Synchronized Phasor Measurements with GPS Time Stamping using 64 Point DFT in PMU

R.Alekya[1] Ravi Ponnala[2] Aleti Soumya[3] B. Shiny Sucharitha[4]

Abstract—This paper describes about the time synchronization of different locations voltage or current signals for accurate comparison of signals on single phasor graph, all the measured phasors are synchronized with Global Positioning System (GPS) time stamping. Day to day power demand increases very rapidly, to meet the growing demand of electrical energy new energy resources are required and manage them efficiently. For efficient allocation of sources there should be a good monitoring and fast control system. For better monitoring and control of the system accurately it requires "Wide Area Monitoring" of power system. In the wide area monitoring system collection of data from the power system should be at a faster level. The collection of data from the power system at faster level is possible by using "Phasor Measurement Units(PMUs)". PMU collects the data at faster rate rates like 50-60 samples for cycle, this information is send to local Phasor Data Concentrator (PDC). Local phasor data concentrator collects the data from different PMUs which are located in different areas. This PDC helps to take the necessary action on power system. For synchronization, pulse per second(PPS) is taken from GPS module. From this 1PPS, 3200 pulses is generated for high accuracy of 64 point DFT of 50Hz signal using microcontroller. System frequency is calculated by using time period between the two consecutive raising edges or falling edges of square wave. This is in synchronous with the input sinusoidal signal.

Key words: GPS, phase angle, PMU, 1PPS, magnitude, frequency.

I. Introduction:

The world becomes a smarter day to day. The power system basic operation and control block diagram is shown in Fig.1. It is very much required to implement real time monitoring of the system because to meet the growing demand of the power system the strongest things is the renewable energy sources [2]. The renewable energy sources or distributed energy sources are connected at low or medium voltage levels of the power system. Due to the random nature of availability of the renewable energy sources may cause operational and technical difficulties in the power systems. The major disadvantage with the existing system is that the measurements are not synchronized [3]. The PMU estimates a sinusoidal quantity in a power system in the form of magnitude (RMS) and phase angle or real and imaginary values. These values are time stamped with GPS timing for synchronization of different PMU readings which are located at various areas in the world [4]. By using synchronized phasor measurements various aspects like real time demand scheduling, fault detection, phase angle of voltage or current, frequency, rate of change of frequency and state estimation is possible [5]. That means PMUs are introduced new things like measuring of fundamental component of the signal, phase angle etc.

The fundamental component of the signal is extracted from the distorted signal by using the butterworth filter. By Appling the Discrete Fourier Transform (DFT) the magnitude and phase angle of the signal is estimated. This is also helpful for the power spectrum analyzer [6].

The PMU measures the magnitude of the voltage at connected bus and all the incident branch currents of that bus. These values are time stamped with GPS [7] timing and transferred together via the communication module to a server (PDC) [8].

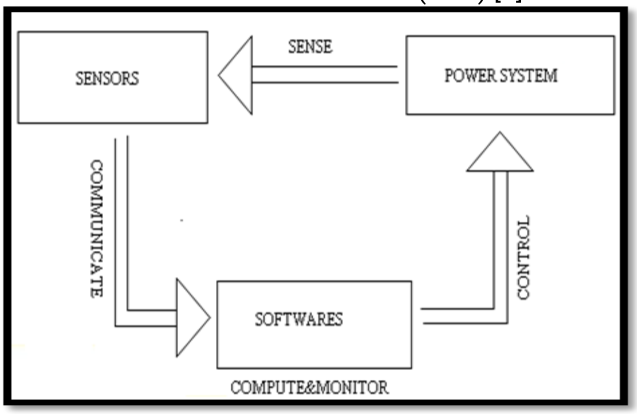

Fig. 1. Basic block diagram representation of power system

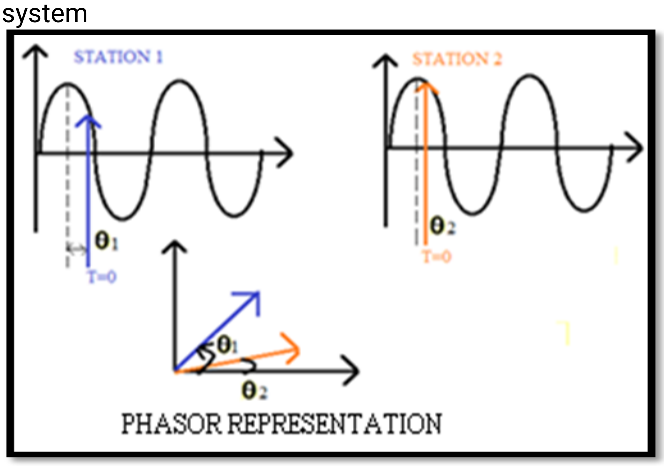

Fig. 2. Phasor measurement comparison

II. GLOBAL POSITIONING SYSTEM (GPS):

For PMU measurements synchronization the reference time signal is taken from GPS NEO6MV2 module. This GPS module gives 1PPS it is applied to Arduino to generate required number of pulses is called Global positioning System Disciplined Oscillator (GPSDO). This is shown in Fig.4.

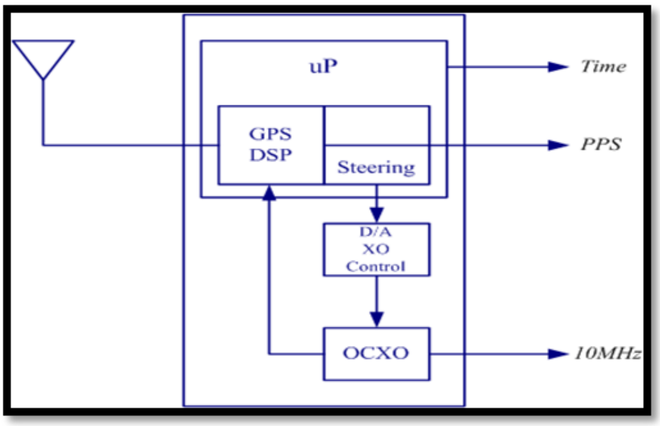

Fig. 3. GPSDO block diagram representation.

NEO6MV2 GPS Module have four terminals. Vcc-Supply Voltage(2.7 to 3.6V), Gnd-Ground pin, TX and RX-These 2 pins acts as an UART interface for communication. TX must be connect Rx pin of the Arduino and RX pin should connect Tx pin of the Arduino. The 1PPS signal is converted into 3200(64*50) pulses per second by Arduino Uno[9]. These 3200 pulses are equally time spaced with 0.3125msec.

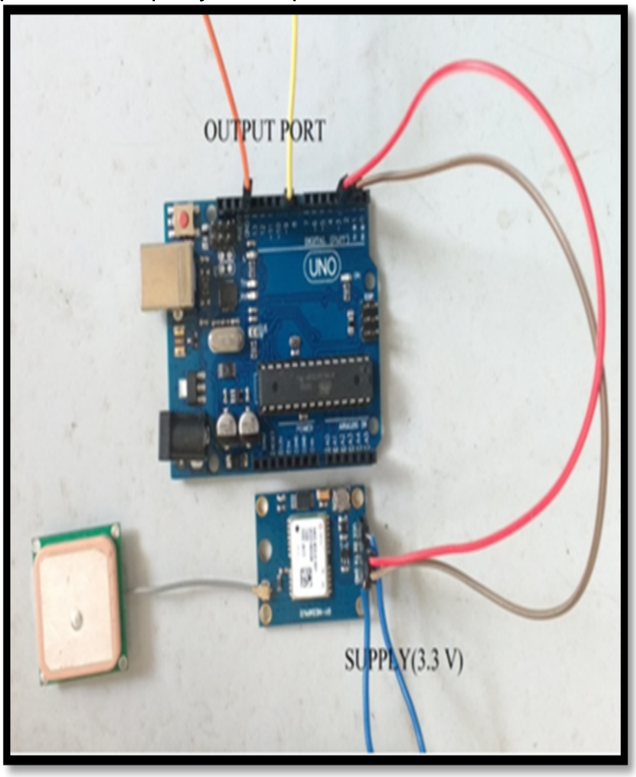

Fig. 4. Physical connection of GPS to Arduino

Once pulse is received from the GPS counter starts and generating required number of pulses [10]. The flow chart of GPSDO is shown in Fig.5.

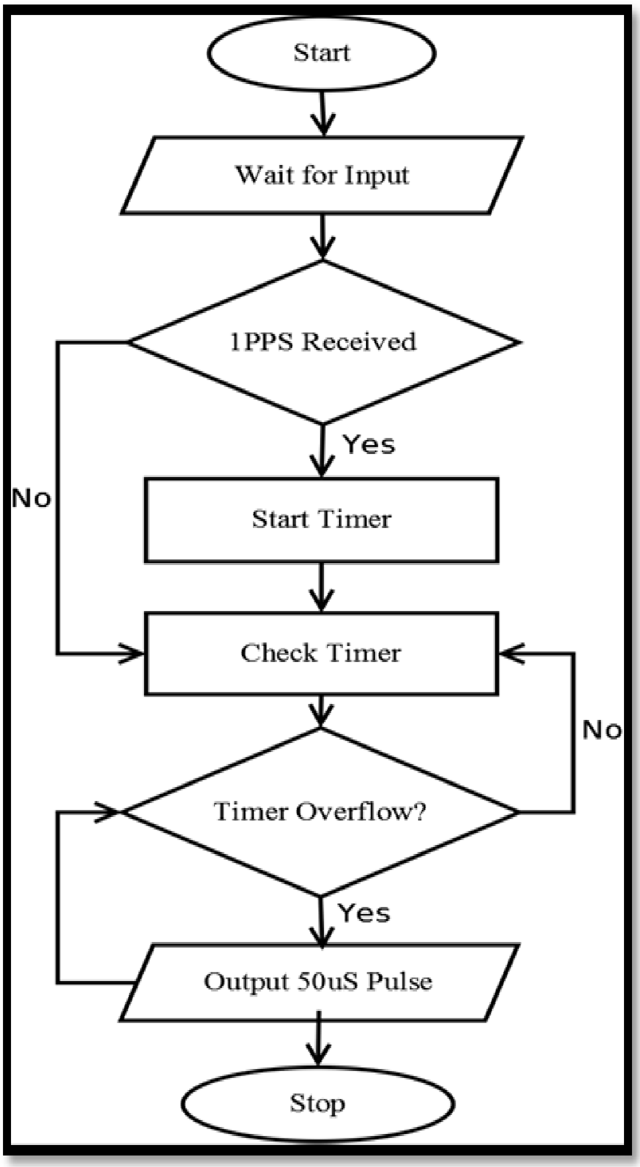

Fig.5 Flow Chart of GPSDO

arduino programming code for GPSDO is shown below. In arduino IDE software install the TimerOne.h heder file and then program can execute.

```
#include <TimerOne.h>
 const int sampling_clock_out_pin = 9;
void setup()
 {
 pinMode(2, INPUT);
   attachInterrupt(0, pulsePPS, RISING);
    Timer1.initialize(312.5);
  Timer1.pwm(sampling_clock_out_pin , 100);
  }
 void loop()
  void pulsePPS()
{
   Timer1.restart();
}
```

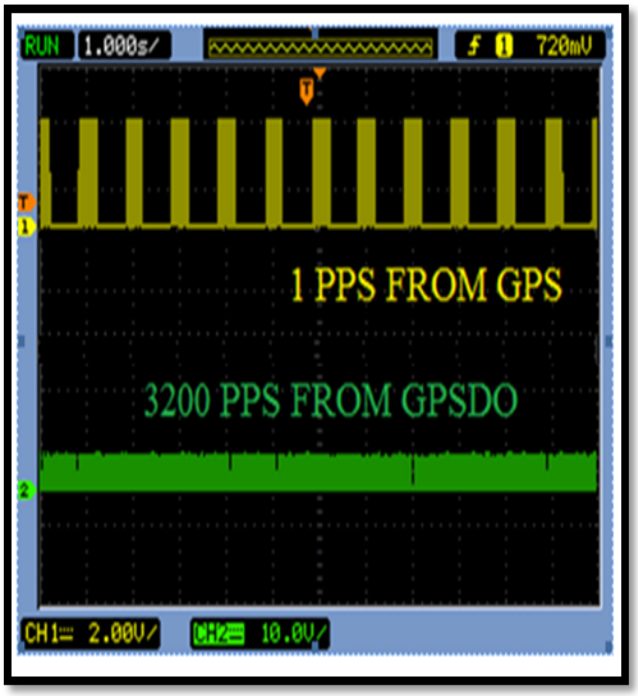

Fig. 6. 1 PPS from GPS and Respective output pulses of GPSDO

In the fig. 6 it is shown that the 1PPS is converted into required number of pulses(3200). For clear observation it is shown in Fig.7.

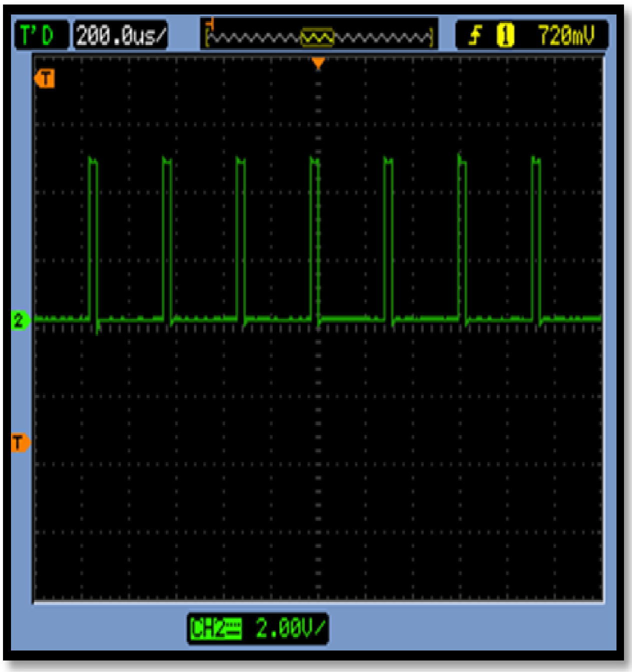

Fig. 7. 3200 Pulses Per Second from GPSDO

In the fig.7 it is shown that the time period between the any two pulses is 1.6*200US=3.2mS or it will generate 3200 pulses per second. The

III. TEST SYSTEM

Let us consider a four bus system, in which the two PMUs are located at station 1 and station 2. These two PMUs will calculate the magnitude of that bus voltage and all the incident branch currents [11]. Based on the branch currents and branch impedances the other bus voltages can be estimated.

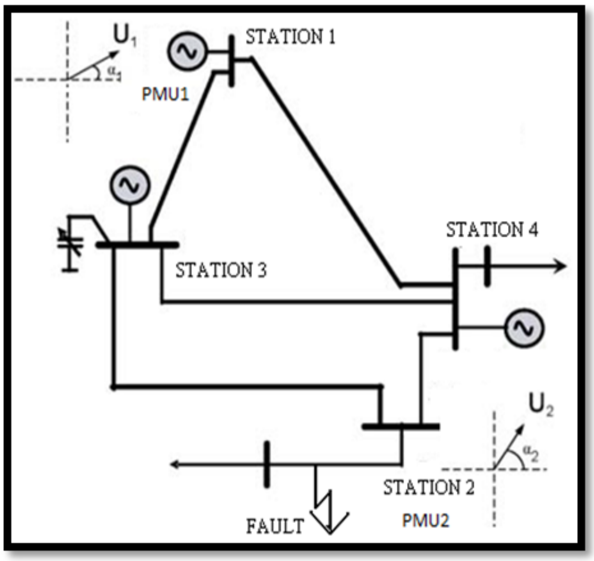

Fig. 8. Four bus model test system.

In order to calculate phasor of system, Window system is used in DFT. Impulse input to a system may give Finite Impulse Response (FIR) or Infinite Impulse Response (IIR) [12]. The analysis of IIR is difficult, so to take finite series response window (Rectangular or Kaiser or Hamming) is useful. In this window input signal is sampled at f_s=Nf (f_s=64*50=3200) and sampling time $T_s=1/f_s$ (T_s=1/3200 = 0.0003125 sec) Where f_s is sampling frequency, N is window size, f is input signal frequency and T_s is sampling time period.

By considering fault occur at the bus station 2 and normal working conditions at bus station 1 the PMU readings are shown in below Fig.9 The branch signal will gets disturbed due to harmonics present in the fault, the corresponding simulated waveform with magnitude and phase angle variations are shown in fig.10.

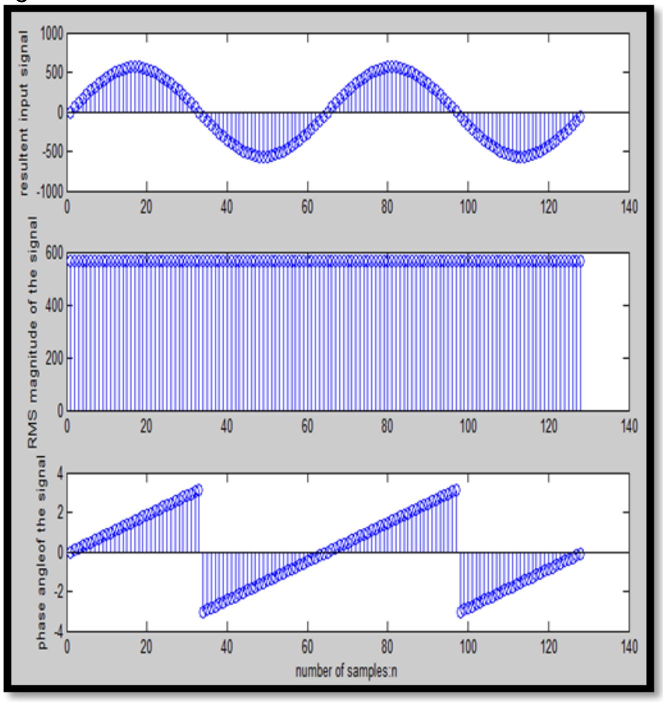

Fig. 9. PMU1 signal, magnitude and phase angle readings

A distorted, periodic waveform is shown in fig.10. It consist of a different odd harmonic components. The distorted waveform, magnitude and phase angles are simulated and it is shown in Fig. 10.

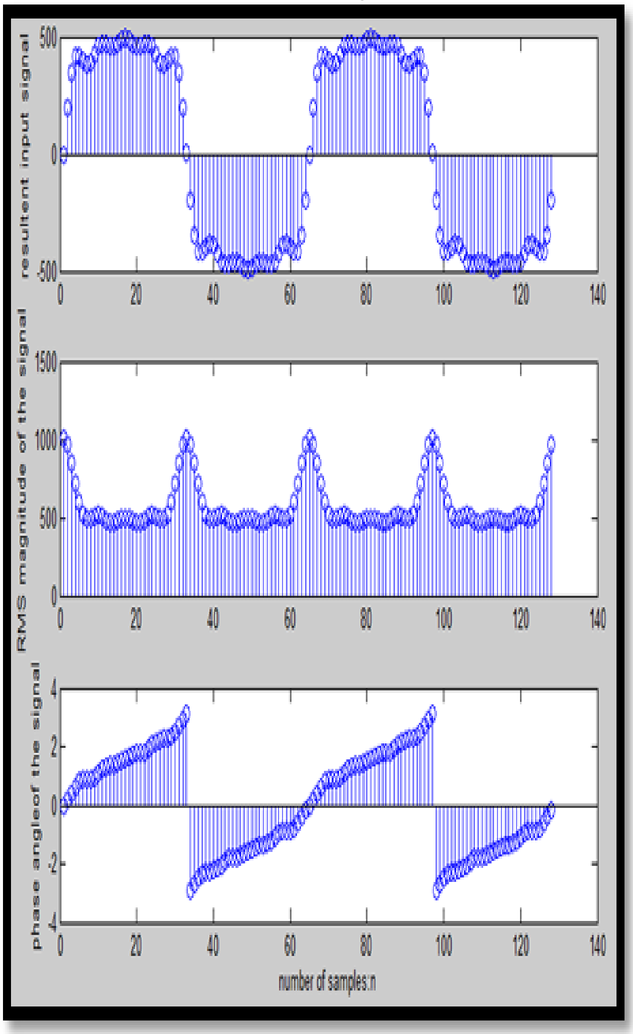

Fig. 10. PMU2 signal, magnitude and phase angle readings

IV. PHASOR CALCULATION AND TIME STAMMPING

The readings of the two PMUs are time stamped with GPS timing which is shown in table 1. PMUs are calculating the magnitude and phase angles using Discrete Fourier Transform (DFT). In DFT for magnitude and phase angle calculation, Non-Recursive based algorithm is used [1]. In each window 64 samples are taken (N=64) to calculate magnitude and phase angle. Normally the sinusoidal waveform is represented with

$X(t)=X_m \cos(2\pi ft+ \varphi)$ ---------(1)

The phasor form of the signal is given by

$x(t) = X_{rms}\, e^{j\Phi} = X_{rms}[\cos\Phi + j \sin \Phi]$---(2)

The measured values are coordinated to universal coordinated time (UTC). System frequency can be calculated by using sine to square wave converter. This converts the sine wave signal into square wave signal for easy calculation of time period of the signal [13]. The frequency of the signal is “f=1/T”, where T is the time period between two consecutive raising edges or falling edges. The single phase sine to square wave converter is shown in fig. 11, and respective output square wave is shown in fig.12.

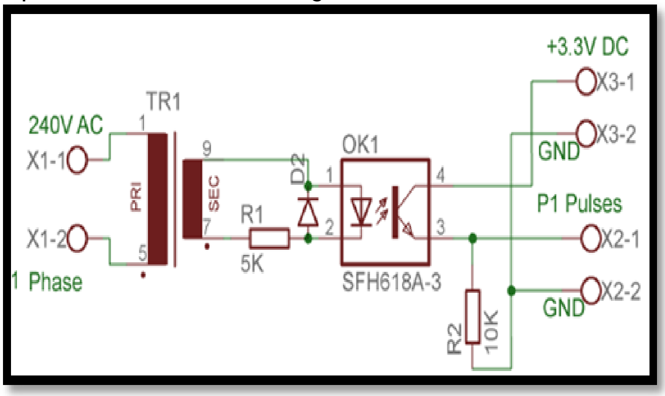

Fig. 11. sine to square wave converter

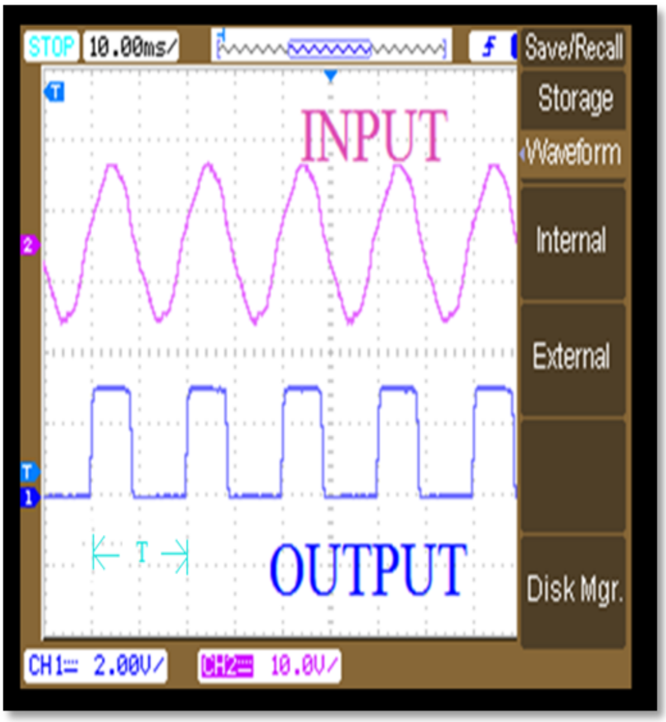

Fig. 12 Square wave signal for frequency estimation

V. NON-RECURSIVE DFT ALGORITHM FOR PHASOR CALCULATION

The normal DFT equations for measurement of the the magnitude and phase angle is

$$X^{N-1} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_n[(\cos(n\theta) - j\sin(n\theta)]$$

$$X^{N} = \frac{\sqrt{2}}{N}\sum_{n=0}^{N-1} x_{n+1}[(\cos(n\theta) - j\sin(n\theta)]$$

In recursive algorithm first data window is computed for n=0 to n=N-1 and in next window n=0 value is omitted and n=N sample is included means in further windows next coming sample is including and respective starting samples are excluding. Recursive algorithm is numerically less stable because if error occur in first window that will be carry forward to next windows also. This will greatly effect on the total system window computations so non-recursive algorithm is mostly used in all applications.

The MATLAB sample program for phasor calculation is shown below.

```
N=64;
j=sqrt(-1);
n=0:1:2*N-1;
Vr=sqrt(2)*(400*cos(2*pi*n./N)+(133*cos(6*pi*n./N))+
(80*cos(10*pi*n./N))+(57*cos(14*pi*n./N))+(40*cos(18*pi*n./N)));
Vi=(sqrt(2)*(400*sin(2*pi*n./N))+(133*sin(6*pi*n./N))+
(80*sin(10*pi*n./N))+(57*sin(14*pi*n./N))+(40*sin(18*pi*n./N)));
V=Vr+j*Vi;
Vm=abs(V);
Vp=angle(V)
V1=sqrt((Vr.*Vr)+(Vi.*Vi))
V2=180*atan(Vi./Vr);
subplot(3,1,1)
stem(V)
ylabel('resultent input signal');
subplot(3,1,2)
stem(Vm)
ylabel('RMS magnitude of the signal');
subplot(3,1,3)
stem(Vp)
xlabel('number of samples:n');
ylabel('phase angleof the signal');
```

Table 1. Non-recursive DFT based phasor estimation

Time stamping (in Seconds)	PMU1 READING		PMU2 READING	
	Magnitude	*Phase angle (rad)*	*Magnitude*	*Phase angle (rad)*
0	565.68	0	1004.09	0
0.0003	565.68	0.0982	961.7088	0.2083
0.0006	565.68	0.1963	852.1216	0.4180
0.0009	565.68	0.2945	716.7552	0.6188
0.0013	565.68	0.3927	597.0496	0.7797
0.0016	565.68	0.4909	518.7392	0.8654
0.0019	565.68	0.5890	489.7408	0.8871
0.0022	565.68	0.6872	496.6336	0.9107
0.0025	565.68	0.7854	511.5328	0.9822
0.0028	565.68	0.8836	514.368	1.0967
0.0031	565.68	0.9817	502.0544	1.2214
0.0034	565.68	1.0799	482.2464	1.3182
0.0037	565.68	1.1781	466.5408	1.3663
0.0041	565.68	1.2763	464.6016	1.3825
0.0044	565.68	1.3744	475.9168	1.4097
0.0047	565.68	1.4726	489.79	1.4752
0.0050	565.68	1.5708	495.6864	1.5708
0.0053	565.68	1.6690	489.792	1.6664
0.0056	565.68	1.7671	475.9168	1.7319
0.0059	565.68	1.8653	464.6016	1.7591
0.0063	565.68	1.9635	466.5408	1.7753
0.0066	565.68	2.0617	482.2464	1.8234
0.0069	565.68	2.1598	502.0544	1.9202
0.0072	565.68	2.2580	514.368	2.0449
0.0075	565.68	2.3562	511.5328	2.1594
0.0078	565.68	2.4544	496.6336	2.2309
0.0081	565.68	2.5525	489.7408	2.2545
0.0084	565.68	2.6507	518.7392	2.2762
0.0088	565.68	2.7489	597.0496	2.3619
0.0091	565.68	2.8471	716.7552	2.5228
0.0094	565.68	2.9452	852.1216	2.7236
0.0097	565.68	3.0434	961.7088	2.9333
0.0100	565.68	3.1416	1004.09	3.1416
0.0103	565.68	-3.0434	961.7088	-2.9333
0.0106	565.68	-2.9452	852.1216	-2.7236
0.0109	565.68	-2.8471	716.7552	-2.5228
0.0113	565.68	-2.7489	597.0496	-2.3619
0.0116	565.68	-2.6507	518.7392	-2.2762
0.0119	565.68	-2.5525	489.7408	-2.2545
0.0122	565.68	-2.4544	496.6336	-2.2309
0.0125	565.68	-2.3562	511.5328	-2.1594
0.0128	565.68	-2.2580	514.368	-2.0449
0.0131	565.68	-2.1598	502.0544	-1.9202
0.0134	565.68	-2.0617	482.2464	-1.8234
0.0138	565.68	-1.9635	466.5408	-1.7753
0.0141	565.68	-1.8653	464.6016	-1.7591
0.0144	565.68	-1.7671	475.9168	-1.731
0.0147	565.68	-1.6690	489.792	-1.6664
0.0150	565.68	-1.5708	495.6864	-1.570
0.0153	565.68	-1.4726	489.792	-1.4752
0.0156	565.68	-1.3744	475.9168	-1.4097
0.0159	565.68	-1.2763	464.6016	-1.3825
0.0163	565.68	-1.1781	466.5408	-1.3663
0.0166	565.68	-1.0799	482.2464	-1.3182
0.0169	565.68	-0.9817	502.0544	-1.2214
0.0172	565.68	-0.8836	514.368	-1.0967
0.0175	565.68	-0.7854	511.5328	-0.9822
0.0178	565.68	-0.6872	496.6336	-0.9107
0.0181	565.68	-0.5890	489.7408	-0.8871
0.0184	565.68	-0.4909	518.7392	-0.8654
0.0187	565.68	-0.3927	597.0496	-0.7797
0.0191	565.68	-0.2945	716.7552	-0.6188
0.0194	565.68	-0.1963	852.1216	-0.4180
0.0197	565.68	-0.0982	961.7088	-0.2083

VI. CONCLUSION

In this paper it is described that the phasor estimation of the distorted waveform with GPS time stamping. Due to the GPS time stamping of every sample it is possible to calculate the accurate the power spectrum, angles of the different locations. The sampling clock is achieved by using GPS NEO6MV2 which is generating required number of sampling pulses per second by Arduino Uno based GPSDO. The PMUs measured values are precisely (0.3125 msec) time stamped. This is very helpful to system operator to know the exact state of the system at any instant to take necessary actions against abnormal conditions.

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