UROP Proposal:

3-Phase AC Power Monitoring Solution

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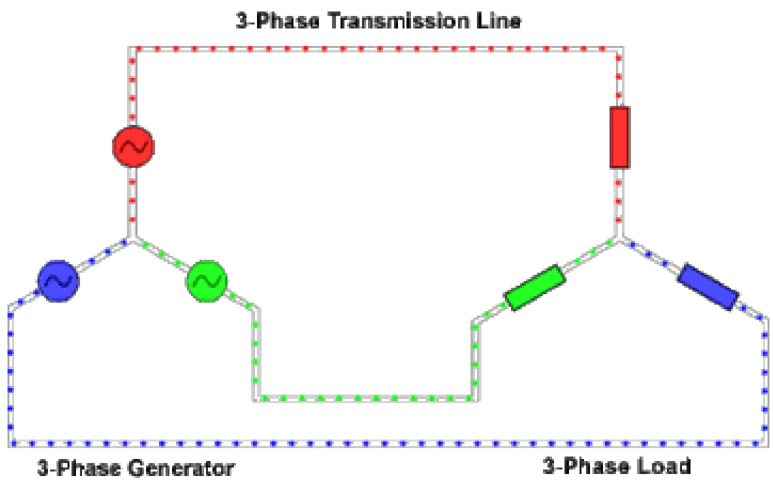
November 21, 2018



Introduction & Thesis:

Sensory devices have become mainstream in commercial households and the industry, causing a huge increase in the amount of data. In relationship to the growth of connected devices and/or Internet of Things (IoT), the accumulation of large data made data analysis easier for optimizing advertising, consumerism, energy management, etc. One particular set of data that this project explores is energy from 3-phase devices. 3-phase devices and its power load are usually present in industrial factories and offices which relies on high amount of power draws for operations. Current 3-phase energy meter solutions use a combination of a polyphase integrated circuit (IC) chipset and a microprocessor. Previously, to accomplish 3-phase energy measurements, engineers would combine separate single phase Analog Front End chipsets (AFEs) that would be dedicated in measuring a single phase voltage or current and use multiple AFEs in sync with each other to create a 3-phase measuring system. This approach had issues as up to six single phase AFEs would be challenging and time-consuming to sync in order to measure data such as phase difference correctly.

A solution to syncing multiple single-phase AFEs would be the a single polyphase energy measuring IC chipset such as Analog Devices ADE9078 IC chipset which solves issues like timing and ensures the synchronization of multiple single-phase AFEs. Our project utilizes the ADE9078 IC chipset and aims to be the foundation toward 3-phase power analytics for optimizing industrial machinery by collecting data of harmonics, patterns of device usages, balance between phases, load patterns, and other important 3-phase energy data. By knowing how much watt-hour a device is rated for, the user is able to track the electricity expenses for the device to remain active. Data, such as voltage/current reactive power, can be used for diagnosis for circuitry quality and prognosis that keeps operational cost and maintenance cost low. This analytics can be done by creating a small size and low power 3-phase AC power monitor solution.

Goals & Objectives:

An issue with using microcontroller based monitoring and logging systems over the Field-Programmable Gate Array (FPGA) would be the data received from the IC chipset would have to be processed quickly for real-time measurements. In addition to real-time measurements of 3-phase voltage and current, we would like to utilize of the functionalities of the ADE9078 because this algorithm has to be applied over 6 total channels: 3 from voltage phase 1, 2, and 3 and current phase 1, 2, and 3. In addition to measuring the 6 voltage and current channels, we would also apply other functions that applies at multiple time scales that also require processing of different type.

In order to solve these problems, the power phase processing system can be designed with the parallel computational capabilities of an FPGA which can measure data from the ADE9078 chipset and apply different algorithms in a pipeline-like manner and streamline efficiency. The combination of high accuracy from a 3-phase energy metering IC chipset and the reprogrammability of an FPGA gives us functionality to have multiple real-time waveforms, noise detection/removal, and predictive analytics.

By the first quarter, our project is to create a solution using a polyphase IC chipset (ADE9078) for measuring 3-phase measurements that uses the waveform sampling of the ADE9078 chipset along with drivers for Arduino to validate the printed circuit board (PCB) design. In the second quarter, we aim to transfer over the Arduino drivers over to an iCE40 FPGA board for parallel computation of reading, writing, and preprocessing data in a pipeline method to add additional functionalities to the 3-phase measuring systems. We're going with this specific board due to its accessibility and its low cost. The low cost was a primary factor since we have limited funding and the built in DSP functions are of great use. It being a consumer grade board hints that it is used for hobbyists and other small projects who are on a budget but still providing functionality that we need such as being able to read, buffer, and process without sacrificing performance and being too expensive.

Why We Chose the ADE9078:

For making a 3-phase power monitoring solution, our group considered two options for measuring 3-phase voltage and 3-phase current. The first option would have an array of single-phase IC chipsets and the second option would have a chipset that could measure polyphase as an all-in-one solution. With the array of 3 single-phase IC chipset solution for 3-phase measurements, the approach is to connect 3 single-phase chipsets in parallel and have them measure simultaneously to get 3 phase measurements. The other option to get a polyphase IC chipset that had 3 phase measurement built into it, and wouldn't require syncing up several chipsets. We compared them based on certain criterias necessary for our project such as accuracy, amount of functionalities, interface compatibility, and ease of use. Our group decided to use the ADE9078 as it met our specifications.

For ease of use, the ADE9078 guarantees synchronization of all of its channels compared to the array of single-phase IC chips method which requires complex circuitry to match the timing of data correctly. Another reason for using a polyphase IC chipset is that this approach is more cost effective and would require less materials, but this can be an issue because an array of single polyphase IC chipsets can be a hassle to sync and take up many SPI interfaces plus there is a solution that does the same, but easier as it is in an all-in-one chipset. Done

In terms of accuracy, ADE9078 IC chipset is Analog Device's latest polyphase chipset which is rated for Class 0.2 which meets the requirements for utility-grade metering according to the American National Standard Institute (ANSI) for Electricity Metering as Class 0.2 refers to ± 0.2% accuracy range. To add, the ADE9078 IC chipset also provides a plethora of data that can be used for analytics such as total active power, volt-amperes reactive (VAR), volt-amperes (VA), watt-hour, VAR-hour, current and voltage root mean squared (rms), line frequency, zero crossing detection, and phase angle measurements. Data such as watt-hour can tell us the rate of power consumption and easily tell the user how much they are spending on keeping the device active.

As for compatibility, some other solutions use either SPI, I^2C, UART, or a proprietary interface. For our project we prioritize the SPI interface over the others as the SPI interface is simpler to use over other interfaces, consumes less power than I^2C, and allows for higher data rate and range.

We used three criteria (ease, accuracy, and interface) to choose a single polyphase IC chipset over an array of single-phase IC chips because the polyphase IC chipset, mainly the ADE9078, would require less complex circuit configuration, has high energy metering accuracy, can take multiple types of measurements, and has simple interface as opposed to its other alternative, the array of single-phase IC chipsets, which has higher cost, requires syncing, and require extra interface ports to use with the processing board.

FPGA as the processing board choice over MCU or DSP cores:

With the polyphase IC chipset (ADE9078) allowing for the synchronization of all 3 voltage and all 3 current measuring channels with up to Class 0.2 metering accuracy, it seems that a simple microcontroller unit (MCU) would be enough for multi-phase energy metering. In order to maintain real-time measurement and access other of the ADE9078 metrics, the parallel computational power of an FPGA board is required. The FPGA that our project uses is the Lattice iCE40 board because of its low cost as an entry-level FPGA board. The low cost of the board would keep the cost down of the overall device we are trying to build. The device has a small form factor, which would allow for an overall reduction in product space utilized. In order for data to be available in real time, parallel computation is needed to avoid a delay in information. Since this board has dedicated DSP functions, it will make it easier to perform the sampling portion due to dedicated sections in its hardware.

The way in which the FPGA and microcontroller are built, ensures that both have a significant effect on one another's strengths and limitations. Unlike a microprocessor with fixed hardware, an FPGA's hardware can be reprogrammed for different tasks and standards, allowing us to work with custom standards and inputs To clarify, the FPGA board has dedicated sections of the chipset devoted to writing, storing, preprocessing energy, metering data while being able to be reprogrammed for different AC voltage utility standards such as 208 to 480 AC voltage range, Wye and Delta configurations, Blondel and non-Blondel compliance, and metering specifications from IEEE or UL standards. Once we have the samples, we can then analyze them to determine how much power is being consumed from the powerlines. The data can also show abnormal spikes in usage which can alert the user to make sure the device connected is functioning properly or is used efficiently to not waste energy.

Project overview

As of Week 8, we have designed a schematic for 3-Phase AC Power Monitoring Solution using the Eagle software. We optimize the circuit, mainly the voltage/current interface, to measure up to 480 AC voltage with 20% overshoot as a safety precaution in case of overvoltage events by modeling the circuit in an LTSpice simulation.We have also started to program some of the firmware. We are now in the phase of starting the board design and have opted for five samples of our device when we are finished. This quarter we hope to finish the board design and send the PCB to manufacture and to order the components that we need for assembly and preliminary testing. We referenced CalPlug's Wattmeter for some of our schematic design and to estimate the cost required as it is the single phase version of the 3-Phase AC Power Monitoring Solution.

Project Schedule:

Fall Quarter

Progress Completed & Upcoming Work
Week 1-4: - Research on 3-phase power delivery, review previous energy metering design
Week 5-6: - Designing Schematic using Autodesk EAGLE - Advisor Feedback & Revisions to Design - Started look at Programming drivers compatible with Arduino Week 7: - Optimized schematic design by adding safety measures such as fuses and calculating resistor and capacitor values using LTSPICE - Finished proposal and continued onto fifth revision of the schematic. - Poster outline created for Fall Review Session. Week 8: - Started on the board design on Eagle. - Working on finalizing the poster for presentation.
Week 9: - Submit poster and create a BOM for the parts needed. Week 10: - Order parts, finish board population, create a prototype and begin testing of the prototype.

Winter Quarter

Future Goals & Plans
Week 1-3: - Update FPGA drivers with additional functionalities
Week 4-8: - Porting drivers to become compatible with FPGA iCE40 chip
Week 9-10: - Testing the complete board on 3-phase devices - Validation that the information displayed is accurate

Itemized Inventory of Purchases:

Items		Cost
iCE40HX8K-DRAGON-EVN FPGA board		**$125**
ADE9078ACPZ IC chipset*		**$30**
PCB board fabrication*		**$100**
Electrical components*		**$335**
Resistors, Capacitors, Opto-isolator, Jumper, LED, fuses, etc.		
Soldering materials*		**$90**
-Soldering gun	$70	
-Soldering wire	$10	
-Soldering paste (KB430 Low Temp Silver Solder)	$7	
-Solder removal wick	$3	
Testing Equipments		**$320**
-Fuji Electric AC Drive (FRN0006C2S-2U)	$153	
-WEG AC Motor (.2518ESE56-S)	$167	
Total		**$1000**

* Note : Estimated to be enough materials for at least 5 samples

Funding

Our team is planning on making five samples of our design. Each PCB circuit is made and designed on Eagle and we will need a PCB fabrication plant to create this custom circuit which will cost around 20 dollars each to make. For the population of our device, we will use a pcb oven and we will hand solder some components. Thus, we will require some basic soldering components like a soldering gun, soldering wire, and soldering wick. In order to test our device, we will need a three phase AC driver with 230V, as well as the WEG AC Motor. The UROP funding will help us improve the existing Wattmeter design by allowing the user to account for and measure the harmonics that are present in three phase power. The primary use of the funding would go towards the fabrication of the PCB boards, the FPGA, components; the materials that would be difficult to acquire on our own.

Team Roles:

Peter Nguyen (EE): Technical lead in charge of the schematic design, overseeing hardware, and assisting in firmware and testing.

Esteban Granizo (EE): Logistical lead in charge of board design, assisting in hardware and firmware, and assisting in PCB population.

Jacky Wan (EE): Hardware specialist mainly in charge of circuit optimization and testing

Jeff Baez (EE): Hardware specialist in charge of PCB population and assisting in programming the Arduino/FPGA board
David Brady (CSE): Programming specialist in charge of programming the Arduino/FPGA board to supplement our PCB design.

References

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