reduce. These new variables in data set ‘y’ are actually the principal components (PC) of the data and are calculated in the following way as shown in the Eq. (1).

$$\begin{bmatrix} y1 \\ y2 \\ \vdots \\ yn \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ \vdots \\ xn \end{bmatrix} \tag{1}$$

The values in the coefficient matrix having ‘a’s’ are the weightages of the original variables in determining the overall principal components. Principal components are determined to maximize the variation of the data and the squared sum of these weightages equals to one as shown in Eq. (2) ~ (4).

$$a_{11}^2 + a_{12}^2 + \cdots + a_{1n}^2 = 1 \tag{2}$$
$$a_{21}^2 + a_{22}^2 + \cdots + a_{2n}^2 = 1 \tag{3}$$

And so on up to,

$$a_{n1}^2 + a_{n2}^2 + \cdots + a_{nn}^2 = 1 \tag{4}$$

Analysis of PCA generates a covariance matrix and mathematical analysis provides Eigen vectors which are the PCs of this matrix along with the corresponding Eigen values. The selection to retain the number of PCs depends on how much information you want to retain in the transformed form of data[11]. The properties and analysis steps of principal components analysis are discussed in detail in reference[11-13]. Graphical representation of PCA is shown in Fig.2 in which P_1 and P_2 represents two principal components of the random data and serves as the line of best fit in the given data. Plotting the data using principal components is a matter of choice and it can be a 2,3 or n dimensional space.

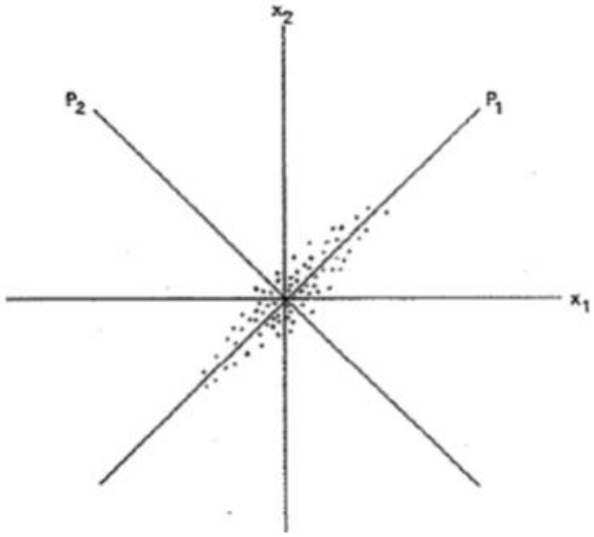

Figure 2: Graphical representation of PCA[11]

In this analysis, the first two PCs have been selected as they were found to retain much of the information and the results have been plotted 2-dimensions in the later section of simulated results.

B. Wavelet Transform

Wavelet transform (WT) is fast emerging and well recognized tool in the field of engineering. It is defined as the "Short duration wave like oscillation which is localized in the sense that it grows form zero, reaches its maximum and then decrease back to zero amplitude again" [14]. It is special type of time-frequency transform which provide certain edge and remarkable advantages over the other analysis of same domain like Fourier series analysis, Fourier transform, short time or window Fourier transform and others. The idea behind the wavelet transform is to better localize the disturbance in time and also to clearly identify the instant of occurrence of different frequencies in it. There are many areas in which this tool is extensively used nowadays such as signal analysis, image analysis, acoustics, radar, human vision, earthquake prediction, optics, magnetic resonance imaging and many other applied field of science[15, 16].

Wavelet Analysis makes use of certain features like multiple basis functions, levels of the basis functions and variable window size. Basis function is used as fundamental feature in approximation analysis of a signal like sine and cosine in Fourier analysis. In WT, there are multiple basis functions "Mother Wavelets" of various shapes and sizes like Meyer, Mexican, Morlet, Gauss, Haar and others. Their selection is an important step in approximating the signal. The details of the fundamental and scaled shapes of mother wavelets are presented in [9, 14, 15, 17].

In reference[8], it is concluded that the basis function whose shape matches the power system disturbance provides better approximation of the signal. This is because fewer components will be require for the approximation and will be computationally efficient too. Therefore, wavelet analysis is serving as the fast growing tool in time frequency analysis of non-periodic rapidly varying signals such as power system transients due to lightning, transformer inrush currents and switching transients and others[9].

One of the fundamental concepts used by WT is that it sets a compromise between time and frequency but do not violate Heisenberg Uncertainty principle. The principle states that it is impossible to sharply localize the signal in both time domain and frequency domain simultaneously i.e. by looking at time domain one losses the frequency resolution and vice versa. It helps in localizing the occurrence of a particular frequency in time domain by making use of variable and scaled windows as shown in Fig.3[18].

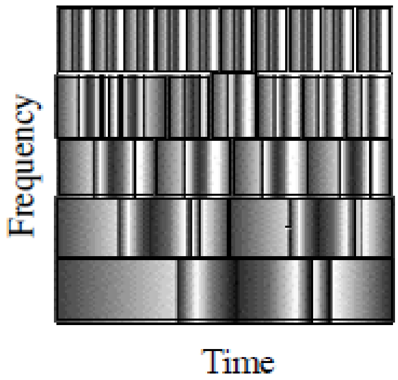

Figure 3: Window size variation in Wavelet Analysis[18]

WT can be used as continuous wavelet transforms (CWT) or discrete wavelet transforms (DWT). In this paper, the data was of discrete nature therefore, discrete form is used. DWT is characterized by the equation (5):

$$DWT = ao^{-m/2} \int_{-\infty}^{\infty} f(n)\psi(ao^{-m}t - nbo)dt \tag{5}$$

Where,
f (n) = discrete signal to analyze
ψ= basis function
a = scaling factor
b = translation factor
m = wavelet width

In this work, faulty bus data after detection from PCA analysis was sent as input to the DWT analysis and HAAR wavelet was selected as the three phase fault matches the shape of this mother wavelet. Results have been plotted in the later section of simulated results.

III. SIMULATED RESULTS

The results are presented for the three phase fault at bus1and 34 only. Simulated results are in the sequence of bus voltages during fault, PCA analysis of the whole data (circle highlighting the contribution of bus in first principal component) and wavelet analysis output for the fault localization at the faulty bus. Similar results can be obtained for the other buses.

A. Fault at bus 1

In Fig. 4, the plot of the voltage data of 39 buses when fault at bus 1 occurs during the time instant of 1 to 1.2 second is plotted in the complete simulation of 2 seconds.

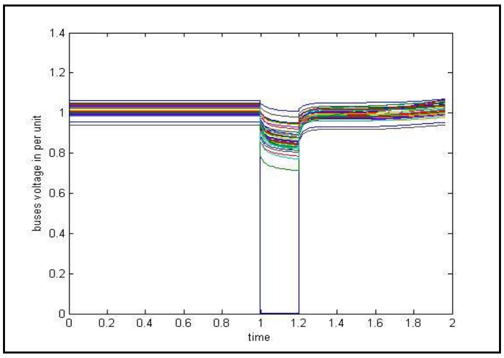

Figure 4: 39 bus voltages data including fault at bus 1

The above diagram clearly presents that the voltage variation is maximum in the faulty bus 1 data. Therefore it should contribute maximum in the creation of first principal component. This idea is depicted in Fig.5 representing the PCA result in which the maximum value weightage of bus 1 can be clearly seen.

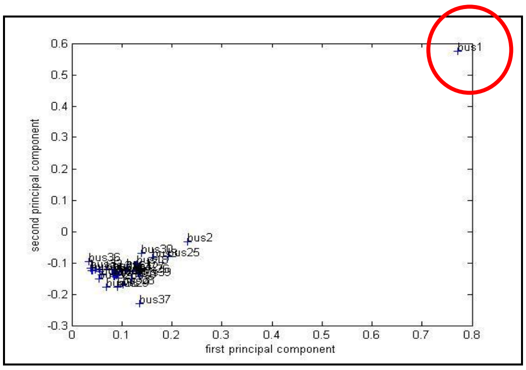

Figure 5: PCA result of fault at bus 1

Now after the detection of the faulty bus i.e. bus 1, its voltage data is provided as input to DWT and the time instant of the fault occurrence is identified. Fig.6 represents this information in the form of sharp spikes at point of discontinuities in the voltage data of the bus in detailed component while the identity of the signal is preserved by the approximate coefficient of DWT.

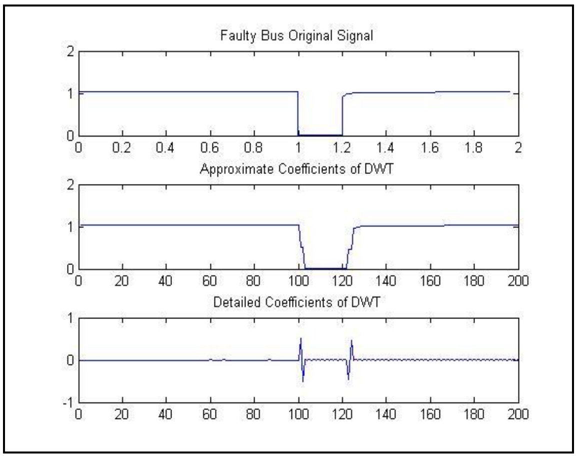

Figure 6: DWT result of fault at Bus 1

B. Fault at bus 34

In Fig. 7, the plot of the voltage data of 39 buses when fault at bus 34 occurs during the time instant of 1 to 1.2 second is plotted in the complete simulation of 5 seconds.

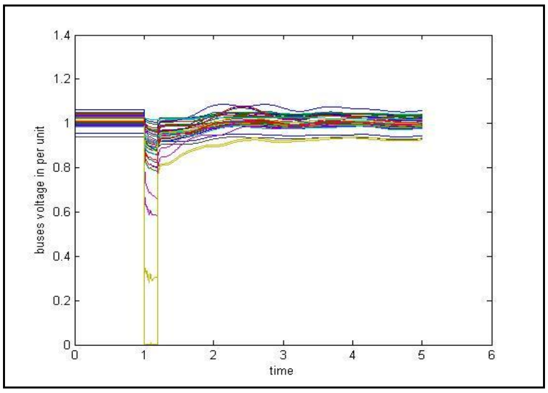

Figure 7: 39 bus voltages including fault at bus 34

The above diagram clearly presents that the voltage variation is maximum in the faulty bus 34 data. Therefore it should contribute maximum in the creation of first principal component. This idea is depicted in Fig.8 representing the PCA result in which the maximum value weightage of bus 34 can be clearly seen.

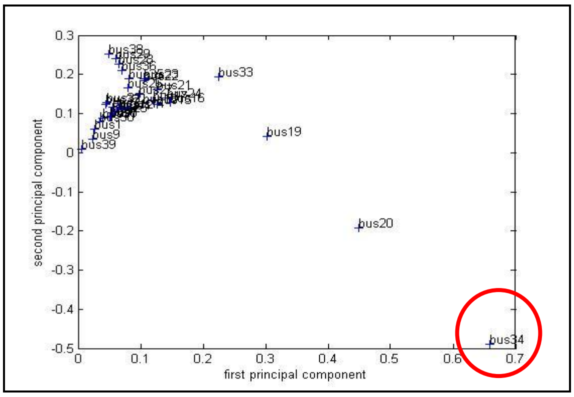

Figure 8: PCA result of fault at bus 34

Now after the detection of the faulty bus i.e. bus 34, its voltage data is provided as input to DWT and the time instant of the fault occurrence is identified. Fig.9 represents this information in the form of sharp spikes at point of discontinuities in the voltage data of the bus in detailed component while the identity of the signal is preserved by the approximate coefficient of DWT.

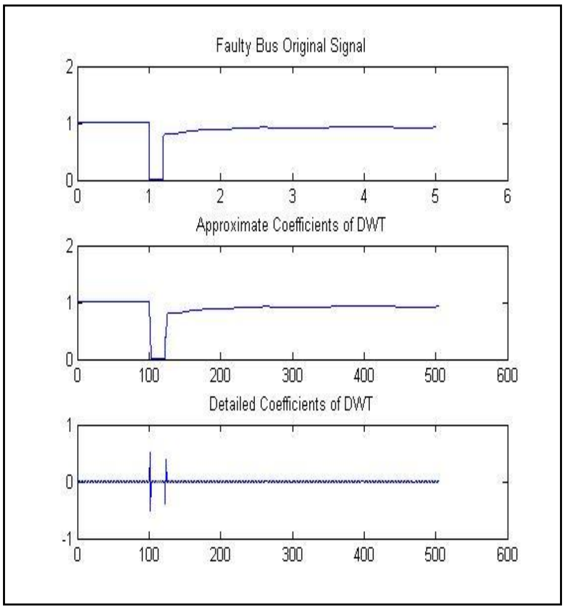

Figure 9: DWT result of fault at Bus 34

V. CONCLUSION

In this paper, the tasks of detecting the faulty bus and identifying the time instant of the fault occurrence were identified. The statistical tools of “Principal Component Analysis” and “Wavelet Transform” have been found successful in achieving the above mentioned tasks.

VI. FUTURE SCOPE

In the modern trends of Power System, there is need of comprehensive protection systems and for this we need such tools that can identify the system state rapidly and make the decisions according to the intelligence provided with them. PCA and DWT can serve as useful tools in detecting the abnormalities in the operation of system. The disturbances that cause severe impact on the system are usually of rapid transient nature and DWT serves as quick algorithm to detect these faults.

Although, the study carried out in this paper was focused on the three phase bolted fault but such conditions are rare to occur practically in Power System. Therefore, need is to focus on the frequently occurring faults like single line to ground, line to line and double line to ground faults and to develop algorithms for fast detection and protection of Power System from such conditions. Future work needs to incorporate with the techniques having some decision making tools to make the power system reliable and protected. The work presented in this paper can serve as the basis and step towards more practical approach of detecting unsymmetrical faults in an efficient way in a dedicated environment of computation.

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