

Realization of Enhanced Phase Locked Loop using Raspberry Pi and LabVIEW

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Abstract— Real-time data is gaining more importance in engineering. With archived data and the real-time data, utilities are making systems more robust by developing new methods for controlling and monitoring. Frequency information of the system is one of the key factors for better controlling and monitoring purpose. So acquiring real-time frequency information at a low cost is really important. Raspberry Pi based frequency data acquisition is one of the solutions to get data remotely. This paper discusses two main topics: (i) The complete procedure for acquiring the real-time data using Raspberry Pi, Multi-chip package 3008 and LabVIEW. (ii) Modeling of Enhanced Phase Locked Loop (PLL) and its integration with the data acquisition system for processing the real-time data to extract the frequency and amplitude information.

Index Terms—Phase Locked Loop (PLL), Adaptive Filter (AF), Data Acquisition, Data Processing, Raspberry Pi, Multi-chip package (MCP) , LabVIEW, Interfacing, Analog to digital converter (ADC)

I. INTRODUCTION

Accurate information regarding the phase angle and the frequency of the voltage is necessary for stable operation of grid-connected power electronic devices [1], [2]. Ideally, the AC system frequency is constant. Due to changes in power generation, consumption, and presence of nonlinear elements, there will be distortions in the AC system which causes frequency deviation [3]. Filters can nullify the distortions caused by the system components, but distortion might exist in phase angle due to unbalance in power generation and consumption. The phase-locked loop (PLL) gives the accurate frequency information used to compensate these distortions. The standard block diagram of the single-phase PLL consists of three components, namely Phase Detector (PD), Loop Filter (LF) and Voltage Controlled Oscillator (VCO). PD generates the signal by comparing the phase of the input and the feedback signal (i.e., output signal). The output of PD consists of two components, the signal corresponding to the difference between the phase of the input signal and the feedback signal and the other one is double frequency ripple [3]. The proper and accurate designing of loop filter bandwidth nullifies double-frequency ripple and the noise in the PD output signal. VCO takes the input of LF and generates the corresponding output.

Many industries are using real-time data to develop new methods for controlling and monitoring operations. Real-time

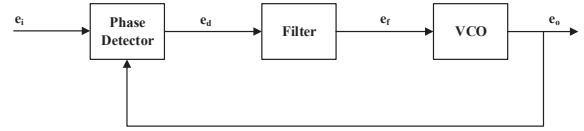


Fig. 1. Single phase PLL block diagram.

data can be defined as the data presented right after acquisition. In the power industry, utilities are making systems more reliable, clean and affordable by using the saved data and real-time data with data analytics. Many applications of energy big data analytics use real-time data collection and real-time actions for automated operations and control [4]. Real-time data monitoring and controlling of distributed energy resources can address issues such as reverse power flow in distribution feeders [4].

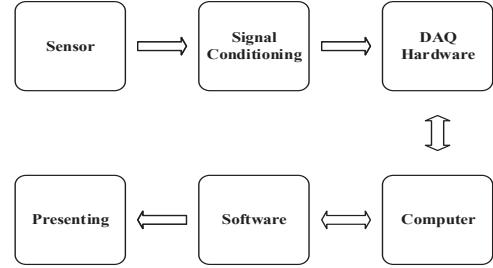


Fig. 2. Real time data acquisition process.

[5]–[7] explains the importance of real-time data in the present world. Data processing is the intermediate step between data acquisition and processing. Data processing is a step by step procedure to retrieve the necessary information from the data acquired. So the term real-time data indicates a combination of two steps namely, data acquisition (DAQ) and data processing(DP). DAQ is the process of collecting the signal with information and passing it to the computer (i.e., the interfacing of real-time physical parameters with the digital computer world). DAQ system involves interfacing of hardware and software (software helps in controlling the hardware). Main hardware components of the DAQ systems are sensors, analog to digital converters (ADC) and Programmer Sequencer. Sensors sense the physical parameters and generate the analog signal corresponding to the parameter value. Signal conditioning block removes the noise in the analog signal and

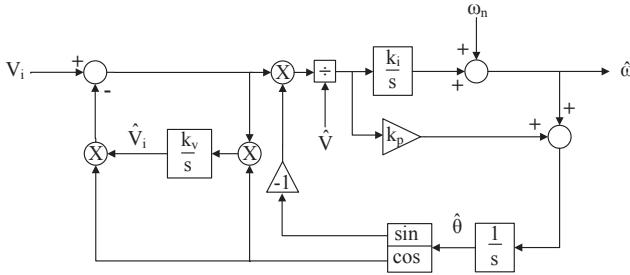


Fig. 3. Block diagram of Enhanced PLL [10]. V_i is the input voltage signal. $\hat{\omega}$, $\hat{\theta}$ and \hat{V}_i are the estimated frequency, phase angle and amplitude, respectively. k_p and k_i are the proportional and integral gain of frequency estimation loop, respectively, and k_v is the proportional gain of amplitude estimation loop. Nominal frequency $\omega_n = -377$ rad/sec.

brings the measured value to the ADC range. ADC converts the analog signal received from the sensor to digital values. Program Sequencer is the digital control unit used to control the hardware in collecting the data. The processing of acquired data gives the additional necessary information.

The rest of the paper is organized as follows. Section II gives the modeling of enhanced PLL, Benchmark test, and testing the enhanced PLL in the grid-connected photovoltaic system. Section III gives the system design, which includes, the description of hardware components used in system design, interfacing of Raspberry Pi with MCP3008, and interfacing of Raspberry Pi with LabVIEW. Section IV gives the complete the procedure of data acquisition and processing of the acquired data using enhanced PLL in LabVIEW.

II. ENHANCED PLL

Power industry companies are using enhanced PLL because of its capability to provide an output signal whose magnitude, phase, and frequency are locked with an input signal fundamental component [8]. Enhanced PLL uses Adaptive Filter (AF) and sinusoidal multiplier for phase detection. AF is used to estimate the input voltage by reducing the objective function so that the frequency of enhanced PLL will be free of oscillations [9]. So enhanced PLL is capable of providing a real-time estimate of the fundamental components (amplitude, phase, and frequency) of the input signal. Fig.3 gives the block diagram of the Enhanced PLL. Along with fundamental components, enhanced PLL gives the accurate estimate of real-time parameters (like amplitude, phase, and frequency) [8]. Adding a low pass filter after VCO helps in obtaining a smooth estimate of the phase angle. Linking together of four enhanced PLL's gives the advantage of using it in three-phase applications [8].

A. Benchmark Test

To find the responses of the enhanced PLL the following tests are conducted and the corresponding performances of enhanced PLL are measured and plotted.

Test 1: With step change on input voltage phase from 0 to 5 at $t = 0.5$ seconds.

Test 2: With step change on input voltage magnitude form 1 volt to 2 volts at $t = 0.5$ seconds.

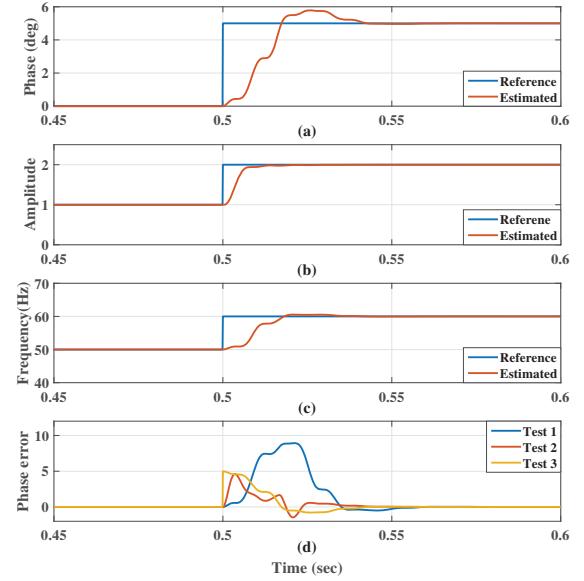


Fig. 4. Performance of enhanced PLL to (a) Test 1, (b) Test 2, (c) Test 3, and (d) phase errors of Test 1, 2, and 3.

Test 3: With step change on input voltage frequency from 50 Hz to 60Hz at $t = 0.5$ seconds.

Enhanced PLL control parameters used in benchmark testing are from [11]. The frequency and the amplitude of the input signal are 1 p.u. and 60 Hz respectively. Figs. 4 (a-c) illustrates the response of enhanced PLL corresponding to the tests 1,2 and 3. Fig. 4 (d) gives the phase error of the enhanced PLL to all the tests. From the figures, we can see that the amplitude and frequency estimated by enhanced PLL reach the reference value in 0.02 seconds, which is fast and accurate.

B. Enhanced PLL Testing on Grid Connected Photo-voltaic (PV) Test Bed

TABLE I
PARAMETERS OF GRID CONNECTED PV SYSTEM

Parameter	Value
Rated power	250 kW
DC-link voltage	480V
Grid voltage	25kV
Grid frequency	60 Hz
Dc- link capacitor	54300 μ F
Transformer 1 ratio	25kV/250V

The major aim of this section is to find the response of the enhanced PLL in PV integration with the grid. PV test bed is taken from Matlab Simulink model [12]. Table 1 gives the parameters of the testbed. Testbed is subjected to two dynamic events (i) phase-to-ground (phase 'a' to ground) and (ii) phase-to-phase fault(phase 'a' to phase 'b') faults are applied at the point of common coupling (PCC). The per unit value of phase 'a' data is used to find the response of the enhanced PLL. In Fig 6 though the input in phase-to-ground fault shows zero,

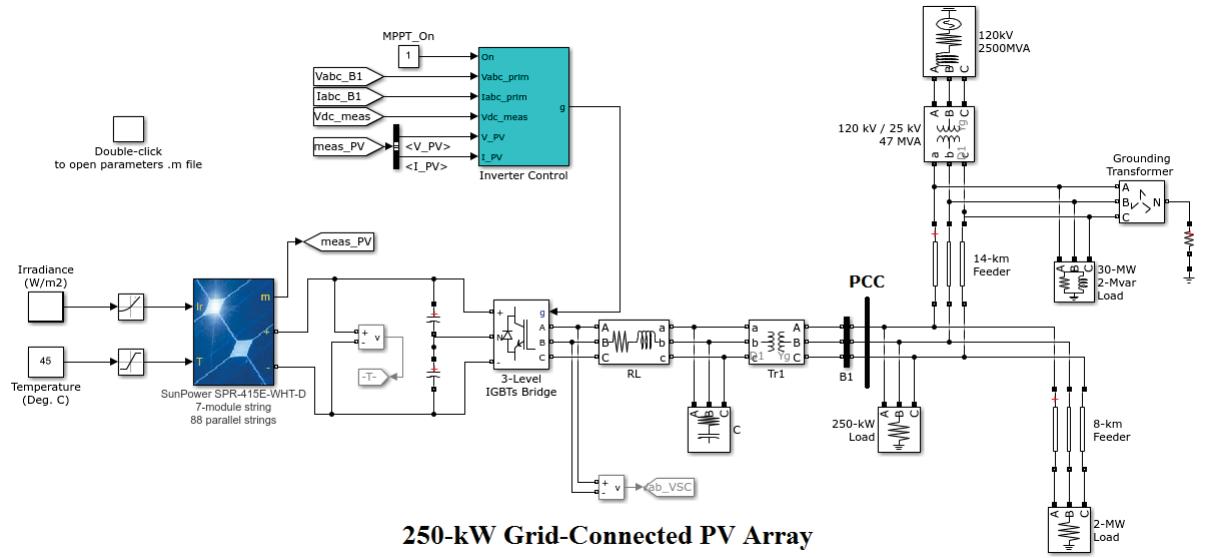


Fig. 5. Detailed Matlab simulink model of 250 kW PV connected to 25kV grid [12].

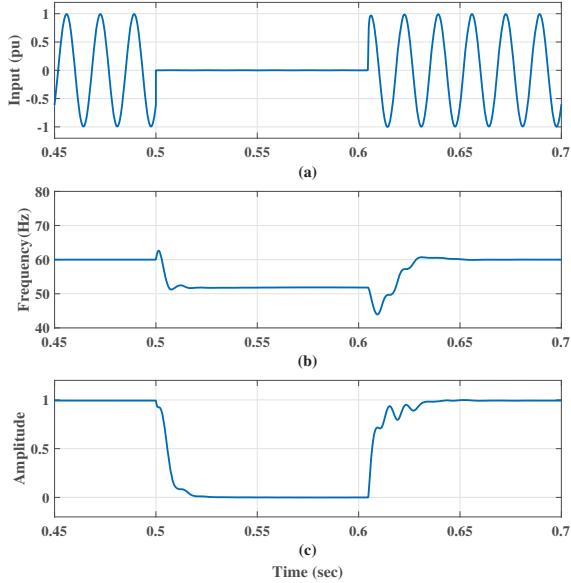


Fig. 6. Performance of enhanced PLL to phase to ground fault (a) Phase A voltage at PCC bus, (b) Estimated Frequency from PLL, (c) Estimated amplitude from PLL.

the measured frequency shows a frequency value because of the presence of nominal frequency with the additional block in frequency estimation loop. Fig 7 gives the response of enhanced PLL for the phase-to-phase fault.

III. SYSTEM DESIGN

A. Hardware

1) *Raspberry Pi*: Raspberry Pi is a small sized (85.6mm x 56.5mm and weighs about 45 grams) micro controller board, which can perform regular small operations done by a normal computer. Raspberry Pi is widely used in DAQ due to its

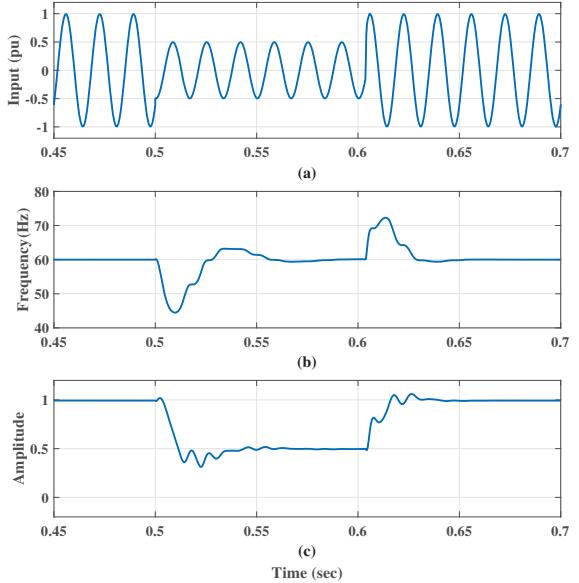


Fig. 7. Performance of enhanced PLL to phase to phase fault (a) Phase A voltage at PCC bus, (b) Estimated Frequency from PLL, (c) Estimated amplitude from PLL.

features like open platform, low cost, small size, etc. Here on, term Raspberry Pi refers to Raspberry Pi 2.0 Model B V1.2 which has 1GB RAM, 900MHz Quad-core ARM Cortex A7 processor. It has four 2.0 USB ports, one Ethernet port, one HDMI port and one 3.5 audio jack as shown in Fig. 8.

2) *MCP3008*: MCP3008 is a 10-bit analog to digital converter (ADC). On left side MCP3008 has 8 analog inputs, and the right side has control pins and digital output pins. MCP3008 can operate in the voltage range of 2.7V to 5.5V. It converts the analog physical quantity to a digital value, which represents the quantity's amplitude. V_{REF} is the highest

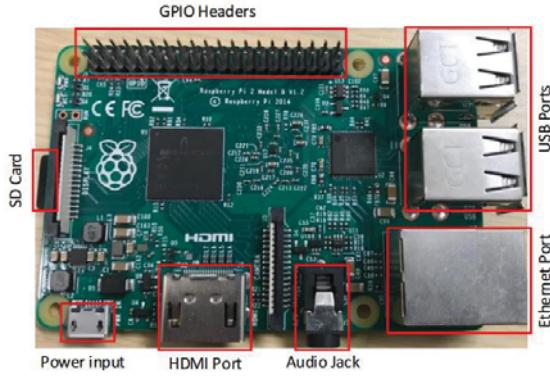


Fig. 8. Raspberry Pi Top View.

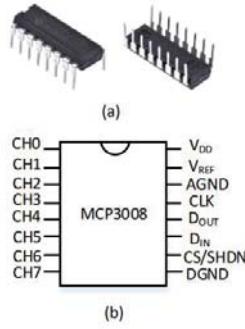


Fig. 9. (a) MCP3008 chip top and bottom views, (b) MCP3008 pin diagram [13].

possible voltage that the ADC can interpret (i.e., 3.3 Volts in this case). The converted digital output can be represented using the formula given below.

$$V_{\text{Digital}} = 1024 \times \frac{V_{\text{in}}}{V_{\text{REF}}}$$

B. Interfacing

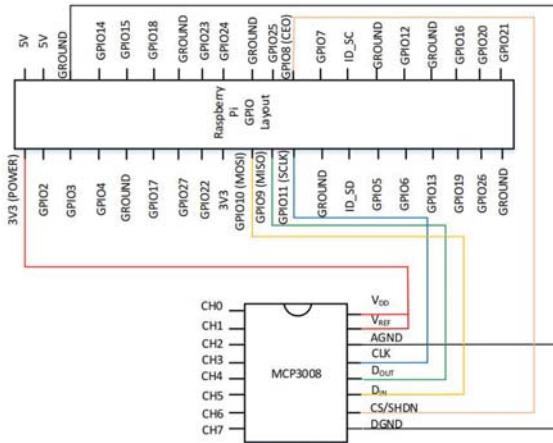


Fig. 10. Interfacing of Raspberry Pi with MCP3008 [14].

1) *Raspberry Pi and MCP3008:* Raspberry Pi does not have an in-built analog to digital converter. So separating analog to digital converter (MCP3008) is used to convert

the input analog signal into digital and the converted digital signal is fed to Raspberry Pi [14]–[16]. The connection to V_{DD} and ground from raspberry pi power-ups the MCP3008. V_{REF} is the voltage used by MCP3008 as a reference in converting the analog signal to digital. The line connecting the CLK of MCP3008 and SCLK of raspberry pi keeps them in synchronization. The line connecting CS/SHDN of MCP3008 and GPIO8(CE0) of raspberry pi is called a data line used to transfer the converted digital values. Lines connecting MOSI, MISO of raspberry pi and D_{IN} , D_{OUT} respectively, helps in establishing a proper connection before transferring the data. Raspberry Pi (master) sends a bit on MOSI (Master Out Slave In) and the MCP3008 (slave) reads it in D_{IN} , likewise, MCP3008 (slave) sends a bit on D_{OUT} and the raspberry pi (master) reads it. Once this process is successful, the data transfer takes place [16]. Fig. 10 shows the connection pin diagram.

2) *Raspberry Pi and LabVIEW:* LabVIEW is a graphical programming software, with the flexibility of building different applications, observe every aspect, which includes debugging, data measurement and hardware configuration. It is a powerful tool which can handle real-time data acquisition and processing. LabVIEW VI has two components named front panel (user interface) and block diagram (back end includes implementation of graphical programming). Makerhub Linx provides the features of connecting raspberry pi with LabVIEW. Linx is an extension to LabVIEW which helps the LabVIEW VI to easily interact with the embedded platforms like myRIO, chipKIT, and Arduino. [17] provides the download link for Linx. LabVIEW BCM2835 Library are necessary for LabVIEW VI to interact with the Raspberry Pi. [18] gives the complete procedure to install the BCM2835 library. Opening and closing of BCM2835 library is necessary for every run of LabVIEW DAQ VI. Table II gives LabVIEW DAQ VI settings.

TABLE II
LABVIEW VI SETTINGS

Control	Selection
Clock Divider	256 (976.6kHz)
CS Polarity	Active LOW
Chip Select	CS0
Clock Divider	256
Mode	0
Channel Select	CH0 (6 to +ve and 7 to -ve)
V_{REF}	3.3
Loop Time	1

IV. DATA ACQUISITION AND PROCESSING

Figs. 12 and 13 shows the block diagram and experimental setup of DAQ system using Raspberry Pi, MCP 3008, and LabVIEW. The input sinusoidal signal is generated using the analog signal generator. MCP3008, operates only with DC voltage, so DC offset value is applied to the sinusoidal signal generated by the analog signal generator to push the signal to the positive x-axis. Later, same negative DC offset value is added to the acquired data in LabVIEW to bring back the

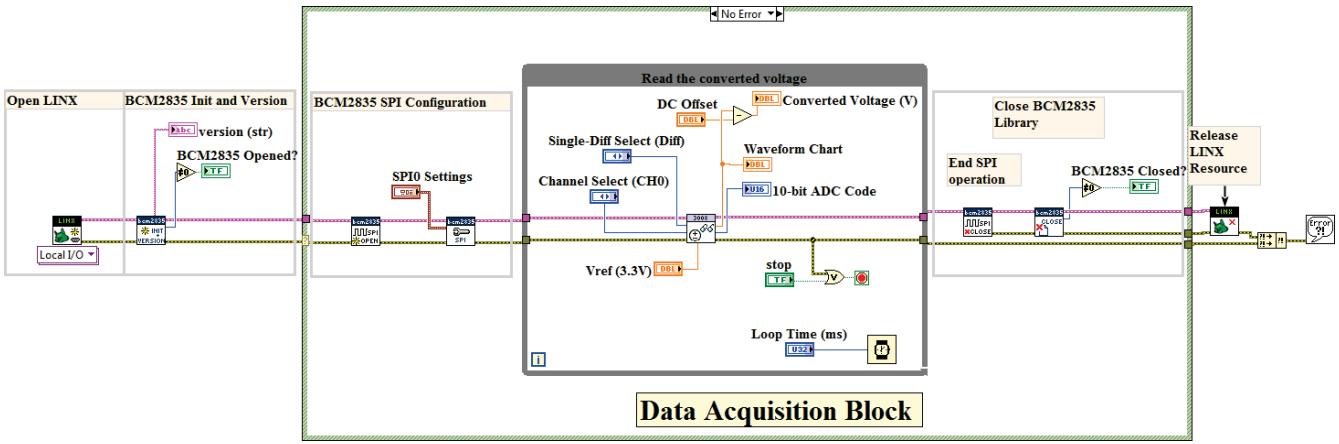


Fig. 11. LabVIEW data acquisition VI block diagram.

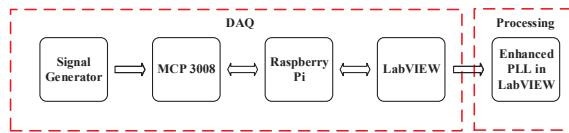


Fig. 12. Blocked diagram of proposed data acquisition system.

signal to sinusoidal form. After converting the analog signal to digital using MCP3008, data is passed to Raspberry Pi. The generated analog signal is converted to digital using MCP 3008 and is given to Raspberry Pi. Here Canakit (helps in easy accessibility of raspberry pi GPIO pins) and breadboard (helps in making easy connections) is used for interfacing the raspberry pi and MCP 3008. LabVIEW VI shown in Fig. 11 acquires the converted signal to LabVIEW by establishing the serial connection between the Raspberry Pi and the LabVIEW. Data processing VI shown in Fig. 14 uses enhanced PLL for LabVIEW data processing to retrieve the frequency and magnitude information.

The signal generator output is selected as a sinusoidal signal. Input signal parameters are set to unity amplitude and 60 Hz frequency using an oscilloscope and are given as input to the data acquisition system. Running LabVIEW DAQ VI acquires the digital signal into LabVIEW. Fig. 15(a) gives the sample of the acquired signal. Enhanced PLL processes the acquired signal to retrieve the amplitude (Fig. 15(b) gives the sample of measured amplitude) and frequency (Fig. 15(c) gives the sample of measured frequency). Microsoft Excel is used for plotting extracted data.

V. CONCLUSION

Benchmark test of enhanced PLL is conducted. Performance of enhanced PLL in grid-connected PV system is evaluated by applying dynamic events and corresponding responses is presented. The data acquisition system using Raspberry Pi and MCP 3008, proposed in this paper can provide good means of data acquisition with low cost and it is easy to install and maintain. By processing the acquired signal using enhanced PLL, the frequency and amplitude information can

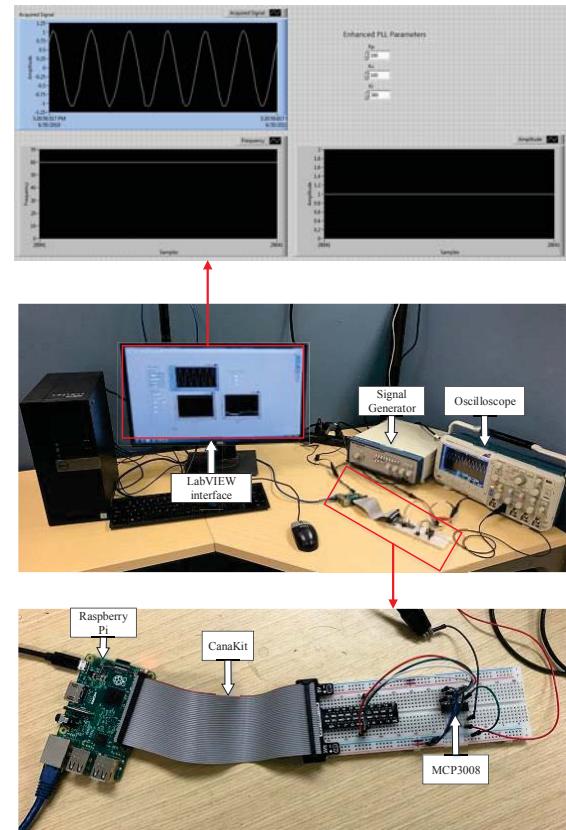


Fig. 13. DAQ hardware setup.

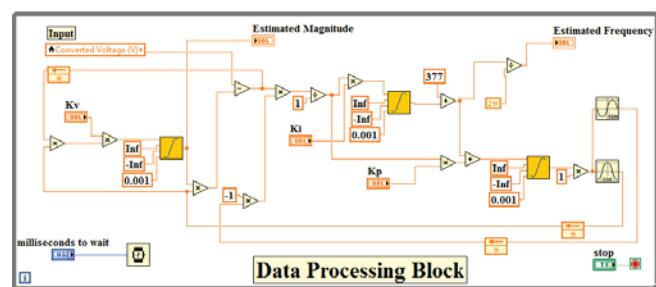


Fig. 14. Implemented enhanced PLL in LabVIEW VI.

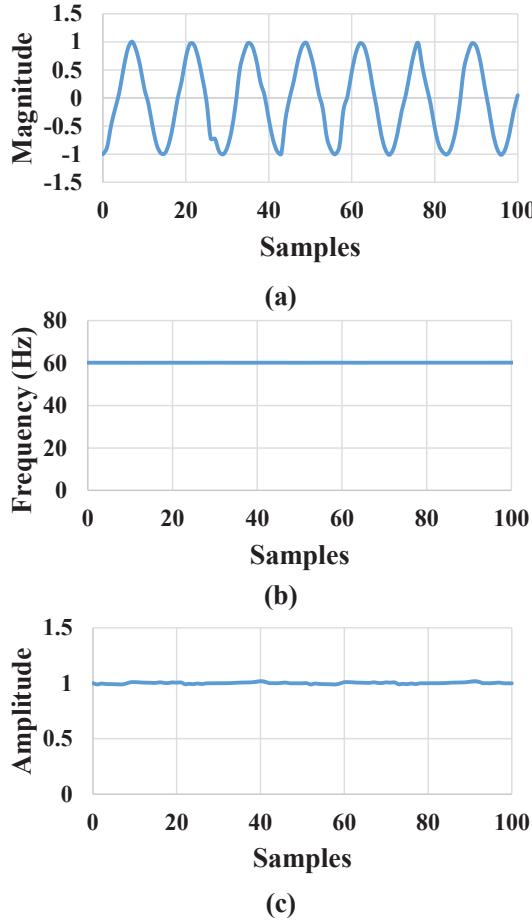


Fig. 15. (a) Sample of the input signal acquired in LabVIEW, (b) Sample of the estimated amplitude by enhanced PLL in LabVIEW and (c) Frequency response of enhanced PLL in LabVIEW.

be accurately measured. The acquired data can be made available online for more reliable and stable operations.

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