Realization of Enhanced Phase Locked Loop Using Raspberry Pi and LabVIEW

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Outline

- Introduction
- Enhanced PLL
  - (i) Benchmark Testing
  - (ii) Dynamic event Testing
- Interfacing
- Experimental Setup
- Results
- Conclusion

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Introduction

- 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 [1].

- Ideally, the AC system frequency is constant, but due to changes in power generation, consumption, and presence of nonlinear elements, there will be distortions in the AC system which causes frequency deviation [2].

[1] H. Akhavan-Hejazi and H. Mohsenian-Rad, "Power systems big data analytics: An assessment of paradigm shift barriers and prospects," *Energy Reports*, vol. 4, pp. 91 – 100, 2018.
[2] S. Eren, M. Karimi-Ghartemani, and A. Bakhshai, "Enhancing the three-phase synchronous reference frame pll to remove unbalance and harmonic errors," *in 2009 35th Annual Conference of IEEE Industrial Electronics*, Nov 2009, pp. 437–441.

Introduction

- 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 [2].

- The phase-locked loop (PLL) gives the accurate frequency information used to compensate these distortions.

- So there is a need to understand the operation PLL structure with real time data . In this paper Enhanced PLL is realized with real time data using the Raspberry Pi and LabVIEW.

[2] S. Eren, M. Karimi-Ghartemani, and A. Bakhshai, "Enhancing the three-phase synchronous reference frame pll to remove unbalance and harmonic errors," *in 2009 35th Annual Conference of IEEE Industrial Electronics*, Nov 2009, pp. 437–441.

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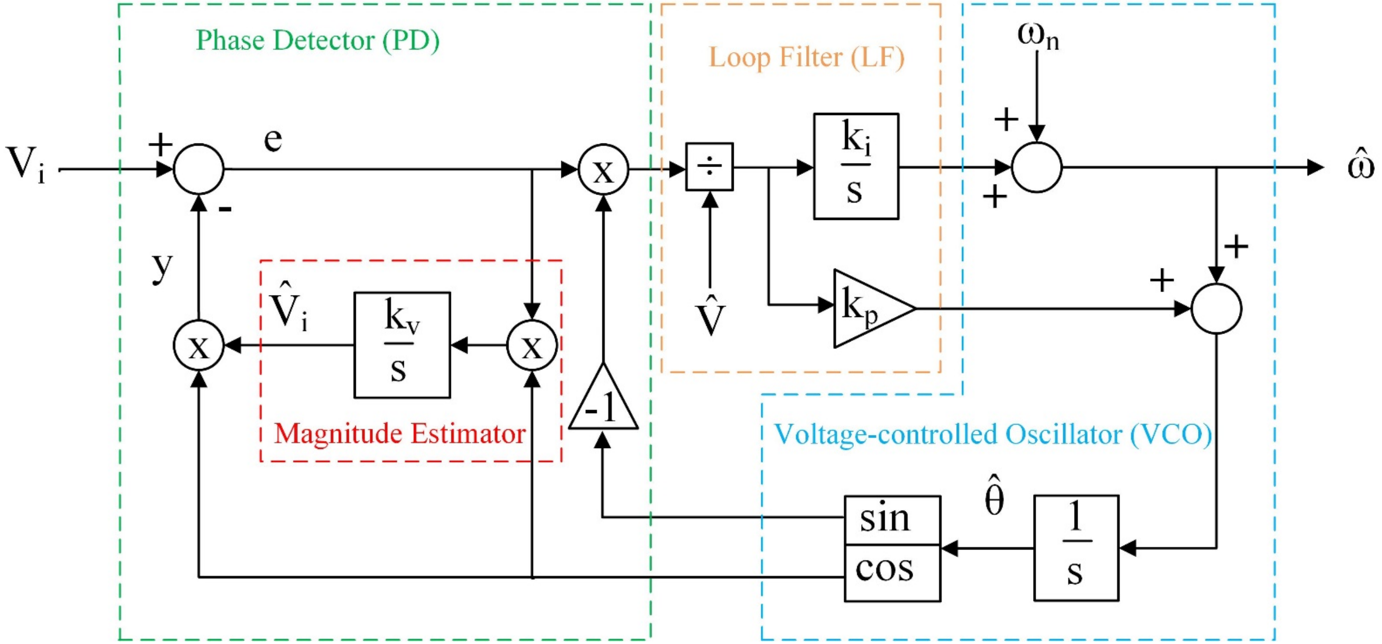
Enhanced PLL (EPLL)



Block diagram of Enhanced PLL [3]. V_i is the input voltage signal. $\hat{\omega}$, $\hat{\theta}$ and $\hat{V}_i$ are the estimated frequency, phase angle and amplitude, respectively. y and e are the output and error signals. 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 ω_n = 377 rad/sec.

- Input signal $v_i(t)$ is compared with output signal y(t) to generate the error signal e(t). The error signal will have the difference of phase between input (V_i)and output signal (y). The error signal e(t) is given to LF to generate the driving signals for VCO
- k_p and k_i controls the rate of convergence of the phase and frequency.
- kv controls the rate of convergence of amplitude.
- LF is incorporated in VCO before integrator to obtain the smooth estimate of the phase angle when the input signal is distorted [4].

[3] S. Golestan, J. M. Guerrero, and J. C. Vasquez. Modeling and stability assessment of single-phase grid synchronization techniques: Linear time-periodic versus linear time-invariant frameworks. IEEE Transactions on Power Electronics, 34(1):20–27, Jan 2019. ISSN 0885-8993. doi: 10.1109/TPEL.2018.2835144.
[4] Karimi-Ghartemani, Masoud, and M. Reza Iravani. "A method for synchronization of power electronic converters in polluted and variable-frequency environments. " *IEEE Transactions on Power Systems* 19.3 (2004): 1263-1270.

Enhanced PLL (EPLL)

Features of EPLL

- Eliminates the double frequency oscillations in the steady state [3].
- EPLL is capable of providing an real time estimate of the fundamental component of the input signal variations in amplitude and frequency by following its variations [4].
- EPLL provides many meaningful signals like estimated amplitude, estimated frequency, estimated phase, estimated rate of change of frequency, estimated rate of change of amplitude, estimated fundamental component (y) and total distortion (e) [5].

[3] S. Golestan, J. M. Guerrero, and J. C. Vasquez. Modeling and stability assessment of single-phase grid synchronization techniques: Linear time-periodic versus linear time-invariant frameworks. IEEE Transactions on Power Electronics, 34(1):20–27, Jan 2019. ISSN 0885-8993. doi: 10.1109/TPEL.2018.2835144.
[4] Karimi-Ghartemani, Masoud, and M. Reza Iravani. "A method for synchronization of power electronic converters in polluted and variable-frequency environments. " *IEEE Transactions on Power Systems* 19.3 (2004): 1263-1270.
[5] Karimi-Ghartema, Masoud. Enhanced phase-locked loop structures for power and energy applications. John Wiley & Sons, 2014.

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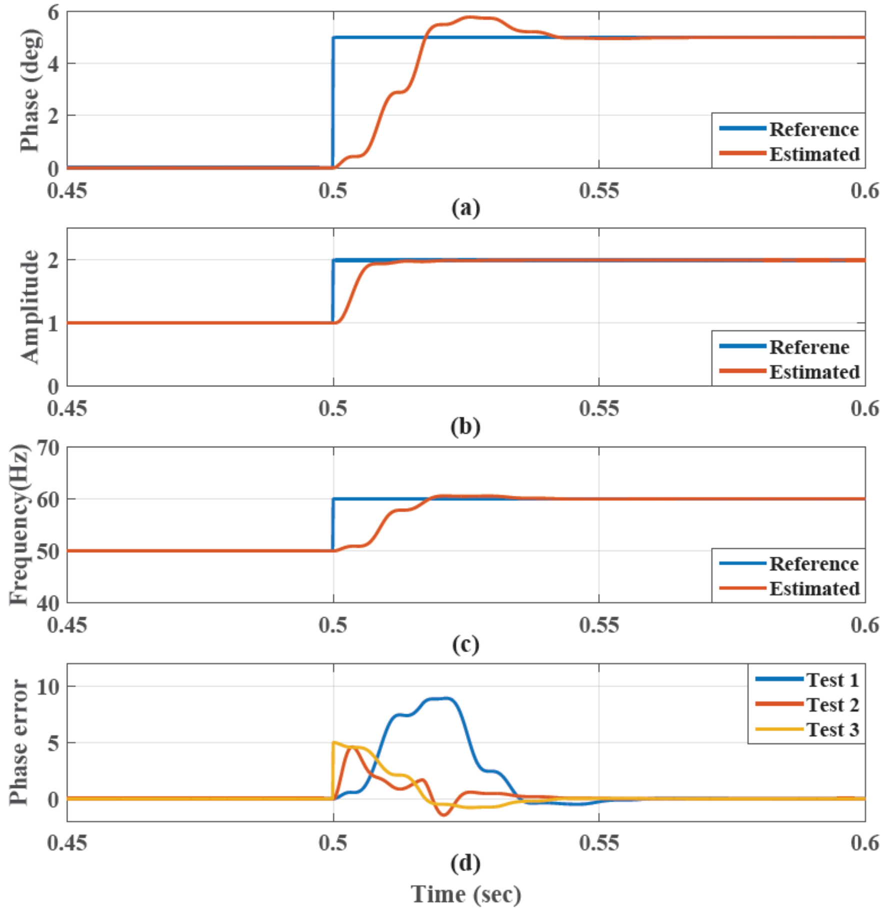
Benchmark Testing

The amplitude and the frequency of input signal are taken as 1 p.u. and 60 Hz respectively.

- Test 1: A step change is applied on the input voltage phase: from 0 to 5 at t = 0.5 seconds.
- Test 2: A step change is applied on input voltage magnitude: from 1 volt to 2 volts at t = 0.5 seconds
- Test 3: A step change is applied on input voltage frequency: from 50 Hz to 60Hz at t = 0.5 seconds

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.



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

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Dynamic Event Testing

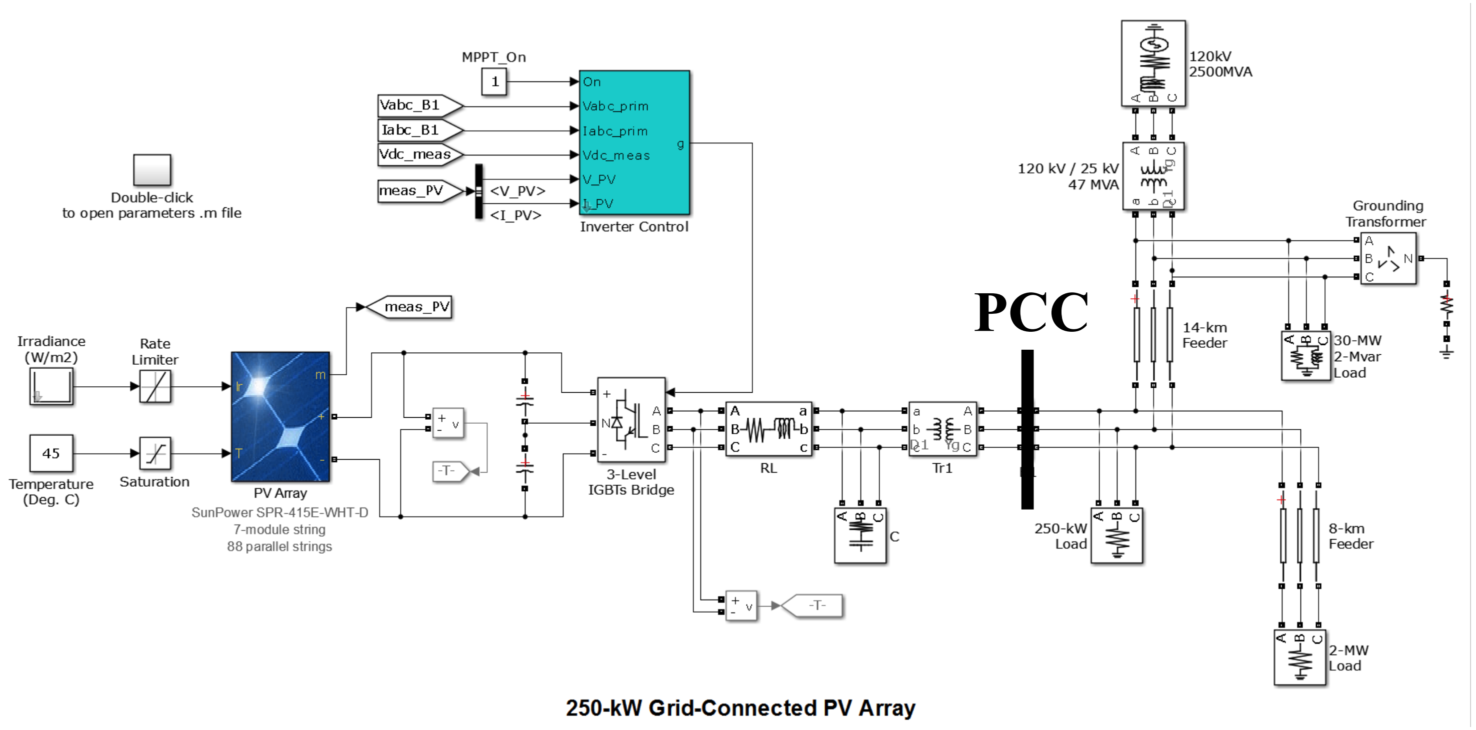
- Testbed is subjected to two dynamic events

  (i) phase-to-ground fault (phase ’a’ to ground)

  (ii) phase-to-phase fault(phase ’a’ to phase ’b’)

  faults are applied at the point of common coupling (PCC).

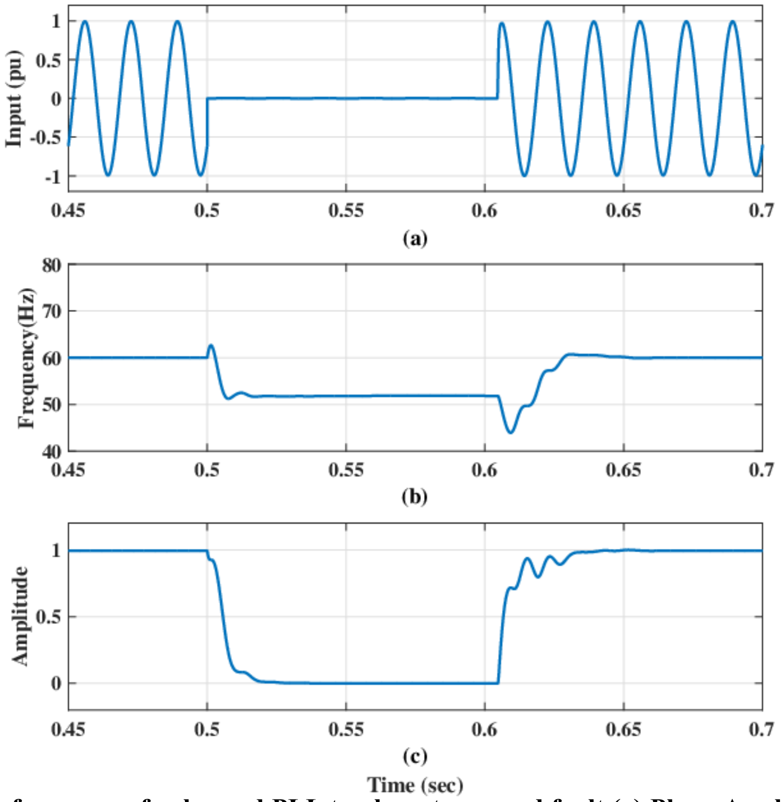
- The per unit value of phase ’a’ data is used to find the response of the enhanced PLL.



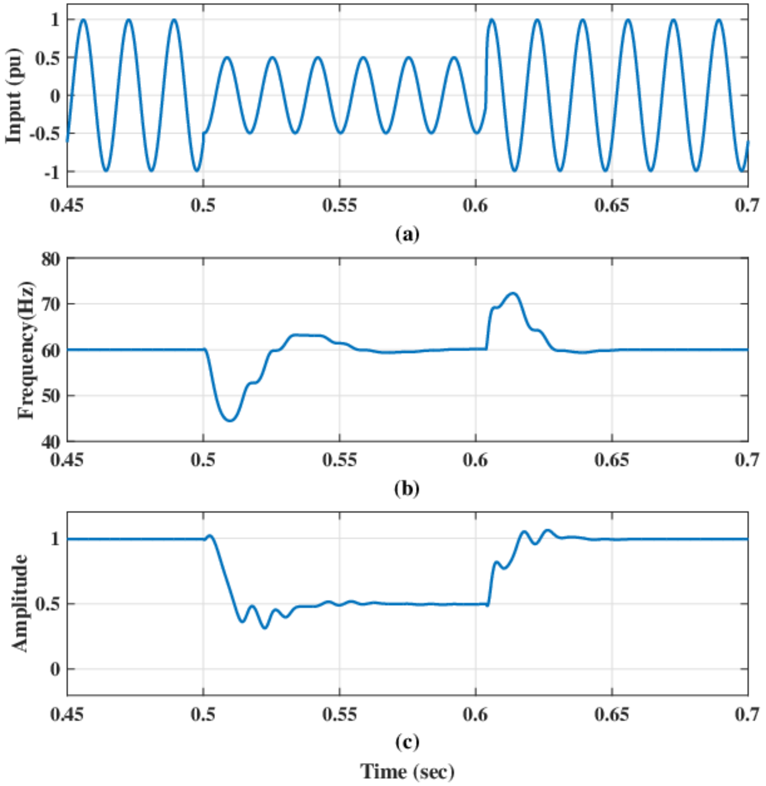
Detailed Matlab Simulink model of 250 kW PV connected to 25kV grid [6]

[6] Matlab, “A detailed model of a 250-kw pv array connected to a 25-kv grid via a three-phase converter.” [Online]. Available: https://www.mathworks.com/help/physmod/sps/examples/250-kwgrid-connected-pv-array.html

Dynamic Event Testing



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.



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.

- Though the input in phase-to-ground fault shows zero, the measured frequency shows a frequency value because of the presence of frequency limits.

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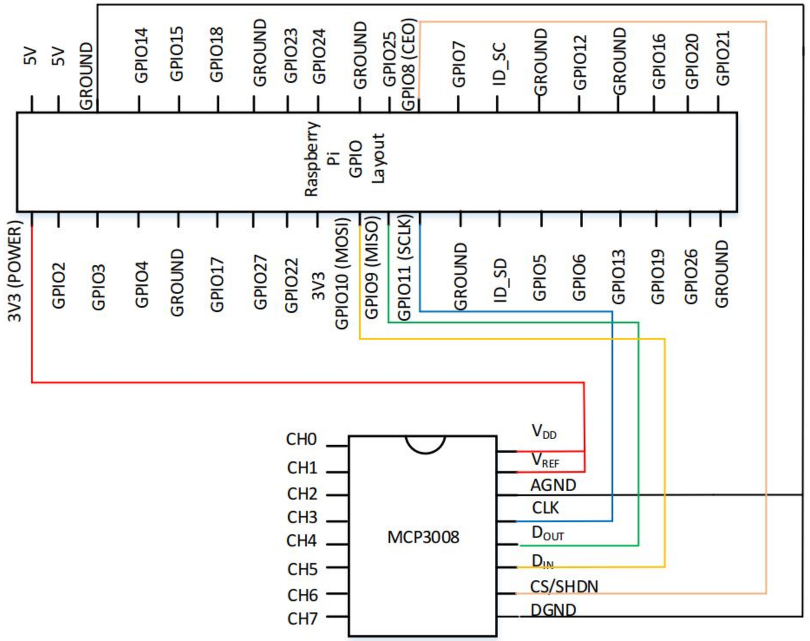
Interfacing

Raspberry Pi and MCP3008

- Raspberry Pi does not have an in-built analog to digital converter. So MCP3008, an analog to digital converter, is used to convert the input analog signal into digital.
- The connection to VDD and ground from raspberry pi power-ups the MCP3008.
- VREF 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.



Interfacing of Raspberry Pi with MCP3008 [7]

[7] A. Gupta, R. Jain, R. Joshi, and R. Saxena, "Real time remote solar monitoring system," in 2017 *3rd International Conference on Advances in Computing, Communication Automation (ICACCA) (Fall)*, Sep. 2017,pp. 1–5.

Interfacing

- Lines connecting MOSI, MISO of raspberry pi and DIN, DOUT respectively, helps in establishing a proper connection before transferring the data.

- 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 [8].

Raspberry Pi and LabVIEW

- Raspberry Pi is interfaced with LabVIEW using Serial Peripheral Interface (SPI).

- LabVIEW BCM2835 library and LINX (LabVIEW extension) must be installed for successful connection of Raspberry Pi and LabVIEW.

[8] P. Patil and K. Bhole, "Real time ecg on internet using raspberry pi," in 2018 *International Conference on Communication, Computing and Internet of Things (IC3IoT),* Feb 2018, pp. 267–270.

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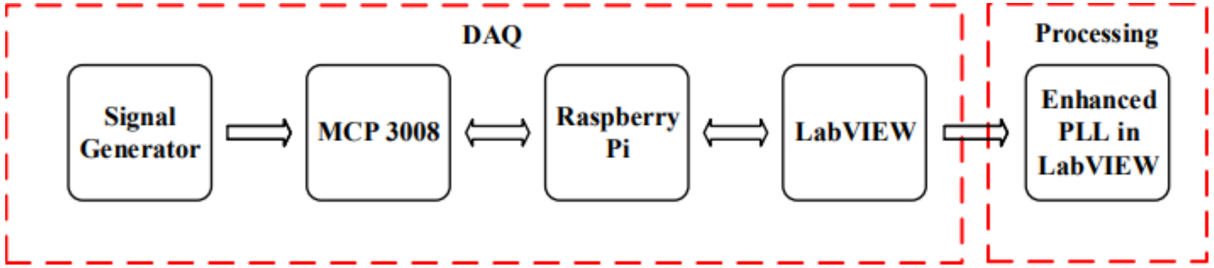
Experimental Setup

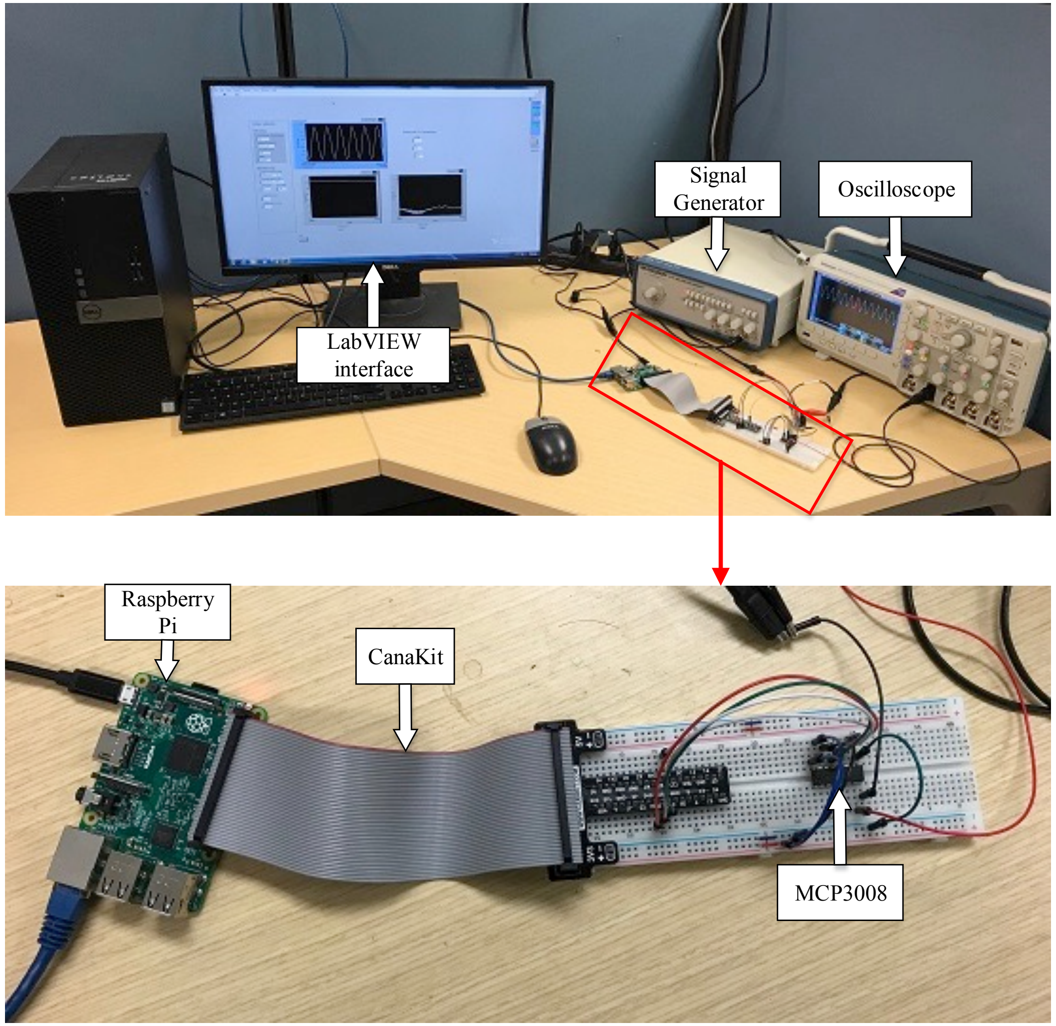


Block diagram of proposed data acquisition and Processing system

- The input sinusoidal signal is generated using the analog signal generator.

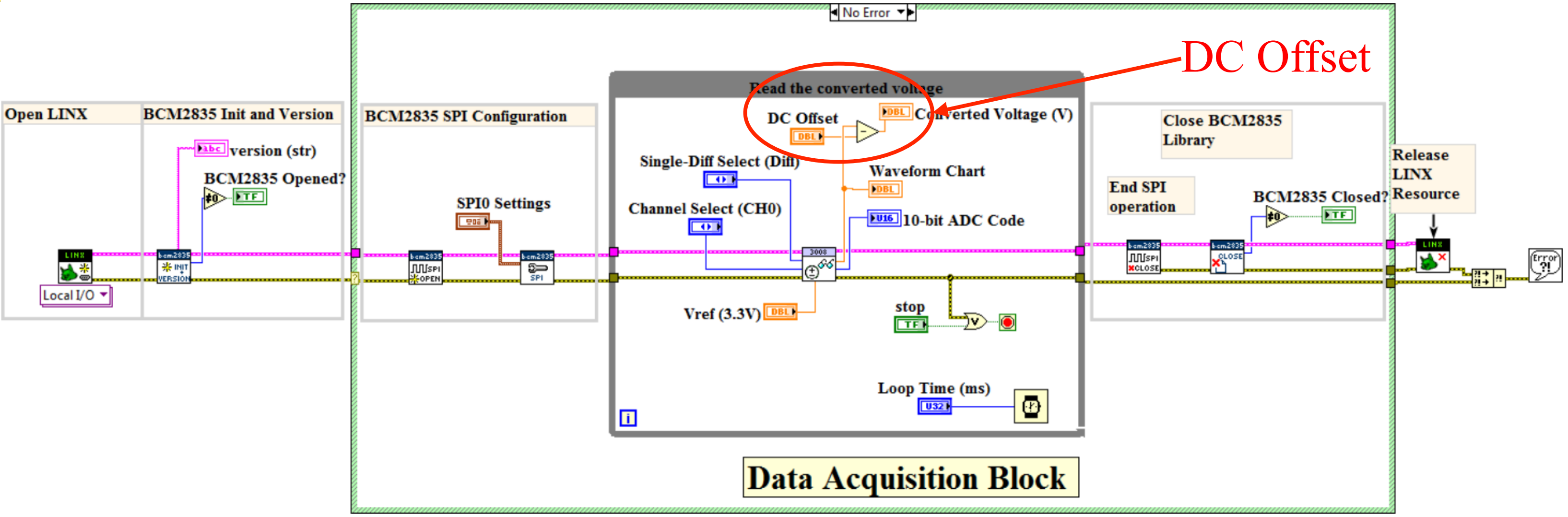
- LabVIEW data acquisition VI acquires the converted signal to LabVIEW by establishing the serial connection between the Raspberry Pi and the LabVIEW.

- Data processing VI uses enhanced PLL for LabVIEW data processing to retrieve the frequency and magnitude information.



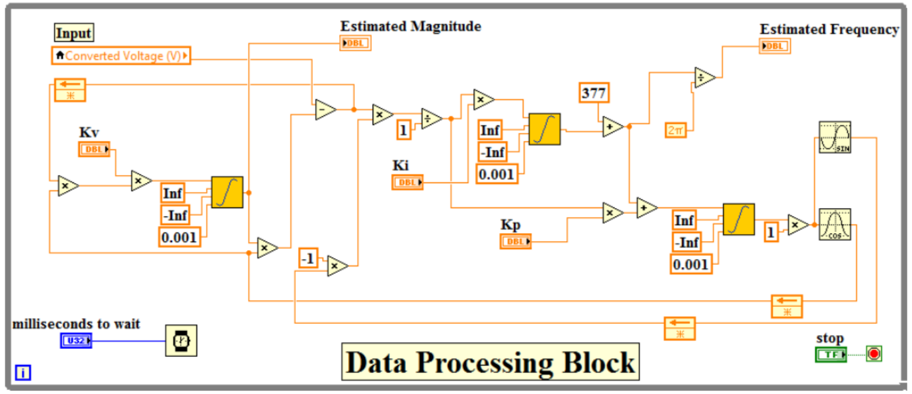
Data Acquisition (DAQ) hardware setup

Data Acquisition and Processing VI



LabVIEW data acquisition VI block diagram

- Since MCP3008, operates with DC voltage only (positive voltage values), so a DC offset value is applied to the sinusoidal signal generated by the analog signal generator.
- Later, the DC offset value is taken off from the acquired data in LabVIEW to bring back the signal to sinusoidal form.



Implemented enhanced PLL in LabVIEW

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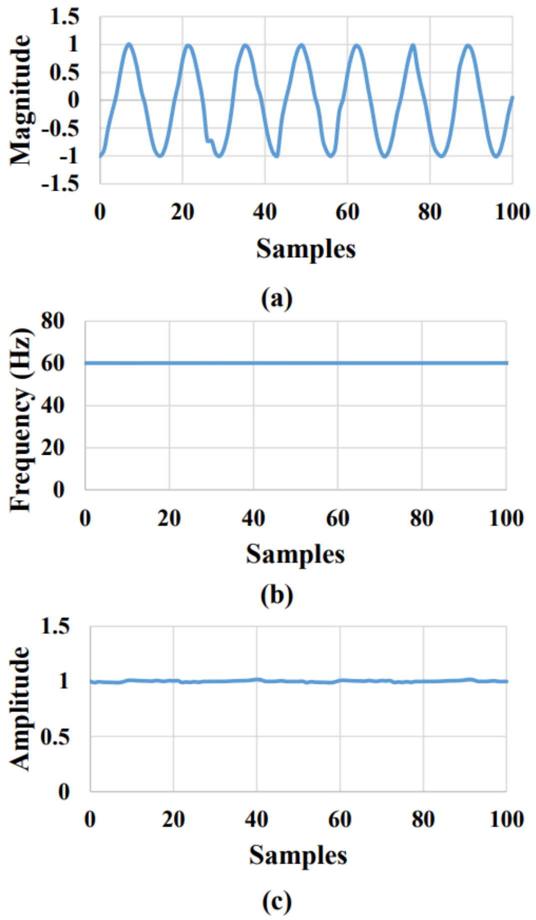
Results

- 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
- Acquired data is processed by LabVIEW processing VI to extract the frequency and amplitude of the signal.



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

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Conclusion

- Single-phase enhanced PLL is realized in hardware using Raspberry Pi and LabVIEW data acquisition system.

- The data acquisition system using Raspberry Pi and MCP 3008, 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 VI, the frequency and amplitude information can be accurately found by LabVIEW control algorithm.

Thank You !