TECHNIQUES TO DETECT CHANGES IN POWER GRID USING SYNCHROPHASOR DATA

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Abstract : PMUs have gained importance in the field of smart grids because they transmit high resolution (40-250 samples/sec) synchrophasor data which help the grid operators visualise the real time state of the grid. Synchrophasors are time tagged voltage and current phasors. PMU data has helped in the Wide Area monitoring of the power grid which was not possible with earlier systems. Data arrives to a Phase Data Concentrator (PDC) in the form of a stream and it has to be analysed to make appropriate decisions for controlling the state of the grid. But analysing the data streams from various PMUs is a cumbersome task as the data size may be huge and the processing algorithm needs to be competent with the rate at which data is being obtained. Stream Data Mining concepts can be used for achieving the required performance parameters. This paper tests the weighted average algorithm for processing a data stream being sent by PMU on MATLAB.

Keywords: Data stream, PMU, Synchrophasor

1. INTRODUCTION

Power Grids are conventionally monitored using Supervisory Control and Data Acquisition (SCADA) systems. But this system suffers from drawbacks. SCADA systems provide data at 2-5 samples per second and are affected by time skew. State estimation techniques have to be used to in order to determine the state of the power grid which is a time consuming process .Important events may go unnoticed due to the time lag. These problems have been solved by deploying Phasor Measurement Units. PMUs measure power system quantities like voltage and current as complex phasors. These PMUs have a GPS module embedded in them which is synchronised with the UTC with an accuracy of 1μs. The phasor data transmitted by PMUs are time tagged with the UTC time. Therefore, these phasors are known as synchrophasors. 40-250 synchrophasors are sent by each PMU every second to a Phase Data Concentrator which arranges the data according to their time stamp. Since all the PMUs are synchronised with the UTC and data is being updated at a very high rate, state of the grid can be directly visualised without the need of state estimation. While this high resolution data can prove to be a critical tool for the real time monitoring of the grid, the amount of data that needs to be processed simultaneously increases drastically. Such data cannot be mined using simple methods because it needs to be processed immediately and cannot be stored owing to its size. Algorithms that process this data need to be competent enough with the rate of arrival of the data else the whole point of installing PMUs is lost. Stream Data Mining techniques combined with statistical analysis can be used to extract important information. In this paper, we discuss two methods which can be used for analysis of synchrophasor data streams. The first half of the paper deals with change point analysis while the second half discusses weighted average analysis. The latter algorithm was run on MATLAB and the experimental results have been discussed.

2. CHANGE POINT ANALYSIS:

A change point at a time T_j in a sequence of ordered data $z_{1:n} = (z_1, z_2\ldots,z_n)$ is a point which divides the data set into two subsets $\{z_1, z_2...z_j\}$ and $\{z_{j+1}\ldots z_n)\}$ which have different statistical properties. This algorithm can be applied to a time ordered set. Therefore, it seems apt to use it on a stream of synchrophasor data so that any abrupt changes in a grid. The confidence in the change can also be computed. So, depending on the magnitude of change detected and the confidence in the change, appropriate control action can be taken to stabilise the grid. To detect an event in the power grid which otherwise was functioning normally, we can apply the following sequence of steps:

1 Initialise stream of data X= $\{x_1, x_2\ldots x_i\}$ where xi is the synchrophasor data at ith instant.

2. For j = 1: k (where k is the instant of time)

if $x_j>x_l$ and $x_j<x_u$ (where x_l and x_u are the lower and upper permissible values of the variable x.)

go to step else go to step 3.

3. Initialise data window W = $\{x_{i-n}, x_j\}$ where n = size of window to be considered.

4. Calculate average w of W.

5. Set cumulative sum s_0 to 0;

6. For m = 1 : j

i) Calculate cumulative sum $s_m= s_{m-1} + (x_m – w)$;

ii) Calculate $r_m = s_m- s_{m-1}$;

iii) Calculate $t_m = r_m – r_{m-1}$

if

$t_m < \epsilon$ go to step 6.(i)

else

flag = 1 , go to step 7.

7. Predict confidence in change using bootstrapping algorithm (as follows)

Bootstrapping algorithm:

7.1 Order the elements in data window obtained in step 2 randomly.

7.2 Calculate cumulative sum on the above window.

7.3 Compute the maximum, minimum and difference of cumulative sum on bootstrap window.

7.4. Compute confidence interval as I = $(N_b/N)*100$ where N_b = no of samples in which the difference of cumulative sum on the bootstrap window was less than the difference of cumulative sum on original window and N is the total number of bootstrap windows.

7.5 If $I\geq\alpha$ where α is the threshold, initiate control action.

3. WEIGHTED AVERAGE ANALYSIS:

The data collected by each PMU, even in few minutes, is huge and requires suitable real time algorithms in order to process the incoming data in suitable time and take control actions in case of power system problems. This can be implemented by using Data stream mining which consists of acquiring knowledge from dynamic data by application of algorithms on the rapid data by sliding data windows on which the process is executed time and again.

Data window is a set of data points considered at an instant, required by the algorithm. The algorithm is executed accordingly and data window is shifted by one to the next real time data obtained.

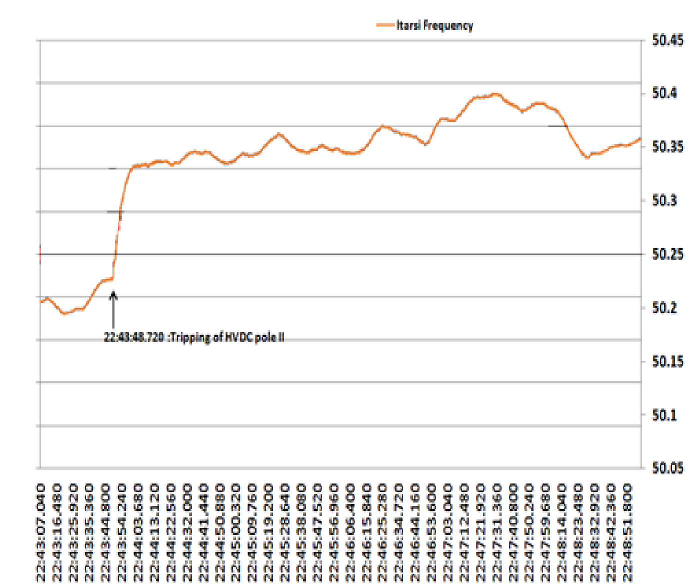
CONCEPT OF WEIGHTED AVERAGE ANALYSIS:

The algorithm given below uses the concept of weighted average – assigning more weight to the data which is more recent with respect to time. In this way the data which is recently recorded will have more contribution in decision making in power grids than the data which was obtained some time before.

Weighted average can more clearly be understood as:
Let number of data points in a data window be 5.
Then, the most recent one can be assigned weight 5, next recent 4 and so on. So, weighted average will be sum of quantities multiplied by the respective weight divided by sum of total weights. As in this case,
weighted average =
$(5*A_5+4*A_4+3*A_3+2*A_2+1*A_1)/15$

To analyse the PMU data stream, we tested the following algorithm: Let the quantity on which algorithm is performed be A. Initialize number of points in data window (n) and number of permissible times (m) process can be repeated when average value exceeds the upper or lower threshold (A_U, A_L). 'm' should be decided based on time span so that difference between temporary and permanent faults can be detected.

1. Initialize first data window.
2. Flag=0.
3. Calculate the weighted average of the data window.
4. If (A_{avg}>A_L && A_{avg}<A_U):
   i) Slide the data window by one.
   ii) Flag = 0
   iii) Repeat the above process.
5. Else:
   i) If (Flag = = m):
      Take control action.
   ii) Else: Flag = Flag +1
   iii) Repeat the above process.



4. EXPERIMENTAL RESULTS FOR WEIGHTED AVERAGE ANALYSIS

This algorithm was tested on MATLAB for a given PMU data set with data given at period of 40 msec, taking n=5 and m=3, and initializing the upper and lower threshold for the quantity tested for.

This algorithm worked with the accuracy of ±560 msec on a system with Intel i5 processor, 4 cores, 4 GB RAM in time approx. 28 msec on a set of data with 8702 data points of rate of change of frequency. The fault was detected at 1058th data point and as fault is detected, it was programmed to break the loop. 30 msec was the time to analyse the fault i.e., 1058 data points which seems efficient. Specific system totally dedicated for data stream analysis for grid stability will definitely have a larger storage and better performance as compared to the system it was tested on. The processing time of the algorithm and efficiency will, thus, be improved. Time delay can be introduced between successive algorithm applications to synchronise it with the incoming real time data.

The above figure shows the tripping of Itarsi at 22:43:48.720 and according to the algorithm tested, the fault was confirmed at 22:49:280 by applying algorithm for rate of change of frequency with upper and lower threshold at 0.01 and -0.01 Hz/sec.

Although the algorithm was tested for rate of change of frequency, it can similarly work for voltage, frequency and other quantities.

Inferring lower and upper threshold from the previous data, the table shows the result of different data set on which algorithm was tested:

Data set	Actual fault time	Fault time from algorithm	Time taken by algorithm (msec)
1. Line Voltage	04:40:49.000	04:40:49.040	6
2. Phase Voltage	04:40:48.920	04:40:49.040	6
3. Frequency	04:40:50.080	04:40:50.480	6

5. CONCLUSION:

This paper elucidated how weighted average scheme can be implemented on real time data of PMUs without large storage requirements. Data can be processed as soon as it is received and fault, if present can be detected by suitable real time algorithms as suggested.

Further extension of the weighted algorithms can be done by operating the algorithms in parallel for different PMU data received by the phase data concentrator. The deviation in any of the quantity (several operating in parallel at the same time) can be suitably detected and control action can be initiated immediately. Algorithm can be generalised by developing techniques in which the lower and upper threshold of the data can be detected by the algorithm itself without the operating having to set the threshold limits.The algorithm can be applied over the data for signals like rate of change of frequency, voltage, frequency, current, angle with an appropriate choice of weights. Care should be taken that this algorithm, if being applied on angle, should use unwrapped angles.

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