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Effective monitoring of power system with phasor measurement unit and effective data storage system

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ABSTRACT

In the recent years the monitoring and operation of the power system became complex, due to the more demand from the different linear and non-linear loads and generation from the different sources. For the effective monitoring and operation of the power system, existing power system monitoring methods need to improve or new technologies are required. For the effective monitoring and operation of the power system phasor measurement unit (PMU) based monitoring is suitable, because it provide the dynamic state monitoring system. In this paper PMU based monitoring is proposed with effective data storage system and protection. With this method phasor values of voltage and current signals are calculated at the location of PMU and with the help of software based program effective data storage also possible. With this proposed model the phasor values in the power system at different locations monitoring also possible and required phasor data only stored and total data is only monitored. The phasor values of signals are calculated with direct phasor measurement technique in LabVIEW and by adding time stamping to the each phasor value accurate measurement of power flow is possible.

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1. INTRODUCTION

Due to the modernization, the demand for electricity is rapidly increasing which has a direct impact on the power system. Due to the improper planning and indefinite expansion to meet the demand, the power system network became complex to operate. The present technology supervisory control and data acquisition (SCADA) and express mail service (EMS) which is used for the measurements and monitoring the power system is having the limitations of inaccurate measurements, slower reporting rates which are in the range of once in 4-6 seconds [1], [2] and does not possess common reference time at the measurement stations for the accurate phase comparison between the different stations [3]. The advanced technology phasor measurements with time stamp will overcome the limitations of the SCADA and EMS system [4]. For this, intelligence electronic device is used, by using this voltage magnitude, phase angle, frequency, and change of frequency can be measured at faster rates with a common reference time [5], [6]. Common reference time can obtain from the global positioning system (GPS) signal available on all places of the world. For the dynamic monitoring of power system the collection of data should at faster level [7], [8]. According to IEEE C37.118.1 standard for dynamic monitoring of power system requires at least 10 samples per second. But due to the more data availability more storage system is required [9], [10]. In the power system phasor measurement unit (PMU) are used for the dynamic monitoring of the system, it is generates the data 29 giga bytes (GB) for one hour or 714 GB for one day, so for this large storage system is required [11], [12]. Instead of storing the total data, only the data is stored in disturbance conditions. In the remaining conditions only live signal phsor values are shown in the screen and recorded by the operators [13], [14]. When the fault occurs in the system then total data is stored and is helpful for the post disturbance analysis [15]. For dynamic monitoring of power system magnitude and phase angle of voltage and current calculation is very important [16], [17]. The change in the magnitude of voltage and frequency effects on the load, leads to malfunction of the system. The change in the angle of voltage represents the stress on the electrical grid [18]. Disturbances on the grid can be known by using the rate of change of phase angle [19]. Real and reactive power flow in the line can be determined with phase angle difference between the voltage and current phases [20]. For phasor estimation of voltage and current conventionally many phasor measurement techniques are available. They are shifting window average method [21], [22], discrete Fourier transform (DFT) method [23], phase locked loop [24], Newton's method [25], wavelet transform [26], state estimation, and kalman filter. Among all these methods DFT and shifting window average methods are accurate for phasor measurement in a steady state when it satisfies the sampling theorem. In this paper in the section 1 Introduction about the work is presented. In the section 2 Archeture of the PMU and basic phasor equations are presented. In the section 3 direct phasor calculation results are presented. In the section 4 effective data storage system is presented. Conclusion of the work is presented in the section 5.

2. ARCHITECTURE OF PHASOR MEASUREMENT UNIT

The PMU is a device used for the synchronized phasor measurements. It will measure the magnitude, phase angle, frequency and rate of change of frequency (ROCOF) of a signal. The phase is estimated concerning the global reference time (GPS or UTC) [27]. The architecture of PMU is given in Figure 1.

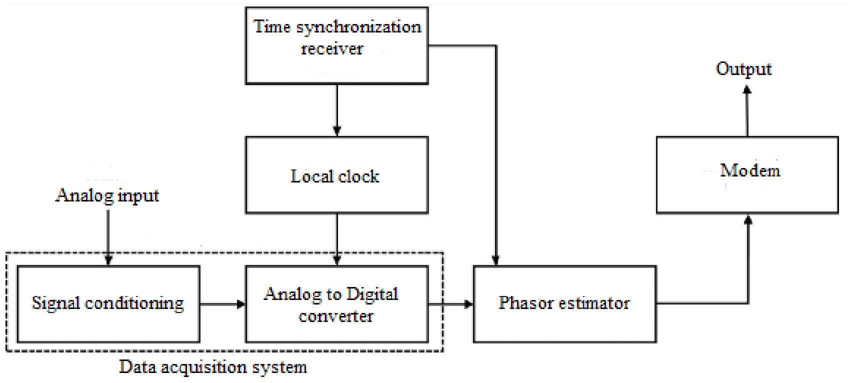

Figure 1. PMU architecture

With the PMUs two major advantages are there, they are not described in the earlier systems such as:

a. Synchronized phasor measurements with précised time indications
b. The root mean square (RMS) value gives the direct information about the magnitude of the system. The complete information about the PMUs are indicated in the IEEE standard C37.118.1, in this two types of PMUs are introduced:
   - P-class, type PMU are particularly applicable for protection with fast response
   - M-class, Type PMUs are very accuracy in measurement

Initially, the signal is acquired by the data acquisition system which consists of a signal conditioning unit and analog to digital converter (ADC). In the signal conditioning unit, the signal is amplified and filtered out according to the requirement of the analog to digital converter. After conversion, the digital signal passes through the phasor estimator which gives the magnitude and phase angle of the signal [28], [29]. The estimated values are then sending to the main receiver station through the communication module. Time synchronization receiver followed by local clock acts as a GPS or UTC signal which is used for the synchronization of the signal. The sampling of the input signal is an important criterion in the entire process of measurements done by PMU. This is done by taking the signal of 1pps from the GPS and is converted to

3600 PPS by using GPS disciplined oscillator (GPSDO). But commercially the cost of PMU's is very high. Instead of PMUs, phasors can be calculated by using IED, LabVIEW with Non-Recursive DFT technique.

The non-recursive DFT is one of the techniques used for the phasor measurements are shown in Figure 2. Window 1 is used to calculate the phasor 1 and window 2 is to calculate the phasor 2. In (1) gives the representation of the continuous signal in time domain, (2) repreasents the signal in disctrete space. In the window 1, the first sample is lagging concerning reference time by an angle Φ, while the first sample of window 2 (n=1) lags the reference time by an angle (Φ + θ), θ being the angle between the samples.

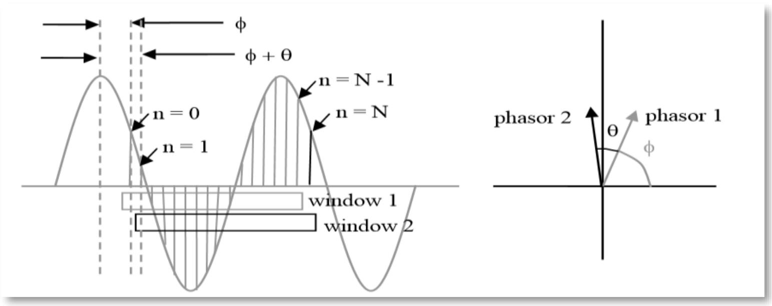

Figure 2. Nonrecursive windowing technique of a signal

Considering a signal which is sampled for N times with a sampling frequency as Nf_0 is represented by

$$x(t) = X_m \cos(\omega t + \emptyset) \tag{1}$$

N samples of the sinusoid x_n: {n=0, 1... N-1} are obtained from

$$X_n = X_m \cos(n\theta + \emptyset) \tag{2}$$

$$\text{where } \theta = \frac{2\pi}{N},$$

The fourier series for the signal (2) is given by (3)

$$X_k = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n \left[\cos(kn\theta) - j\sin(kn\theta)\right] \tag{3}$$

$$X_{kc} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n \cos(kn\theta) \tag{4}$$

$$X_{ks} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n \sin(kn\theta) \tag{5}$$

Where (4) and (5) are the cosine and sine terms for the K_{th} frequency components

Considering the (N-1) term as the last sample in the window, the non-recursive DFT formula for the signal is given by

$$X^{N-1} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n \left[\cos(n\theta) - j\sin(n\theta) = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_n e^{-jn\theta}\right. \tag{6}$$

$$X^{N} = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_{n+1} \left[\cos(n\theta) - j\sin(n\theta)\right] = \frac{\sqrt{2}}{N} \sum_{n=0}^{N-1} x_{n+1} e^{-jn\theta} \tag{7}$$

In (6) and (7) shows the phasor values at $(N-1)^{th}$ sample ane N^{th} sample respectively. The direct phasor calculation technique is presented in [20]. In (8) represents the direct phasor calculation

X=Xm (Sin Φ Cosωt + cos Φ Sinωt)

Assume A=Xm Sin Φ, B=Xm Cos Φ

X=A Cos ωt + B Sin ωt

Angle θ= Arctan(B/A)

Magnitude |X|= Magnitude of $\frac{\sqrt{2}}{N}\sum_{n=0}^{(\frac{N}{2})-1} x_n e^{-jn\theta}$

The final Phasor is represented as

$$|X|<\theta \quad (8)$$

3. DIRECT PHASOR CALCULATION BASED THREE-PHASE VOLTAGE PHASOR MEASUREMENT IN LABVIEW

The three-phase voltage measurement is done based on a Direct phasr measurement [20]. The simulated signal and real signal line voltage amplitude is taken as 415 V with a frequency of 50 Hz and each cycle is sampled for 72 points with a sampling frequency of 3600 Hz and the outer for loop with shift register is used to obtain the moving window and the inner for loop is used to obtain the 72 samples. The clock in the outer loop is used to get a sampling time of one window with a period of 20 milliseconds. The polar plot is used for the phasor representation of the voltage magnitude and phase angle which is shown in Figure 3. The write to measurement file is used to store the obtained voltage values.

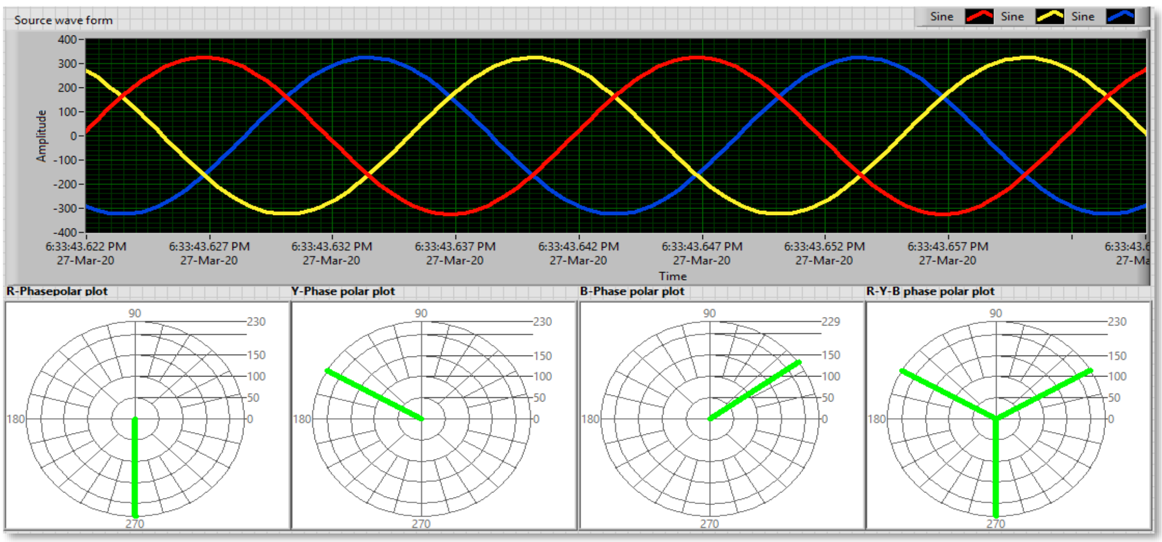

Figure 3. Polar plot of a three-phase voltage phasor measurement

The live picture of the three-phase system can be monitored by using polar plots. The individual phases and combined phases phasor values are shown in the Figure 3. The simulated phasor values can be stored in the excel file. At any time, voltage magnitude of all phases is same, phase angles are 120^0 apart. These values are better for for dynamic monitoring of power system. With the help of phasor values of current bus, neighboring bus phasor values also can estimate without physical placement of PMUs.

4. IMPLEMENTATION OF EFFECTIVE DATA STORAGE SYSTEM

The laboratory-based experimental setup is shown in Figure 4. For different case studies. Like variation of voltage magnitudes, variation of frequency and load. In Figure 5 the analog AC signal is taken to the program through myDAQ AI0 with a voltage range of +/-3V. The simulation process is started when the AC signal crosses the positive zero of a first time. Once this simulation is initiated, continuous samples are entered into the simulation with a sampling rate of 72 samples/cycle. This 3V signal is step up into 230V using a multiplier. Based on the 230V ac signal voltage magnitude, phase angle, frequency, and change of frequency is calculated, and all these values are storing in a file with the time stamp. If in the voltage magnitude ±5% of change or in the frequency ±1% or in the change of frequency is greater than 0.5 Hz then datais stored in the file. If variation values are more thsn allowable range then trip signal is generated and it will be applied to the relay contact through myDAQ D0 port. This digital output is applied to the relay through a 20 kΩ resistor in order to limit the current. This relay coil is connected to the 3-phase contactor. If in the phasor value or in the magnitude variations of voltage or frequencies are more than allowable range then contactor will open and that fault system is isolated from the health system.

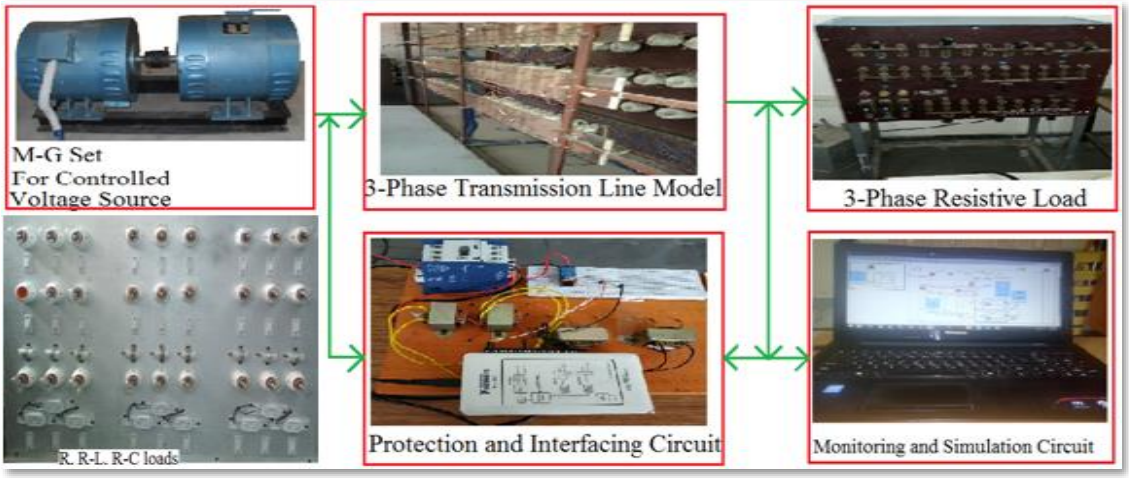

Figure 4. Block diagram representation of hardware setup

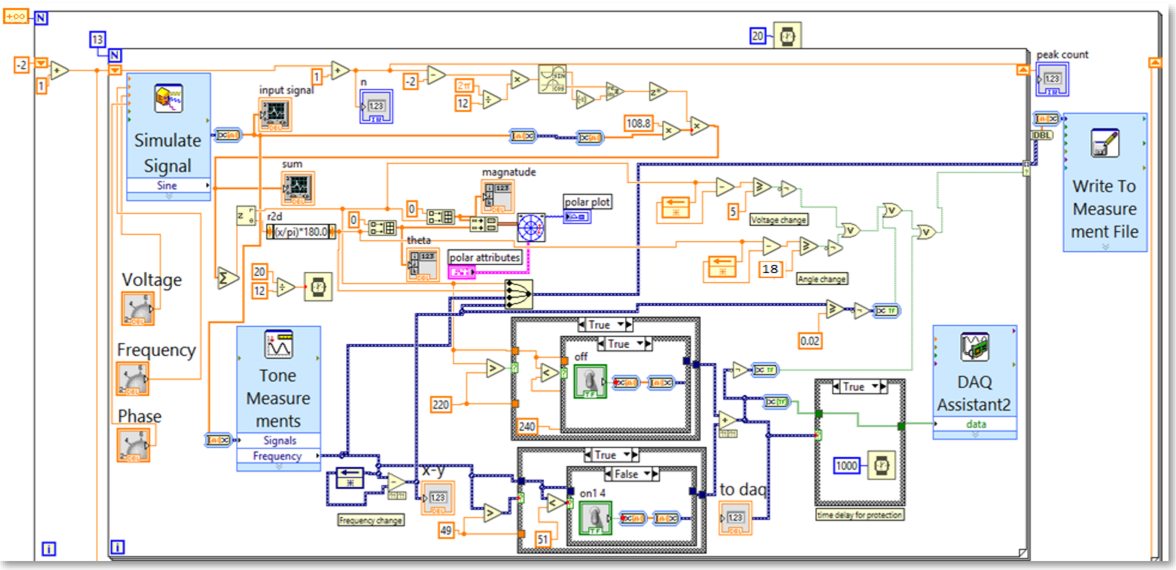

Figure 5. Effective data storsge system uder various distrubances

In the above circuit, the data is stored when there is any change in magnitude of the voltage phasor like in transient period or in a fault condition. During normal operating condition, the magnitude of the voltage is constant so during this period data is not stored in the file thereby it reduces the data storage requirement. In important conditions, total data also can store by removing the conditionally based loop indexing. The capturing of data during the distrubance conditions is shown in the Figure 6.

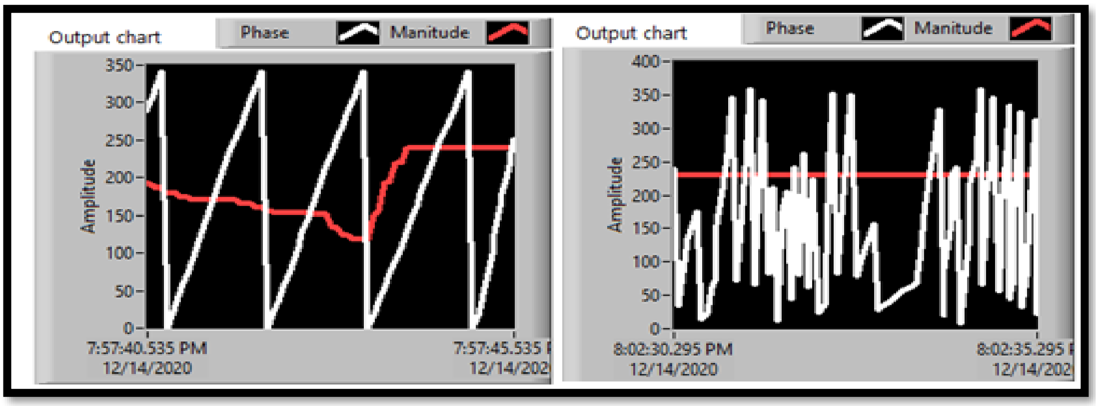

Figure 6. Voltage variation and frequency variation capturing

In the measurement accuracy or protection standards, any changes are occur based on industry requirement then without change of hardware by modifying in the software programme, it can be applied. By providing conditional based storage system, the write to measurement file will store only required data. normally 90% the power system operates under normal operating condition during this period no need to store the data. Whenever any change in magnitude of the voltage phasor occurs due to load change or fault or dynamic state only data is stored in the file. By using the software programme if any case total data need to store then by only enabling the index in for loop (LabVIEW) and by removing condition total data will store in the file. The conditional based storage system data is presented in the Table 1. It shows that when any distrubance occour then only data is stored.

Table 1. Effective data storage system

Time	Instant value (V)	Voltage Magnitude (V)	Phase angle (Deg)	Real value (V)	Imaginary value (V)	Frequency (Hz)
04-12-2020 17:50:54.015	0	229.8097	0	230	0	49.5
04-12-2020 17:50:54.115	100.5137	229.8097	18	151.8727	-172.727	49.7
04-12-2020 17:50:54.215	191.1884	229.8097	36	-29.4316	-228.109	49.8
04-12-2020 17:50:54.315	263.1482	229.8097	54	-190.741	-128.521	49.9
04-12-2020 17:50:54.415	309.3493	229.8097	71.99999	-222.467	58.38069	48.9
04-12-2020 17:50:05.415	-309.349	200.6328	252	179.9096	143.2918	50
04-12-2020 17:51:05.215	-325.269	202.3624	269.9852	225.7825	-43.8435	50
04-12-2020 17:51:05.315	-309.349	208.6235	288	119.0932	-196.766	50
04-12-2020 17:51:05.415	-263.148	213.6598	306	-69.1297	-219.365	50
04-12-2020 17:51:05.515	-191.188	215.3652	324	-210.388	-92.9354	50
04-12-2020 17:51:05.615	-100.514	217.3253	342	-208.716	96.63179	50
04-12-2020 17:51:05.715	0	221.3569	0	230	0	50
04-12-2020 17:53:26.115	100.5137	240.2536	18	151.8727	-172.727	50
04-12-2020 17:53:26.215	191.1884	241.8097	36	-29.4316	-228.109	50
04-12-2020 17:53:26.315	263.1482	243.5632	54	-190.741	-128.521	50
04-12-2020 17:53:26.415	309.3493	246.3214	71.99999	-222.467	58.38069	50
04-12-2020 17:53:26.515	325.2691	248.1431	89.98517	-99.9965	207.1249	50
04-12-2020 17:53:26.615	309.3493	245.3652	108	86.36702	213.1683	50
04-12-2020 17:53:26.715	263.1482	241.3698	126	217.1164	75.89786	50
04-12-2020 17:53:26.815	191.1884	240.3658	144	200.3641	-112.935	50
04-12-2020 17:56:26.615	309.3493	245.3652	108	86.36702	213.1683	50.2
04-12-2020 17:56:26.715	263.1482	245.3652	126	217.1164	75.89786	50.3
04-12-2020 17:56:26.815	191.1884	245.3652	144	200.3641	-112.935	50.5
04-12-2020 17:56:26.615	309.3493	245.3652	108	86.36702	213.1683	51.6
04-12-2020 17:56:26.715	263.1482	245.3652	126	217.1164	75.89786	51.3
04-12-2020 17:56:26.815	191.1884	245.3652	144	200.3641	-112.935	50.9
04-12-2020 17:59:34.015	0	229.8097	0	230	0	50
04-12-2020 17:59:34.115	100.5137	229.8097	25	151.8727	-172.727	50
04-12-2020 17:59:34.215	191.1884	229.8097	59	-29.4316	-228.109	50
04-12-2020 17:59:34.315	263.1482	229.8097	48	-190.741	-128.521	50
04-12-2020 17:59:34.405	309.3493	229.8097	30	-222.467	58.38069	50

5. CONCLUSION

In this paper, the three-phase voltage phasor measurement is implemented based on direct phasor calculation algoritham. The data is stored during only the disturbance conditions with this required data storage system is less. The disturbances are created artificially and tested for less data storage system. The voltage magnitude and phase angles are represented by the polar plot which shows the live picture of the power system. This is very helpful to the system operator to know the exact state of the system at any instant to take necessary actions against abnormal conditions. This technology is adaptive which can apply for any type of the system without modifying hardware by changing only in software. In this technology only required data is stored from the system. This data is enough for effective monitoring, protection and post-disturbance analysis of the power system.

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