Smart Devices and Electric Vehicle Chargers for Grid Demand Response

Final Report

by Team HAM

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Executive Summary (5 points)

California's energy climate is rapidly changing. With aging power plants slowly being phased out of commission, California is left to deal with an increasing demand for energy with seemingly fewer sources [22] [23]. With a demand response system, California only creates as much energy to fill the current demand with relatively little energy being stored for later use. The issue here is that although demand can fluctuate very rapidly, supply is difficult to ramp up accordingly. However if the demand can be controlled in a manner that these spikes do not occur, than the ramping up of supply will not be needed. Energy storage does exist however battery systems are slated to maintain a capacity of 1325 MW by 2024 [20]. The capacity for renewable energy is not sufficient enough to meet this growing demand, especially during night time, and as a result California still relies on a heavy usage of fossil fuels during parts of the day with little solar power. With two of major forms of renewable energy unavailable during the night time, solar PV and solar thermal, wind power dominates however it is not always enough to fill the demand. This can be seen by the net load curve which shows load minus the renewables at each time of day [21]. One of the many contributors to this growing demand is due in part by the increase in popularity of Electric Vehicles (EVs). EVs are part of California's Clean Air goals and are being heavily incentive by programs put out by the EPA and the California Air Resources Board (CARB) [19]. EVs are a green alternative to their gas counterparts however the energy the relative amount of energy they require from the grid is more than that of most households [15] [16]. As most EV owners tend to plug in their vehicles in the evening, towards the end of day when most solar power is unavailable the demand is filled by fossil fuels [24]. We planned to create a proof of concept of a system consisting of a network of Internet of Things (IoT) enabled car chargers that will allow for a smart demand response to EV charging through the use of smart scheduling. IoT enabled chargers have the functionality of being controlled wirelessly via WiFi. Our system, handled by the utility companies, factors in various weather inputs and smart scheduling algorithms in order to optimize charging rates while also minimizing demand at any single time. We set out to create this algorithm, as well as a simulator in order to model the effects of such a system. Also, in order to provide the utilities with such an infrastructure, we modified an open-source car charger to be IoT enabled. We delivered both sides of our system separately: a scheduling controls system and an IoT modified car charging unit. The next step would be to integrate these two and turn this proof of concept into a viable, scalable system. Our system has the potential to give utilities this window into residences to allow for much more control over California's grid demand response.

A three-minute demo video of this project can be found at:

https://www.youtube.com/watch?v=A_X8azfPPag

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Chapter 1. Introduction (15 points)

Energy efficiency is a top priority and the creating sustainable energy should be the goal of utility companies and all citizens alike. The market potential is growing as Electric Vehicles (EV) become more popular and allowing our system to gain more relevance in the current market.

1.1 Motivation (5 points)

Energy sustainability and efficiency is a main focus for California as a state. As we phase out renewable energy sources, California has to rapidly adapt in order main stability. EVs are helping from a clean-air standpoint however they add to a much larger problem. Tackling an issue as large as this, we understand that it would take a variety of solutions to better the situation. Nevertheless we decided to take on the issue in a way that would allow as little change from a user as possible. Our program schedules car-charging time to reduce the demand of power throughout the evening. Urging consumers to not charge their vehicles all at once is not realistic. Behavior modification is difficult as there is no practical or systematic way to coordinate charging schedules across an entire geographic region in the absence of some sort of automation. Instead we built on the idea that if utilities, who control the supply of energy, were able to regulate the demand for power over a certain time, then they would be able to utilize their resources as efficiently as possible.

1.2 Potential Impact of Work (10 points)

1.2.1 Relation to EE, CpE, and CSE (2 points)

Attempting to solve this complex issue, we were required to conduct large amounts of research in order to come up with the best solution. Especially since we were creating a simulation, we required precise data in order to see the effects of our system. For example, in order to account for the variability of wind power we formulated an equation that relates the increase in wind power across California and the resulting generated power. After collecting the data, we also needed to analyze the data and came up with an efficient algorithm. We also modified the controllers in order to make them WiFi and Bluetooth enabled. As for programming knowledge, we developed our scheduling controls engine on MATLAB and basic control function GUI on processing in addition to developing the firmware for the ESP8266, the

WiFi enabled module. We implemented this proof of concept design using these tools in order to produce sufficient functionality in a short time frame.

1.2.2 Global Context (2 points)

We are focusing on California as a starting point. California is leading by example when it comes to energy usage, energy efficiency, and even renewable energy [17] [18]. Implementing our system on California's energy model gives our system credibility and scalability. California has the political climate to issue these changes. A prime example is the bill proposed by Governor Jerry Brown that would require California to produce 50% of its energy from renewables [31]. Energy is a growing necessity in most aspects of everyday life and its availability at all times of day is absolutely vital. Decreasing our dependence on fossil fuels is a top priority as it would work towards managing climate change and air pollution.

1.2.3 Economic Context (2 points)

Our product can be seen as beneficial to both the consumers and the utility companies which sell them. We envision that a rebate program would be put into place to make our product much more appealing to the consumers than their current vehicle car charger. That in turn would allow utility companies to control the demand for their energy and hence decreases their costs. For example, by replacing their current charging system with this one, customers will be granted a flat rate percentage discount on their monthly bills. An additional discount could be applied for the amount of smart scheduling customers choose to use since customers will always have the ability to charge at their own rate and any time. This would prove to be more effective than peak-time rebates or critical peak pricing which saw 95% of incentives paid to customers who were either not expected to or did not reduce load significantly [26].

1.2.4 Environmental Context (2 points)

Our system would allow for renewable energy to play a larger role in filling the demand for energy that it currently does. California would not have to rely as heavily on fossil fuels to compensate for the lack of availability of renewable energy to meet demand, as seen in California's net load curve. Allowing for a larger dependence on renewable energy and the subsequent decrease on the dependence of fossil fuels, our system would give way to a cleaner, more sustainable energy for years to come.

1.2.5 Societal Context (2 points)

Although utilities would have more control on how a consumer's EV is charged, it is not with the intention to hinder the amount of charge present in a consumer's EV once they are set to use it after charging overnight. We plan to allow the user to still have a certain amount of control over the charging of their vehicles in emergencies. Eventually we plan to introduce user selectable modes that control how aggressively the demand response acts on a charger--another variable that can be tied into the rebate program. Users that charge during the day will have large amounts of solar power at their disposal which in essence gives way to zero net energy where the total amount of energy used is equal to the amount of energy created by renewables. When over-generation such as this occurs, a notification may be sent from the solar control system notifying the utility which in turn requests immediate charge of a user's EV instead of selling it back at a relatively low rate. We want to carry this idea of zero net energy even when users decide to charge overnight.

Chapter 2. Background and Related Work (10 points)

2.1 Background (5 points)

California is attempting to have renewable energy account for at least 50% of all energy usage by 2030 [4]. Solar, wind, biomass, geothermal energy and hydroelectric power are the main types of renewable energy that are currently being used [14]. These methods for creating energy may be cleaner but they are unstable due to the fact that they do not always produce energy 24/7, unlike non-renewables such as nuclear, gas and coal plants [5]. Renewable energy depends largely on uncontrollable environmental factors. Sunlight, wind speeds and other factors change the amount of energy created. Clouds can block a PV array and decrease output [29]. During the middle of a sunny day, there is much more power been generated due to the availability of renewable power. It is the opposite during the night time due to lack of sunlight. California Independent System Operator (ISO) introduced such curve, "Net Load Curve", which also been called as "Duck Curve" due to the shape of the curve. The following diagram is a prediction based on ISO's research [1]:

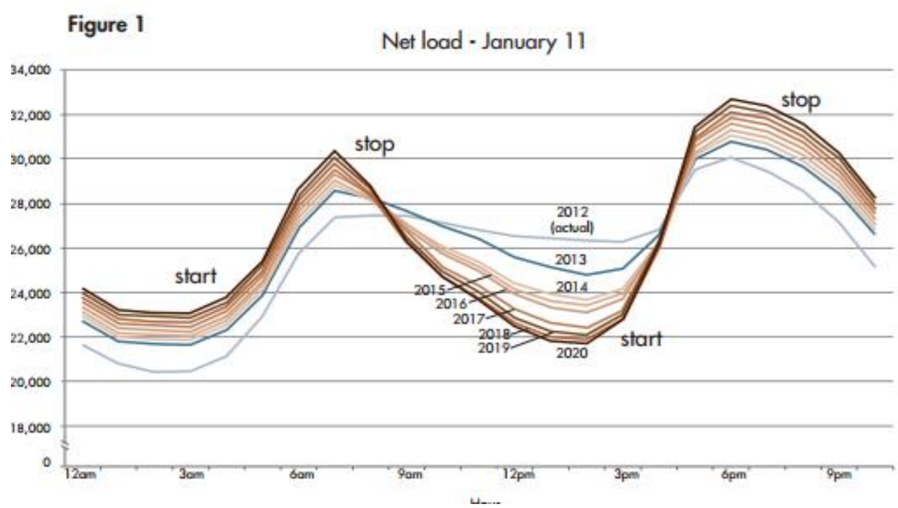

Figure 1: Predicted Net Load Curve from ISO [1]

Our approach to the problem resembles just one way to try to reduce the instantaneous increasing on the "Duck Curve." Our system can be applied to EV charging but it is also serves as inspiration for how it can implemented in other aspects of a household to further smooth the net load. The stakeholders in this project are utility companies and the consumers. For a utility company like Southern California

Edison, the end result of this project allows for more control over the net demand and ultimately reduce the dependency on nonrenewable energy during the night. Many of the current strategies to reduce California's dependence on nonrenewable energy comes from bolstering the energy grid with more renewable energy while reducing gas powered power plants. Our system will contribute to the goal of California having 50% of its energy source coming from renewable energy through different means [4]. By allowing for more control over the demand, the utility companies can adapt the current load to the current supply. Because it is in the best interest of the utility companies for their customers to have the system, it creates a possibility for an incentives program for the customers. The charger we used in our demonstration system is from the OpenEVSE project that was started by Christopher Howell [3]. We are building on this by implementing new features, namely IoT capability. Such IoT capability allows us to turn a simple EV charger into a "smart" charger that's able to optimize charging based on a price and energy availability model.

2.2 Related Work (5 point)

In the current market, there are no EV charging systems that provides control and schedules a charge time for each plugged in car. Our system works via a scheduling controls engine, which scheduling the energy distribution from utility companies to the individual EVs depends on the current renewable energy and also providing EV owners the ability to overwrite the commands from utility companies, that provides control to both utilities and the EV owners. We decided to develop our system by using the charger from the OpenEVSE project. In the other words, the potential competitors are from different EVSE (Electric Vehicle Supply Equipment) projects. The basic requirement for the EVSE for our system is the ability of support both 120VAC and 240VAC and as well as be programmable. Through extensive research, one potential competitor is the AeroVironment TurboCord. Their EV charging system uses a compact and durable design. It is a simple plug and go type of charging device. To make up for slow charging speeds, it is equipped with two Charge Levels, 1 and 2, for 120VAC and 240VAC respectively, however, it requires customers to purchase an additional adaptor in order to use 240VAC [2]. For our system, customers can choose what voltage level they would like when the system gets installed without any additional charges. TurboCord is only provide a simple passive charging solution, it does not allow for adjustments in power output, such as adjusting the charging current. It is an easy plug and go type device. Our charging system will include these features but will also use smart scheduling to optimize charging on a macroscopic level. Each device will be installed within a homeowner's garage by the utility companies or homeowners themselves. It then will communicate through our online system; this allows homeowners and the utility companies to control when and how fast the EVs get charged based on the availability of energy. The utility control will be dictated by a scheduling controls engine that calculates the amount of available power, and the ability to charge cars with current available power. Weather data will be constantly sent to our scheduling controls engine, and the engine will then control the charging accordingly to the available resources. On users' side, as is currently implemented in the proof of concept demonstration, they will have two user interfaces, the buttons on the OpenEVSE, which allows them to overwrite the controls from utilities, and a web based utility. The main problem that our product is trying to solve is the variable demand for electricity. The demand varies throughout the day and as EVs become more and more popular, the load on the power grid will increase during the night as a result of day workers returning home to charge their vehicles [3]. Not only does the demand change as the day shifts to night, but also the supply. Utility companies generate electricity through numerous ways. These methods are limited by natural resources such as wind and solar. For example, as the wind blows, the turbines blades starts spinning. The turbines have some sort of generator inside to generate the electricity [30]. Obviously, without any wind, the wind turbines would not be able to generate any energy. Solar renewables are nonexistent during the night so supply in that regard is absent. Wind is also variable as seasonal changes by seasons if not day by day. As a result of monitoring the demand and supply of electrical energy on a large scale, we can distribute power efficiently to charging stations throughout the system based on the current capacity of the power grid. Of the six most popular forms of renewable energy, (Wind, Solar Thermal, Solar PV, Biomass, Geothermal, and Small Hydro), Wind and Solar dominate [13]. However at night, wind makes up for most of the power created [12] [25].

Chapter 3. Project Design (30 points)

3.1 System Block Diagram (5 points)

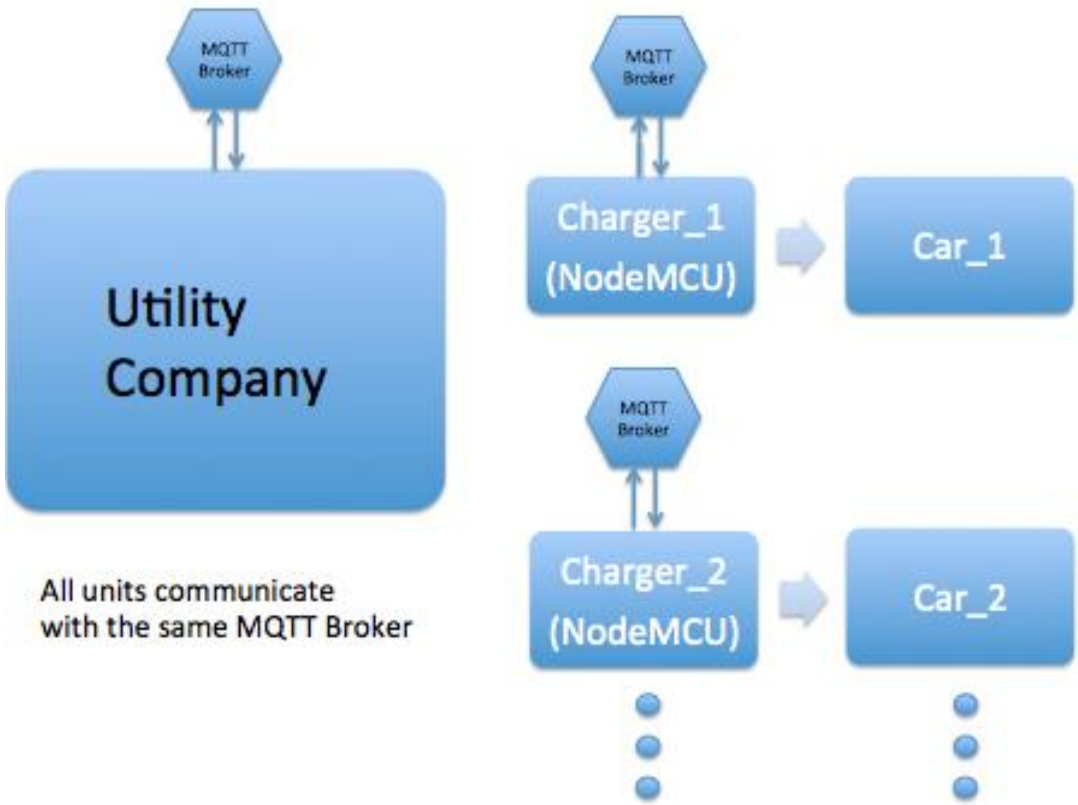

Figure 2: System Block Diagram

Our scheduling controls system dictates when, how many, and how long cars should be charged. This system is largely autonomous, and maintenance would be from the utility company in charge. The utility company will have access to the exact amount of power currently available as well as forecasted power due to weather patterns. This information is fed the the scheduling system so that it can determine the optimal charging situation. It will send the proper commands to each charging unit via a WiFi enabled board that will enable the charger to provide WiFi connectivity and MQTT connectivity. In our demonstration system we used the ESP8266 in order to integrate it into our network. The MQTT broker plays as the intermediary between the utility company and the individual chargers.

3.2 Subsystems (15 points)

There are two major subsystems within the current design layout.

The first major interface is the IoT enabled OpenEVSE box, which is typically installed in the user's garage. The box can be found with two external connectors and one internal communication device. One external connector is connected to utility power. The other external connector is the J1772 standard car connector. This will hook up to and provide power to the car. The internal device is the WiFi enabled board providing the charger with IoT capability. With remote commands and controls via MQTT, the utility company will be able to control each and every charger in their network reliably and with ease. In regards to security, there was another team (team 22) that demonstrated the ability to create an encryption engine for this chip set. This means that AES-128 end to end system is secure, and that this automated system will be protected from unwarranted control.

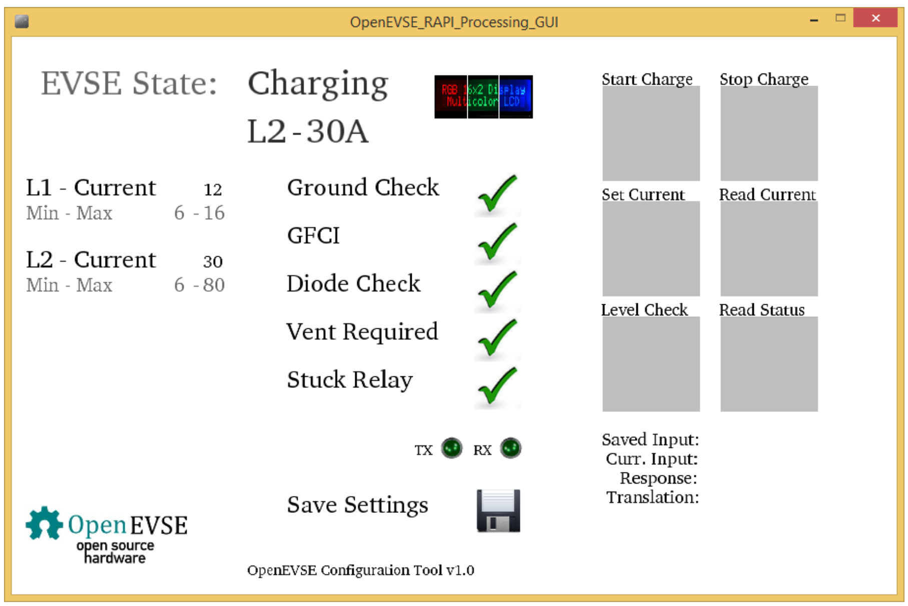

Figure 3: Graphical User Interface of OpenEVSE Charging Box

The second subsystem is the scheduling control engine at the disposal of the utility company. The scheduling control engine manages the charging rate of each car depending on the current availability of renewable resources and the number of EVs in the network. The calculated charging rate is sent to each individual EV using RAPI(Remote API) protocol, the proprietary, but documented, OpenEVSE protocol for charger control. A standard RAPI protocol is composed of a 2-letter command for setting/getting parameter, the numerical value for the parameter, and a 2-hex-bit checksum to ensure that message was correctly received at the receiver side. This protocol allows the remote hardware to control the

OpenEVSE board using a serial port, with the FTDI/UART pins on the board. However, our current scheduling controls engine design still relies on Bluetooth, which is not a widely used IoT protocol. The Bluetooth module was only used as means for establishing serial communication with the unit for testing purposes. The ultimate goal of this project is to incorporate MQTT into the scheduling controls engine. However, there are currently no open source MQTT libraries available for MATLAB. Designing our own MQTT library is beyond the scope of this project and is unrealistic within a short amount of time. Nevertheless, our software control module has already proved the viability of designing the entire system using MQTT as its only communication protocol. Our MATLAB code would have to be re-implemented in C/Python in order to be scalable for deployment as our project is a proof of concept.

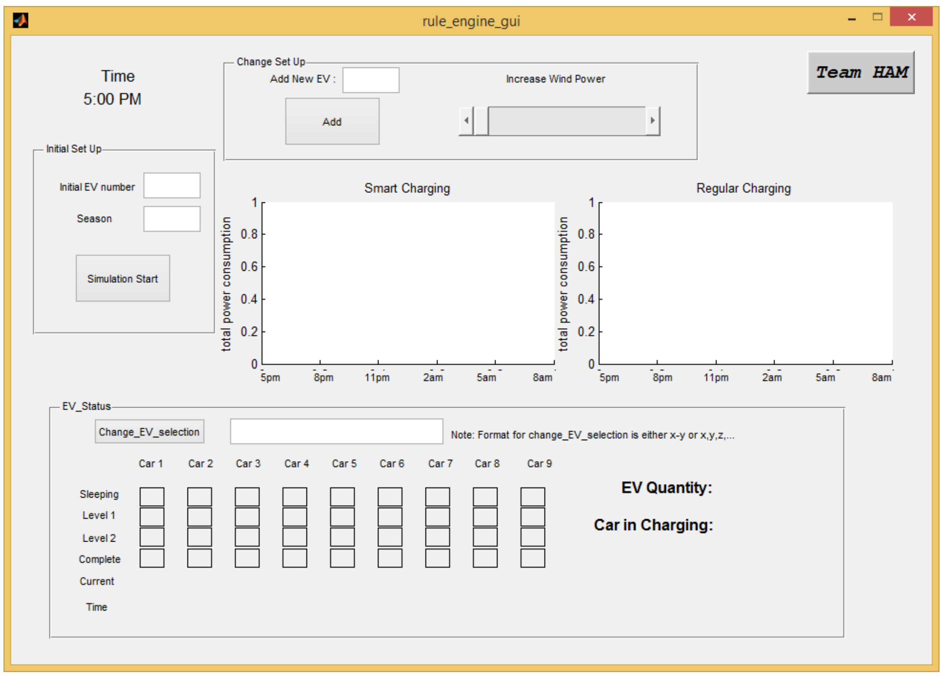

Figure 4: Graphical User Interface for Scheduling Controls Engine

For a detailed explanation please refer to Appendix A.

3.3 Interfaces (5 points)

Currently, the OpenEVSE unit that is linked to the Scheduling Controls System communicates with the GUI via Bluetooth. However the other OpenEVSE unit that is IoT Enabled can communicate via MQTT to our Processing GUI. Processing was used in order to demonstrate the functionality of our system. This Processing GUI is a modified version of the open-source version provided by Christopher Howell, creator of the OpenEVSE.

3.4 Technology Options (5 points)

The charger block is the major hardware unit, which contains the actual charger and a microcontroller. The charger contains multiple relay switches to wait for the commands from the microcontroller and decide how and when to deliver the power. The microcontroller will receive input signals from one of two locations. The utility company will ultimately have access to these chargers to control and optimize charging timing per household for maximum efficiency. The input signals received from the utility company would be the standard source of input signals. In addition, the consumer will have a mechanism to override that normal operating system and request more power for special circumstances. The input signals will tell the charger to turn on or turn off the power relays.

Charger Station: OpenEVSE 30A deluxe charger station

Justification: Both hardware and firmware for this product is open source. Unlike the other charging regulation systems, we know this system will not cause damage to the charging system. This product follows J1772, which is a SAE Recommended Practice for an EV conductive charge system [28]. The SAE-J1772 connector is the North American standard for electrical vehicle connectors. It has two AC lines, a ground pin, proximity detection pin and a control pilot. It can support both 120V and 240V. For safety, there are several levels of shock protection and the pins are isolated. When mated, no physical access to the pins are available, and the pins draw no power unless connected and a vehicle requests power. The DPDT relay can be found within the system for additional protection. The EVSE box is a simple interface for power. It monitors functions, such as charging rate, and can relay that information back when connected to a connectivity device.

Connectivity: NodeMCU(Esp8266) and Bluetooth unit (SparkFun Bluetooth Mate Gold)

Justification: This wifi-enabled device allows for easy integration into an MQTT network. With easy integration with the Processing GUI, it was a great choice. Processing is a method for rapid prototyping a GUI and has easy implementation for communication capabilities. As mentioned earlier, the current scheduling controls engine design relies on Bluetooth connectivity for serial communication since there is no MQTT open source library available for MATLAB. This was merely a way for us to demonstrate our work.

Chapter 4. Evaluation (20 points)

4.1 Experimental Setup (5 points)

In order to test our Scheduling Controls System created via MATLAB, we installed a Bluetooth module to an OpenEVSE unit and used a 2012 Chevy Volt as the test car in our system. Using the GUI we created, we were able to use the Chevy Volt as the real node in our simulation while simulating the charge of hundreds of other vehicles using virtual nodes. We tested the behavior and control of the system in this manner.

In order to test the IoT Enabled OpenEVSE we installed the NodeMCU ESP8266 unit and modified the firmware to connect to our MQTT Broker (CloudMQTT was used as a broker service). We integrated this MQTT framework into our modified Processing GUI in order to wirelessly send commands to the charger. The process of sending a commands and receiving responses to and from the unit is illustrated below:

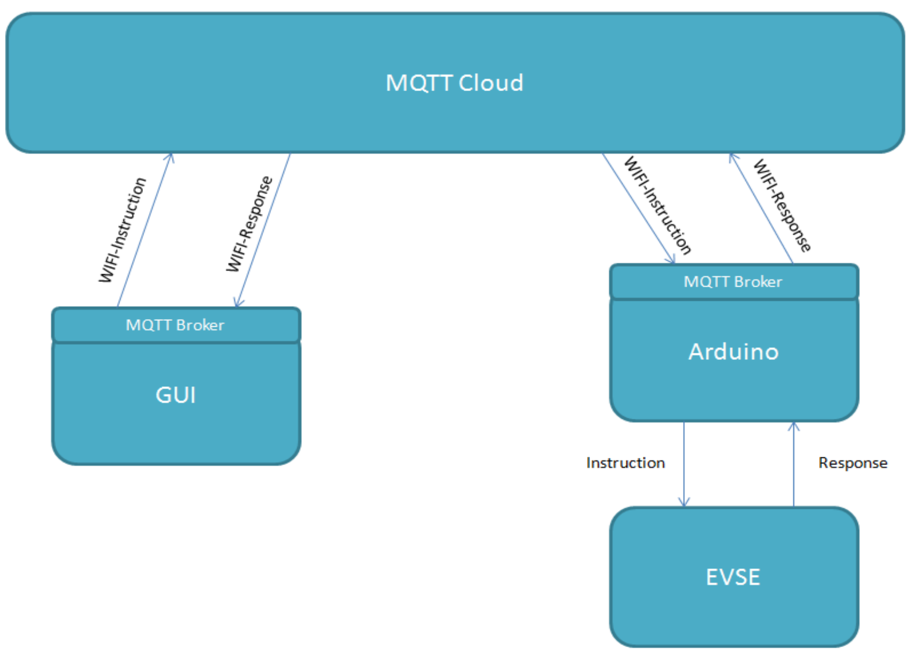

Figure 5: Flowchart of the Scheduling Controls Engine

4.2 Experimental Results (15 points)

Data Collection and Regression

In order to simulate the availability of energy at each time of day for our scheduling controls engine, we gathered Solar PV, Solar Thermal, and Wind energy data based on 1 MW solar devices and 2 MW wind devices across four different months (January, April, July, and October), one for each season [12]. Scaling this data up in accordance with the total capacity available in California, we were able to come up with the amount of energy available at any time of day due to a certain type of renewable energy [13]. We focused on these three sources of renewable energy because they are the most popular and their capacity seems to be growing the fastest. We wanted to simulate the variability of weather patterns in order to show the adaptation of our charge scheduling algorithm. To do this we used data from a 1 MW capacity turbine that correlated the wind speed (m/s) with the amount of power generated. Regressing this data gave us an equation that allowed us to input the wind speed and generate the subsequent power generated. The graph for the data is below. We scaled this up across California's capacity for wind power.

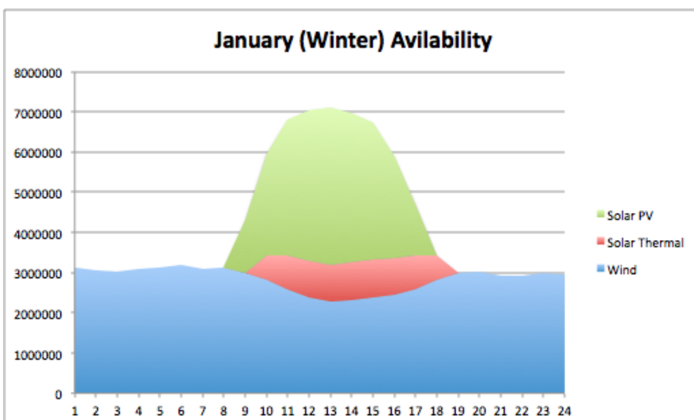

Figure 6: Power Availability for Winter

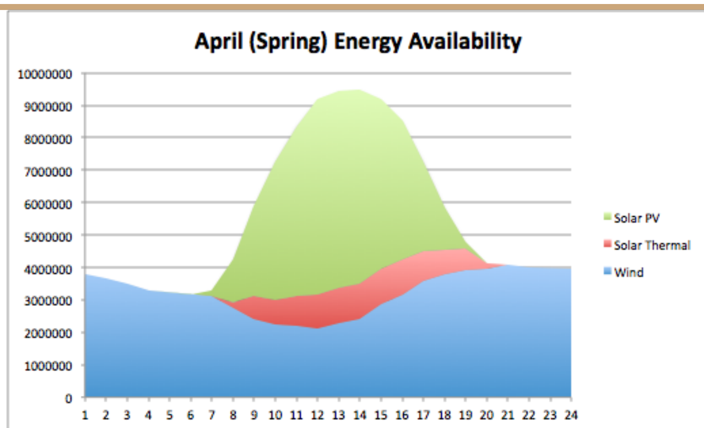

Figure 7: Power Availability for Spring

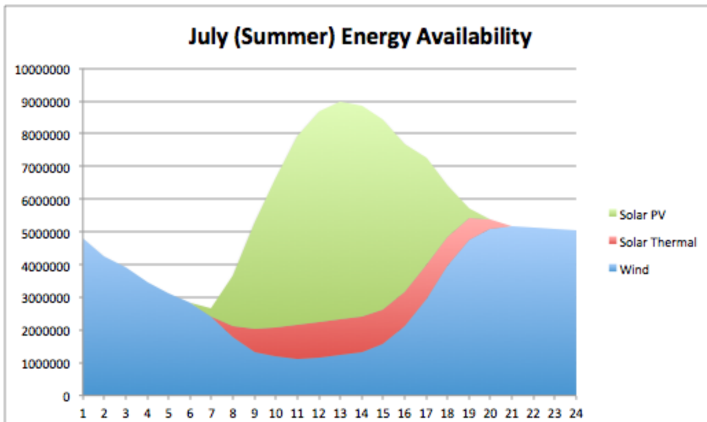

Figure 8: Power Availability for Summer

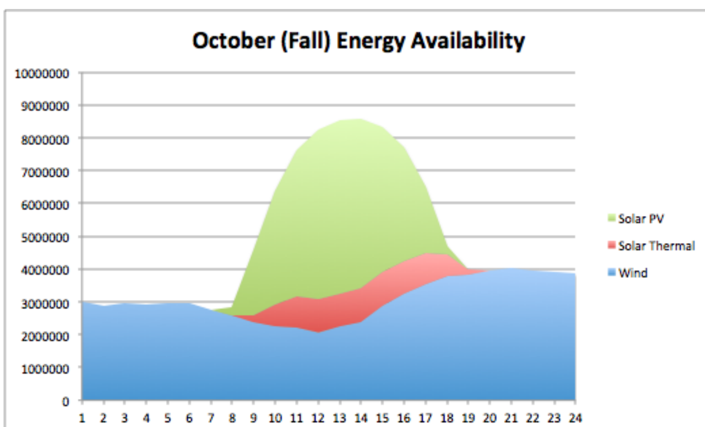

Figure 9: Power Availability for Fall

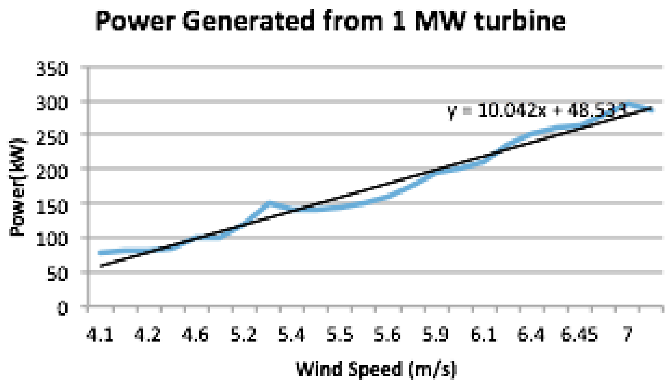

Figure 10: Effect of Variable Weather Patterns

Scheduling Controls Engine Simulation

Figure 11: Scheduling Controls Engine Simulation

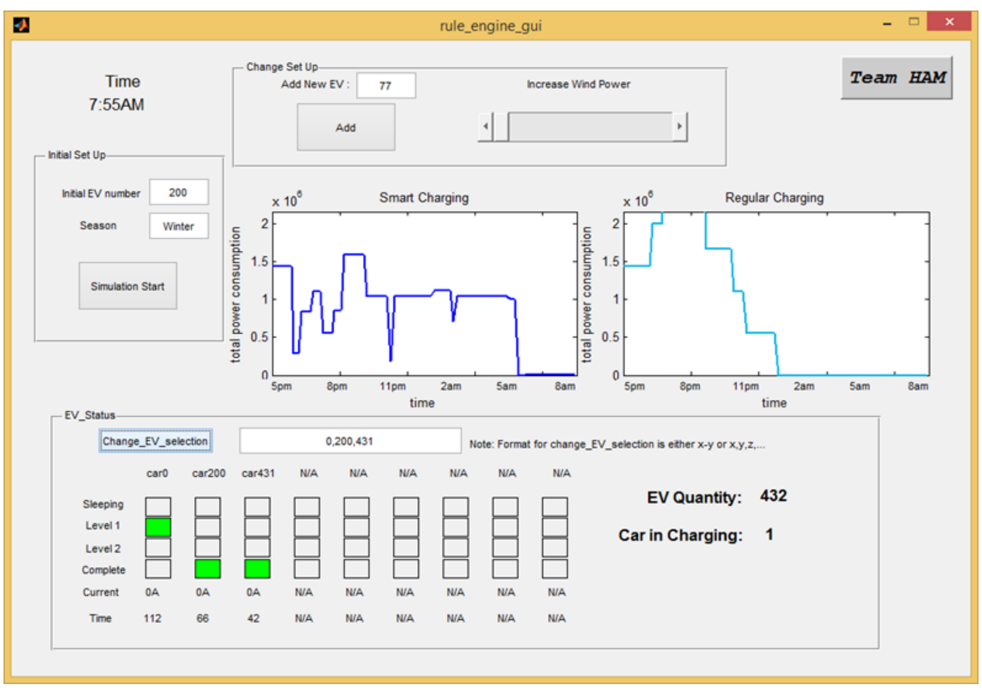

Figure 12: Scheduling Controls Engine Simulation

For a detailed explanation please refer to the following paragraph.

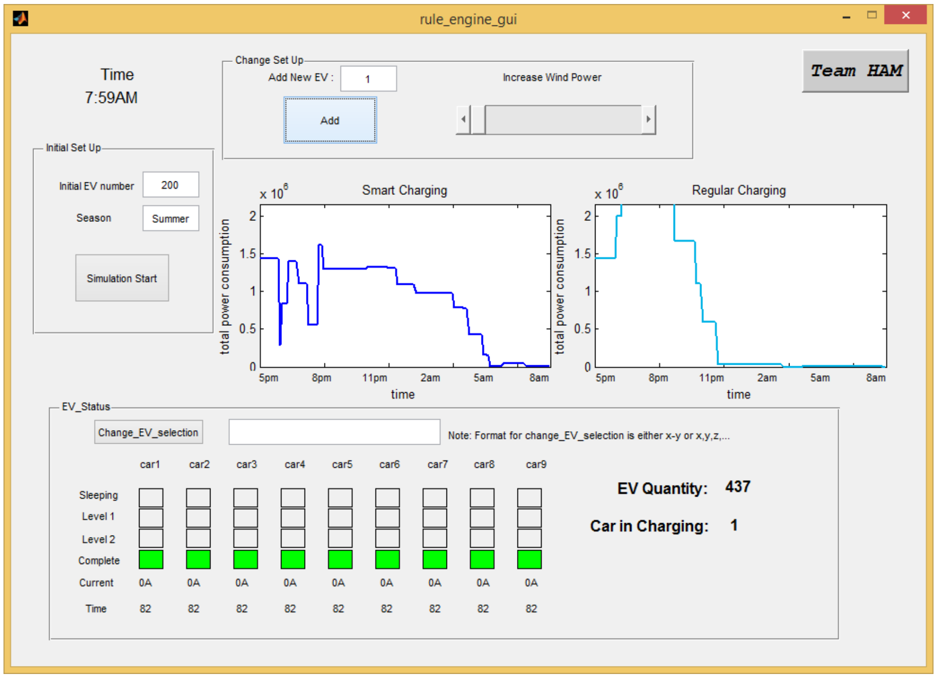

Figure 13: Scheduling Controls Engine Simulation

The experiment of the scheduling controls engine showed that it was able to control the charging rate of individual EV according to the availability of resources. The behaviors of both the real and virtual nodes were as expected. For example, in the winter season, we observed that all the EVs were charged at the maximum speed for one hour once they had joined the network. After 8pm the first group of EVs (including the real node) were enabled and were charged continuously at the maximum speed for 3 hours. After that, the first group of EVs is turned into sleeping mode again. Ideally, most EVs in that group should get fully charged by that time because according to our research most EVs such as Nissan Leaf need only 4 hours' charge under AC level 2 [27]. Similar process repeats for other groups. After 5pm, all the remaining EVs, which have not been fully charged, will be enabled and charged at the maximum speed as shown in the figure above. Of course, the real node is turned on at this period because our simulator takes 6 seconds as 1 hour and the real EV will never get fully charged in this case. Other seasons work under similar principles as the winter season. The results will not be discussed in great detail. Comparing the load consumption curve of our smart charging system with that from regular charging, one can easily see the former's curve is much smoother, which indicates our system reduces the stress on the power grid compared to the regular charging process.

Figure 14: Estimated Charging Completion time for AC 12A

Figure 15: Estimated Charging Completion time for AC 10A

As we change commands using our scheduling system, the 2012 Chevrolet Volt changes its charging rate.

Chapter 5. Lessons Learned (15 points)

5.1 Project Management (7 points)

5.1.1 Team Organization (5 points)

We were able to effectively work as a team to complete all scoped goals within the amount of time were given. We were in charge of different parts that were all interlinked, and worked together to complete our task. We had multidisciplinary skills; working both in software and hardware development. We agreed on our goals early on, which helped facilitated progress throughout the quarters. We worked together in understanding and manipulating software -- for both the commands to the OpenEVSE as well as code for the MQTT broker. We also worked with hardware by creating a load system to show our box could truly start charging, measure current and more, as well as opening up the EVSE box to implement communication devices -- bluetooth communication in one box, and WIFI communication in the other.

Ming Wang: In charge of monitoring the entire flow of the project. Constantly in communication with the mentor and each team member regarding the process of our project. Collaborated with Hong and Arunav for the rules engine, mainly focused on scheduling.

Arunav Singh: In charge of collecting data components for the simulation, and integration of MQTT within the unit (firmware).

Anthony Vu: In charge of understanding communication systems to the EVSE box and writing the code for a potential user interface in bluetooth, and then later WiFi communication.

Hongnian Yu: Collaborate with Arunav and Ming, and develop the scheduling controls engine part using data provided by Arunav.

5.1.2 Resources (2 points)

The funding we were provided by Microsemi, Calplug, and CalIt2 was the key to support the completion of the project. Combined with the direction provided to us by our dedicated mentor, we were able to make rapid progress to complete our project.

5.2 Technical Approach (5 points)

We believe that we demonstrated a design that can be scaled and integrated how we proposed. However, the RAPI protocol still has a few bugs that affect stability. A certain pattern of commands will cause the code to break. This is out of our control without putting more time and effort into upgrading the firmware for the OpenEVSE. However, it will not be an issue at the end, because this is just a demonstration to serve as the proof of the concept. The scheduling controls engine and the charge scheduling have been designed very well and are the focal point of our system.

5.3 Concluding Remarks and Credits (3 points)

We believe that our work has the potential to have a huge impact on the California's energy grid demand response. We were determined to tackle an important issue and we believe that we have built upon a promising idea that will later have a substantial affect on energy systems worldwide.

Our ideas could not have come to life without the constant support from our mentor Dr. Michael Klopfer. Mike was always available for help and guided us through several roadblocks.

A big thanks to CalIt2, CalPlug, Microsemi, and Smartenit who provided us with all the funding and tools we needed. Another thanks to Christopher Howell, the founder of the OpenEVSE, the foundation for our work.

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Appendix A

Processing Graphical User Interface Documentation:

The RAPI user interface was used to demonstrate the possibility of using MQTT communication within the system. Initially the code was developed over bluetooth communication. Then the system was converted to adapt to MQTT. The code is originally based off an open source project that can be found: https://github.com/chris1howell/OpenEVSE_RAPI_Processing_GUI. This code was adapted to add functional commands and converted to communicate in Processing. Each of the buttons added are simplistic and send commands up to the cloud for the arduino within the EVSE box to process. The arduino send commands to the box and gets the appropriate response. The response is then formatted and sent back to the processing console. The processing console is supposed to wait for a response before displaying the proper answer to the screen. However, due to time constraints of the project deadline, the arduino currently acts as a relay of information. The Processing takes the response and interprets it before displaying it on screen. Because of this, there is an issue with the timings of when a response is received, and the code will freeze.

Scheduling Controls Engine Software Documentation:

The rule's engine program is composed of following files: Rule_engine_gui.m, Rule_engine_gui.fig, Smart_charging.m, Dumb_charging.m, smartnit_update.m, map_charginglevel2power, and Availablepower.xlsx. The program will simulate the charging process for real node (Real EV) and virtual nodes (created to mimic the behavior of a real EV) according to the charging algorithm we proposed. Moreover, this program will draw the power consumption curve in real time and compare it to the regular charging process. To start simulation, users need to provide two inputs: Intial EV quantities in the network at 5 pm and the season for the simulation. In the simulation process, users can still do the following things to alter the simulation process. 1. Add new EVs into the network. Letting new EVs to join the network in real time is necessary to ensure the simulation process is close to the real world scenario. 2. Change wind speed. Even in the same season, wind power generated from the turbine still varies day by day. By changing the wind speed slide bar, users can simulate the charging process for a specific day. 3. Check EV status. User can type either ID or the range of ID for EVs to check each individual EV status. For instance, in order to check EV with ID 0,1,2, users can type "0,1,2" or "0-2" to check the results. The ID number "0" is always reserve for real node.

Rule_engine_gui.m: This the main module for the program. It contains the structure of each EV, which includes each EV's charging rate, charging time since joined the network, energy consumption and charging level. All the EVs are then represented using an array. The program does not use linked list as the data structure for the EVs because Matlab can support dynamic array. ID 0 is always reserved for the real node. Virtual nodes will take ID starting from 1 according to the time they join the network.

Rule_engine_gui.fig: This is the figure file for rule's engine GUI. It contains information of each button and text in the GUI.

Smart_charging.m: This is the file that manages the smart charging process. It takes two inputs—EV structure and available power, and then generate an output array. Each element of the array indicates the charging rate for each EV.

Dumb_charging.m: This is the file that manages the regular charging process, which is used for comparison purpose.

Smartnit_update.m: This file manage any update to the EV structure. For example, it add new EVs to the structure according to the user's input and remove EVs which are fully charged from the structure.

Map_charginglevel2power: This function maps different charging rate to its corresponding power consumption. For example, the 30A current in level 2 will correspond to 7200watts' power consumption.

Availablepower.xlsx: A excel file contains all the wind power information in different season. The data in the file comes from our research.

Copy Right Info

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Appendix B

B.1 Layout

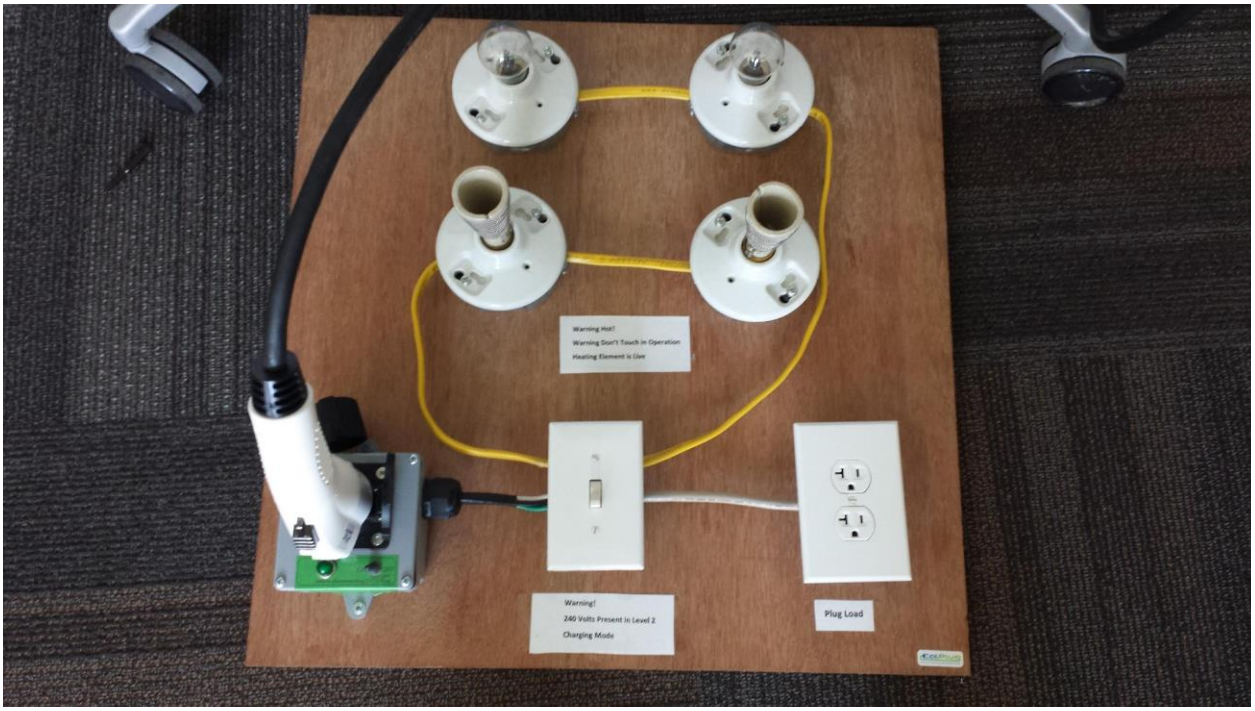

Figure 16: EV Simulator

The two light bulbs and the plug are always connected, while the two heaters are controlled by the switch.