The Journal of CPRI,
Vol. 9, No. 3, September. 2013 pp. 399–406

Application of Synchronised Phasor Measurement Technology in Renewable Energy Systems

K Sornalatha*, N Rajkumar*, K Pradeep*, C Viswanatha**, Giridhar P Kini***

This paper throws light on application of synchronised phasor measurement in renewable energy systems. Power generation from renewable energy system connected to the grid is highly dynamic, nonlinear which needs to be monitored continuously for efficient and reliable system. There are various methods of monitoring of power from renewable energy system to grid. Nowadays, Time synchronisedphasormeasuring method proves to be a revolutionary method for power system monitoring. Synchronised PMU has wide application such as wide area monitoring, Real time monitoring, post even analysis, visualization, state estimation etc. They are employed in micro grid and distributed generation plants mainly for solving islanding issues. This paper summarises the synchrophasor application and its future scope in renewable energy system.

Keywords: *Phasor measurement unit (PMU), synchrophasor, real-time monitoring, state estimation, islanding*

1.0 INTRODUCTION

Synchrophasor has a history of only 30- 40 years in the world power system dynamics. The catastrophic failure in the power grid in the United States let to the invention of PMU and synchrophasor. To operate the power system economically, efficiently and reliably, the existing conditions and its value have to be monitoring and measured accurately to avoid any major mishap [1]. Time synchronized measurement proves to be a revolutionary method. The first prototype model of PMU was invented by Arun G. Phadke and James S. Thorp at Virginia State University in the year 1988 to monitor the state power system. They utilised the concept of Global positioning system (GPS) for simultaneous monitoring of data from various PMU placed in different locations on a power system network to observe the data at the same time domain. The first synchrophasor standard IEEE 1344 was established in the year 1995. It set the basic concepts for measurement [2-4]. Phasors can be measured using commercially available phasor measurement units (PMU) located at multi points in the substations or generation station which needs to be monitored. All the PMUs are synchronized by global positioning system (GPS) clock for simultaneous measurements. The data is then transferred to a phasor data center. These are referred to as “synchrophasors”. Once synchrophasor data is collected it is transferred to a user’s computer equipped with a software visualization application that creates a graphical representation of the data. It is then evaluated for improving their situational awareness of interconnected power systems. PMU measurements are usually taken at 30 observations per second[5,10,12]. It can provide precision in phase angle measurement upto 1μs error. When all data from multiple PMUs is put together, the information received is elaborate and gives a comprehensive view of the entire system of interconnection [6]. The phasor measurement data is used to visualise

*Energy Efficiency and Renewable Energy Division, Cental Power Research Institute, Bangalore-560 080, India. Email: ksl.cpri@gmail.com
**Diagnostics Cables and Capacitors Division, Central Power Research Institute, Bangalore 560 080, India.
***Dept. of Electrical and Electronics Engg., Manipal institute of technology, Manipal,Karnataka- 576 104. India..

the power system signal depicting the actual system status. Synchrophasors enable a superior indication of grid stress, and areoften used to trigger corrective actions to maintain reliability. The first commercial PMU was manufactured by Macrodyne in the year 1991. The original standard is IEEE 1344-1995. It is now replaced by IEEE standard C37.118-2005 [3,7]. This standard is further split into two: IEEE 37.118.1 which covers the measurement part anIEEE 37.118.2 which covers the data communication part. The phasor Measuring unit PMU has significantly improved the efficiency of power system monitoring and analysing. Synchronized phasor measurement has its applications both in steady state and dynamic state in power systems.

2.0 CONCEPT OF SYNCHRONISED PHASOR MEASUREMENT

Synchrophasor are nothing but devices having an inbuilt phasor measurement unit (PMU), GPS device used for measuring power parameters. Synchrophasor utilises 2 or more phasor measuring unit which is time tagged and made to monitor and record the various variable of power such as voltage, current, Power factor, frequency etc. The phasor measurement process is mainly divided into two subdivisions [8]:

1) **Sampling:** Here the sampling of voltage or current waveforms with an analog to digital converter (ADC). This requires pre-filtering to avoid high frequency signals into the converted data.

2) **Phasor calculation process:** It projects the power signal to cosine and sine function which are real and imaginary components of the phasor representation.

Typicallysynchrophasor consists of a phasor measuring unit (PMU) and clock. The PMU has an inbuilt Potential transformer (PT) and current transformer (CT) to transform voltage and currents of the power system to low safe values. Then an external clock whose signal is derived from a phase locked oscillator which provides the time tag data. By synchronising the sampling process of different signals which are miles away, it becomes possible to place their phasors on the same phasor diagram that are time tagged. The sampling rate is of few kilohertz which sufficiently produces the required waveform [8]. The phasor equivalent of an AC signal is given as

$$x(t) = X_m \cos(\omega t + \theta) \quad ....(1)$$

where ω=2Πf

Synchrophasor are calculated using discrete fourier transform (DFT) from the waveform using the standard equation [4]:

$$X(i) = \frac{\sqrt{2}}{N} * \sum_{j=-n}^{n} xi+j * \exp(-j(i+k)\Delta t\omega_0 \quad ....(2)$$

where,

X_i-waveform samples from the timedomain signals

X(i) - synchrophasor estimates

Now assume a waveform described by the phasor value

$$P = X_t + jX_i \quad ....(3)$$

where, X_t=Real component

X_i=Imaginary component

Then at instant t_0, the estimated phasor value for that instant is

$$P(t_0) = X_t(t_0) + jX_i(t_0) \quad ....(4)$$

Total Vector Error, TVE is given by,

$$\text{TVE}= \sqrt{\frac{(X_r(t_0) - X_r)^2 + (X_i(t_0) - X_i)^2}{X_r^2 + X_i^2}} \quad ....(5)$$

Total Vector Error provides accurate method of evaluating the PMU measurement. Basic measurement requires magnitude and phase accuracy [4]. The standard requirement show in Table 1.

TABLE 1		
STEADY STATE PERFORMANCE REQUIREMENT FOR C37.118-2005		
Signal being tested	**Level 0 Range**	**Level 1 Range**
Signal frequency	± 0.5Hz	± 5 Hz
Signal magnitude	80-120% rated	10-120% rated
Phase angle	± π radians	± π radians
Harmonic distortion	1%,any harmonic up to 50^{th}	10%, any harmonic up to 50^{th}
Out of band interfering signal, at frequency f_1 where $\lvert f_1 - f_0 \rvert > F_S/2$, F_S=phasor reporting rate, $f_0 = F_{nominal}$	1.0% of input signal magnitude	10% of inout signal magnitude

3.0 PARAMETERS MEASURED USING SYNCHROPHASOR

Synchrophasor are like any other power analyser with data logger. The system component consists of

- phasor measurement unit PMU
- Clock
- Phasor data concentrator PDC
- Visualization software
- Communication interface

All the power parameters such as voltage, current, p.f., frequency, harmonics with respect to current and voltage, transients, Total harmonic distortion, efficiency, phasor, waveform etc. are recorded. Power quality refers to any problem or unexpected situation which is manifested in voltage, current frequency, p.f., etc. which leads to deviation, malfunction or failure of power system or equipment is referred to as power quality issues. The parameters are sag, swell, flicker, harmonics, transients etc .[9]

4.0 APPLICATION OF SYNCHROPHASOR

There are various applications of synchrophasor for the improvement of power system. Few of the applications are discussed in this paper which is as follows.

4.1 Real time monitoring

Synchrophasor are widely used for real time monitoring leading by providing wide area monitoring of the grid which can be further led to relay control operations. Phasor-RTDMS (Real time dynamic monitoring system) provides situational awareness, and grid dynamics through actual sub-second measurements. Power flows are monitored in real-time. Change in the phase shift is measured across parts of the grid through which stress and future stability estimates are made. synchrophasor measurements, compliant with IEEE Standard C37.118, should not be in error by more than 1% 'total vector error' (TVE), where this error includes components due to time offsets in the PMU clock; phase errors or delays in the signal processing circuitry; and magnitude errors. 1% TVE corresponds to a phase angle error of 0.57 degrees, if no other errors are present [11,13]. This is about 32 microseconds at 50 Hz.

They provide details on grid dynamics like the following:

- Phase Angle Differences (Grid Stress)
- Small Signal Stability (Oscillations & Damping)
- Frequency Instability
- Generation-Load Imbalance
- Power-Angle Sensitivity
- Power-Voltage Sensitivity

4.2 Visualization

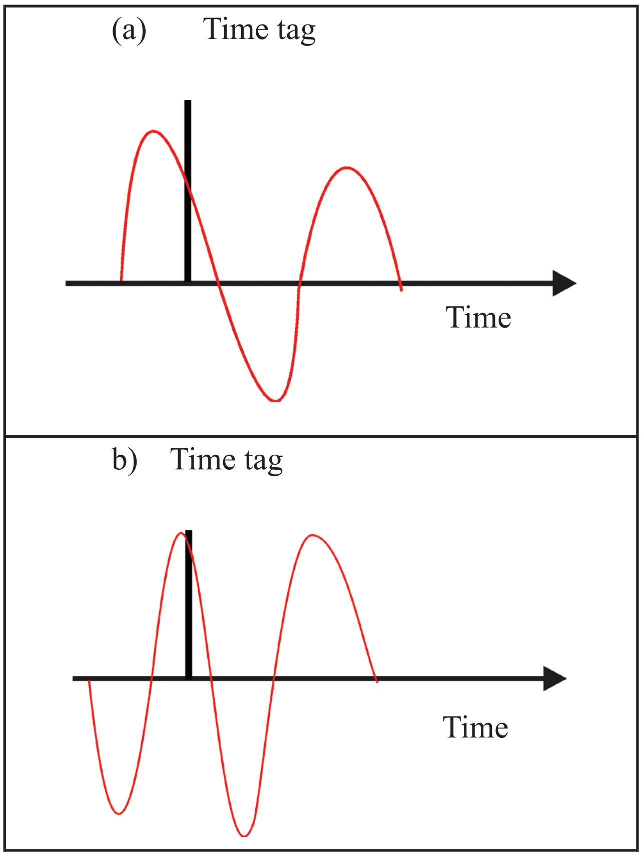

FIG.1 SYNCHRONIZED SAMPLE OF WAVEFORM ON SAME TIME AXIS

The Figure.1 ggives a clear picture of visualization of 2 phasors (a,b) on same time domain at different locations using GPS clock. There are various upcoming software for the visualization. The commonly used software is LABVIEW. The visualization application shows the location, magnitude and the related event message on the visualization display in real-time by integration with the on-line event triggering and location of disturbance applications. Visualization application also includes both real time monitoring and post event analysis using historical synchrophasor data.

4.3 State Estimation

It is the process of determining the state of the power system. This enhances the operator to make better decision at maintaining power system security. The introduction of PMU enables improvementin the efficiency and accuracy of the state estimation of the power system. Earlier state estimation had the disadvantages of poor real-time, long calculating time, non-synchronous remote sensing value etc., leading to state estimation deviation. [9]

5.0 ISLANDING ISSUES WITH RENEWABLE ENERGY INTERGRATION WITH GRID

Synchrophasor technology is picking up pace for the application of detecting islanding and Anti-islanding issues. Traditional method use local voltage and frequency details to compare and check if the values are outside the predetermined threshold levels. But this method results in poor reliability due to communication link.The use of synchrophasor for the purpose of detecting islanding and anti- islanding the renewable energy production such as solar PV plant, Wind farms is appreciating. Synchrophasor are capable of detecting islanding in less than 2 seconds [15] which also includes tripping the circuit breaker. Apart from anti-islanding the synchrophasor data can facilitate resynchronization of the islanded system back into the grid with fast operation with minimal system impact. A schematic example is show below

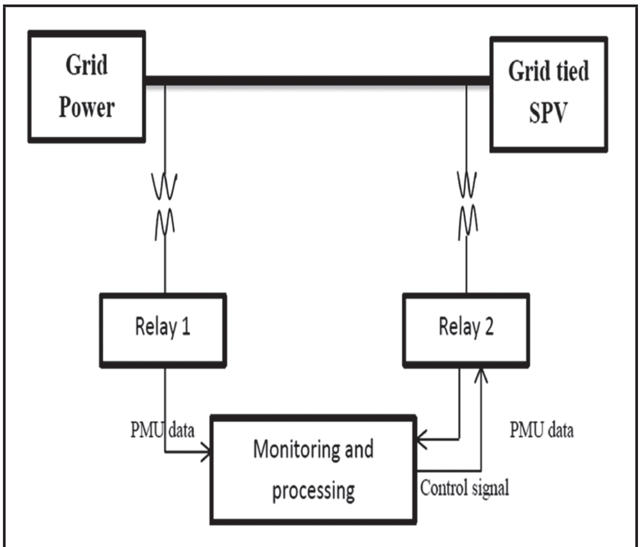

FIG.2 ANTI-ISLANDING SCHEME USING SYNCHROPHASOR IN ROOF TOP SPV SYSTEM

To monitor distributed generation connected to the grid, distribution level PMU have TVE value less is desired [16] due to limited power flows and smaller line length etc. The PMU used for monitoring transmission system cannot be used here.

The test results of the grid connected inverter is shown in figure 3-6.The experiment was conducted as per IEC 61727 standard to monitor and demonstrate the power parameters and detect islanding using time synchronised measuring technique in a grid tied inverter. This measuring technique is conducted in a 250W roof top solar PV system connected to the grid system via inverter. Two phase power analyser were time-synced and Timers were set at same time for both the power analyser. Both power analyser are connected to grid and inverter output from the roof top PV module respectively. It is noticed that when the grid supply goes off the inbuilt sensor in inverter senses it and gets itself disconnected from the grid almost at the same time. This is recorded in the power analyser which is shown clearly in graph below.Figure 3 and 4 shows that both voltage and current from the utility and grid tied inverter reaches zero value at the same time. Also the resynchronisation is also monitored which is show in figure5 and 6.

The inherence from the study depicts the usage of synchronised measuring technique for monitoring the power dynamics with renewable energy generation connected to the grid system.

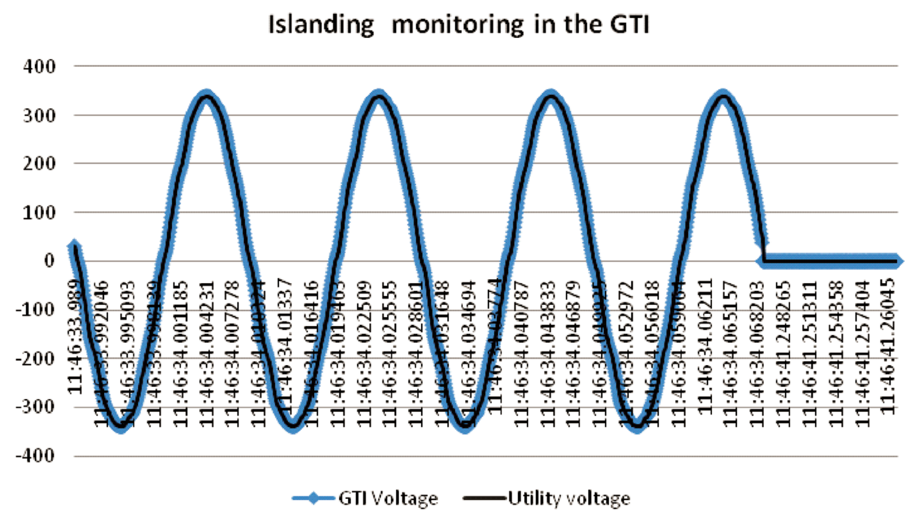

FIG.3 ISLANDING MONITORING (VOLTAGE) IN THE GRID TIED INVERTER USING SYNCHRONISED MEASURING TECHNIQUE

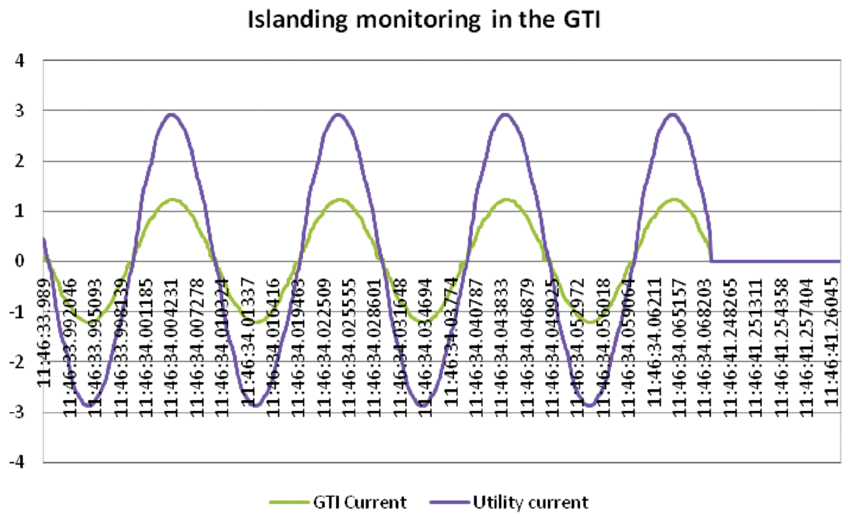

FIG.4 ISLANDING MONITORING (CURRENT) IN THE GRID TIED INVERTER USING SYNCHRONISED MEASURING TECHNIQUE

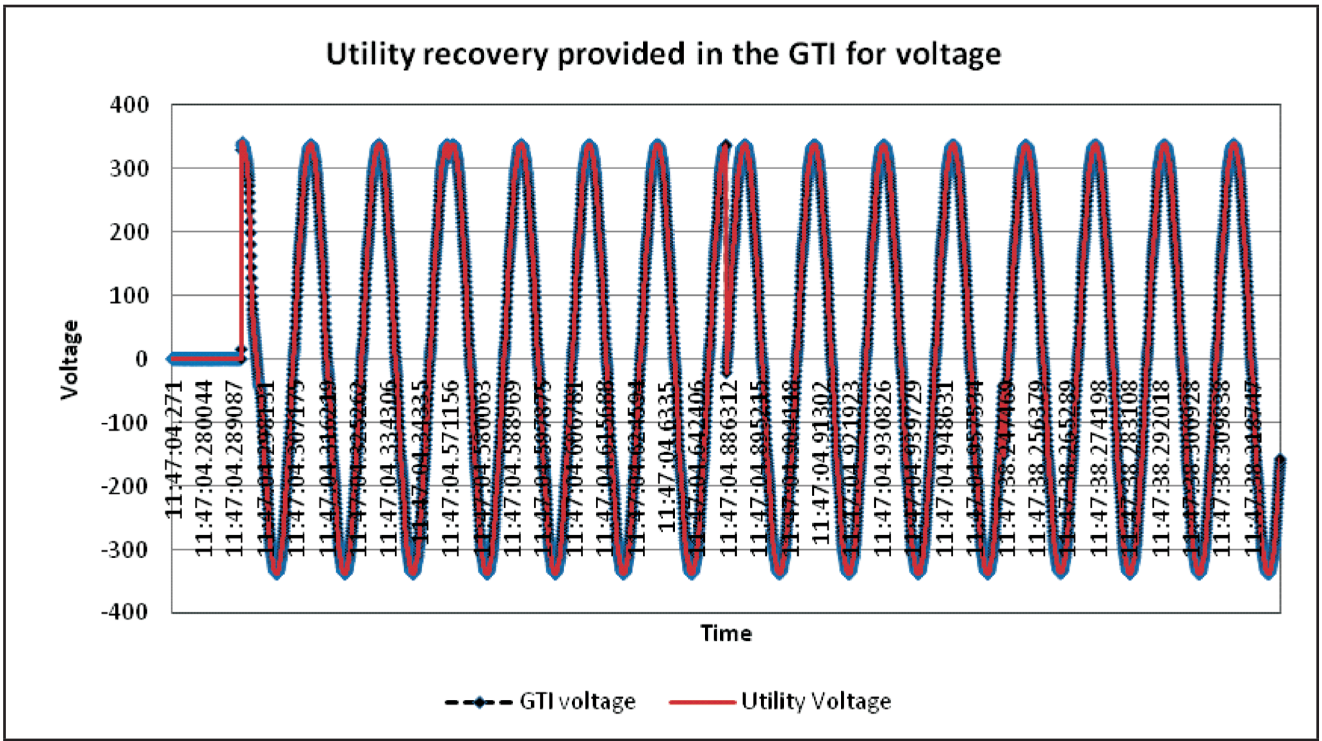

FIG.5 UTILITY RECOVERY (VOLTAGE) PROVIDED IN THE GRID TIED INVERTER

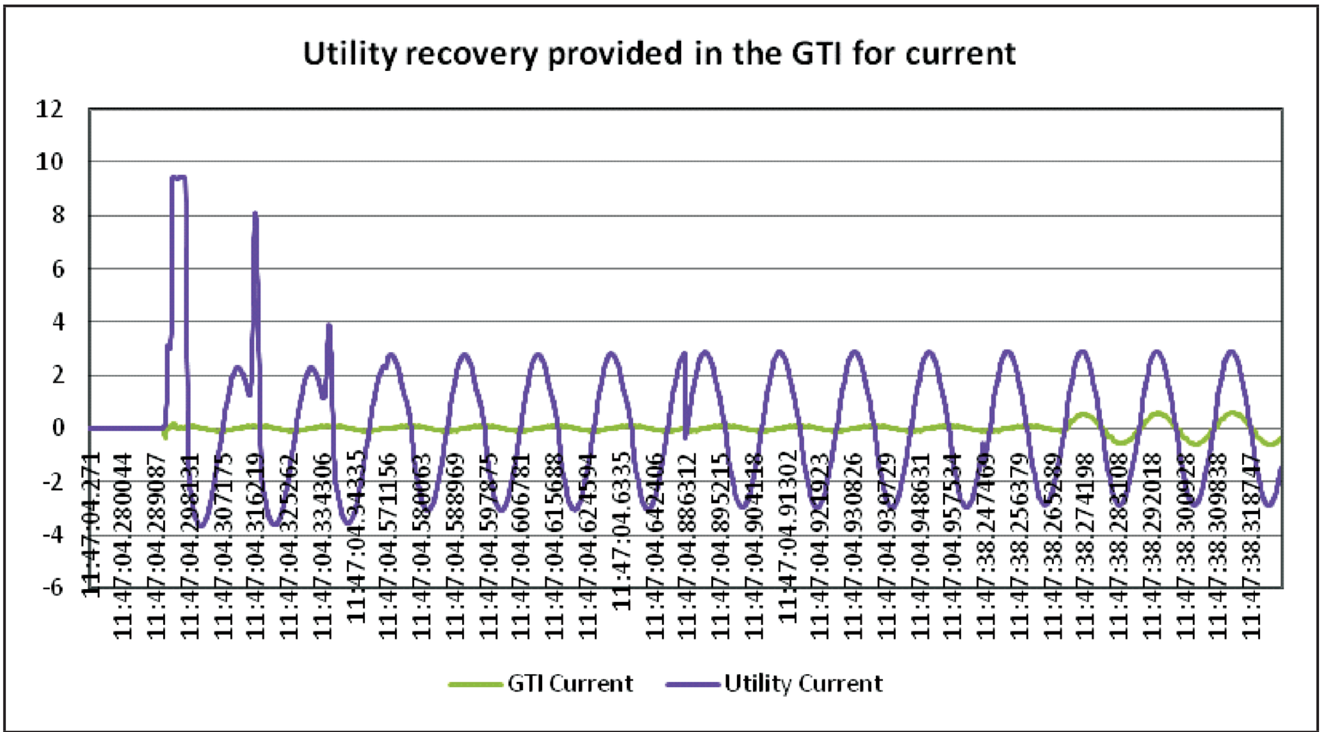

FIG.6 UTILITY RECOVERY (CURRENT) PROVIDED IN THE GRID TIED INVERTER

6.0 CONCLUSION

Application of Synchrophasor technology has been increasing widely in the past few years yielding better power system dynamics. Also the scope is developing on distribution system operation, control and monitoring with renewable components.

REFERENCES

[1] Phadke A. G., Virginia Polytech. Inst. & State Univ., Blacksburg, USA, "Synchronized phasor measurements- a historical overview" Transmission and Distribution conference and Exhibition, 2002, vol. 1, Oct. 2002, pp. 476-479.

[2] Martin K. E., Harmai D, Adamiak M. G., Anderson S., and Phadke A.G., "IEEE standard for synchrophasors for power system," IEEE Transactions of Power delivery, vol. 13, no. 1, Jan. 1998, pp. 73-77.

[3] Martin K. E., Harmai D., Adamiak M. G and Anderson S, "Exploring the IEEE standard C37.118-2005 synchrophasors for power systems", IEEE Transactions on power delivery vol. 23, no. 4, Oct. 2008, pp. 1805-1811.

[4] Kenneth E. Martin, "Synchrophasor standards development – IEEE C37.118 & IEC 61850", Proceeding of the 44th Hawaii international conference on system science, Jan. 2011, pp. 1-8.

[5] Kenneth E. Martin, John F. Hauer and Tony J. Faris, "PMU testing and installation considerations at the Bonneville power administration", IEEE transactions on Power engineering society general meeting, June 2007, pp. 1-6.

[6] Phadke A. G., "A new measurement technique for tracking voltage phasors, local system frequency and rate of change of frequency", IEEE transactions Power Apparatus and Systems, vol. 102, no. 5 May 1983, pp. 1025-1038.

[7] De La Ree, "Synchronized phasor measurement application in power systems", IEEE transactions on Smart Grid, vol. 1,no. 1, June 2010, pp. 22-27

[8] AbderrahmaneOuadi, Hamid Bentarzi and Jean claudemaun, "A new computer based phasor measurement unit framework", 6th International multi conference on system, signals and devices, Mar.2009, pp. 1-6.

[9] Lei Luo, Nengling Tai, guangliang Yang, "Wide area protection research in the smart grid", International conference on future energy, environment and materials, 2012, Elsevier, pp.1601-1606

[10] Dawei fan, "Synchronized measurements and application during power system dynamics", Ph.D. Thesis, Feb 1, 2008.

[11] Mills,Bend, Scharf, Hummel, S. Ropp, "Interconnection control of distributed generation with time-synchronized phasors", Power Systems Conference and Exposition, March 2011, pp. 1 – 8.

[12] Sehwail, H. Dobson, I., "Locating line outages in a specific area of a power system with synchrophasors",North American Power Symposium, Sept. 2012, pp.1 – 6.

[13] KasembeA.G., Muller Z., SvecJ. Tlusty J."Synchronous phasors monitoring system application possibilities", 27th IEEE Convention of Electrical & Electronics Engineers in Israel (IEEEI),Nov.2012, pp. 1 – 3.

[14] Cheng-I Chen, "A Phasor Estimator for Synchronization between Power Grid and Distributed Generation System", Industrial Electronics, IEEE Transactions on Vol. 60, no. 8, Aug. 2013, pp. 3248 – 3255

[15] Ropp M., PerlenfeinS., Joshi D., Mettler C., "Synchrophasors for island detection",38th IEEE Photovoltaic Specialists Conference, June 2012, pp.602 -607

[16] Sexauer J., Javanbakht, Mohagheghi S., "Phasor measurement units for the distribution grid : Necessity and benefits", IEEE Innovative Smart Grid Technologies (ISGT), Feb. 2013, pp. 1 – 6.