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Continuously Varying Valley Filling Smart Charging Techniques

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Continuously Varying Valley Filling Smart Charging Techniques

THESIS

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for the degree of

MASTER OF SCIENCE

in Mechanical and Aerospace Engineering

by

Theron Smith

Thesis Committee:
Professor Gregory Washington, Chair
Professor Faryar Jabbari
Professor Jack Brouwer

2019

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Abstract of Thesis

Continuously Varying Valley Filling Smart Charging Techniques

By

Theron Smith

Master of Science in Mechanical and Aerospace Engineering

University of California, Irvine, 2019

Professor Gregory Washington, Chair

As fossil fuels continue to deplete, and emission standards become more strict, plug-in electric vehicles (PEVs) become more attractive. However, higher PEV penetration increases power demand on the grid, and immediate charging can induce large peak demands. A control algorithm, Continuously Varying Valley Filling (CVVF), is presented to enhance PEV charging at the local power level while minimizing the effects of uncontrolled PEV charging. Two decision mechanisms within CVVF are explored, crisp and fuzzy logic, to implement a centralized real-time valley-filling strategy that determines the preferred charging rate for vehicles to minimize distribution transformers damage. The algorithm assessed in this analysis reduces the highest peak and the average load during charging of 75 kW transformers by 15.80% and 13.75%, respectively.

1 Introduction

California's large population, sunny climate, and mountainous topography work together uniquely to create poor air quality. The power needed to sustain the state's population produces many pollutants, the climate helps ozone formation, and the topography entraps pollutants, causing them to accumulate and increase concentration levels [1]. In 1967 The California Air Resources Board (CARB) was formed to address this problem and improve air quality in California. CARB's efforts to enhance air quality standards led to the development of tailpipe emission standards, catalytic converters, and on-board vehicle diagnostic throughout the 1960s-1980s [1].

More recently, the California Global Warming Solutions Act was established in 2006, ordering California to reduce greenhouse gas emissions to 1990 levels by 2020. In 2011, Governor Edmund G. Brown, Jr., signed Senate Bill X1-2, setting the Renewable Profile Standard (RPS) target at 33% by 2020. Brown later signed Senate Bill 350 in 2015, setting the RPS target at 50% by 2030. In addition to Senate Bill 350, Brown signed Executive Order B-30-15, making California's new target of reducing emissions 40 percent below 1990 levels by 2030 and 80 percent below 1990 levels by 2050.

Zero emission vehicles (ZEV) are a pragmatic solution for sustainable transportation needs in the future. Executive Order B-16-2012 issued by California's Governor Brown, an initiative to lower the greenhouse gas emissions due to transportation, promotes Zero electric vehicles (ZEV) in California and sets a goal of reaching 1.5 million ZEVs in California by 2025 [1]. ZEVs are plug-in electric vehicles (PEVs), Battery Electric Vehicles (BEVs), and fuel cell electric vehicles (FCEVs). As highlighted in Figure 1, cumulative sales for PEVs are approaching 800,000 with California accounting for almost half of those sales [2]. Since PEVs and BEV's draw power from the grid, as these vehicles become more prevalent, they will impact and stress the electric grid in ways beyond the initial design.

A PEV can easily double a household electricity demand [3]. Furthermore, the additional load from multiple PEVs on a distribution transformer can shorten transformer life [3]. These concerns have led to the development of “smart charging” protocols that enable the penetration of PEVs to increase while maintaining the electric grid operation within safe limits and minimizing the need for grid investments to accommodate larger loads [4].

2 Literature Review

Generally, a strategy referred to as "valley filling" is utilized to shift the charging demand of the PEVs to the late evenings and early mornings when the overall demand on the electric grid is the lowest. Several charging control algorithms have been explored to modulate PEV charging, generally falling into two categories: decentralized control and centralized control [5].

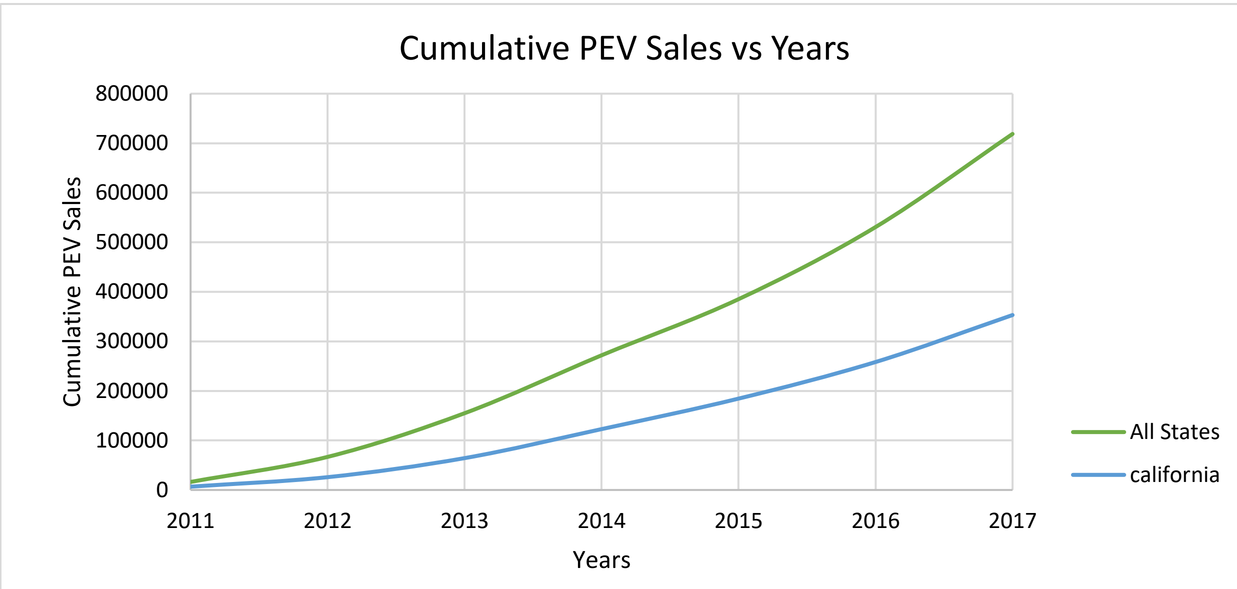

Figure 1. PEV Sales in the U.S.

Decentralized, or distributed, charging strategies allow for individual PEVs to determine their charging pattern [6]. PEV owners can create their charge patterns based on an electricity pricing scheme or non-price instruction [7]. These profiles are then sent to a central operator to update the load. Several existing decentralized algorithms [3, 4, 6, 8] valley fill. Decentralized controlling strategies are attractive because they allow each PEV to determine its charging pattern individually. Unfortunately, there is no guarantee that optimal charging will occur [6, 9, 10]. However, Ref. [4] introduces a grid valley filling algorithm that achieves a near ideal valley filling solution, but it induces significant transformer overload and overheating. Ref. [11] expands the grid valley filling algorithm, mitigating transformer stress by incorporating timeslot rejection and a modified timeslot rejection technique. The results indicate the Modified Timeslot Rejection strategy produces a valley filling profile at the grid level while preventing overloading with 75 kW transformers. Although this study presents impressive results, most decentralized platforms do not function in real time, which is a significant limitation given how these systems must be implemented.

Centralized smart charging strategies utilize a central system operator to control the charging patterns for customers [6, 12, 13, 14, 15]. The centralized controller receives information such as dwelling period, requested state of charge (SOC), and plug-in time from the customer and information from power plants to determine the optimal charging profile for each PEV connected [6, 16, 17]. Moreover, there have been several centralized charging studies incorporating fuzzy logic that operate in real time. Ref. [18] introduces a centralized algorithm based on maximum sensitivity selection (MSS) optimization and improves it using fuzzy reasoning. Ref. [19] enhances the solution of Ref. [18] and purposes two algorithms to minimize the costs associated with energy generation and grid losses while also maximizing the delivered power to PEVs. Ref. [19] uses fuzzy logic to make two types of optimization methods, Discrete Particle Swarm Optimization, and Genetic Algorithm, more efficient. However, the limitation is that vehicles cannot input a plug-out time. In another study, Ref. [20] applies fuzzy logic controllers at a distribution substation level and EV charging stations. The controller at the substation level determines the total amount of power for all connected charging stations, and the controller at the charging station level determines the amount of power each charging station receives. This approach demonstrates it can for valley fill, peak-shave, and flatten of load profiles; however, it is under the assumption that vehicle to gas (V2G) is used. Unfortunately, Ref. [21] shows that V2G bulk energy and ancillary services cause additional wear on a PEV battery and accelerates the frequency of replacement. Although these studies operate in real time, transformer reliability and variations in PEV charging rates are not considered.

The study in this thesis focuses on enhancing PEV charging at the local power level by developing a centralized real-time valley filling strategy to avoid excess damage to distribution transformers from uncontrolled charging peaks. As few as four high capacity PEVs simultaneously drawing power during an early summer evening can degrade transformer performance [11, 22]. This study is chosen because the relatively rapid growth of electric vehicles in California could negatively affect neighborhood transformers in the short term and a centralized solution provides the most efficient framework for mitigating this challenge in the short-term. The primary rationale for this is that it is easier to implement a strategy at one electric municipality than it is to implement a strategy in more than 25 automobile manufacturers producing ZEVs. Transformers are also targeted because uncontrolled charging is most likely to negatively affect local distribution systems, out of all the components in the U.S. power system [23].

In the simulations performed in this analysis, it is assumed a controller is attached to the distribution level and strategically varies the output rate to each vehicle. It is assumed that the aggregator has access to PEV information using smart metering technology that allows the aggregator to know general PEV locations, initial and requested SOCs, plug-in times, and dwelling periods. The algorithm will produce a valley fill effect to reduce high peaks caused by uncontrolled charging by monitoring when transformers are operating near the limit load.

A real-time valley filling algorithm, Continuously Varying Valley Filling (CVVF) , with two decision mechanisms, crisp logic and fuzzy logic, is presented in this thesis. The decision mechanisms are used to determine the output rate that a PEV shall receive when charging. Utilizing these decision-making mechanisms are advantageous in this application because they can optimize nonlinear systems, are computationally fast, and they allow CVVF to be easily scalable and operate in real time.

The contribution of this thesis explores how algorithms can be implemented in future technology to control the load observed by residential transformers and develops a working relationship of how future home PEV chargers and transformers can interact together. The goal of this study is to create a continuously varying valley filling algorithm that operates in real time and allow vehicles to charge to desired SOC levels while imposing minimal damage to distribution transformers. This goal is realized by accomplishing the following objectives: 1) Creating a valley filling algorithm with continuously varying charging rates using crisp logic; 2) Creating a valley filling algorithm with continuously varying charging rates using fuzzy logic; and 3) Verifying the algorithms using data reported in the literature.

3 Structure of the Electric System and Power Plant Load Balancing

The U.S. electricity system also referred to as the electric grid network, or utility grid network is comprised of 4 primary sets of components: electric generation, transmission, distribution, and customers (or load) [24]. Generally, electric generation is categorized as centralized generation and decentralized generation. Centralized generation is large-scale electricity generation, usually located far from customers. Decentralized generation is small-scale electricity generation, usually located close to customers. Distributed generation may be connected to a residential home, commercial or industrial building, part of a microgrid at a large industrial facility, a military base, or academic institution [24].

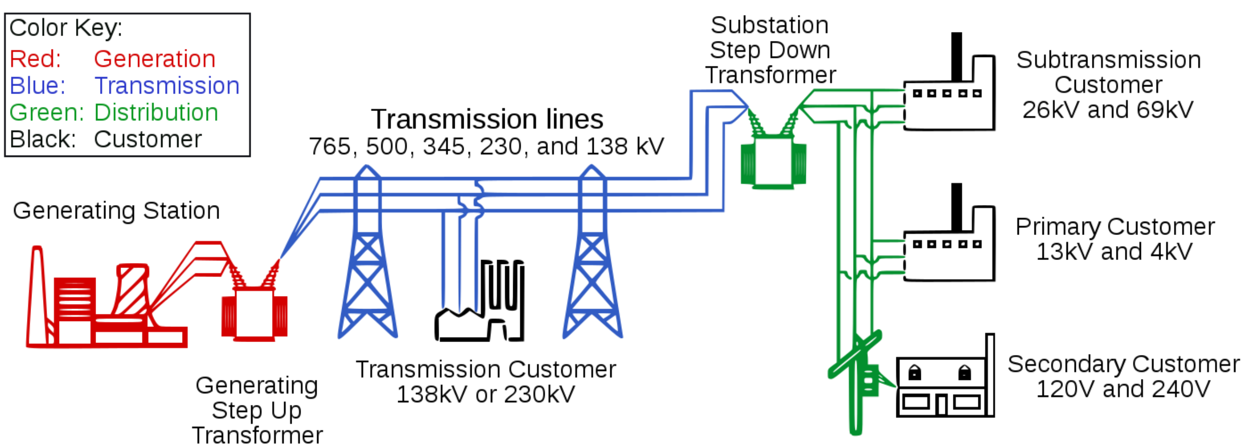

Figure 2: U.S. Grid

3.1 Electric Generation

Electricity generation is the process of converting primary energy sources from their natural form to create electric power [25]. These sources, generally divided into two categories, are non-renewable and renewable. Renewable energy sources are those that are naturally replenished quickly, whereas non-renewable energy sources are seen non-replenishing [26]. Within the U.S. electric grid, electricity is produced as 3-phase alternating current (AC) power in the generation stage [27]. 3-phase AC power, comprised of three different phases of AC power, are phase shifted by 120 degrees. From each generating station, four wires are typically used to transfer electricity to the subsequent section of the more extensive grid network. Three wires are used for the three phases of power, and the fourth is used a common ground to the other three wires [27]. As a function of time, the three-phase power for one complete cycle is presented in Figure 3.

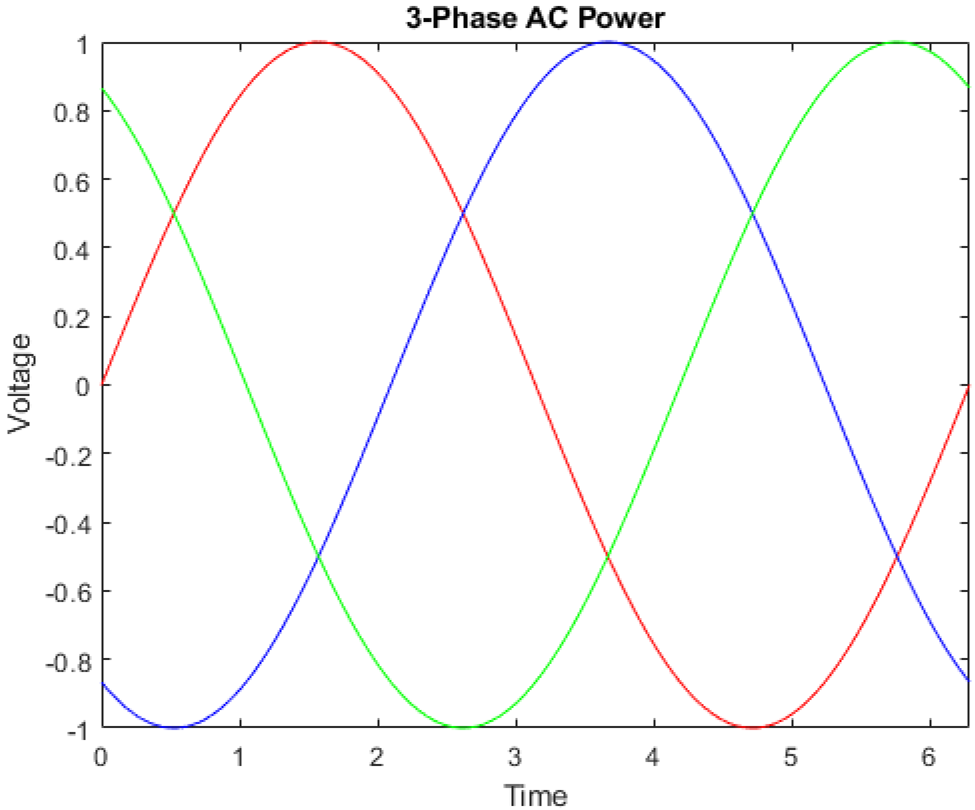

Figure 3: Three Phase Power

3.1.1 Non-renewable Energy Sources

Non-renewable sources used to create electric power are coal, natural gas, and uranium [28]. Four classifications of coal are used to create electric power: anthracite, bituminous, sub-bituminous, and lignite. The classifications are derived from the amount of carbon each type contains which correlate to how much heat energy the coal can produce [28]. Anthracite contains

86%–97% carbon, bituminous contains 45%–86% carbon, sub-bituminous contains 35%–45% carbon, and Lignite contains 25%–35% carbon [28]. Coal is burned in boilers of coal-fired power plants to produce heat to convert water into steam. The steam is used to drive a steam turbine connected to an electric generator [29].

Natural gas is a gaseous mixture comprised of mostly methane (CH_4) but also contains other hydrocarbons like ethane, propane, and butane. Also, other gases like nitrogen, helium, carbon dioxide, sulfur compounds, and water vapor comprise natural gas [28]. Natural gas is extracted from three sources: associated and non-associated gas from conventional gas fields, and unconventional gas found in basin-centered gas, coal-bed gas, shale gas, fractured-reservoir gas, and tight-reservoir gas [30]. Associated gas is natural gas found with oil with a reservoir when natural gas is discovered without oil; it is non-associated gas [31]. Natural gas is used to produce electricity from gas turbines operating on the Brayton cycle. Fuel is compressed in a compressor,

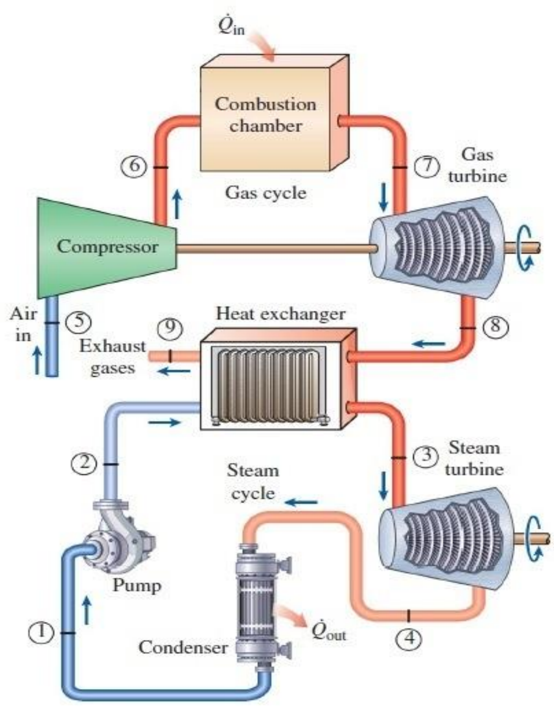

Figure 4: Combined Cycle Power Plant

then heated in a combustor, and moves through a turbine, causing the turbine blades connected to an electric generator to spin. The hot exhaust gases from the gas turbine are commonly used for steam generation in a combined cycle. The exhaust gases are used to convert water into steam to drive a steam turbine and create electricity [32].

Nuclear power plants use a specific type of uranium, U-235, as fuel because its atoms are easily split apart. Although uranium is about 100 times more common than silver, U-235 is relatively rare. Reactor cores in nuclear power plants split atoms into smaller atoms to release energy and heat in a process called nuclear fission. The heat produced during nuclear fission is used to convert water into steam to spin turbine blades coupled to an electric generator [28].

3.1.2 Renewable Energy Sources

Renewable sources include hydropower, biomass, wind, geothermal, and solar. Hydropower produces hydroelectricity by using the water cycle. This cycle describes water natural process of circulating between the earth's oceans, atmosphere, and land. The sun heats water on the surface of rivers, lakes, and oceans, causing evaporation into the atmosphere. Water vapor condenses in the atmosphere and returns to the earth’s surface through precipitation in the form of rain and snow. That precipitation collects in streams and rivers, which empty into oceans and lakes, where it evaporates and begins the cycle again [28]. Hydropower plants are built next to flowing rivers and use the energy in the flowing water to spin turbines connected to generators [33].

A form of wind power is generated from the "The Daily Wind Cycle." In the day, the air above water heats up slower than the air above land. This natural phenomenon creates wind by causing warm air above land to expand and rise, allowing heavier, cooler air above water to migrate

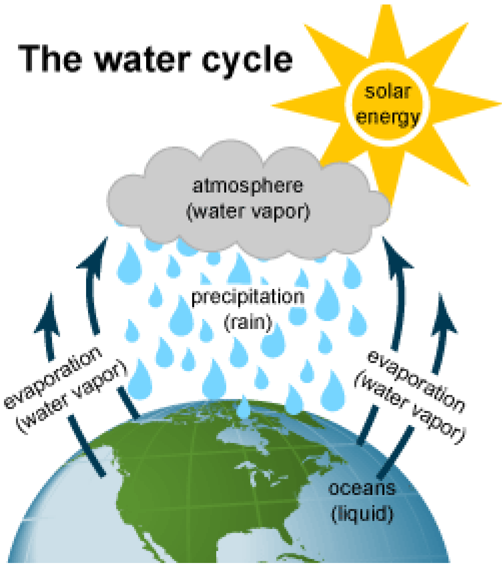

Figure 7: The Water Cycle

in and take its place. At night, the effect is reversed because the air cools slower above water than over land [28]. Energy from wind is used to create electricity using wind turbines. Wind travels across wind turbine blades, and a combination of lift and drag causes the blades to spin, turning a shaft, which connects to a generator and makes electricity [34].

Solar power conversion technologies absorb solar energy from the sun and convert it into electricity. There are two primary forms of solar technology, solar thermal collectors and solar photovoltaic (PV) cells. Solar thermal systems make electricity by heating a working fluid with solar thermal power and using a thermodynamic cycle to generate electricity. The main components in this system are reflectors (mirrors) that collect and concentrate sunlight onto a receiver. The focused sunlight is used to heat a fluid and produce steam for a steam turbine. A photovoltaic (PV) cell is composed of a semiconductor material that converts sunlight directly into electricity. Sunlight is composed of photons, which are particles of solar energy. Photons contain energy, and they are absorbed by PV panels they are converted into electricity [28].

Geothermal energy uses heat within the earth to operate steam turbines. There are three types of geothermal power plants: dry steam plants, flash steam plants, and binary cycle plants. Dry steam plants insert directly from geothermal reservoirs into steam-driven turbines. Flash steam plants extract high-pressure hot water from reservoirs, convert it to steam, and then use it to drive steam turbines. Binary cycle power plants transfer heat from geothermal hot water to another liquid, causing the other liquid to evaporate into steam and sent through a turbine [28].

Biomass used for energy purposes can be classified into four categories: wood, solid-waste, landfill gas, and alcohol fuels. Wood and solid-waste are burned in combustors of the power plant to create heat. Methane gas formed in landfills from decomposing plants, animals, and food. Landfills collect the gas, clean it, and use as fuel, known as landfill gas. The landfill is used in

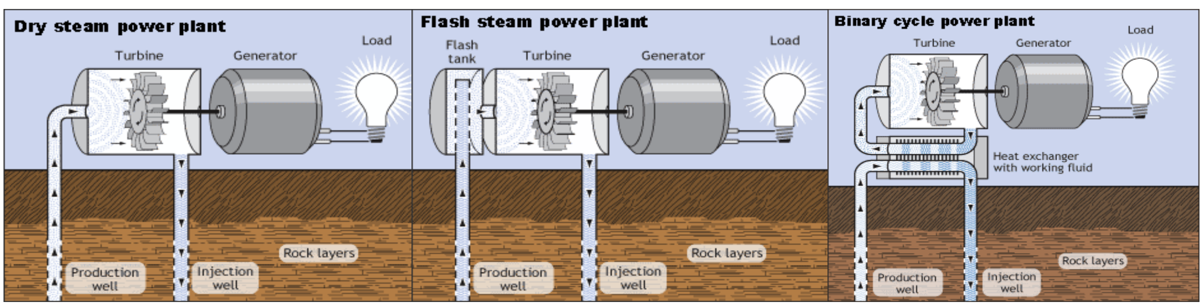

Figure 8: Geothermal Power Plants

natural gas power plants [28].

3.2 Transmission

Three-phase power leaves generation stations by entering a transmission substation, also referred to as a generating step-up transformer. This substation converts the voltage from the generation station to extremely high voltages between 115,000 to 345,000 volts to travel through primary transmission lines [35]. After being increased, power at this high voltage then leaves the substation and travels long-distances to a transmission step down transformers. Typically, the maximum transmission distance is about 300 miles (483 km) [27]. Upon entering the transmission step down transformer, the voltage is reduced between 34,000 to 69,000 volts to travel through secondary transmission or sub-transmission transmission lines. After being reduced, power travels through the secondary transmission lines to two locations: the secondary transmission connected customer, large industrial facilities, and to distribution step down transformers.

3.3 Distribution

Power enters a distribution step down transformer where voltage is reduced to values between 4,200 to 13,800 volts to travel through primary distribution lines and deliver electricity to small industrial facilities, large commercial buildings through distribution transformers. Secondary distribution lines connect distribution transformers, which reduce the voltage from primary distribution lines to 120/240/480 volts, to individual residential homes, commercial buildings, and industry. The recommended operating limits for distribution transformers are shown in Table 1 [36].

Recommended Limits of Temperature and Loading for Distribution Transformers	
Top Oil Temperature	110˚C
Hottest Spot Conductor Temperature	180˚C
Short Time Loading (30 minutes or less)	200%

Table 1: Recommended operating limits for distribution transformers (from: [36])

4 Fuzzy Logic

Since the mechanisms related to when and how much power vehicles receive are primarily non-linear and require a rule base, logic instruments such as crisp and fuzzy logic are utilized.

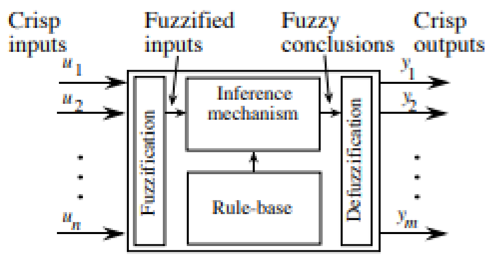

Figure 9: Fuzzy Logic Diagram

Crisp logic and fuzzy logic are used in this thesis to determine the power a PEV shall receive when charging. Crisp logic behaves similarly to binary values where rules are determined by yes or no, whereas fuzzy logic allows intermediate values. Fuzzy logic provides a formal methodology for representing and implementing a human's heuristic knowledge to control a system [37]. There are four main components to fuzzy logic: fuzzification, rule-base, inference mechanism, and defuzzification. Fuzzification convert inputs to fuzzy sets, the inference mechanism uses fuzzy rules from the rule-base to interpret the meaning from the input, and defuzzification converts the interpretation back into a real number.

4.1 Fuzzification

Fuzzification converts input variables, which are interpreted as linguistic variables, u_i, into information, the controller can quantify by creating linguistic values or fuzzy sets, A_i^j. Linguistic values are defined over U_i, the universe of discourse, which is the domain of all possible values of u_i. Assuming multiple linguistic values exist for each linguistic variable, u_i takes the elements from the set of linguistic values denoted by

$$A_i = \{A_i^j : \text{j} = 1, 2, \dots, N_i\} \quad (1)$$

A function $\mu_{A_i^j}(u_i)$, referred to as a membership function, is associated with A_i^j and maps U_i to [0,1]. This membership function describes the certainty that an element of U_i, with a linguistic description u_i, may be classified linguistically as A_i^j. For the purposes of this thesis, only the triangular membership function will be defined.

	Triangle Membership Function	
Left	$\mu^L(u)\begin{cases} 1 \\ \max\{0, 1 + \frac{c^L - u}{0.5 * w^L}\} \end{cases}$	If $u \leq c^L$ Otherwise
Centers	$\mu^c(u)\begin{cases} \max\{0, 1 + \frac{u - c}{0.5 * w}\} \\ \max\{0, 1 + \frac{c - u}{0.5 * w}\} \end{cases}$	If $u \leq c$ Otherwise
Right	$\mu^R(u)\begin{cases} \max\{0, 1 + \frac{u - c^R}{0.5 * w^R}\} \\ 1 \end{cases}$	If $u \leq c^R$ Otherwise

Table 2: How to calculate the triangle Membership Function

4.2 Rule-base

The rule-base is a set of if-then rules which contains a fuzzy logic quantification of the expert's linguistic description of how to optimally control a system. The rules are formed in the following form,

If premise, **Then** consequence (2)

Which generalizes to equation 3.

If u_1 is A_1^j **and** u_2 is A_2^j **and**, . . ., **and** u_n is A_n^j **then** y_q is B_q^p (3)

where y_q is an output variable interpreted as a linguistic variable and B_q^p is a linguistic variable denoted by

$$B_i = \left\{B_i^p : \mathrm{p} = 1, 2, \ldots, M_i\right\} \quad (4)$$

These sets of linguistic rules are specified by the expert and are used to control the system to the desired state.

4.3 Inference Mechanism

The inference mechanism emulates the decision-making process of the expert. It assesses which combination of if-then statements are satisfied and formulates a decision on the principles of the rule base. The inference mechanism requires two steps. The first step, matching, determines which rules are on or apply to a certain situation. The second step determines the certainty of the result from step 1. This step is also a two-step process that involves using the minimum of the input membership certainties, represented by equation 4.

$$\mu_{premise_i} = \min\left(\mu_{A_i^j}(u_1), \mu_{A_i^j}(u_2), \ldots, \mu_{A_i^j}(u_n)\right) \quad (4)$$

After $\mu_{premise_i}$ is determined, it is used to determine the implied fuzzy sets, found by taking the membership function from the consequence (output membership function) and using the minimum to quantify the “then” operation. The combination of these two implied fuzzy sets is called the overall implied fuzzy set, shown in equation 5.

$$\mu_{(i)}(u) = \min\left(\mu_{premise_i}, \mu_{B_i^j}(u_i)\right) \quad (5)$$

4.4 Defuzzification

Defuzzification converts the fuzzy conclusions of the inference mechanism to actual inputs to the system [38]. The most popular method is the "center of gravity" (COG) method. There are many other possibilities as well however COG will only be covered for the purposes of this thesis. The output, yY_i, is calculated by using equation 6,

$$Y_i = \frac{\sum_{k=1}^{R} b_k^i \int A}{\sum_{k=1}^{R} \int A} \quad (6)$$

where R is the number of rules, b_k is the center of the area of the output membership function, and

$$A = \int u_k(y_i) dy_i \quad (7)$$

is the area under the corresponding membership function.

5 Problem Formulation

The optimization variable in this study is the delivered charging rate (power). The objective function,

$$\min \mathrm{F} = \left| t_i - \left(\sum_{j=1}^{n} y_i + x_i \right) \right| \quad (8),$$

is defined for the PEV coordination problem to maximize the delivered charging rate, y_i, to PEVs at each timeslot such that the total load is lower than the limit load curve denoted as t_i. The variables t_i and x_i, the forecasted load, in the objective function are known variables that do not change during in each timeslot. The scheduling begins at midnight for 24 hours and is divided into 1440, 1-minute timeslots expressed as i. The limit load may or may not be the rated transformer limit, but for this thesis, it will be the transformer rated limit. During each timeslot, CVVF accesses how many vehicles are plugged in and assigns a charging rate to each car based on the priority ratio defined as

$$p = \frac{SOC\ Needed}{Remaining\ Dwell\ Time} \text{ (9)},$$

and the load difference (Δ) defined as (limit load - forecasted load),

$$\Delta(i) = t_i - x_i \text{ (10)}.$$

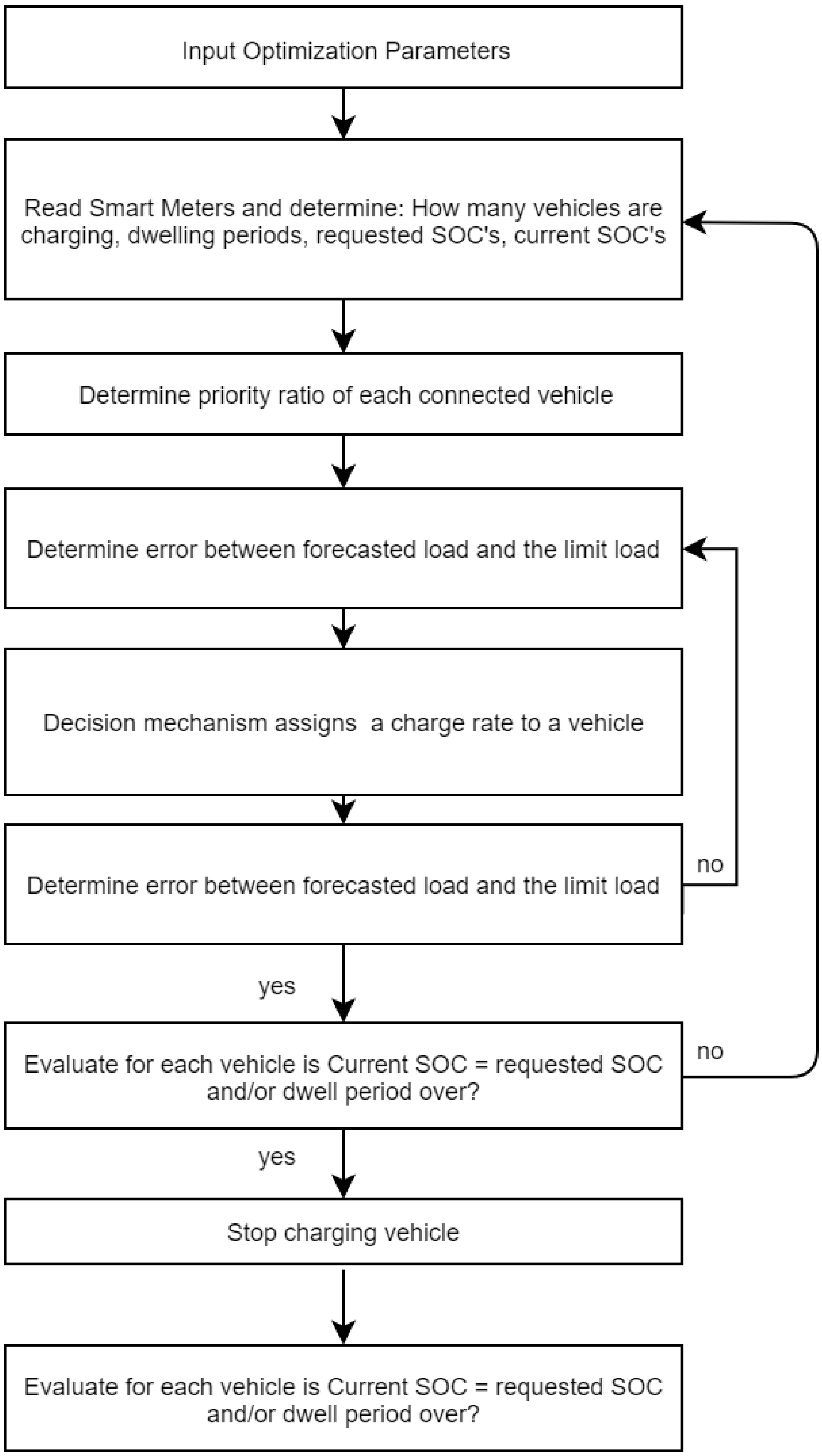

Figure 10: CVVF Flow Chart

5.1 CVVF with crisp logic used to determine PEV charging rates:

The crisp logic decision mechanism begins determining the delivered charging rate, y_i in

Load difference (Input)	Charge Rate (kW)
less than 1.9	0
Greater than 1.9 & less than 3.3	1.9
Greater than 3.3 & less than 7.2	3.3
Greater than 7.2	7.2

Table 3: Load Difference Chart

equation (1) by first analyzing how many vehicles are charging in that minute. The vehicles are then organized by sorting the priority ratio for each vehicle in descending order, effectively organizing the vehicles from most to least significant. After these are calculated, a set of if-then rules are used to determine how to interpret the value of load difference. These rules dictate the charge rate each vehicle receives, varying between 0, 1.9, 3.3, and 7.2 kW. These rates are selected to provide a comparative analysis of the techniques used in reference [11]. Charging rates are then distributed from highest to lowest to the vehicles that are ordered from most to least significant. This allows the most important vehicles to be charged at the highest rate possible.

5.2 CVVF with fuzzy logic used to determine PEV charging rates:

Similar to the crisp logic decision mechanism, the fuzzy logic decision mechanisms begins by identifying how many vehicles are charging, the requested SOC and the remaining dwell time for each vehicle, to calculate p. After calculating each vehicle's priority ratio, Δ is determined,

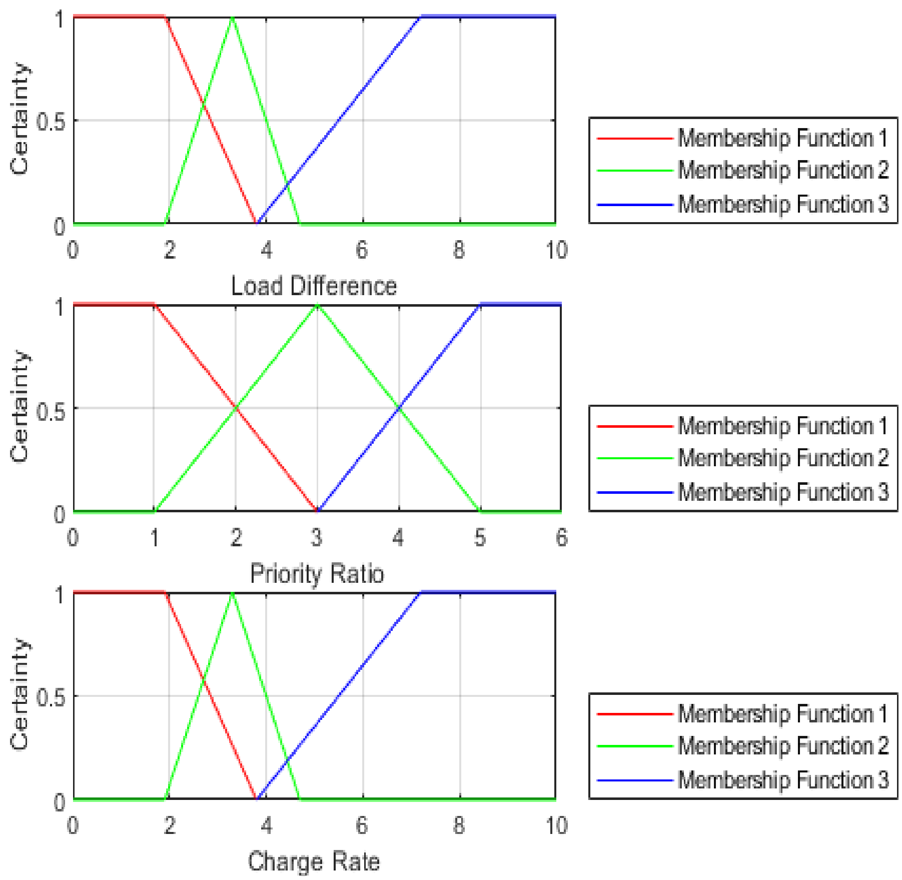

Figure 12: Fuzzy Membership Functions

and are used as inputs to determine y_i in equation (1). A set of rules are used to determine how to interpret load difference and priority ratio for each vehicle. Both values become an input and return an output of 1, 2, or 3. These classifications group similar values of load difference and priority ratio together into membership functions to be read as: small, medium, and large. Once the load difference and priority ratio have been assigned to a membership function, an inference table is then used to determine the output membership function based on the load difference membership functions. The output gives a value 1, 2, 3, which corresponds to "low," "medium," and "high." For example, if a vehicle receives a priority ratio of 1 (small) and the load difference at that instance is 2 (medium), that vehicle will receive a charging rate of 2 (medium). The output is assigned to a membership function and y_i is calculated using equation 6 and 7, determining the output rate for the associated vehicle.

5.3 Algorithm conclusion

The rate that is determined when using either decision mechanism is this then added to the forecasted load at that minute, moving that point up. This process is then repeated for each vehicle charging during this minute. As a result, the point continuously moves up, representing the additional load from each vehicle charging. As the point approaches the transformer limit, to protect the transformer, the rates begin to decrease. This effect can be seen in the inference table, as lower load difference values result in a variety of low delivered charging rates. Once every vehicle that is charging during this minute has been accounted for, and the point has moved to its final location, CVVF will evaluate the next minute. CVVF begins recalculating the priority ratio and load difference, and then proceed to execute the calculation.

<table>
<tr><th colspan="2" rowspan="2">Charge Rate</th><th colspan="3">Load Difference</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><th rowspan="3">Priority Ratio</th><th>1</th><td>1</td><td>2</td><td>3</td></tr>
<tr><th>2</th><td>2</td><td>3</td><td>3</td></tr>
<tr><th>3</th><td>2</td><td>3</td><td>3</td></tr>
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Table 5: Fuzzy Logic Inference Table

6 Results

6.1 Transformer Data

The transformer data used in this thesis is the same as used in Ref. [11]. This allows for direct comparison and analyzation. While Ref. [11] uses Thursday, September 25, 2014, this study will additionally use Monday, August 25th, 2014, and Tuesday, September 16th, 2014. The data used to obtain the baseloads for the simulations is measured from a 75 kW residential transformer located in Irvine, California, on three different days. The baseload is the load on the transformer before PEV charging is added. The measured 75 kW transformer serves 20 homes, with 8 of these homes having air conditioning. The size of these homes' ranges from 1900 to 2900 square feet. The baseload transformer data used throughout this thesis did not include any electric vehicle charging. Monday, August 25th, 2014, experienced highs of 27.2 C (81.0 F) and lows of 21.1 C (70.0 F). Tuesday, September 16th, 2014, had highs of 27.2 C (81.0 F) and lows of 22.2 C (72.0 F). Thursday, September 25, 2014, had highs of 31.1 C (88 F) and lows of 22.1 C (72 F). The transformer data has a sampling time of five minutes. This sampling time could exaggerate changes in the load.

The baseline data used in this thesis is recorded from midnight to midnight. To analyze overnight charging, each day's load profile is extended from 24 to 48 hours, and the middle region (12-36 hours) is extracted, therefore creating an overnight interval spanning noon to noon.

6.2 PEV Data

Similar to the studies outlined in Ref. [4] and Ref. [11], data from the 2009 National Household Travel Survey (NHTS) are used to simulate vehicle travel behavior. The processing steps utilized in Ref. [4] will be used. Trips without a personally owned vehicle were deleted, person-chain data was converted to vehicle chain data, daily trip data with unlinked destinations or significant over-speed were deleted, and tours were organized to start and end at home. This processing resulted in travel data for 20,295 vehicles. Using assumption from Ref. [11], 20,295 PEVs are randomly assigned to the 2255 transformers, maintaining a ratio of 9 PEVs per transformer. The original random assignment is maintained throughout all simulations.

In these results, all three days (August 25th, 2014, September 16th, 2014, and September 25, 2014) of data are used to provide three different baseloads for PEV charging. Uncontrolled charging is applied to each day and is used to measure the performance of CVVF using crisp and fuzzy logic. Uncontrolled charging assumes all PEVs are charged at a rate of 7.2 kW, while the rate in the controlled cases may vary.

The results from uncontrolled charging are compared to 10 controlled charging cases to determine the best case. Each case utilizes a different limit load and simulates CVVF, utilizing both decision mechanisms, charging PEVs on the baseloads from the three days of data, producing six situations per case. The objective is to observe how varying the limit load affects the charging profile the algorithm produces and then determine the best limit load by assessing: the absolute high peak a transformer reaches; the average highest load each transformer reaches; the average transformer load during charging; and how many vehicles are fully charged.

Two methods are used to vary the limit load for CVVF. The first method equates the limit load to a percentage of the current rated limit. Method 1 includes four cases (cases 1-4) where the limit load in case 1, 2, 3, and 4 are equal to 75%, 100%, 125% and 150% of the rated limit, respectively. Method 2 includes six cases (cases 5-10) where the limit load is equal to the average baseload plus a multiple of the standard deviation. In cases 5, 6, 7, 8, 9, 10 the multiple of the standard deviations is equal to 0, 0.5, 0.75, 1, 1.5, 2 respectively. For brevity, only case 7 is included in the results; the remaining cases are attached in Appendix A.

In all the subsequent figures, the green curves represent the load on all 2255 randomly assigned transformers. The red curve represents the baseload, the blue curve represents the rated transformer limit, and the black curve represents the limit load.

6.3 Algorithm Verification

	0-40%	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
Real time valley filling with crisp logic	283	71	83	95	107	165	19544
Real time valley filling with fuzzy logic	216	63	64	96	89	72	19695

Table 3: Algorithm Validation Table

The Modified Timeslot Rejection strategy in Ref. [11] produces a valley filling profile at the grid level while preventing overloading with 75 kW transformers. To demonstrate CVVF's filling ability, the data from Ref. [11] (i.e., same baseloads, the same number of vehicles, plug-in times, dwell periods, and requested SOC's) will be ran, using both decision mechanisms, with the optimized load profile for PEV charging from each transformer found in Ref. [11] as the limit load. The results from Ref. [11] serves an optimal case, and the purpose of this experiment is to show that given the proper limit load curve, CVVF can fill to and produce sufficient results. In Table 3, the results show CVVF can charge at least 96% of vehicles above 90% using the optimized profile from Ref. [11].

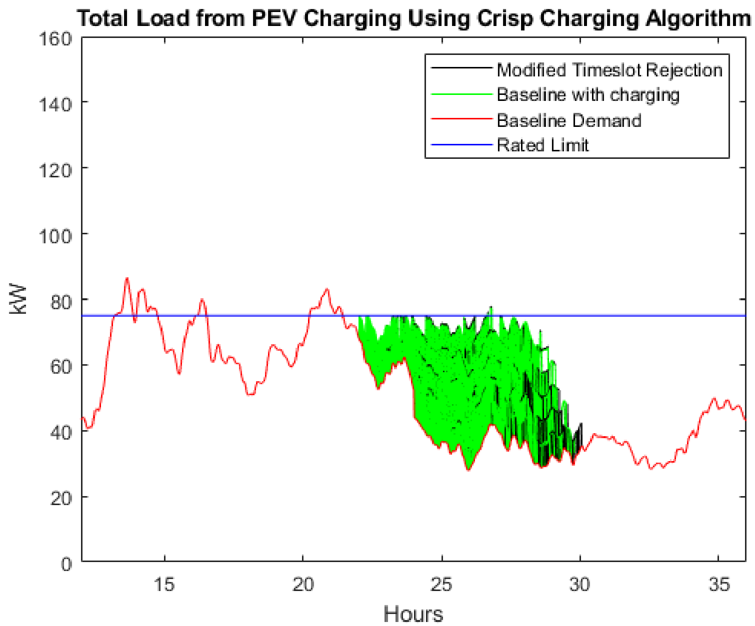

Figure 13: CVVF with crisp logic using the Modified Timeslot Rejection algorithm as the load limit on September 25th, 2014 Baseload

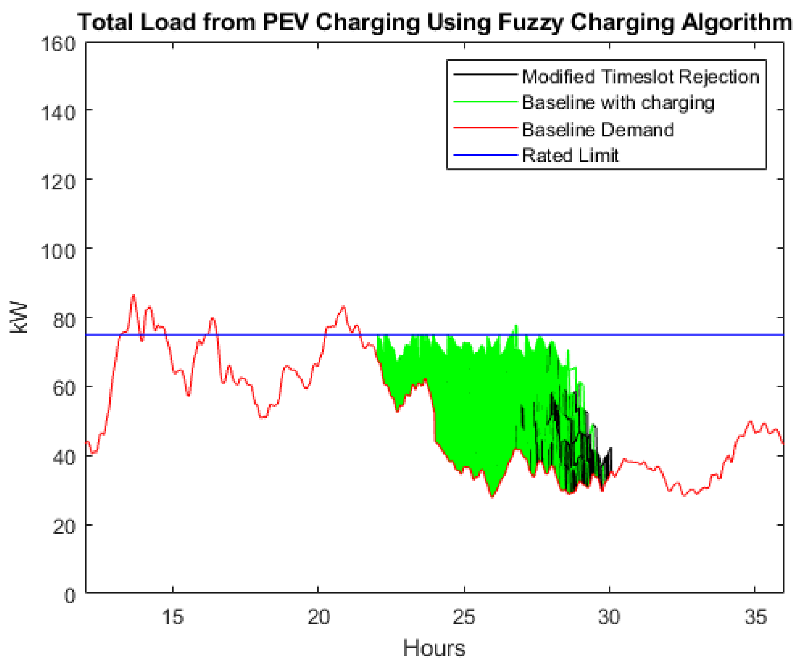

Figure 14: CVVF with fuzzy logic using the Modified Timeslot Rejection algorithm as the load limit on September 25th, 2014 Baseload

6.4 Uncontrolled Charging:

This section will show the effects of PEVs charging without a scheduling protocol and be used to compare the performance of CVVF using both decision mechanisms.

6.4.1 Day 1: August 25th, 2014

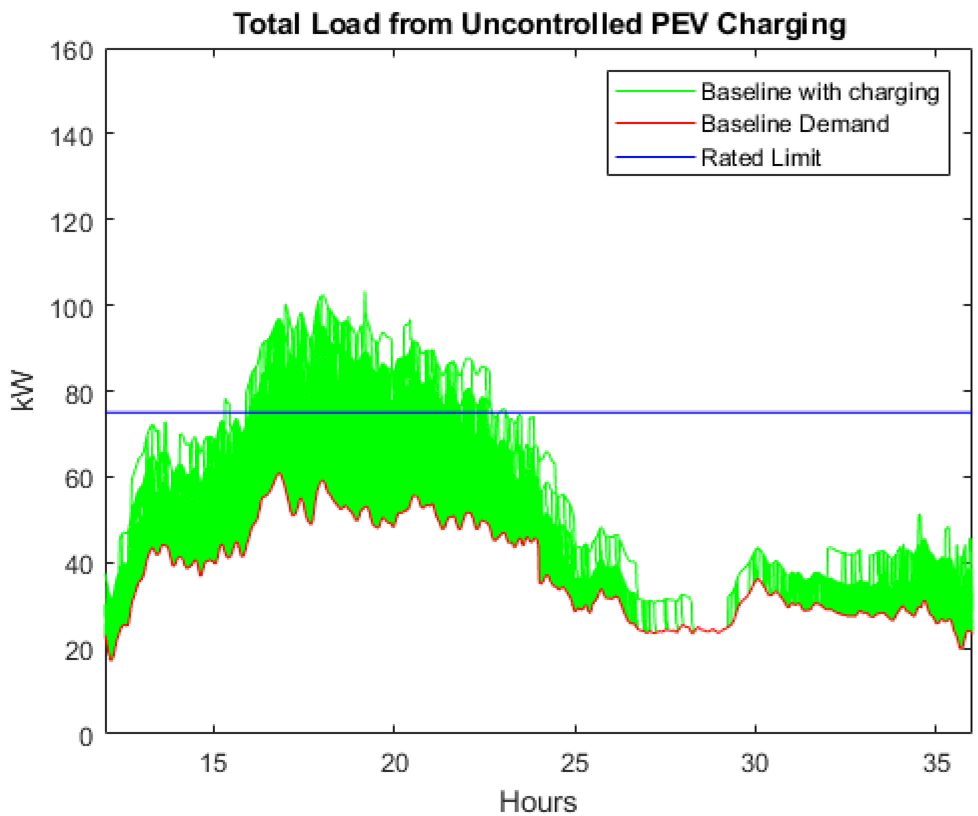

Figure 15: Uncontrolled Charging on August 25th, 2014 Baseload

The highest peak power reached amongst any of the transformers is 103.30 kW. The average highest peak point amongst all transformers is 78.35 kW, and highest peak power from baseload is 60.85 kW, meaning that the highest peak power is a direct result of PEV charging. The average load during charging is 57.87 kW.

6.4.2 Day 2: September 16th, 2014

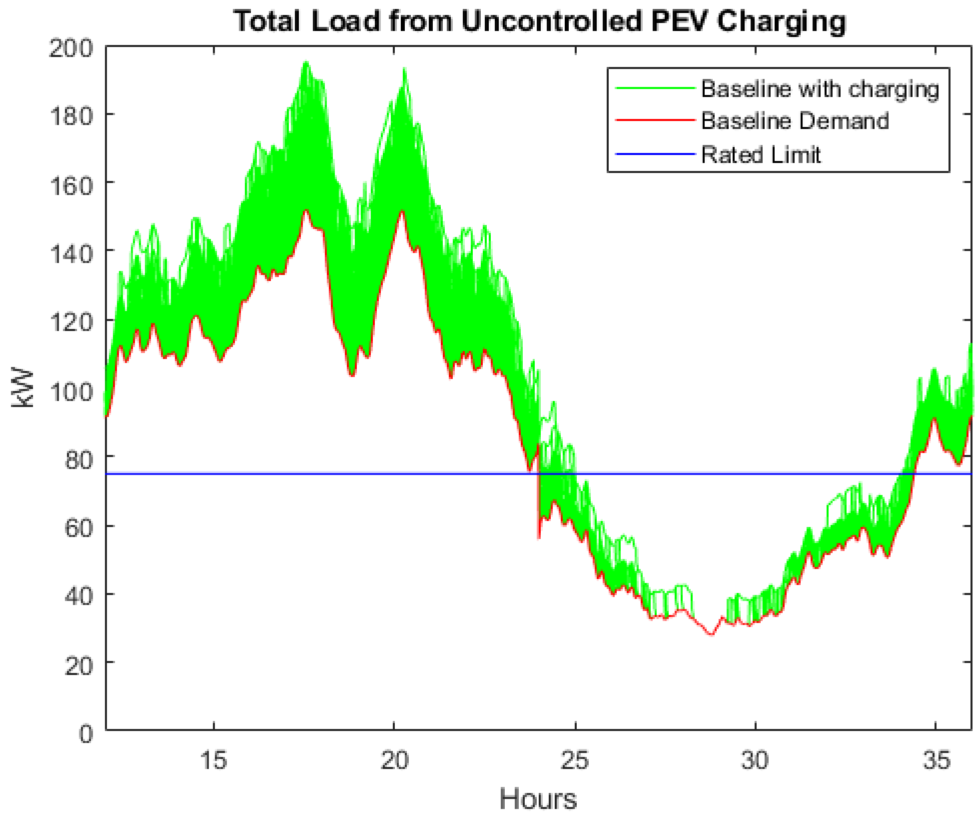

Figure 16: Uncontrolled charging on September 16th, 2014 baseload

The highest peak power reached amongst any of the transformers is 195.13 kW. The average highest peak power amongst all transformers is 168.07 kW, and highest peak power from baseload is 151.93 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 127.52 kW.

6.4.3 Day 3: September 25th, 2014

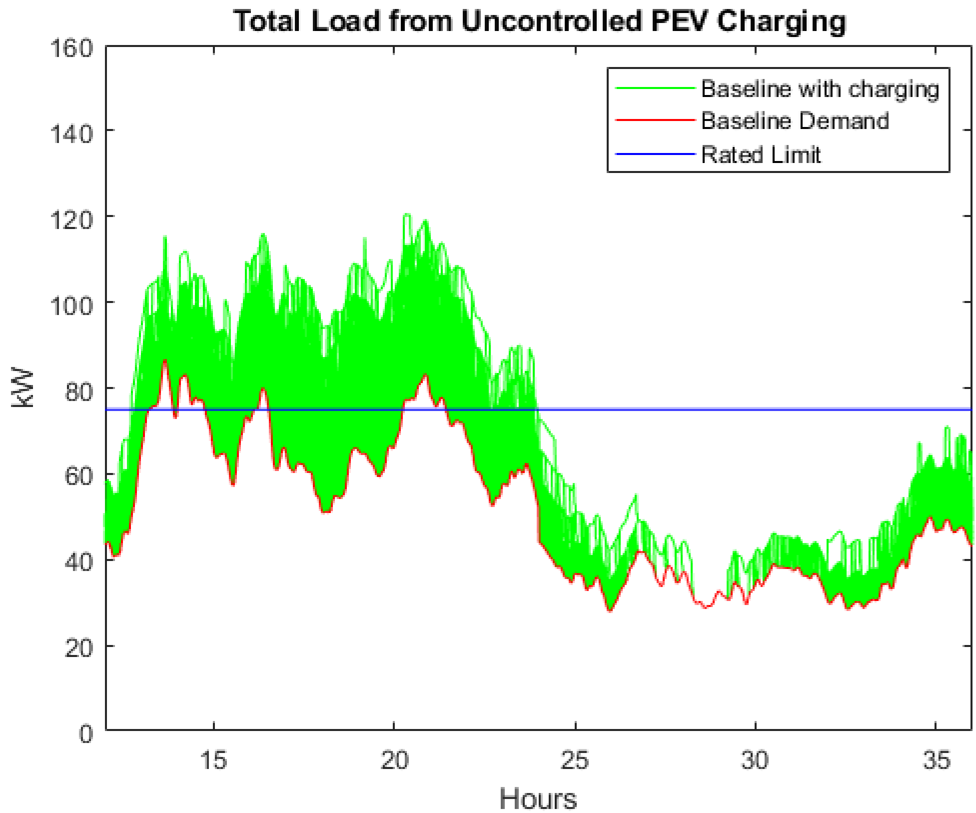

Figure 17: Uncontrolled charging on September 25th, 2014 Baseload

The highest peak power reached amongst any of the transformers is 120.58 kW. The average highest peak power amongst all transformers is 97.79 kW, and highest peak power from baseload is 86.58 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 74.36 kW.

6.5 Algorithm Performance

6.5.1 Case 7 – (Limit load = Mean Baseload + 0.75*STD)

For the purposes of this section, the limit load will be equal to the average value of the baseload plus 0.75 standard deviations; meaning that CVVF will fill to this value. The average value of the baseload plus 0.75 standard deviations on August 25th, 2014, September 16th, 2014 and September 25th, 2014 was 45.79 kW, 112.35 kW, and 64.47 kW respectively.

6.5.1.1 Day 1: August 25th, 2014

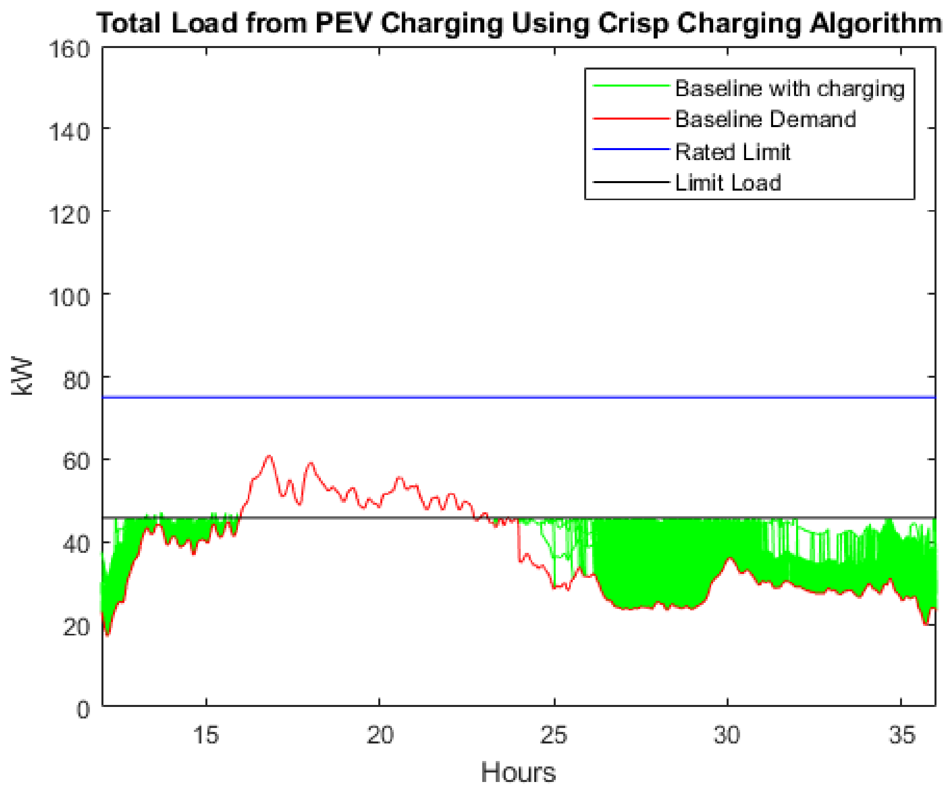

Figure 18: CVVF with crisp logic using the average value of the baseload plus 0.75 standard deviations (45.79 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the

baseload, not PEV charging because CVVF restricts charging when the baseload is above CVVF limit load. The average load during charging is 47.71 kW.

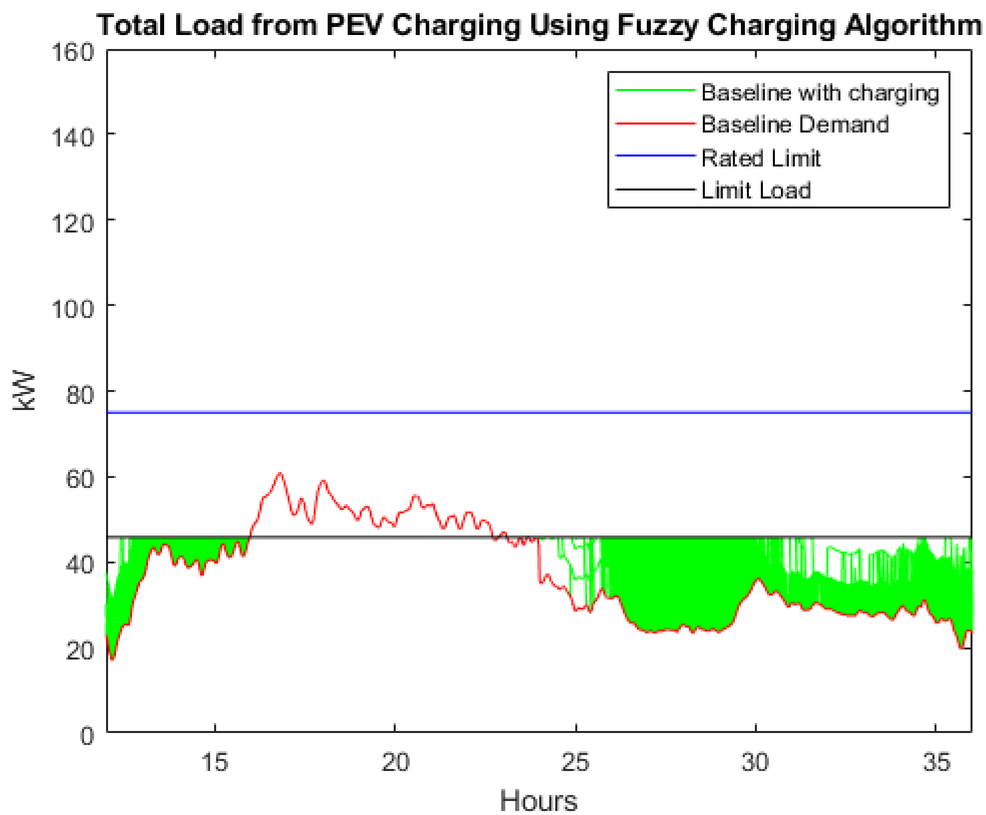

Figure 19: CVVF with fuzzy logic using the average value of the baseload plus 0.75 standard deviations (45.79 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 48.16 kW.

6.5.1.2 Day 2: September 16th, 2014

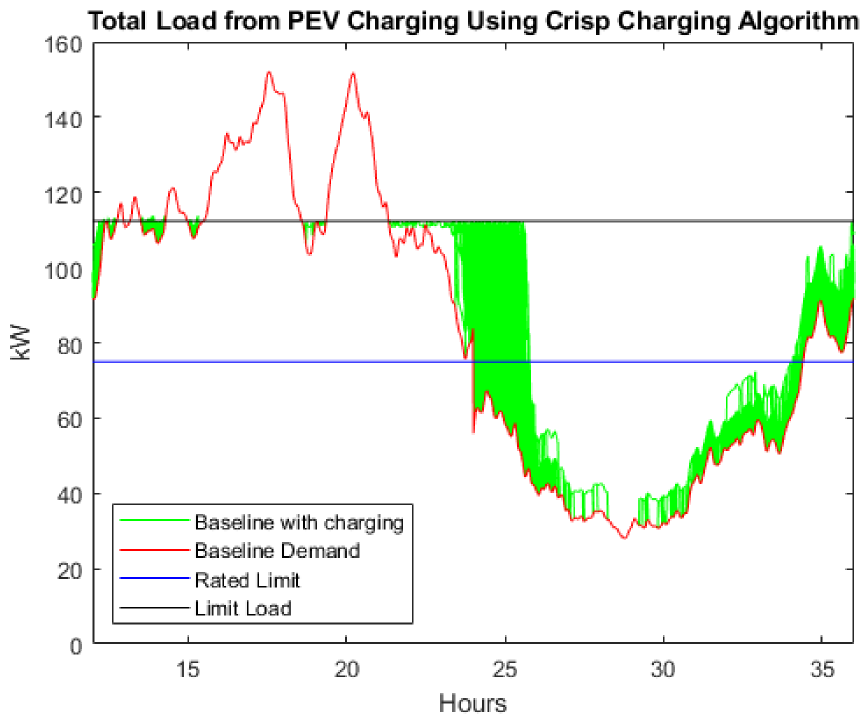

Figure 20: CVVF with crisp logic using the average value of the baseload plus 0.75 standard deviations (112.35 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 118.23 kW.

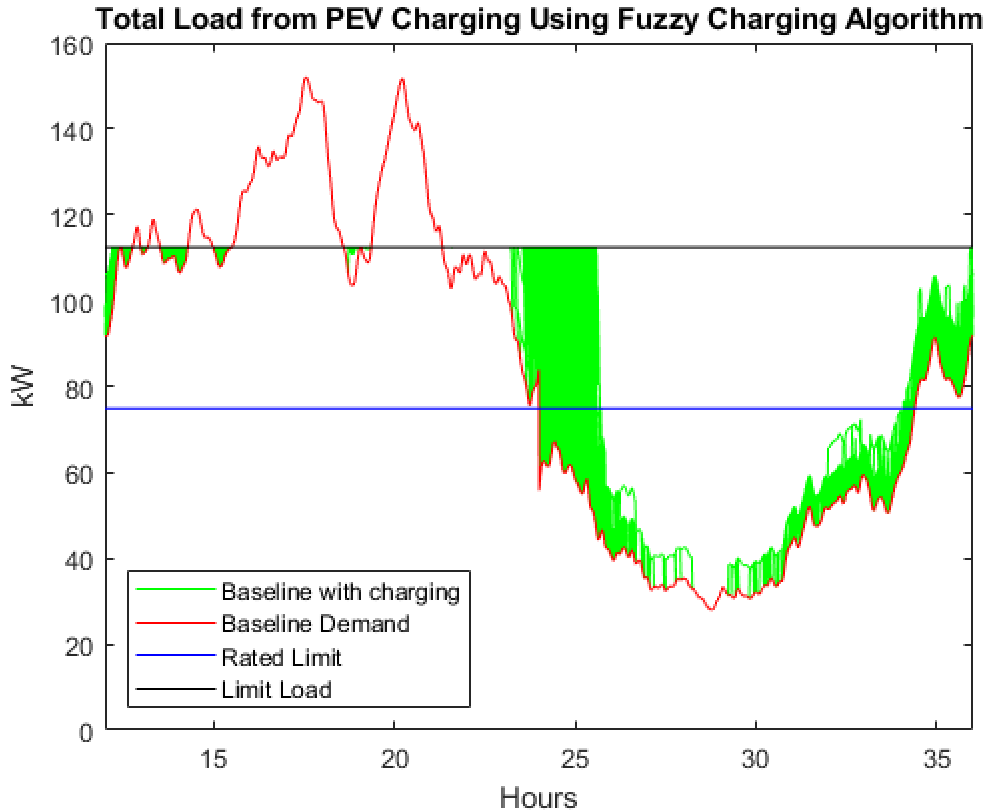

Figure 21: CVVF with fuzzy logic using the average value of the baseload plus 0.75 standard deviations (112.35 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 118.63 kW.

6.5.1.3 Day 3: September 25th, 2014

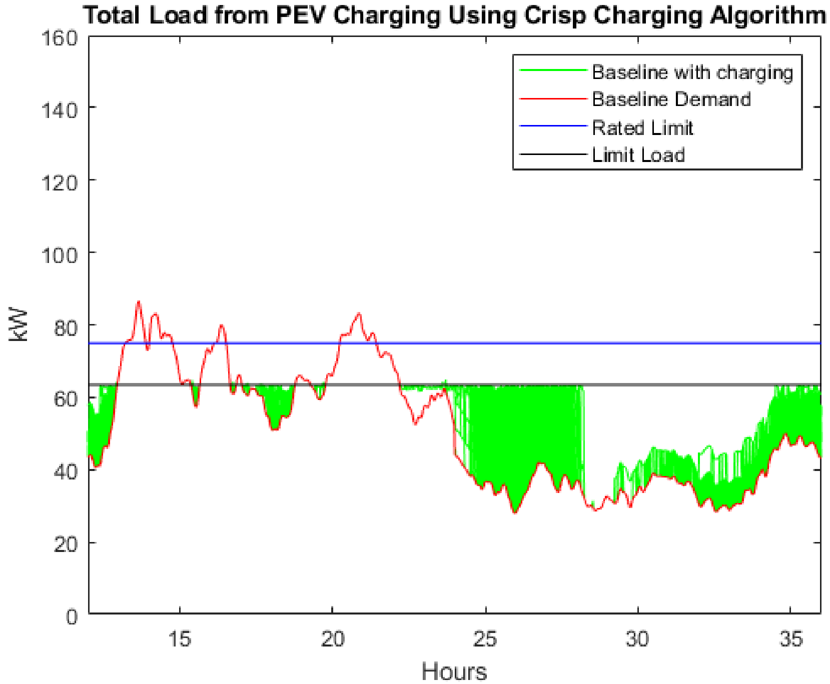

Figure 22: CVVF with crisp logic using the average value of the baseload plus 0.75 standard deviations (64.47 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 66.30 kW.

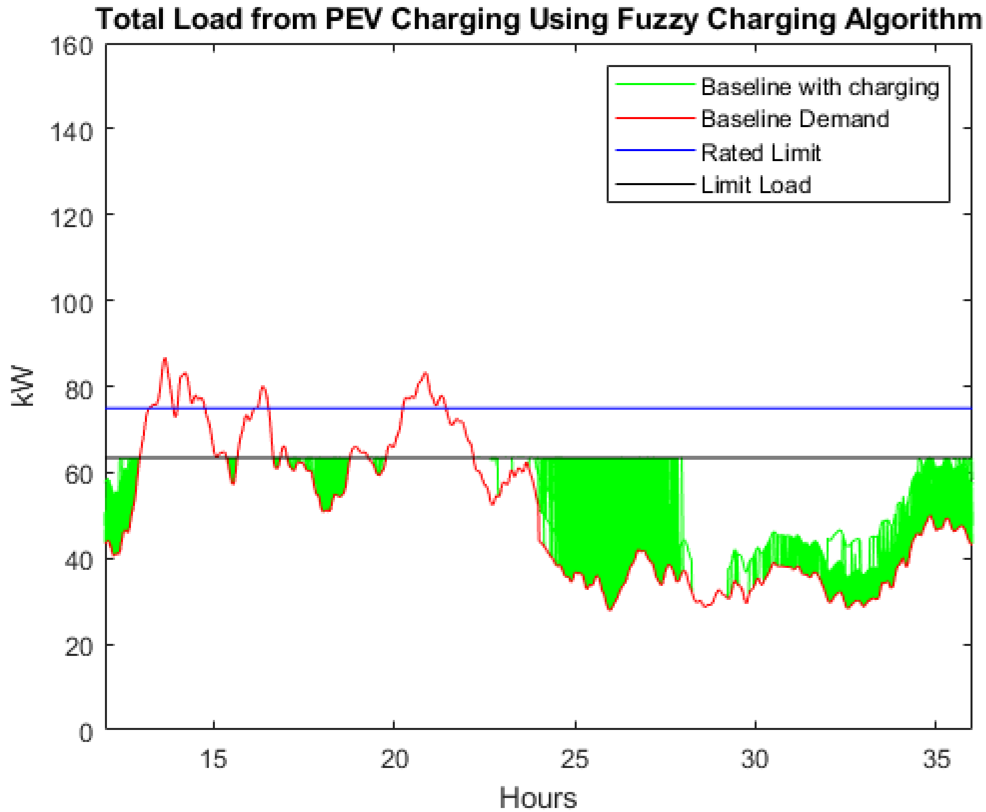

Figure 23: CVVF with fuzzy logic using the average value of the baseload plus 0.75 standard deviations (64.47 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 66.78 kW.

6.5.1.4 Number of Vehicles Charged

Table 6 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged. Both decision mechanisms charged all 20295 vehicles above 90% on every baseload.

Day	Decision Mechanism	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
1	Crisp	0	0	0	0	0	0	20295
	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
2	Crisp	0	0	0	0	0	0	20295
	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
3	Crisp	0	0	0	0	0	0	20295
	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 6: Number of cars charged using the average value of the baseload plus 0.75 standard deviations as the load limit on each day's baseload.

6.6 Results Analysis

6.6.1 Load Limit Analysis

Method 1 includes four cases (cases 1-4) where the limit load in case 1, 2, 3, and 4 are equal to 75%, 100%, 125% and 150% of the rated limit, respectively. Method 2 includes 6 cases (cases 5-10) where the limit load is equal to the average baseload plus a multiple of the standard deviation. In cases 5, 6, 7, 8, 9, 10 the multiple of the standard deviations is equal to 0, 0.5, 0.75, 1, 1.5, 2 respectively. Beginning the analysis, cases that allow all vehicles to charge to above 90% will be extracted and further investigated.

Examining method 1, case 4, equating the limit load to 150% of the rated limit is the only case that allows all vehicles to charge above 90%, shown in Table 7. Evaluating method 2, cases 7, 8, 9, 10 charges all vehicles above 90%, shown in Table 8.

Case	Day	Decision Mechanism	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
1	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	1474	24	25	27	23	21	18701
		Fuzzy	1434	27	23	19	18	16	18758
	3	Crisp	1	2	21	37	25	24	20185
		Fuzzy	0	1	1	20	22	31	20220
2	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	1194	15	19	20	15	12	19020
		Fuzzy	1190	9	19	10	26	19	19022
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
3	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	29	37	34	43	42	44	29	20066
		20	35	32	35	37	46	20	20090
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
4	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295

Table 7: Number of cars charged in each case within method 1

Case	Day	Decision Mechanism	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
5	1	Crisp	28	73	336	341	440	699	18378
		Fuzzy	9	22	139	190	235	370	19330
	2	Crisp	472	113	88	56	56	60	19450
		Fuzzy	351	97	93	75	62	57	19560
	3	Crisp	121	63	75	65	55	70	19846
		Fuzzy	76	51	56	64	51	57	19940
6	1	Crisp	0	0	0	0	13	22	20260
		Fuzzy	0	0	0	0	0	12	20283
	2	Crisp	0	7	11	33	25	24	20195
		Fuzzy	0	0	16	18	31	25	20205
	3	Crisp	0	0	0	0	3	20	20272
		Fuzzy	0	0	0	0	0	1	20294
7	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
8	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
9	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
10	1	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	2	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295
	3	Crisp	0	0	0	0	0	0	20295
		Fuzzy	0	0	0	0	0	0	20295

Table 8: Number of cars charged in each case within method 2

Analyzing cases 7, 8 9, and 10 further, case 7 generally produces the minimum absolute peak, the average highest peak, and the average load during for all three days, shown in Table 9.

Case	Day	Decision Mechanism	Absolute Highest Peak	Average Highest Peak	Average Load During Charging
7	1	Crisp	60.85	60.85	49.06
		Fuzzy	60.85	60.85	49.52
	2	Crisp	151.83	151.83	123.21
		Fuzzy	151.83	151.83	123.63
	3	Crisp	86.58	86.58	68.59
		Fuzzy	86.58	86.58	69.03
8	1	Crisp	60.85	60.85	49.06
		Fuzzy	60.85	60.85	49.52
	2	Crisp	151.83	151.83	123.21
		Fuzzy	151.83	151.83	123.63
	3	Crisp	86.58	86.58	68.59
		Fuzzy	86.58	86.58	69.03
9	1	Crisp	60.85	60.85	52.09
		Fuzzy	60.85	60.85	52.79
	2	Crisp	151.83	151.83	127.1
		Fuzzy	151.83	151.83	127.1
	3	Crisp	86.58	86.58	72.22
		Fuzzy	86.58	86.58	72.51
10	1	Crisp	60.85	60.85	55.42
		Fuzzy	60.85	60.85	55.85
	2	Crisp	151.83	151.83	127.7
		Fuzzy	151.83	151.83	127.72
	3	Crisp	86.58	86.58	73.91
		Fuzzy	86.58	86.58	74.08

Table 9: Results from cases 7, 8, 9 and 10, using the average value of the baseload plus 0.75, 1, 1.5, and two standard deviations respectively, as the load limit

Comparing case 4 from method 1 and case 7 from method 2, both cases allow all vehicles to charge above 90%. However, case 7 proves to be better; case 4 reveals its limitation when used on day 3, shown in table 40. The absolute highest peak across all transformers, the average highest peak, and the average load during charging are all higher than case 7 for the same day. This occurs because the baseload is generally significantly below the limit load, resulting in an uncontrolled charging effect. Case 7 can adjust its limit load based on the baseload, preventing the uncontrolled charging effect from occurring.

Day	Case	Decision Mechanism	Absolute Highest Peak	Average Highest Peak	Average Load During Charging
1	4	Crisp	60.85	60.85	49.06
		Fuzzy	60.85	60.85	49.52
	7	Crisp	60.85	60.85	49.06
		Fuzzy	60.85	60.85	49.52
	-	Uncontrolled	103.30	78.35	57.87
2	4	Crisp	151.83	151.83	118.32
		Fuzzy	151.83	151.83	118.72
	7	Crisp	151.83	151.83	123.21
		Fuzzy	151.83	151.83	123.63
	-	Uncontrolled	195.13	168.07	127.39
3	4	Crisp	112.5	97.64	74.46
		Fuzzy	112.5	97.63	74.46
	7	Crisp	86.58	86.58	68.59
		Fuzzy	86.58	86.58	69.03
	-	Uncontrolled	120.58	97.79	74.36

Table 10: Results from case 4 and case 7, illustrating the best limit load profile

Case 7 reduces the absolute highest peak, the average highest peak, and the average load during charging caused by uncontrolled charging considerably. Table 11 shows the percent difference between the values of case 7 and uncontrolled charging.

Day	Case	Decision Mechanism	Absolute Highest Peak	Average Highest Peak	Average Load During Charging
1	7	Crisp	-51.72%	-25.14%	-24.21%
		Fuzzy	-51.72%	-25.14%	-23.28%
2	7	Crisp	-24.96%	-10.09%	-7.56%
		Fuzzy	-24.89%	-10.09%	-7.22%
3	7	Crisp	-32.82%	-12.16%	-11.46%
		Fuzzy	-32.82%	-12.16%	-10.74%
Average		Crisp	-36.50%	-15.80%	-14.41%
		Fuzzy	-36.48%	-15.80%	-13.75%

Table 11: Case 7's effectiveness

6.6.2 Algorithm Analysis

Table 12 shows how well each decision mechanism and limit load combination reduces the absolute highest peak, the average highest peak, and average load during charging concerning uncontrolled charging.

Case	Day	Decision Mechanism	Absolute Highest Peak Percent Difference	Average Highest Peak Percent Difference	Average Load During Charging Percent Difference
1	1	Crisp	-51.72%	-25.14%	-12.95%
	1	Fuzzy	-51.72%	-25.14%	-10.10%
	2	Crisp	-24.89%	-10.09%	-23.23%
	2	Fuzzy	-24.89%	-10.09%	-22.81%
	3	Crisp	-32.82%	-12.16%	-16.60%
	3	Fuzzy	-32.82%	-12.16%	-15.99%
2	1	Crisp	-31.74%	-5.91%	-4.95%
	1	Fuzzy	-31.74%	-5.87%	-4.90%
	2	Crisp	-24.89%	-10.09%	-15.72%
	2	Fuzzy	-24.89%	-10.09%	-15.51%

	3	Crisp	-32.82%	-12.16%	-3.35%
	3	Fuzzy	-32.82%	-12.16%	-2.92%
3	1	Crisp	-9.69%	-0.22%	-4.85%
	1	Fuzzy	-9.69%	-0.22%	-4.83%
	2	29	-24.89%	-10.15%	-11.48%
	2	20	-24.96%	-10.15%	-11.31%
	3	Crisp	-25.04%	-4.89%	0.09%
	3	Fuzzy	-25.03%	-4.84%	0.11%
4	1	Crisp	-0.94%	-0.13%	-4.85%
	1	Fuzzy	-0.94%	-0.15%	-4.83%
	2	Crisp	-24.96%	-10.15%	-7.48%
	2	Fuzzy	-24.96%	-10.15%	-7.15%
	3	Crisp	-6.93%	-0.15%	0.13%
	3	Fuzzy	-6.93%	-0.16%	0.13%
5	1	Crisp	-51.72%	-25.14%	-34.69%
	1	Fuzzy	-51.72%	-25.14%	-33.34%
	2	Crisp	-24.96%	-10.09%	-13.49%
	2	Fuzzy	-24.89%	-10.09%	-13.30%
	3	Crisp	-32.82%	-12.16%	-20.28%
	3	Fuzzy	-32.82%	-12.16%	-19.79%
6	1	Crisp	-51.72%	-25.14%	-27.20%
	1	Fuzzy	-51.72%	-25.14%	-26.17%
	2	Crisp	-24.89%	-10.09%	-9.85%
	2	Fuzzy	-24.89%	-10.09%	-9.75%
	3	Crisp	-32.82%	-12.16%	-14.36%
	3	Fuzzy	-32.82%	-12.16%	-13.85%
7	1	Crisp	-51.72%	-25.14%	-24.21%
	1	Fuzzy	-51.72%	-25.14%	-23.28%
	2	Crisp	-24.96%	-10.09%	-7.56%
	2	Fuzzy	-24.89%	-10.09%	-7.22%
	3	Crisp	-32.82%	-12.16%	-11.46%
	3	Fuzzy	-32.82%	-12.16%	-10.74%
8	1	Crisp	-51.72%	-25.14%	-21.45%
	1	Fuzzy	-51.72%	-25.14%	-20.53%
	2	Crisp	-24.89%	-10.15%	-3.44%
	2	Fuzzy	-24.96%	-10.15%	-3.10%
	3	Crisp	-32.82%	-12.16%	-8.07%
	3	Fuzzy	-32.82%	-12.16%	-7.43%

9	1	Crisp	-51.72%	-25.14%	-15.51%
	1	Fuzzy	-51.72%	-25.14%	-14.19%
	2	Crisp	-24.96%	-10.15%	-0.33%
	2	Fuzzy	-24.96%	-10.15%	-0.33%
	3	Crisp	-32.82%	-12.16%	-2.92%
	3	Fuzzy	-32.82%	-12.16%	-2.52%
10	1	Crisp	-51.72%	-25.14%	-9.34%
	1	Fuzzy	-51.72%	-25.14%	-8.57%
	2	Crisp	-24.89%	-10.15%	0.14%
	2	Fuzzy	-24.96%	-10.15%	0.16%
	3	Crisp	-32.82%	-12.16%	-0.61%
	3	Fuzzy	-32.82%	-12.16%	-0.38%

Table 12: The percent difference between the values produced by each decision mechanism and uncontrolled charging per case.

In general, the crisp and fuzzy logic produce very similar results; however, Table 13 shows that the CVVF with fuzzy logic is more effective.

Algorithm	Total Absolute Highest Peak Percent Difference	Total Average Highest Peak Percent Difference	Total Average Load During Charging Percent Difference
Crisp	-31.07%	-12.63%	-10.55%
Fuzzy	-31.09%	-12.65%	-10.56%

Table 13: The average percent difference between the values produced by each algorithm and uncontrolled charging.

Reviewing the number of vehicles that are charged in Tables 12 and 13, the CVVF with fuzzy logic outperforms crisp logic. Moreover, the table shows that on average, the CVVF with fuzzy logic reduces the absolute high peak, the average highest peak, and the average load during charging better than the crisp logic algorithm. The CVVF with fuzzy logic performs better than the CVVF with crisp logic because it can “valley fill” perfectly to the limit load. The crisp logic fills until it cannot meet the lowest level of charge to a vehicle without surpassing the limit load.

7 Summary and Conclusions

An algorithm was developed and evaluated to be a strategic method to reduce peaks from PEV charging at the distribution level. This is important because lower peaks will reduce stress caused by large amounts of PEV charging, thereby improving transformer lifetime [11, 23] while helping to maintain the distribution system. There are situations when these algorithms do not fully charge as many vehicles as other PEV charging optimization algorithms do, however unlike those algorithms; this protocol can operate in real time, can optimize nonlinear systems, is computationally fast, and is easily scalable. These characteristics are the main efficacy of this research and as such, highlights its main contribution.

Initially, the rated limit is used as the limit load, shown in case 2 in Appendix A. However, when the algorithm is applied to the three different baseloads, using this limit load, not all vehicles are able to charge above 90%. To mitigate this effect, two methods of altering the CVVF's limit load are investigated to improve the efficiency of the algorithm. The first method equates the limit load to a percentage of the current rated limit. The second method equates the limit load to a value based on the baseload.

Method 1 demonstrates that the algorithm can create a valley-filling effect. However, the limitation is revealed when most of the load is above or below the limit load. If the baseload is significantly below the limit load, small-scaled uncontrolled charging is produced, shown in case 4, day 1, in Appendix A. The average load during charging on day 1 is equal to average load during charging from uncontrolled charging, meaning it is not effective. Also, if the baseload is significantly above the rated limit, a small number of vehicles reach full charge because the load difference between the curves is negative and/or small, shown in case 1, day 2 in Appendix A. Nearly 1600 vehicles on day 2, in this case, are not charged above 90%.

Equating the limit load to a percentage of the current rated limit, Method 1, proved to have strong limitations, providing motivation to discover another method to determine the limit load. Equating the limit load to a value based on the baseload provides better results than equating the limit load to a percentage of the current rated limit. Using a limit load that can adjust to the baseload allows the algorithm to scale accordingly, preventing small scaled uncontrolled charging and low amounts of vehicles reaching full charge. However, to implement this technique, it is required that the baseload is estimated before execution. To approximate the limit load value, the algorithm will use to produce valley filling; the baseload must be forecasted.

To enhance the capabilities of this method, research should investigate how much of the baseload needs to be approximated before execution and how it will affect the valley filling ability of the algorithm. In addition, the research in this thesis indicates that a limit load equal to the average value plus 0.75 standard deviations of the baseload is desired. However, this value is based on the baseloads that were evaluated in this thesis; more baseloads should be assessed to strengthen the results. As more entities to connect to the grid, transformers evolve, and devices require more power, a continuous analysis should be conducted to determine if the current limit load should change to a new value based on the baseload.

As smart grid systems allow future home PEV charging systems to interact and communicate with transformers, the true efficacy of this system can be realized. The real-time operation and speed of implementation make this concept much more feasible for future implementation. A hardware upgrade is needed to successfully implement a controller at the distribution level to execute this algorithm. In each case the CVVF with fuzzy logic dominates the crisp logic algorithm, allowing more vehicle to charge to higher percentages, due to the ability to fill to the limit load completely. However, due to the complexity of the electrical system, the crisp algorithm can serve in the preliminary stages to apply this technology because it only incorporates three levels of charging, whereas the fuzzy decision mechanism allows a variable charge rate to be applied to a vehicle. This attribute makes the fuzzy decision mechanism more efficient because it can charge more vehicles by assigning a wider variety of rate. However, that also increases the difficulty in implementation

8 References

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9 APPENDIX A

9.1 Case 1 – (Limit load = 75% of Rated Limit)

The rated limit of a transformer is 75 kW. For this section, the limit load will be 75% of the rated limit, equaling 56.25 kW. This means that CVVF will fill to 56.25 kW.

9.1.1.1 Day 1: August 25th, 2014

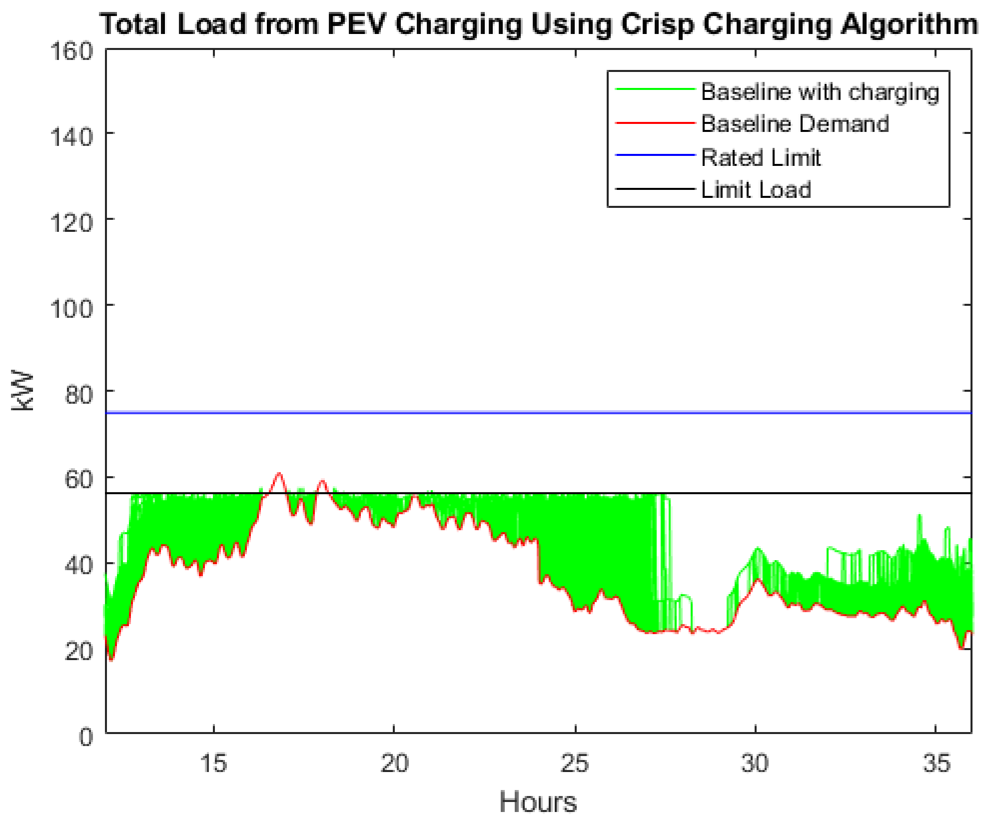

Figure 24: CVVF with crisp logic using 75% of the rated limit (56.25 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging n\when the baseload is above the algorithms limit load. The average load during charging is 53.45 kW.

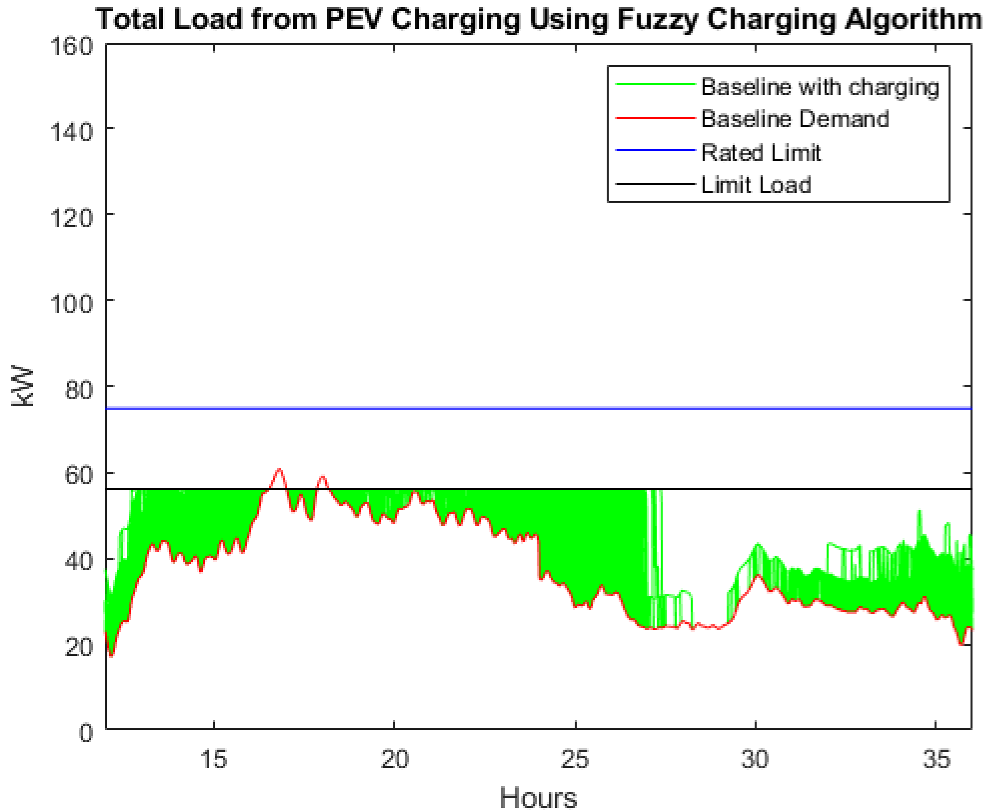

Figure 25: CVVF with fuzzy logic using 75% of the rated limit (56.25 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 54.00 kW.

9.1.2 Day 2: September 16th, 2014

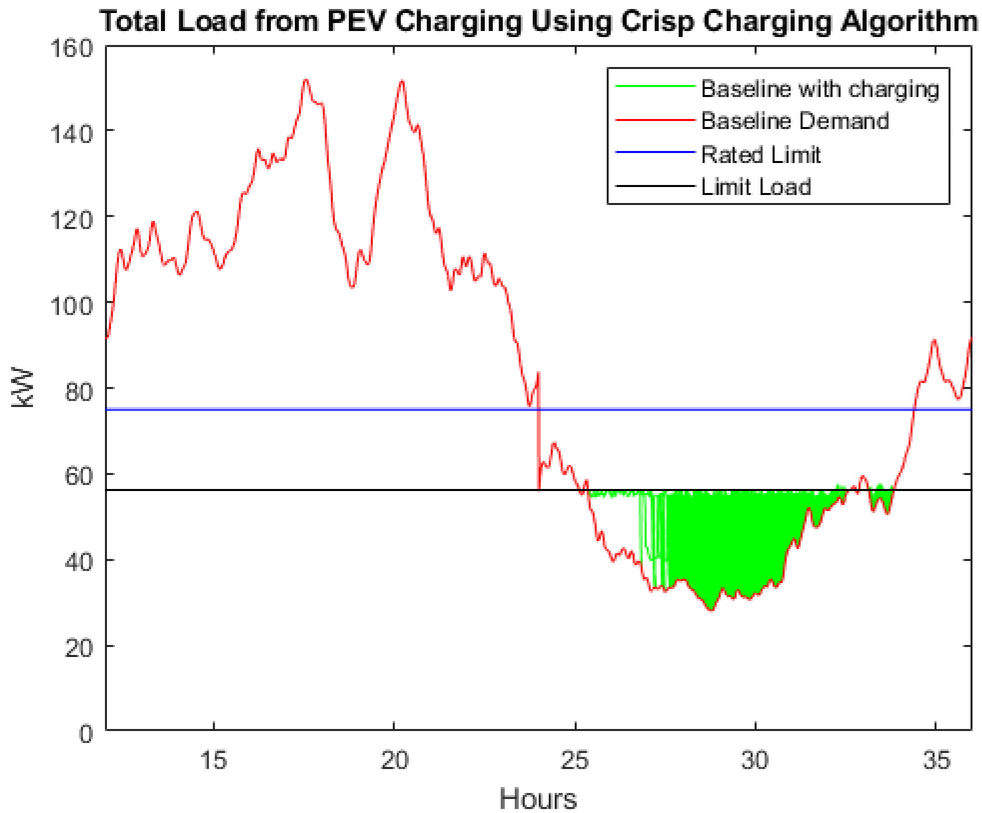

Figure 26: CVVF with crisp logic using 75% of the rated limit (56.25 kW) as the load limit on September 16h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 100.98 kW.

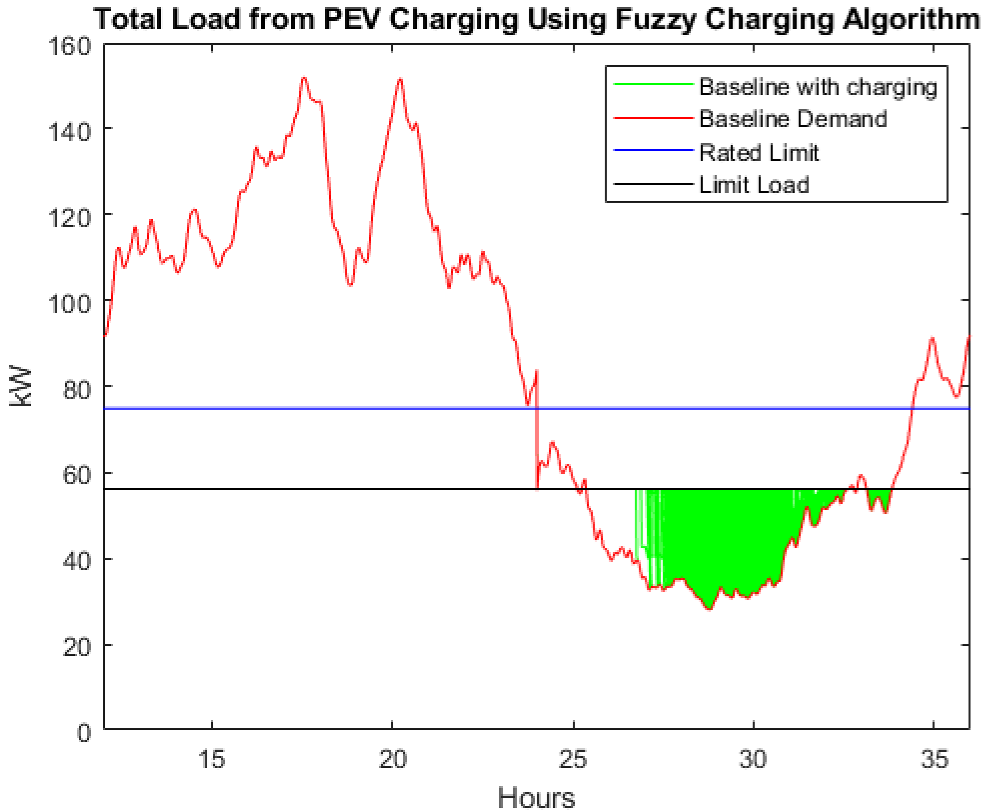

Figure 27: CVVF with crisp logic using 75% of the rated limit (56.25 kW) as the load limit on September 16h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 101.41 kW.

9.1.3 Day 3: September 25th, 2014

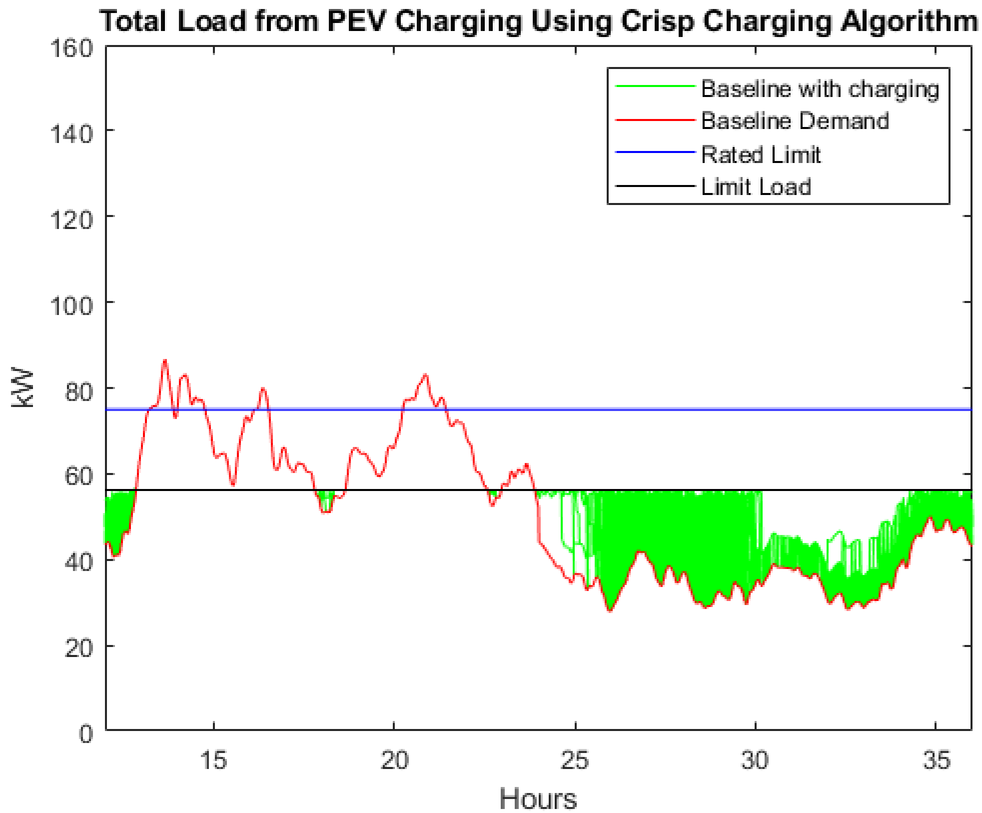

Figure 28: CVVF with crisp logic using 75% of the rated limit (56.25 kW) as the load limit on September 25h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 62.96 kW.

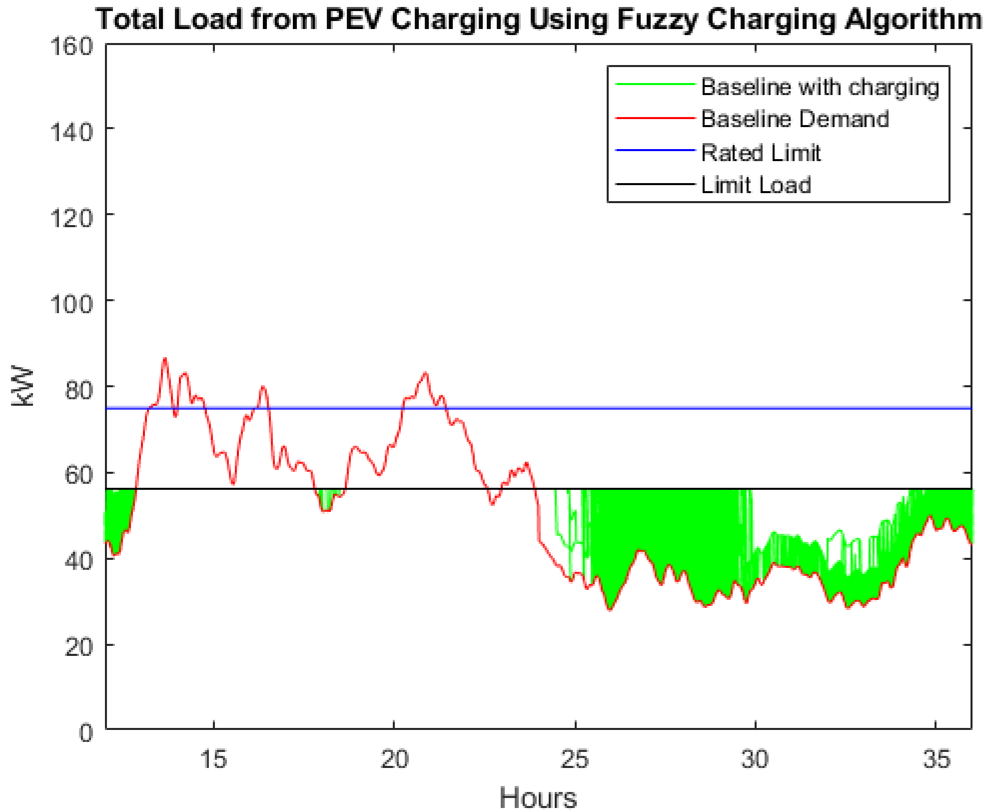

Figure 29: CVVF with fuzzy logic using 75% of the rated limit (56.25 kW) as the load limit on September 25h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any transformer is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 63.35 kW.

9.1.4 Number of Vehicles Charged

Table 15 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
1	Crisp	0	0	0	0	0	0	20295
	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
2	Crisp	1474	24	25	27	23	21	18701
	Fuzzy	1434	27	23	19	18	16	18758
	Uncontrolled	0	0	0	0	0	0	20295
3	Crisp	1	2	21	37	25	24	20185
	Fuzzy	0	1	1	20	22	31	20220
	Uncontrolled	0	0	0	0	0	0	20295

Table 14: Number of cars charged using 75% of the rated limit as the limit load on each day's baseload.

9.2 Case 2 – (Limit load = Rated Limit)

The rated limit of a transformer is 75 kW. For this section, the limit load will be the rated limit, equaling 75 kW. This means that CVVF will fill to 75 kW.

9.2.1 Day 1: August 25th, 2014

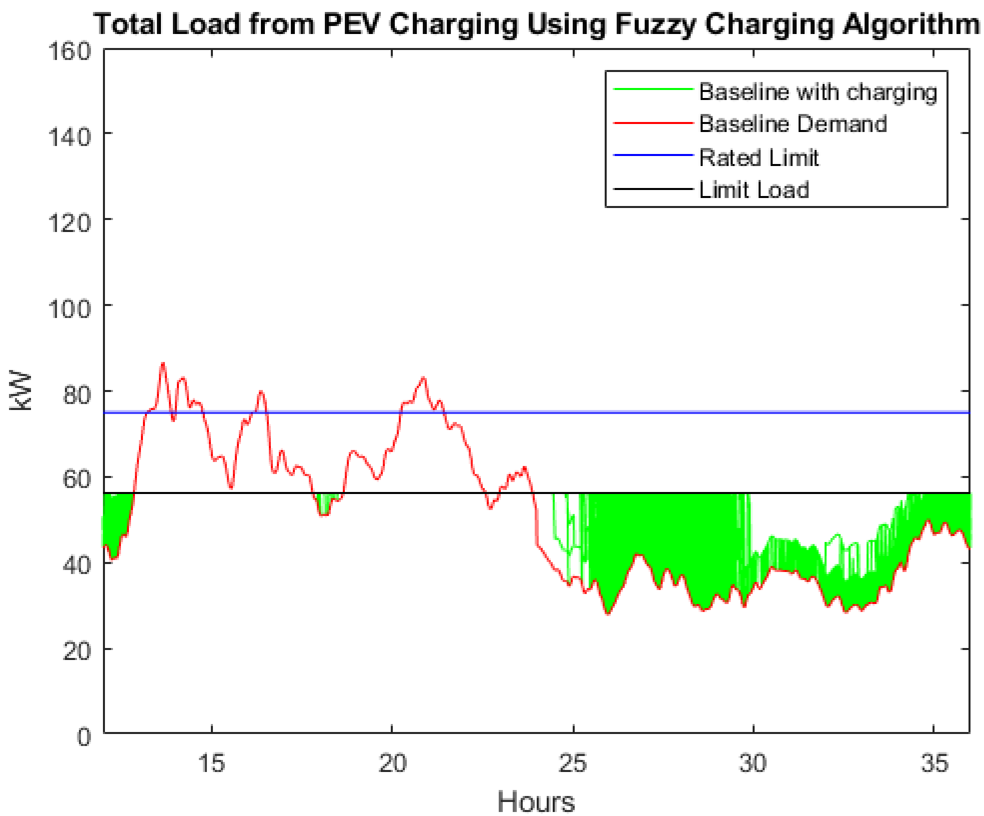

Figure 30: CVVF with crisp logic using the rated limit (75 kW) as the load limit on September 25h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 75 kW. The average highest peak power amongst all transformers is 73.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 57.91 kW.

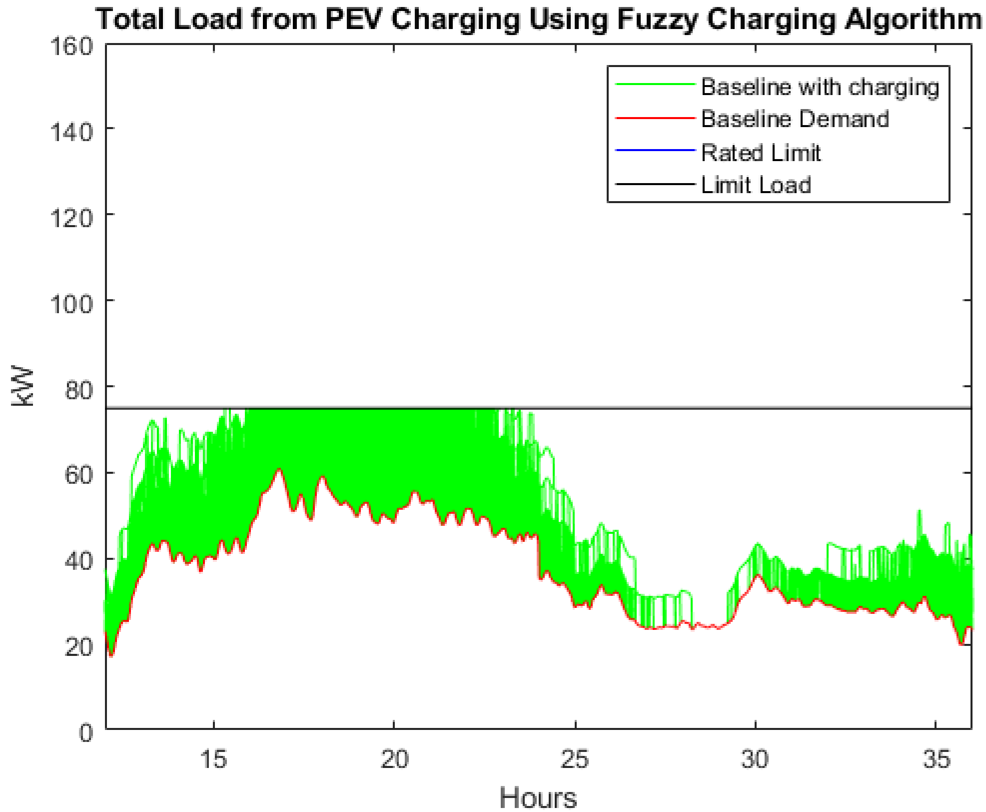

Figure 31: CVVF with fuzzy logic using the rated limit (75 kW) as the load limit on September 25h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 75 kW. The average highest peak power amongst all transformers is 73.88 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 57.94 kW.

9.2.2 Day 2: September 16th, 2014

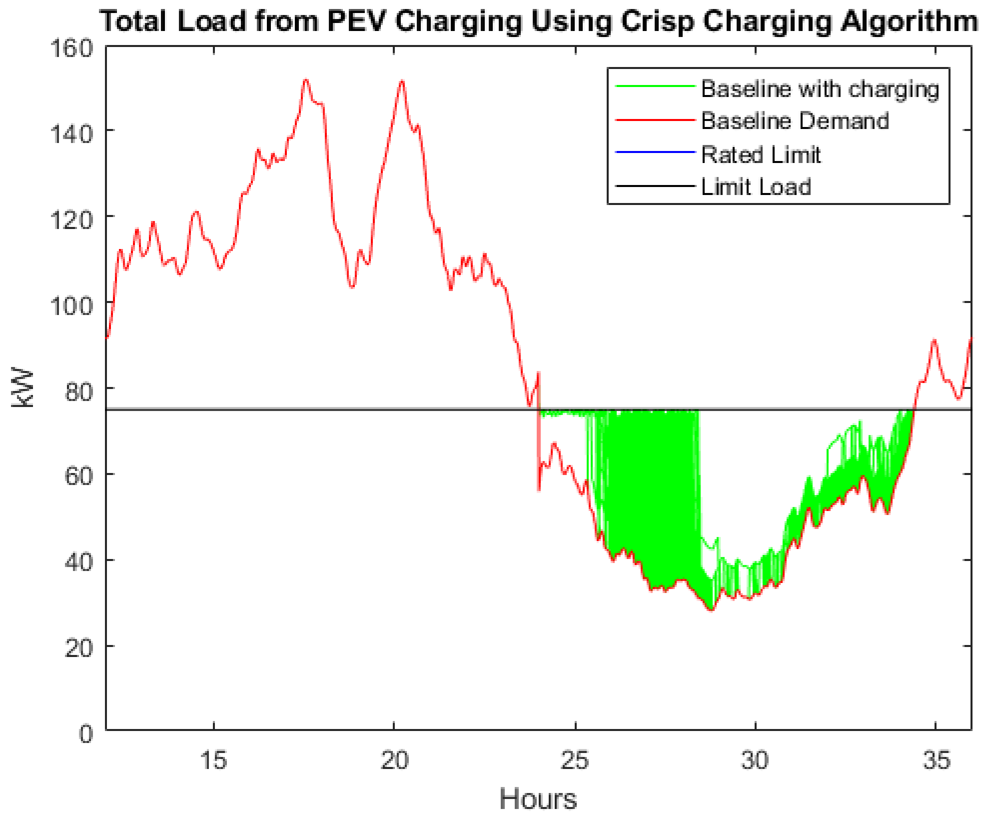

Figure 32: CVVF with crisp logic using the rated limit (75 kW) as the load limit on September 16h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 108.94 kW.

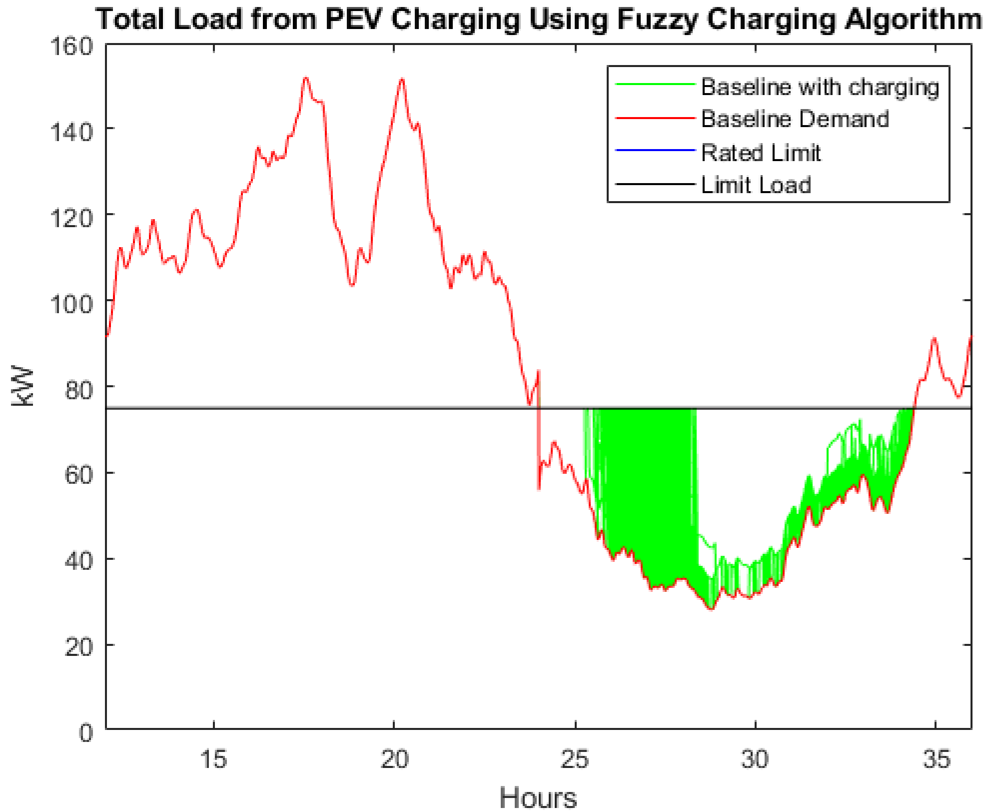

Figure 33: CVVF with fuzzy logic using the rated limit (75 kW) as the load limit on September 16h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 109.17 kW.

9.2.3 Day 3: September 25th, 2014

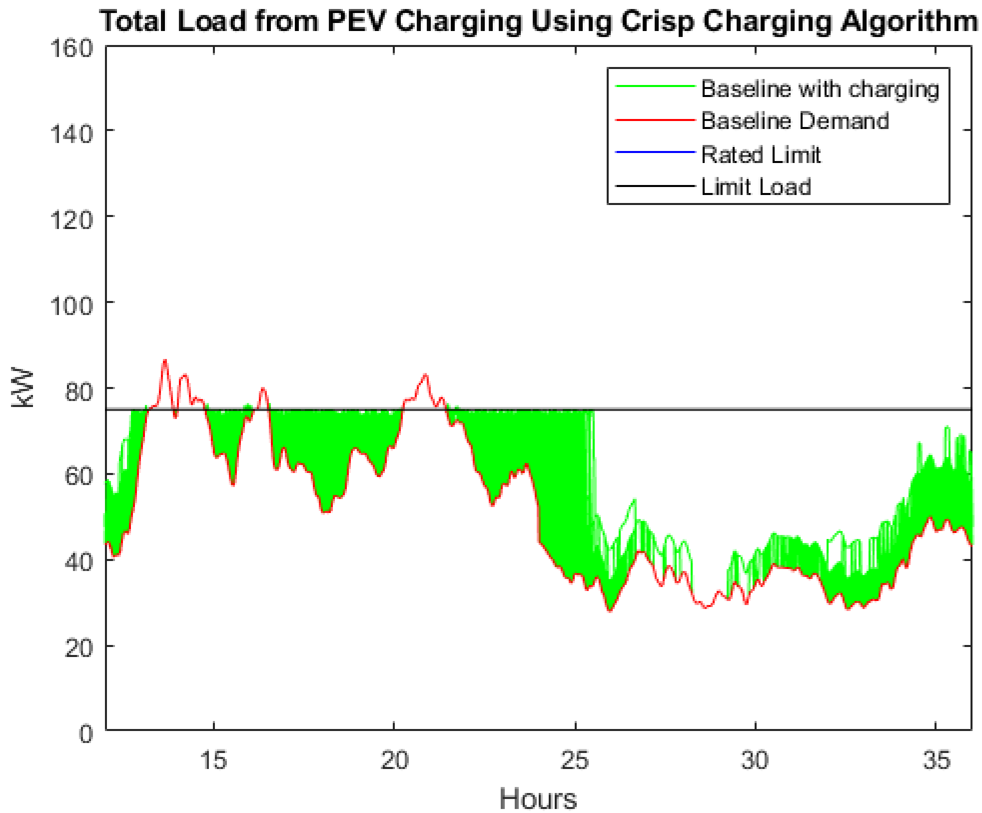

Figure 34: CVVF with crisp logic using the rated limit (75 kW) as the load limit on September 25h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 71.91 kW.

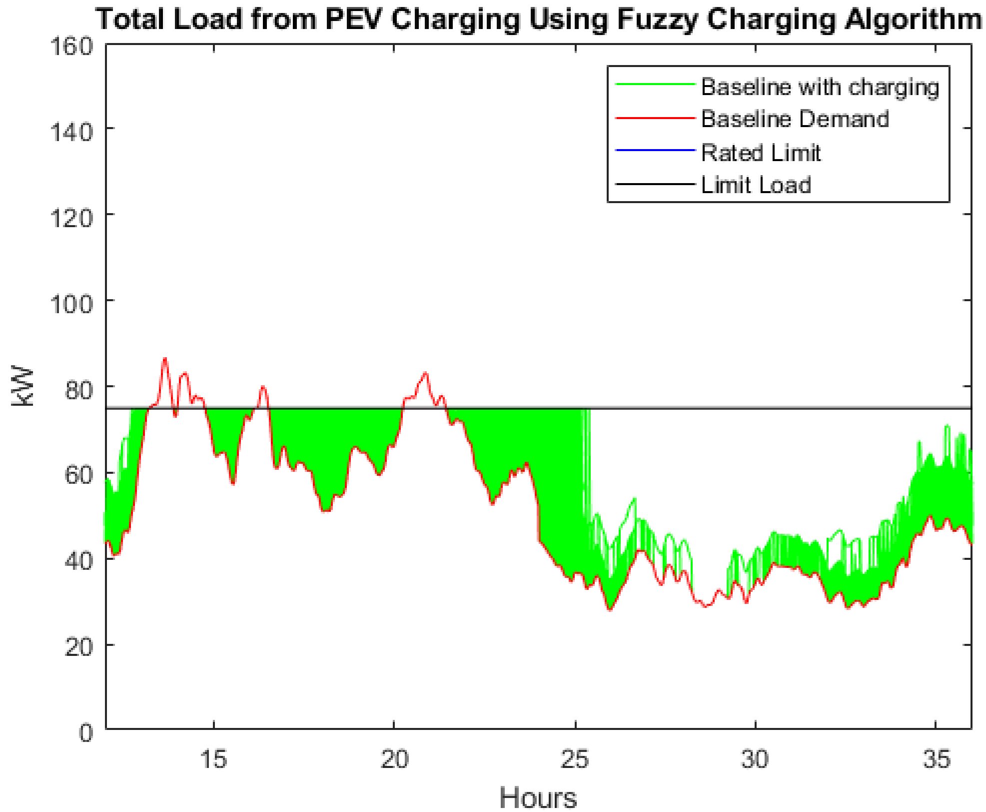

Figure 35: CVVF with fuzzy logic using the rated limit (75 kW) as the load limit on September 25h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 72.22 kW.

9.2.4 Number of Vehicles Charged

Table 16 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	0	0	20295
1	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	1194	15	19	20	15	12	19020
2	Fuzzy	1190	9	19	10	26	19	19022
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
3	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 15: Number of cars charged using the rated limit as the limit load on each day's baseload.

9.3 Case 3 – (Limit load = 125% of Rated Limit)

The rated limit of a transformer is 75 kW. For this section, the limit load will be 125% of the rated limit, equaling 93.75 kW. This means that CVVF will fill to 93.75 kW.

9.3.1 Day 1: August 25th, 2014

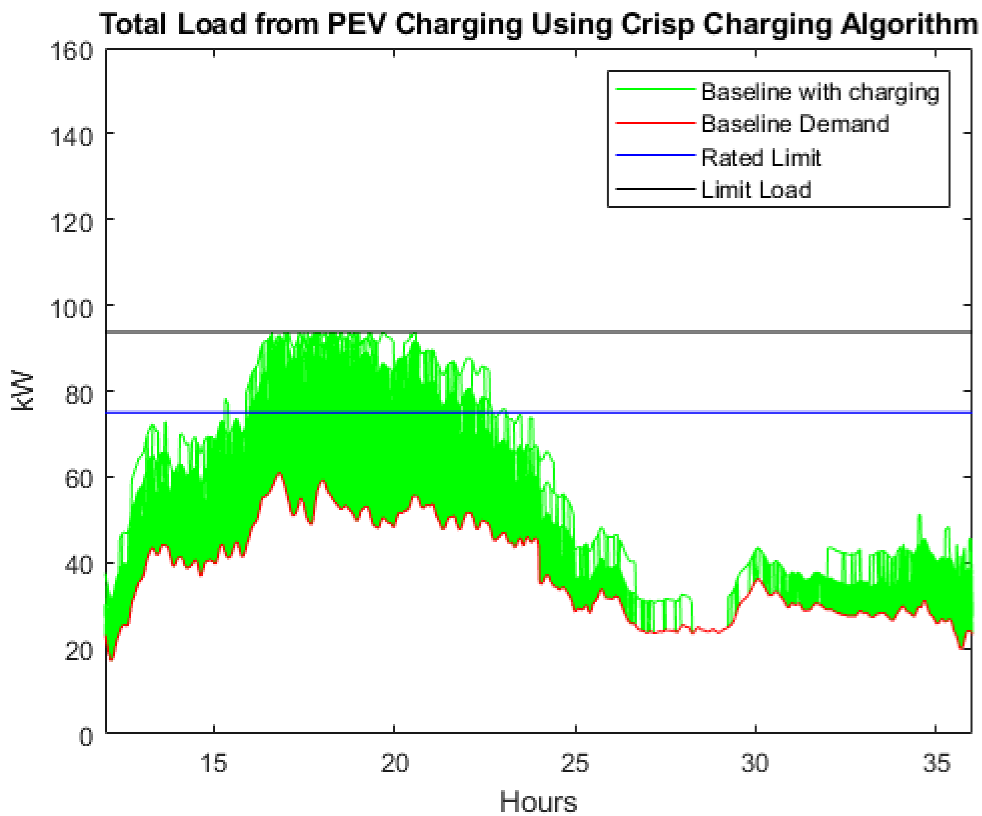

Figure 36: CVVF with crisp logic using 125% of the rated limit (93.75 kW) as the load limit on August 25h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 93.75 kW. The average highest peak power amongst all transformers is 78.18 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 57.97 kW.

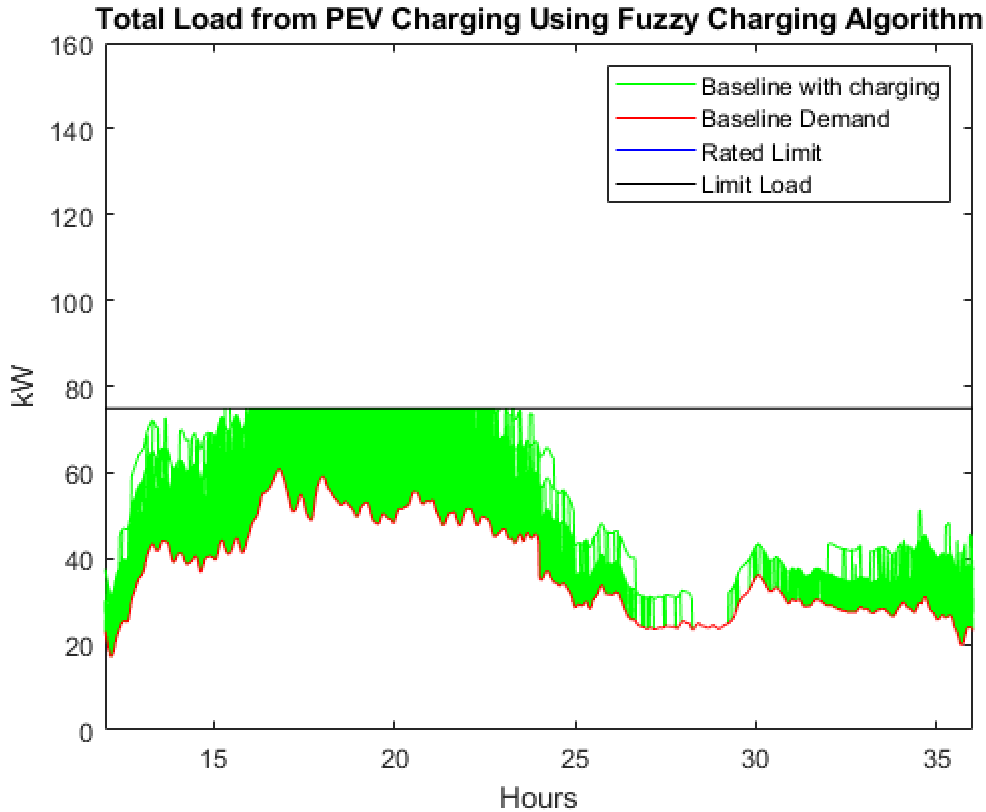

Figure 37: CVVF with fuzzy logic using 125% of the rated limit (93.75 kW) as the load limit on August 25h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 93.75 kW. The average highest peak power amongst all transformers is 78.18 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 57.98 kW.

9.3.2 Day 2: September 16th, 2014

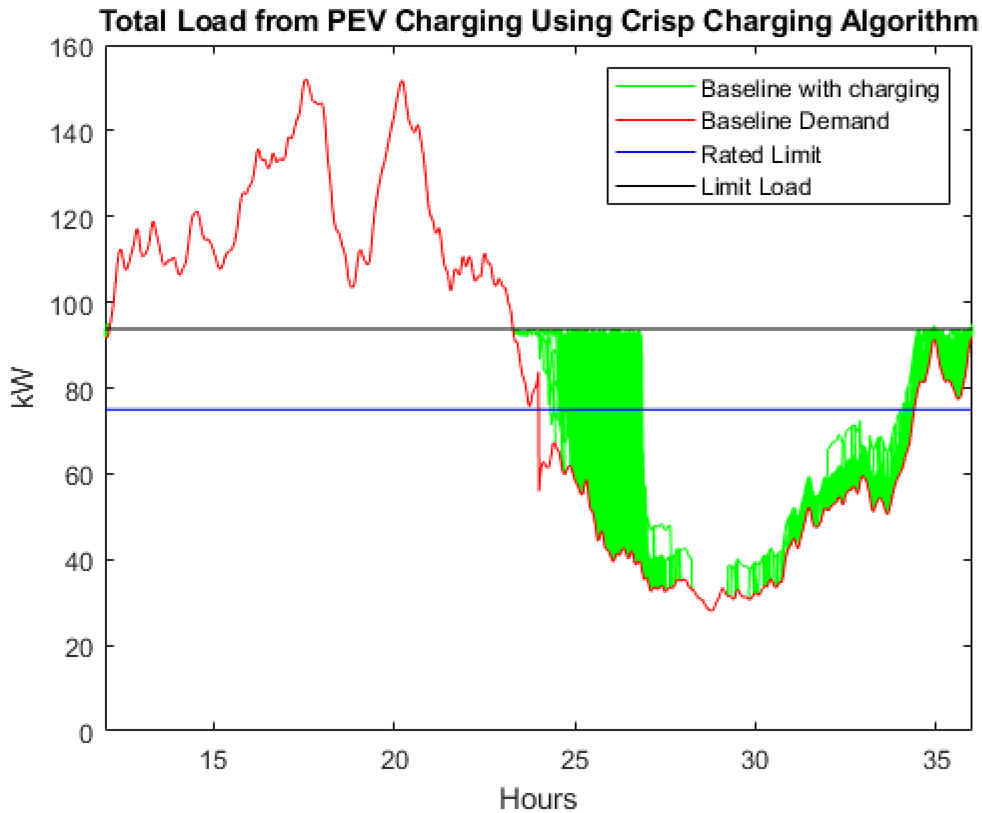

Figure 38: CVVF with crisp logic using 125% of the rated limit (93.75 kW) as the load limit on September 16h, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 113.67 kW.

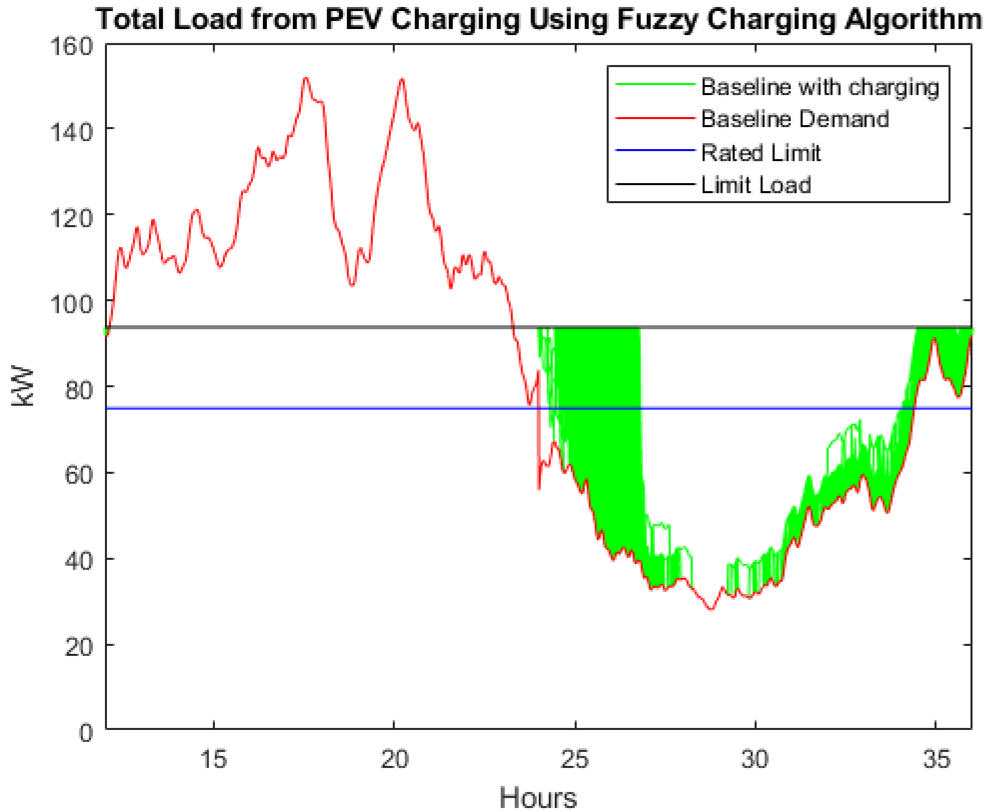

Figure 39: Fuzzy Logic Algorithm using 125% of the rated limit (93.75 kW) as the load limit on September 16h, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 113.87 kW.

9.3.3 Day 3: September 25^{th}, 2014

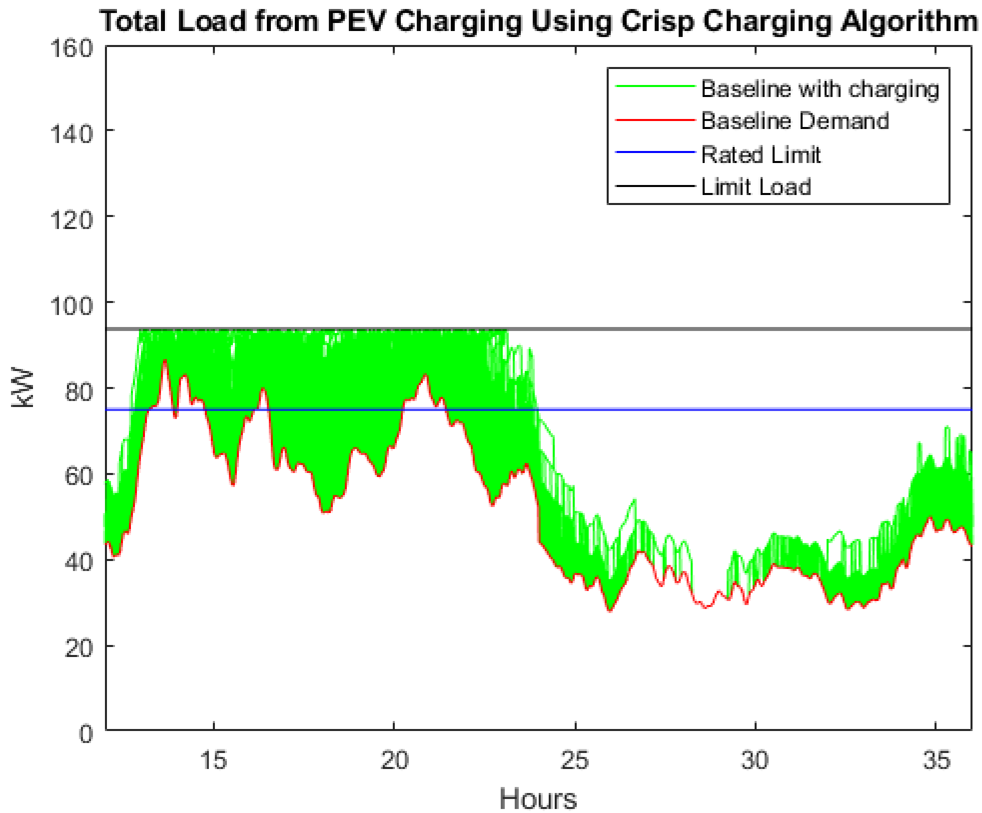

Figure 40: CVVF with crisp logic using 125% of the rated limit (93.75 kW) as the load limit on September 25^{th}, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 93.75 kW. The average highest peak power amongst all transformers is 93.12 kW, and highest peak power from baseload is 86.58 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 74.43 kW.

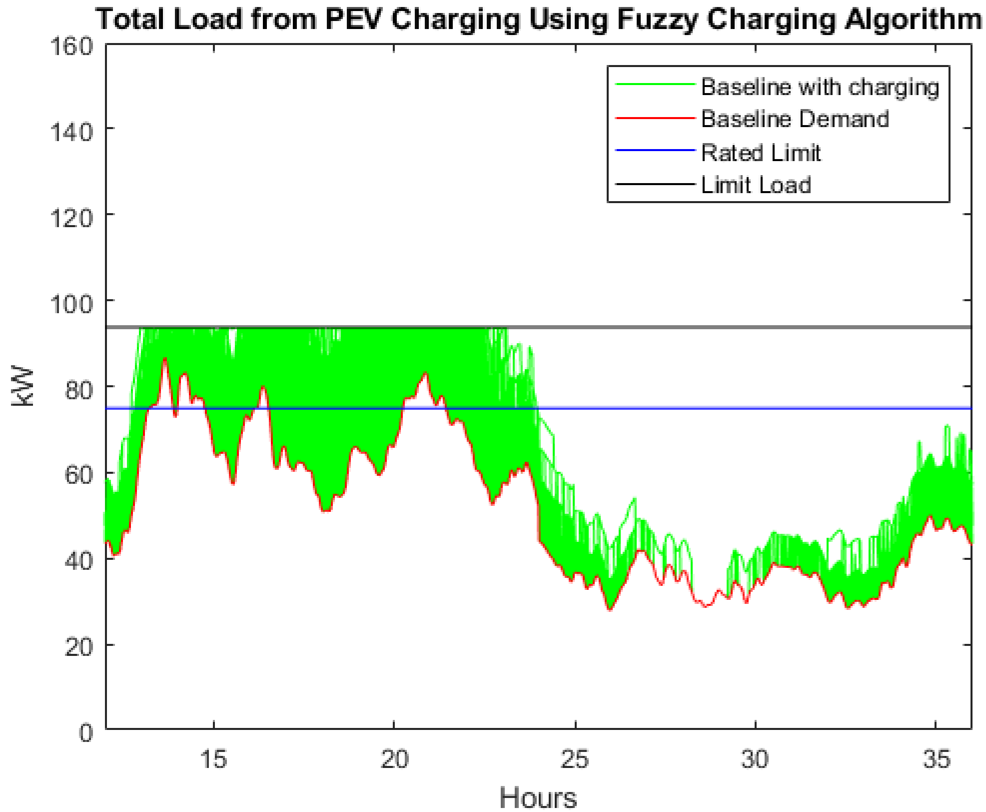

Figure 41: CVVF with fuzzy logic using 125% of the rated limit (93.75 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 93.76 kW. The average highest peak power amongst all transformers is 93.17 kW, and highest peak power from baseload is 86.58 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 74.44 kW.

9.3.4 Number of Vehicles Charged

Table 17 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	0	0	20295
1	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	37	34	43	42	44	29	20066
2	Fuzzy	35	32	35	37	46	20	20090
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
3	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 16: Number of cars charged using 125% of the rated limit as the limit load on each day's baseload.

9.4 Case 4 – (Limit load = 150% of Rated Limit)

The rated limit of a transformer is 75 kW. For the purposes of this section, the limit load will be 150% of the rated limit, equaling 112.5 kW. This means that CVVF will fill to 112.5 kW.

9.4.1 Day 1: August 25th, 2014

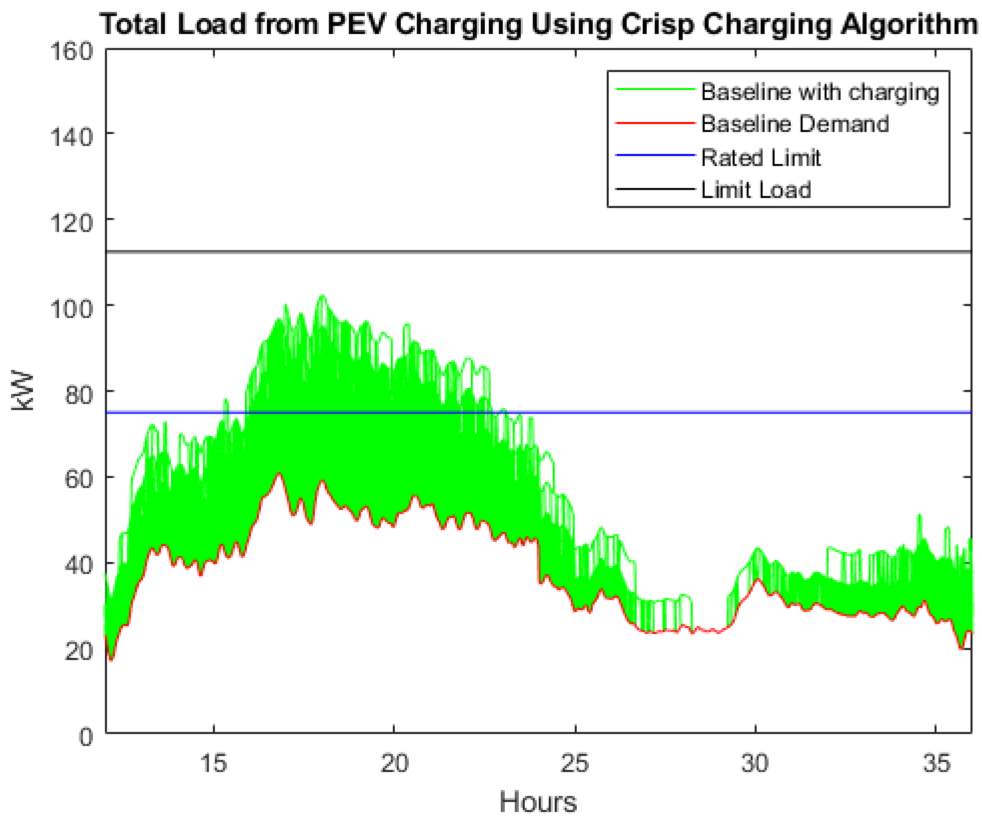

Figure 42: CVVF with crisp logic using 150% of the rated limit (112.50 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 102.33 kW. The average highest peak power amongst all transformers is 78.25 kW, and highest peak power from baseload is 60.85 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 57.97 kW.

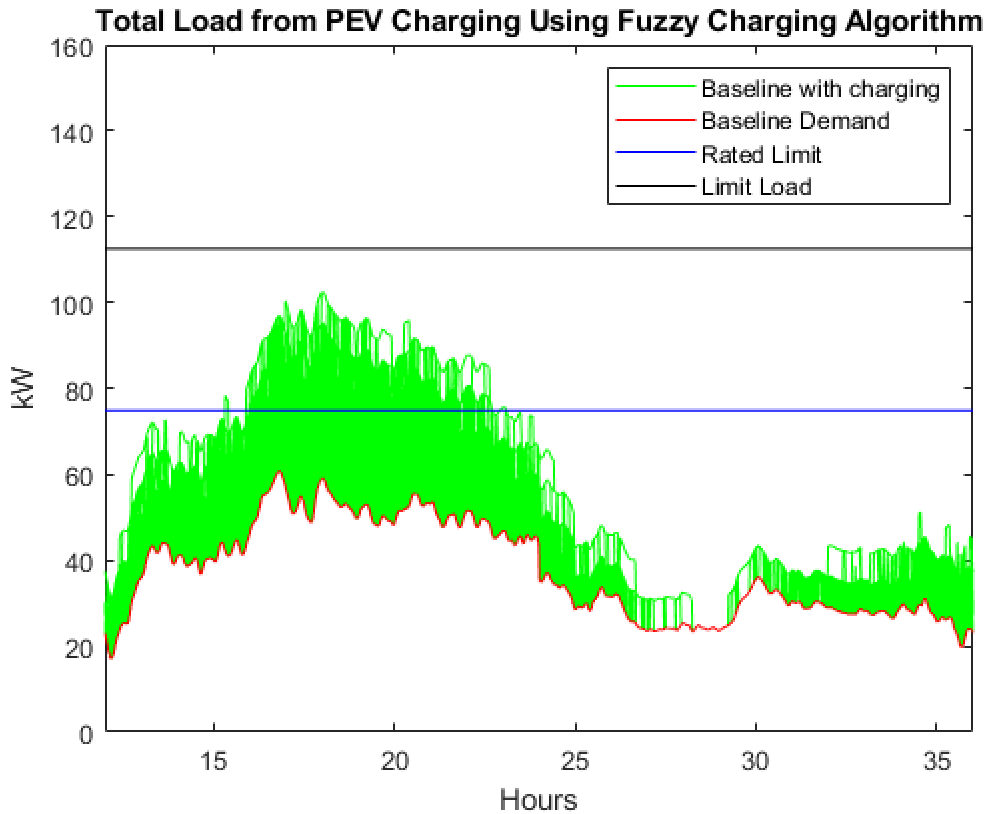

Figure 43: CVVF with fuzzy logic using 150% of the rated limit (112.50 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 102.33 kW. The average highest peak power amongst all transformers is 78.23 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 57.98 kW.

9.4.2 Day 2: September 16th, 2014

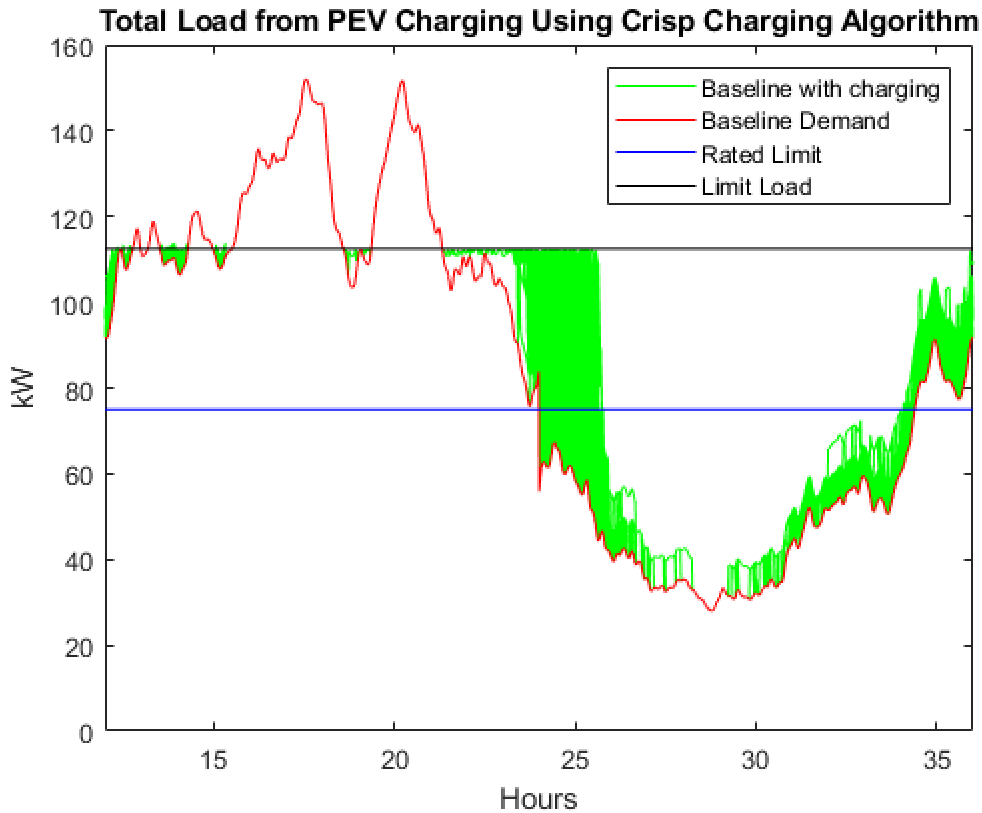

Figure 44: CVVF with crisp logic using 150% of the rated limit (112.50 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 118.32 kW.

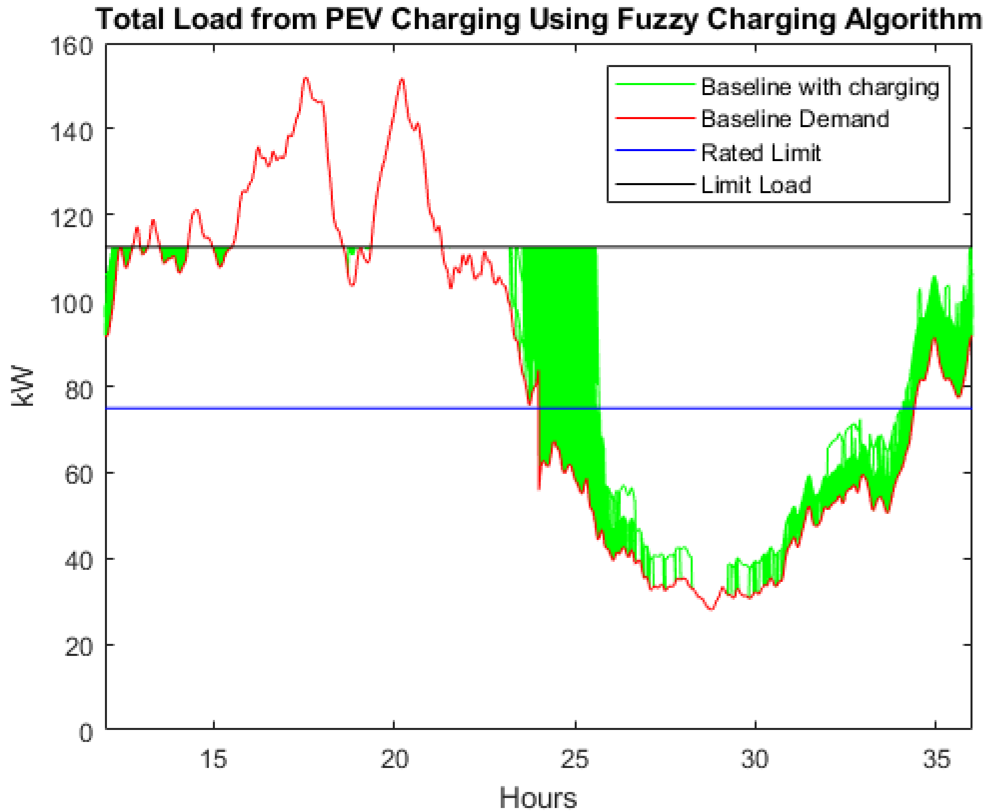

Figure 45: CVVF with fuzzy logic using 150% of the rated limit (112.50 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average baseload is 83.99 kW, and when PEV's are applied, the average load over the day is 87.34 kW, equating to a percentage difference of 3.91%. Moreover, the average load during charging is 118.72 kW.

9.4.3 Day 3: September 25th, 2014

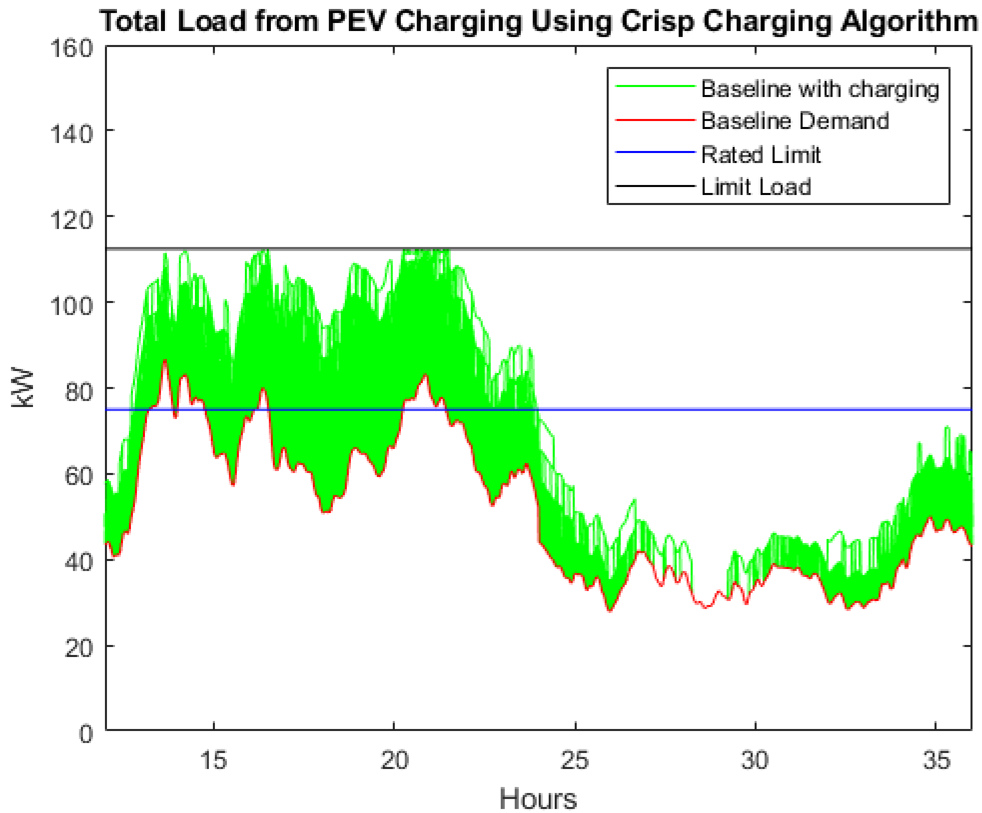

Figure 46: CVVF with crisp logic using 150% of the rated limit (93.75 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 112.50 kW. The average highest peak power amongst all transformers is 97.64 kW, and highest peak power from baseload is 86.58 kW, meaning that the highest peak is a result of PEV charging. The average baseload is 50.90 kW, and when PEV's are applied, the average load over the day is 54.25 kW, equating to a percentage difference of 6.37%. Moreover, the average load during charging is 74.46 kW.

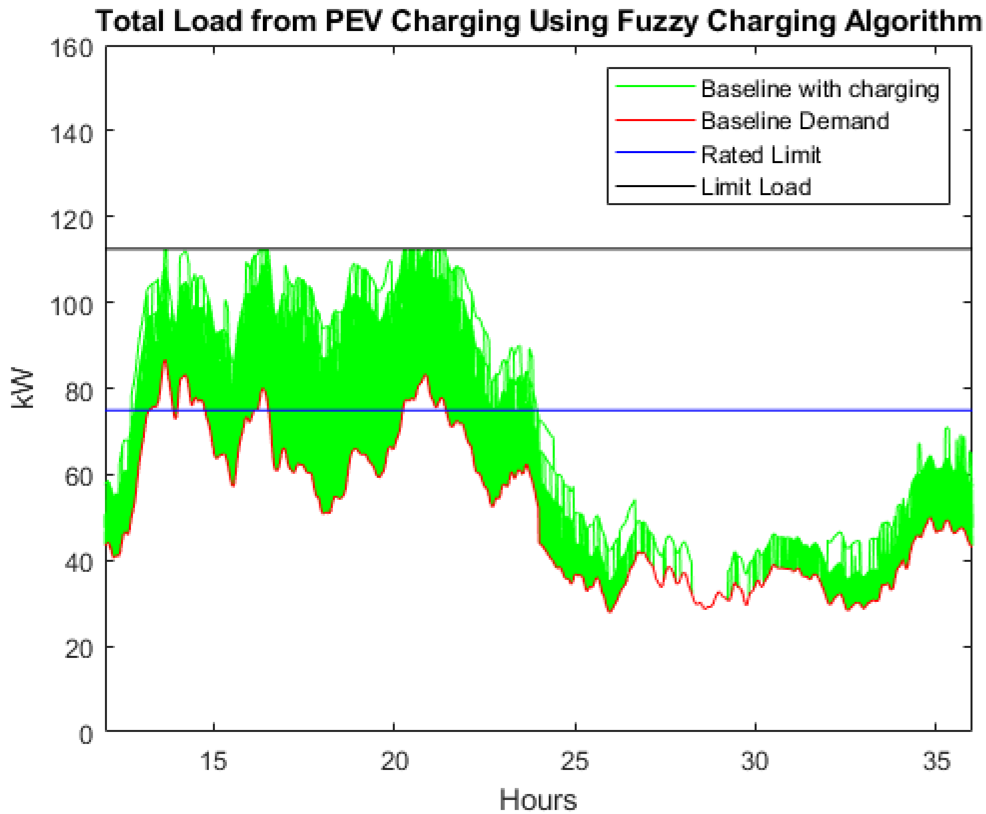

Figure 47: CVVF with fuzzy logic using 150% of the rated limit (112.50 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 112.50 kW. The average highest peak power amongst all transformers is 97.63 kW, and highest peak power from baseload is 86.58 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 74.46 kW.

9.4.4 Number of Vehicles Charged

Table 18 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	0	0	20295
1	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
2	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
3	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 17: Number of cars charged using 150% of the rated limit as the limit load on each day's baseload.

9.5 Case 5 – (Limit load = Mean Baseload)

For the purposes of this section, the limit load will be equal to the average value of the baseload; meaning that CVVF will fill to the average value of the baseload. The average value of the baseload on August 25th, 2014, September 16th, 2014 and September 25th, 2014 was 37.42 kW. 83.99 kW, and 50.90 kW, respectively.

9.5.1 Day 1: August 25th, 2014

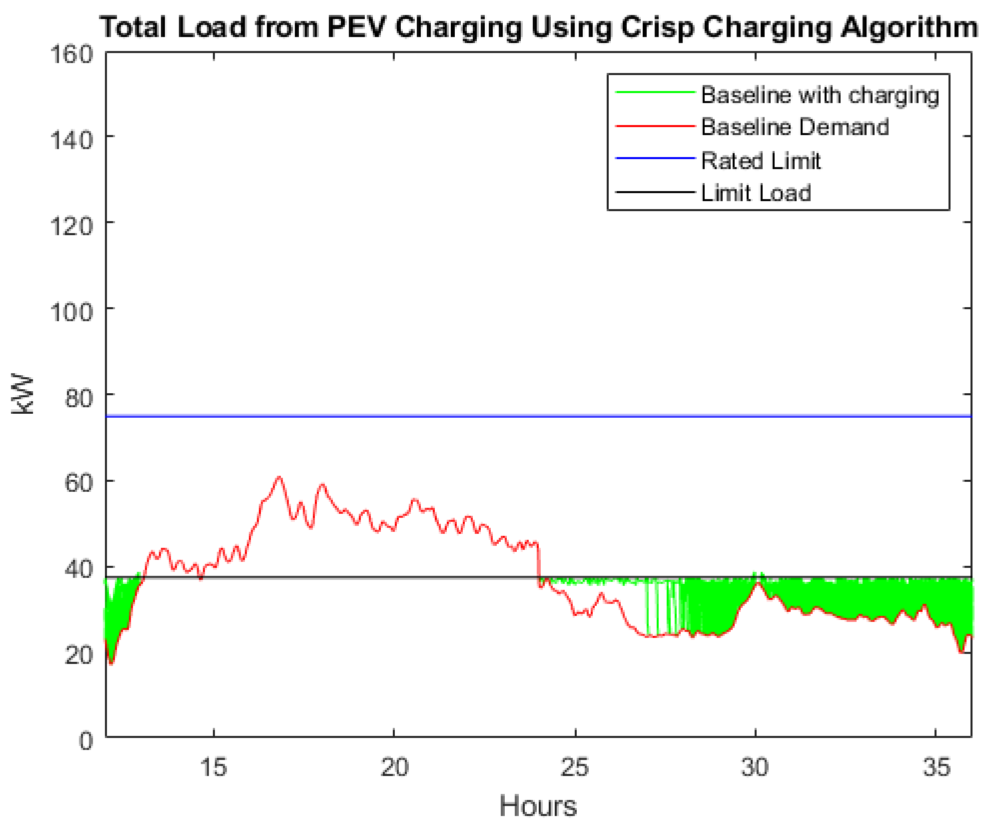

Figure 48: CVVF with crisp logic using the average value of the baseload (37.42 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the

baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 42.86 kW.

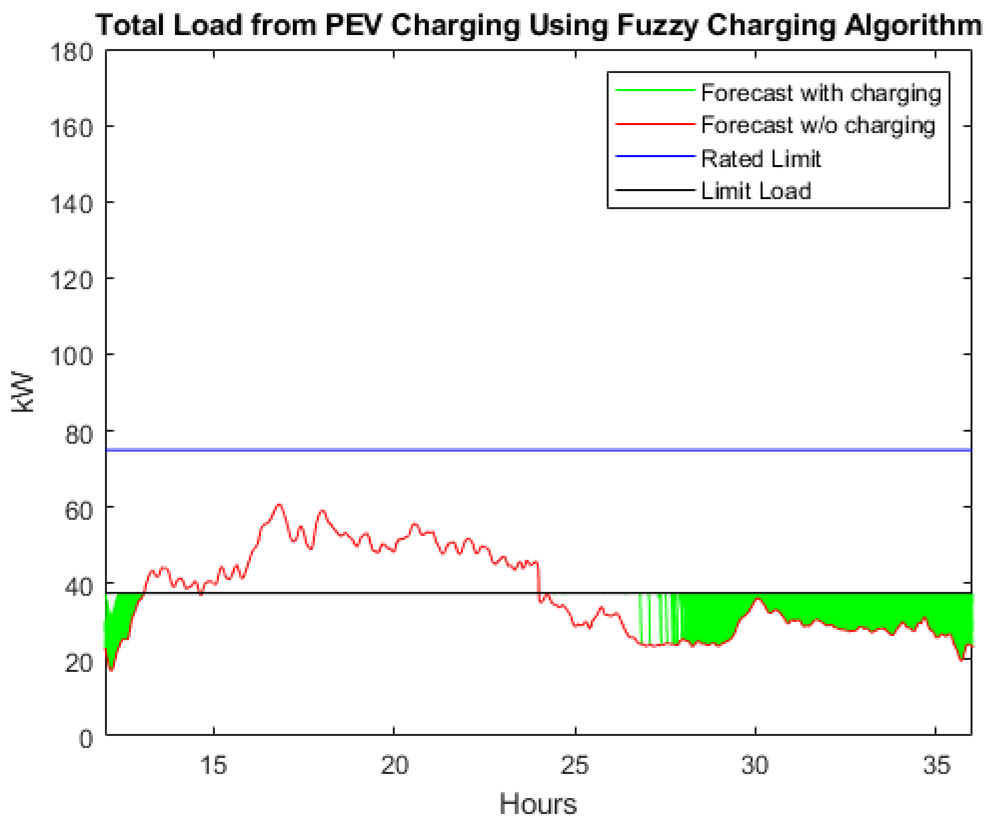

Figure 49: CVVF with fuzzy logic using the average value of the baseload (37.42 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 43.46 kW.

9.5.2 Day 2: September 16th, 2014

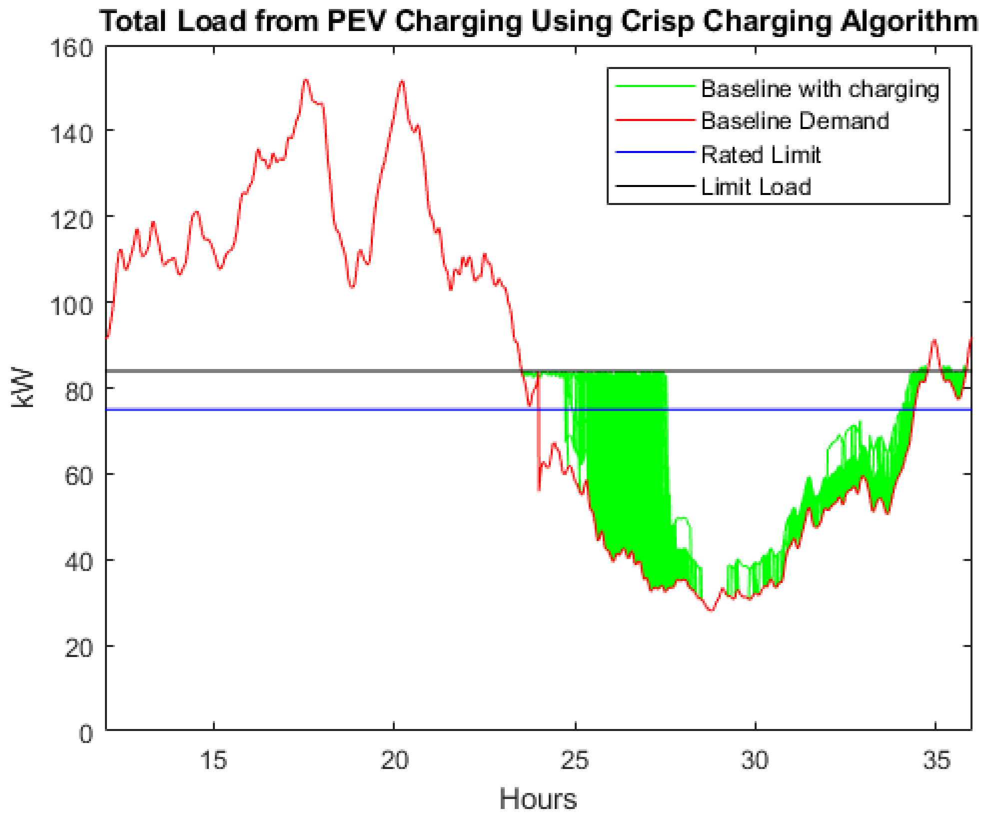

Figure 50: CVVF with crisp logic using the average value of the baseload (83.99 kW) as the load limit on August 25th, 2014 Baseload

The highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 111.41 kW.

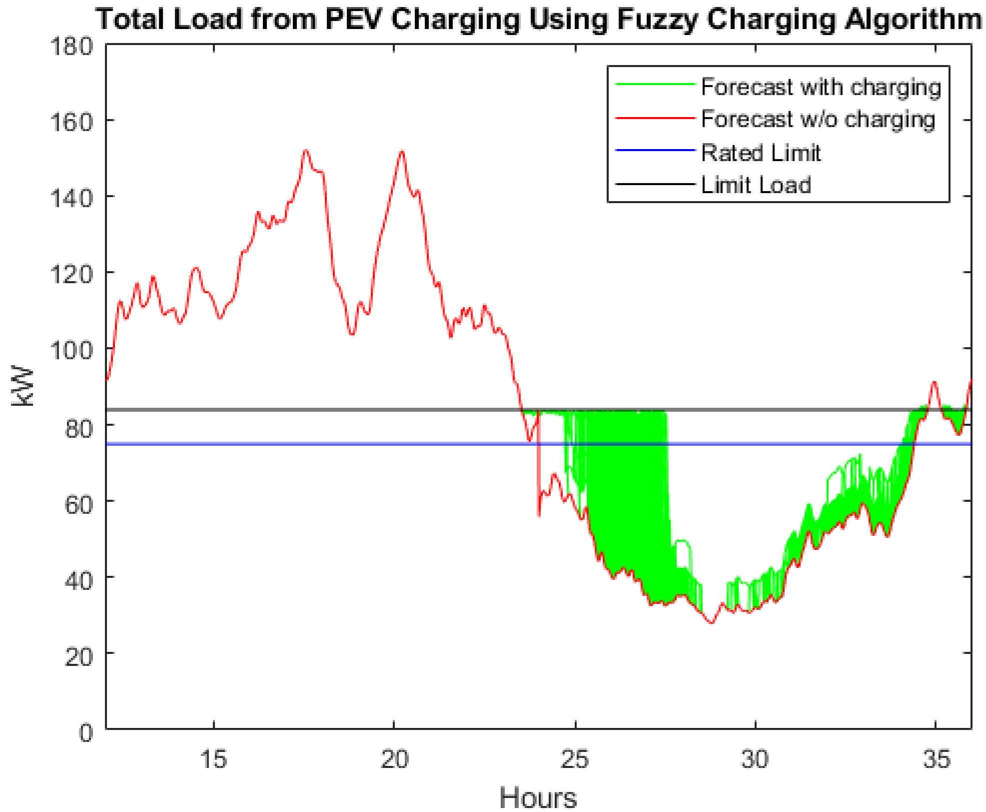

Figure 51: CVVF with fuzzy logic using the average value of the baseload (83.99 kW) as the load limit on September 16th, 2014 Baseload

The highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that the highest peak is a result of PEV charging. The average load during charging is 111.62 kW.

9.5.3 Day 3: September 25th, 2014

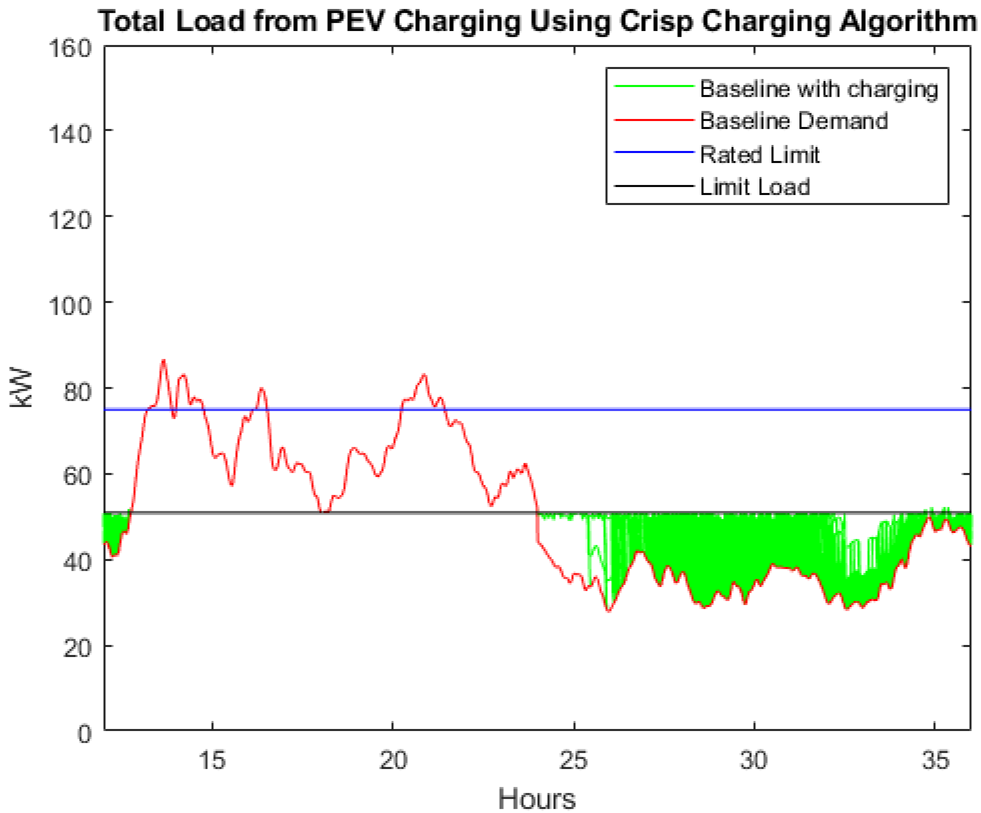

Figure 52: CVVF with crisp logic using the average value of the baseload (50.90 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 60.67 kW.

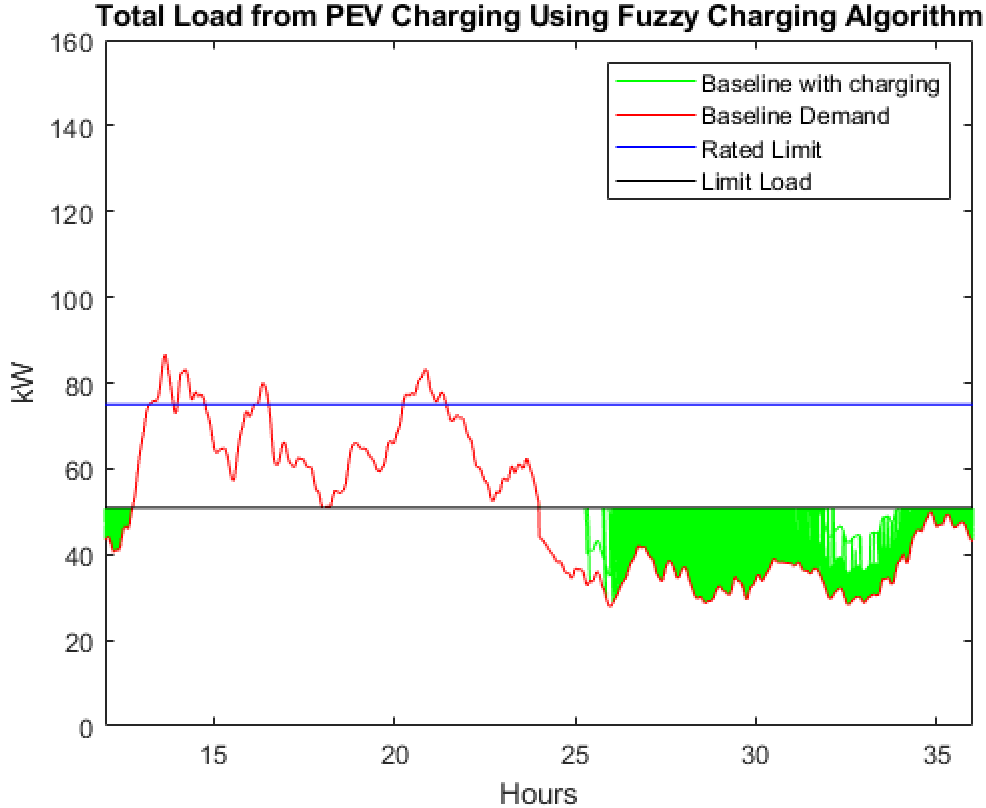

Figure 53: CVVF with fuzzy logic using the average value of the baseload (50.90 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 60.97 kW.

9.5.4 Number of Vehicles Charged

Table 19 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	28	73	336	341	440	699	18378
1	Fuzzy	9	22	139	190	235	370	19330
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	472	113	88	56	56	60	19450
2	Fuzzy	351	97	93	75	62	57	19560
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	121	63	75	65	55	70	19846
3	Fuzzy	76	51	56	64	51	57	19940
	Uncontrolled	0	0	0	0	0	0	20295

Table 18: Number of cars charged using the average value of the limit load on each day's baseload.

9.6 Case 6 – (Limit load = Mean Baseload + .5 *STD)

For the purposes of this section, the limit load will be equal to the average value of the baseload plus 0.5 standard deviations; meaning that CVVF will fill to this value. The average value of the baseload plus 0.5 standard deviations on August 25th, 2014, September 16th, 2014 and September 25th, 2014 was 43.00 kW. 102.89 kW, and 59.28 kW, respectively.

9.6.1 Day 1: August 25th, 2014

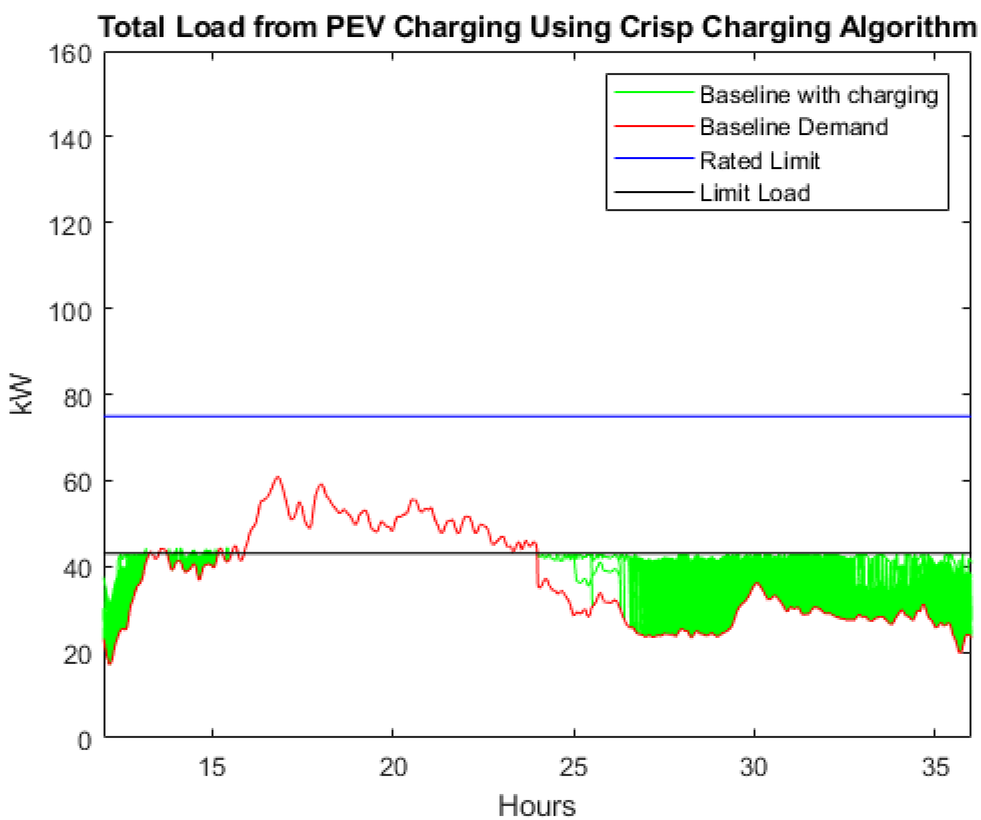

Figure 54: CVVF with crisp logic using the average value of the baseload plus 0.5 standard deviations (43.00 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the

baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 46.28 kW.

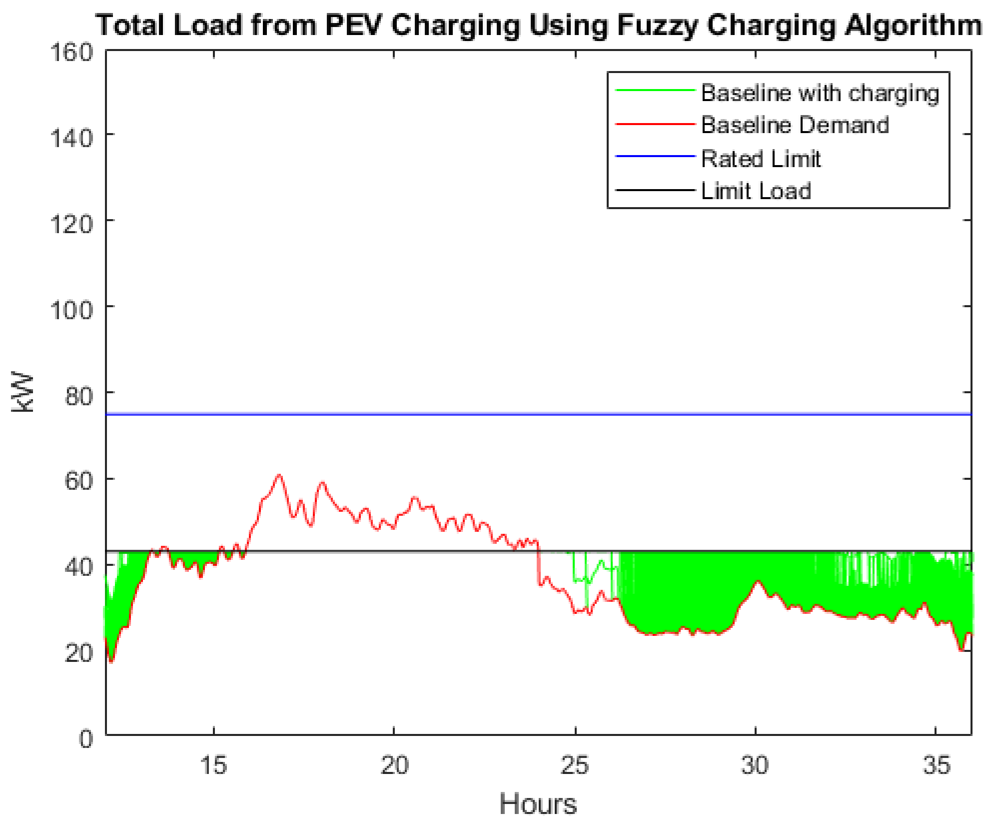

Figure 55: CVVF with fuzzy logic using the average value of the baseload plus 0.5 standard deviations (43.00 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 46.77 kW.

9.6.2 Day 2: September 16th, 2014

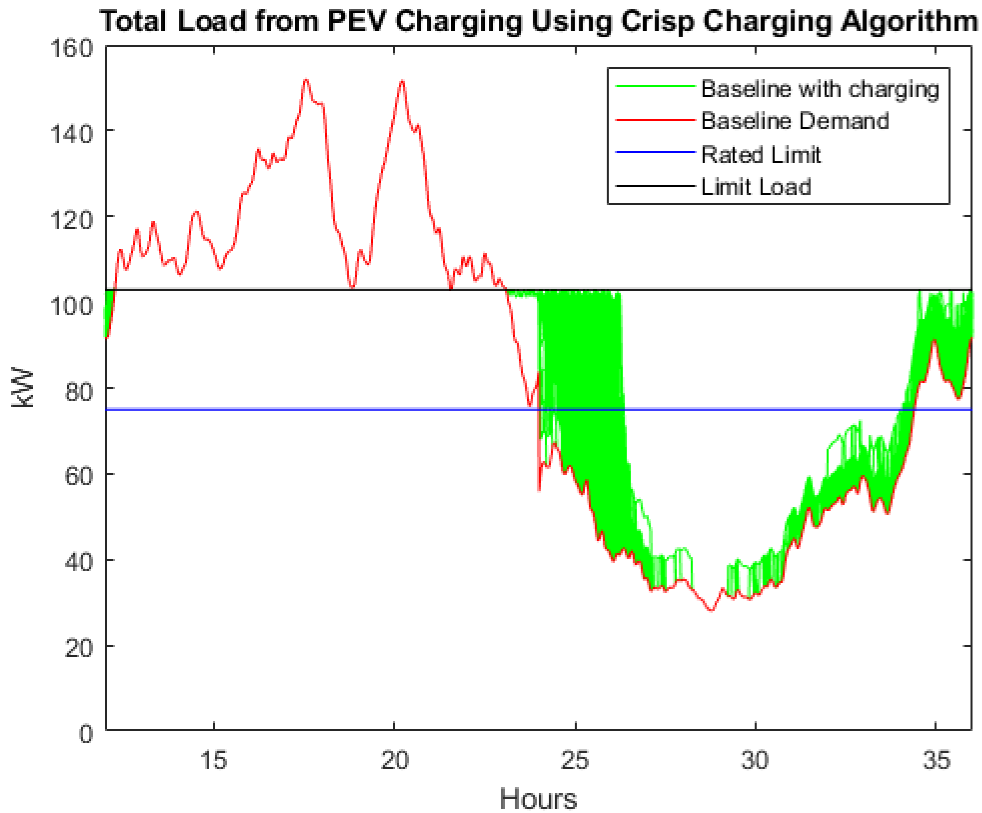

Figure 56: CVVF with crisp logic using the average value of the baseload plus 0.5 standard deviations ((102.89 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 115.55 kW.

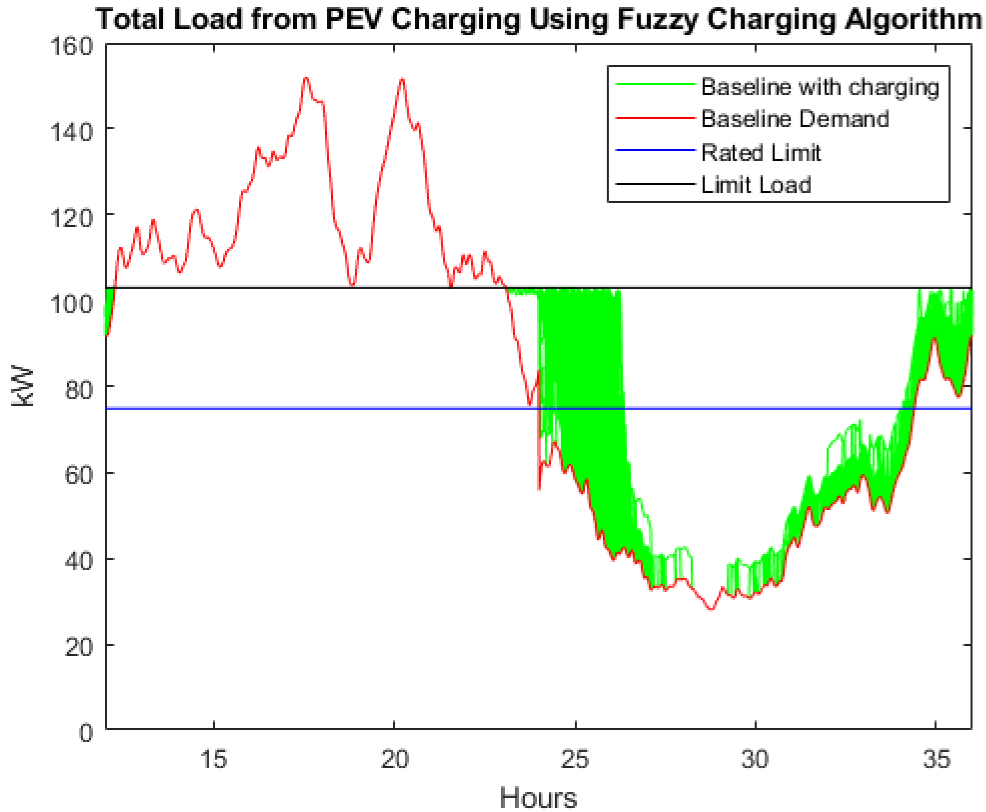

Figure 57: CVVF with fuzzy logic using the average value of the baseload plus 0.5 standard deviations ((102.89 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 115.67 kW.

9.6.3 Day 3: September 25th, 2014

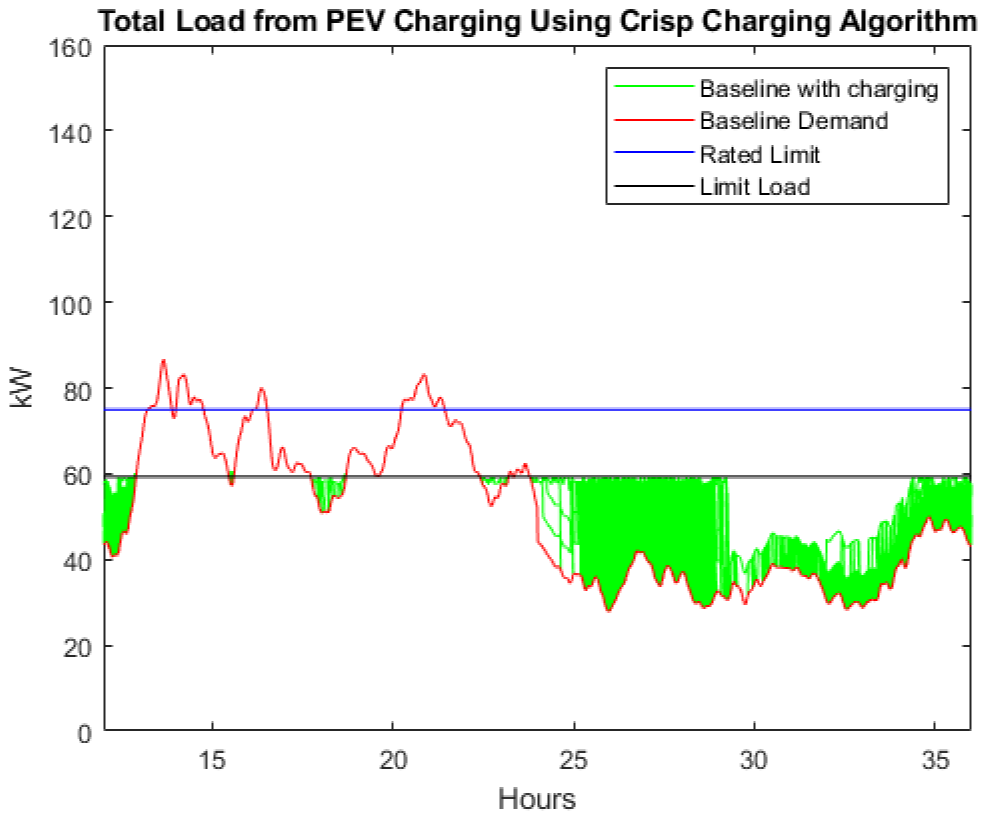

Figure 58: CVVF with crisp logic using the average value of the baseload plus 0.5 standard deviations (59.28 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 64.30 kW.

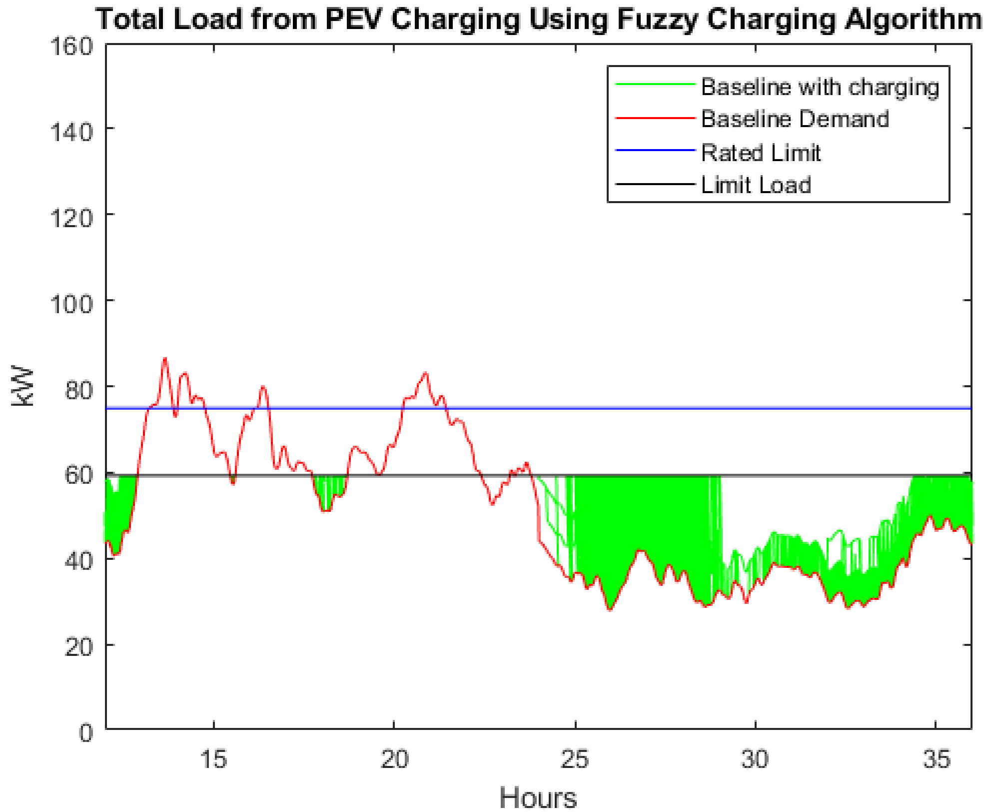

Figure 59: CVVF with fuzzy logic using the average value of the baseload plus 0.5 standard deviations (59.28 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 64.73 kW.

9.6.4 Number of Vehicles Charged

Table 20 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	13	22	20260
1	Fuzzy	0	0	0	0	0	12	20283
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	7	11	33	25	24	20195
2	Fuzzy	0	0	16	18	31	25	20205
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	3	20	20272
3	Fuzzy	0	0	0	0	0	1	20294
	Uncontrolled	0	0	0	0	0	0	20295

Table 19: Number of cars charged using the average value of the baseload plus 0.5 standard deviations as the limit load on each day's baseload.

9.7 Case 8 – (Limit load = Mean Baseload + STD)

For the purposes of this section, the limit load will be equal to the average value of the baseload plus a standard deviation; meaning that CVVF will fill to this value. The average value of the baseload plus a standard deviation on August 25th, 2014, September 16th, 2014 and September 25th, 2014 was 48.58 kW, 121.81 kW, and 67.66 kW respectively.

9.7.1 Day 1: August 25th, 2014

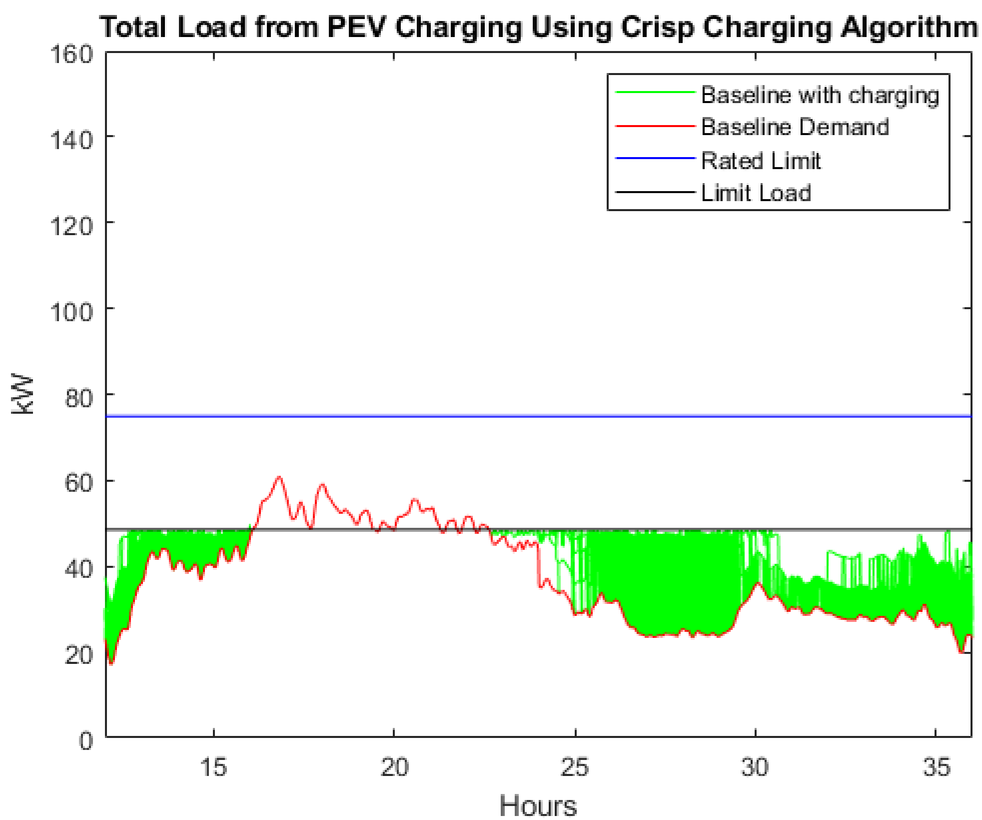

Figure 60: CVVF with crisp logic using the average value of the baseload plus a standard deviation (48.58 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the

baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 49.06 kW.

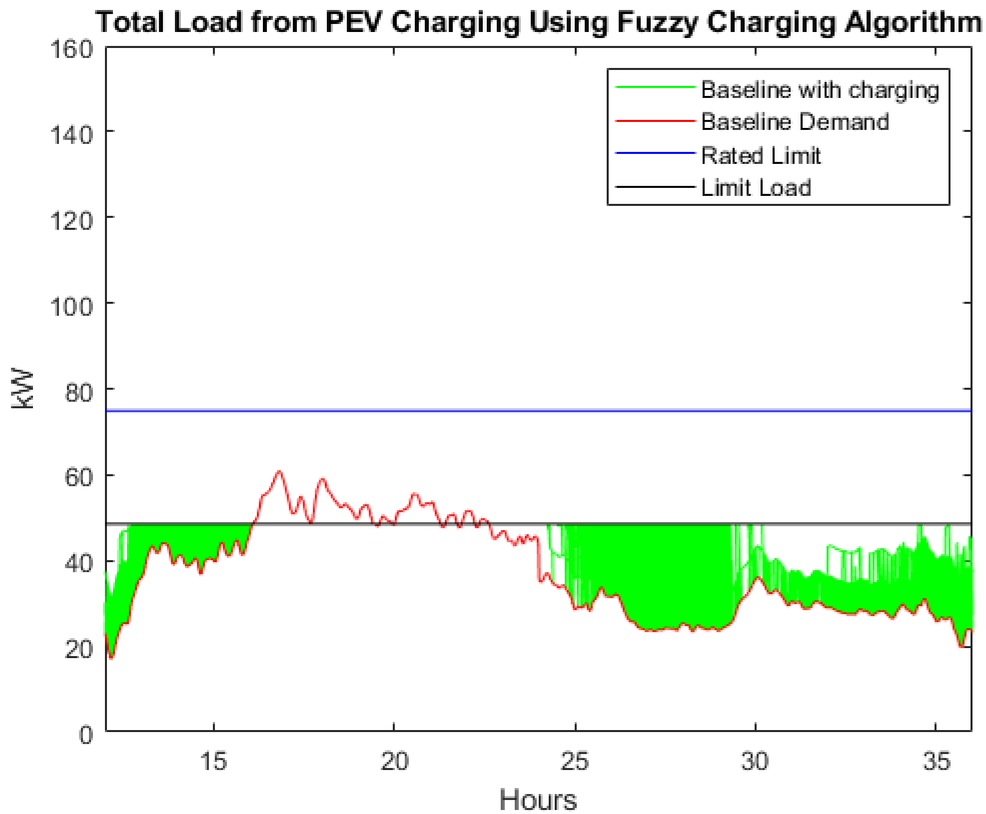

Figure 61: CVVF with fuzzy logic using the average value of the baseload plus a standard deviation (48.58 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 49.52 kW.

9.7.2 Day 2: September 16th, 2014

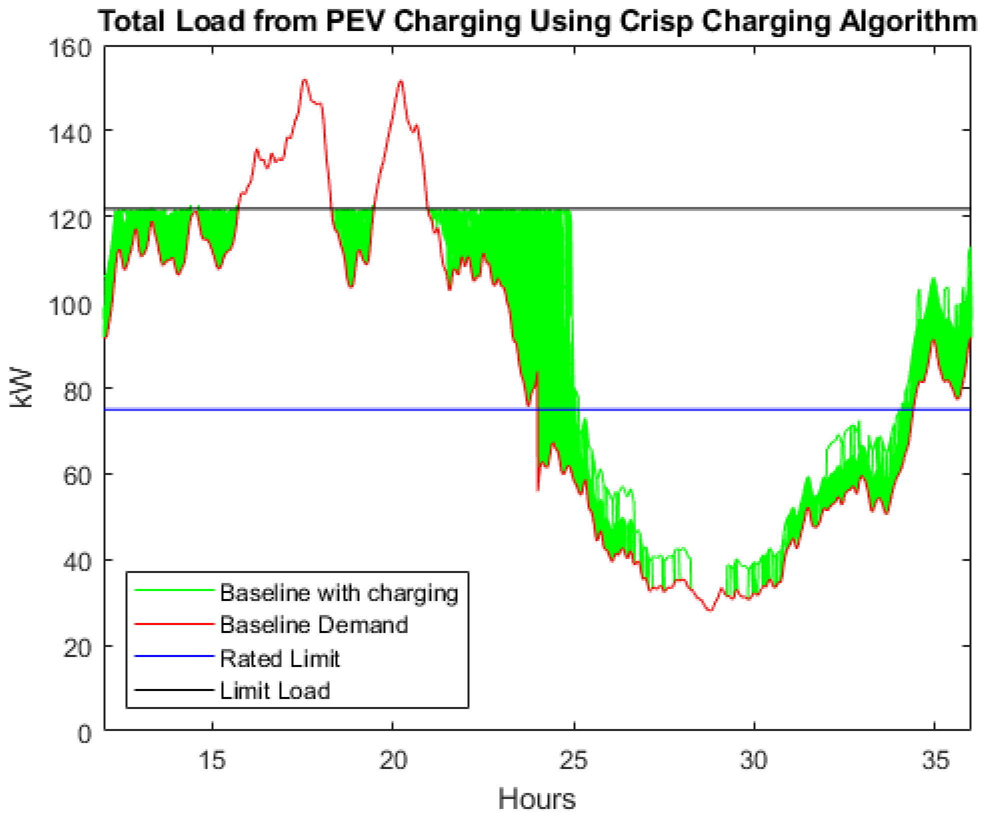

Figure 62: CVVF with crisp logic using the average value of the baseload plus a standard deviation (121.81 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 123.21 kW.

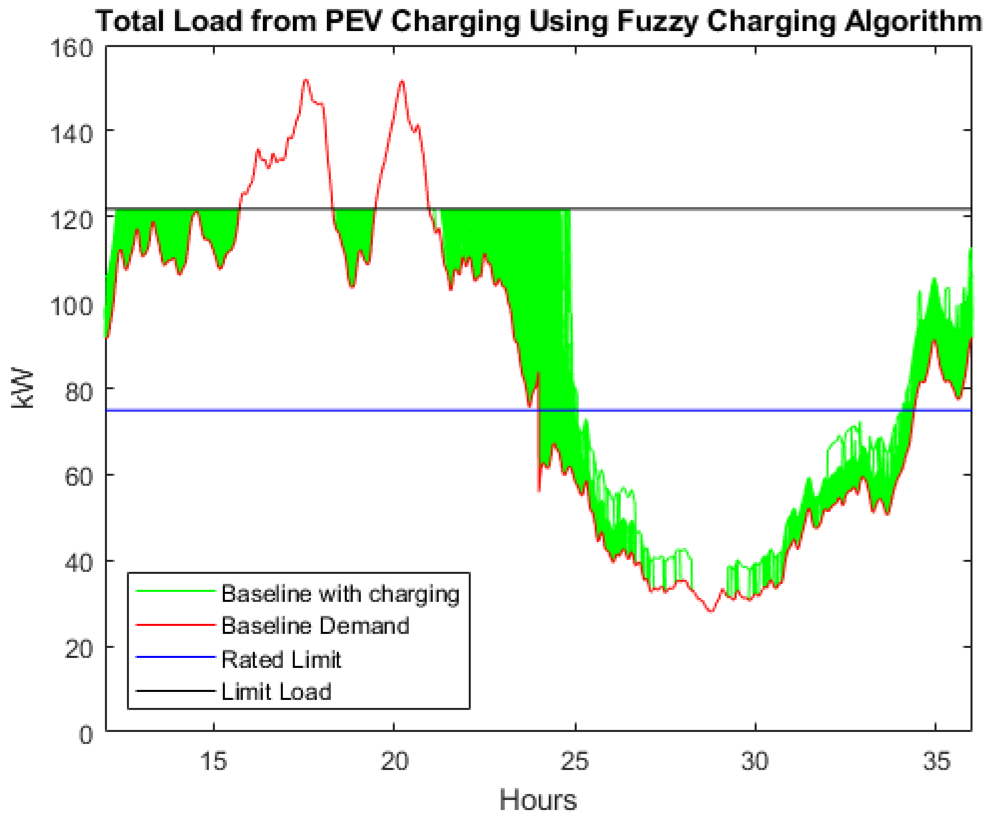

Figure 63: CVVF with fuzzy logic using the average value of the baseload plus a standard deviation (121.81 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 123.63 kW.

9.7.3 Day 3: September 25th, 2014

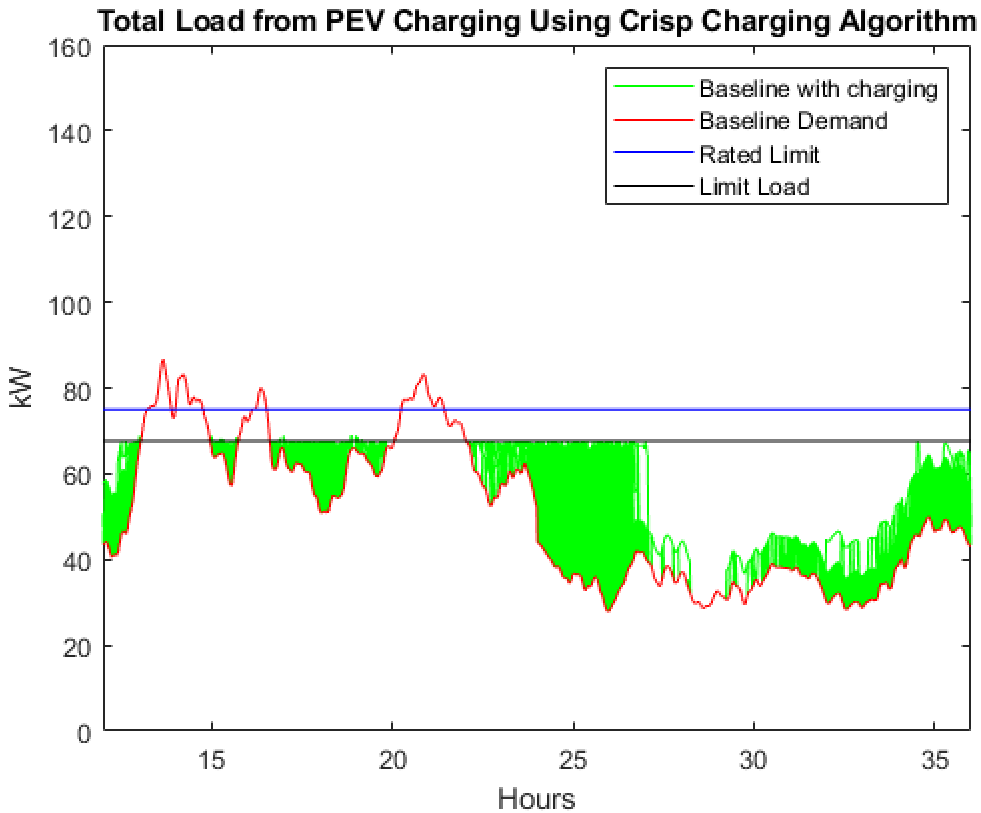

Figure 64: CVVF with crisp logic using the average value of the baseload plus a standard deviation (66.67 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 68.59 kW.

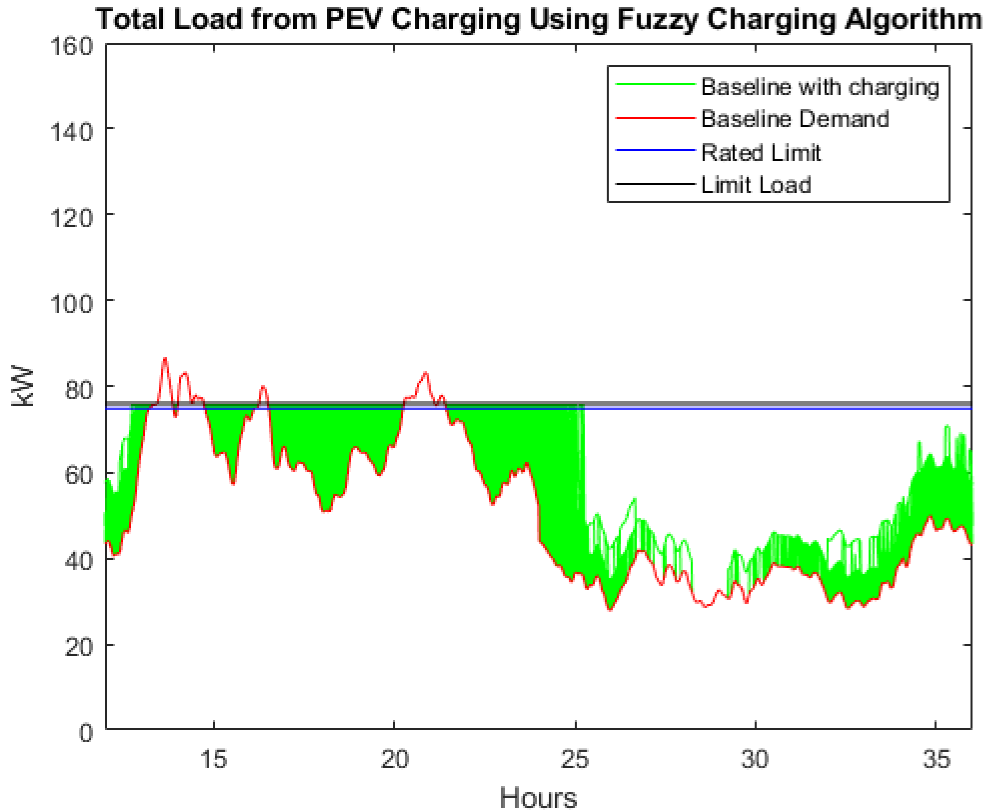

Figure 65: CVVF with fuzzy logic using the average value of the baseload plus a standard deviation (66.67 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 69.03 kW.

9.7.4 Number of Vehicles Charged

Table 21 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	0	0	20295
1	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
2	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
3	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 20: Number of cars charged using the average value of the baseload plus a standard deviation as the limit load on each day's baseload.

9.8 Case 9 – (Limit load = Mean Baseload + 1.5*STD)

For the purposes of this section, the limit load will be equal to the average value of the baseload plus 1.5 standard deviations; meaning that CVVF will fill to this value. The average value of the baseload plus 1.5 standard deviations on August 25th, 2014, September 16th, 2014 and September 25th, 2014 was 54.16 kW, 140.72 kW, and 76.03 kW respectively.

9.8.1 Day 1: August 25th, 2014

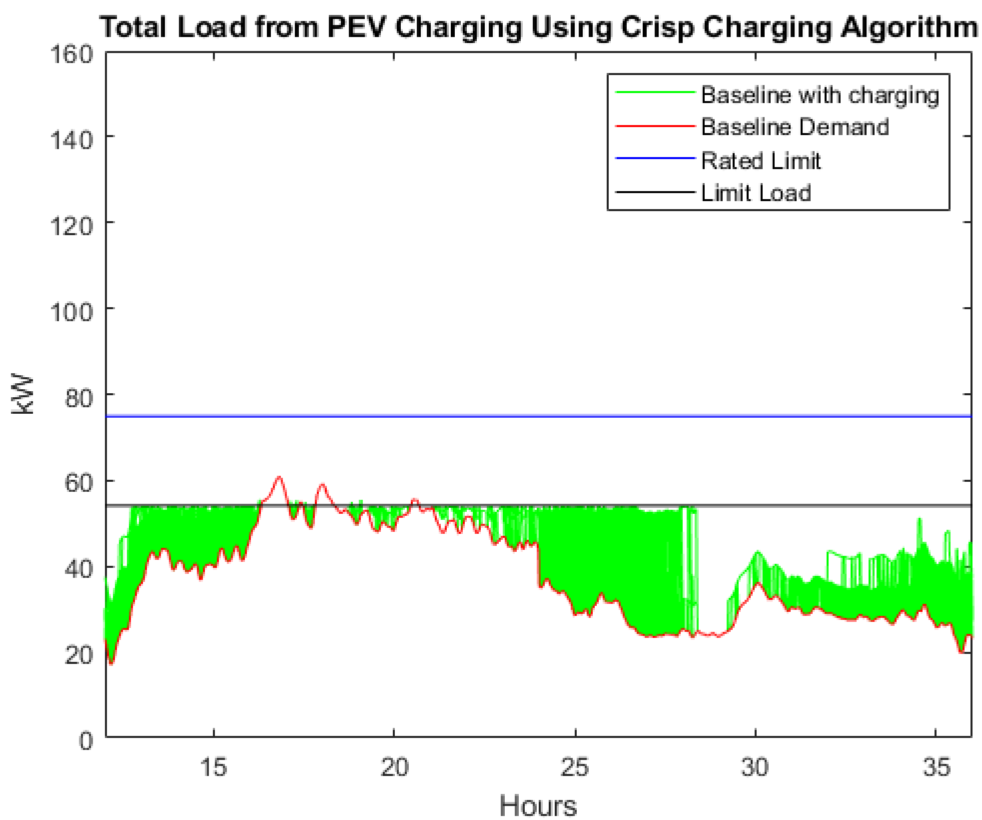

Figure 66: CVVF with crisp logic using the average value of the baseload plus 1.5 standard deviations (54.16 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any transformer is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 52.09 kW.

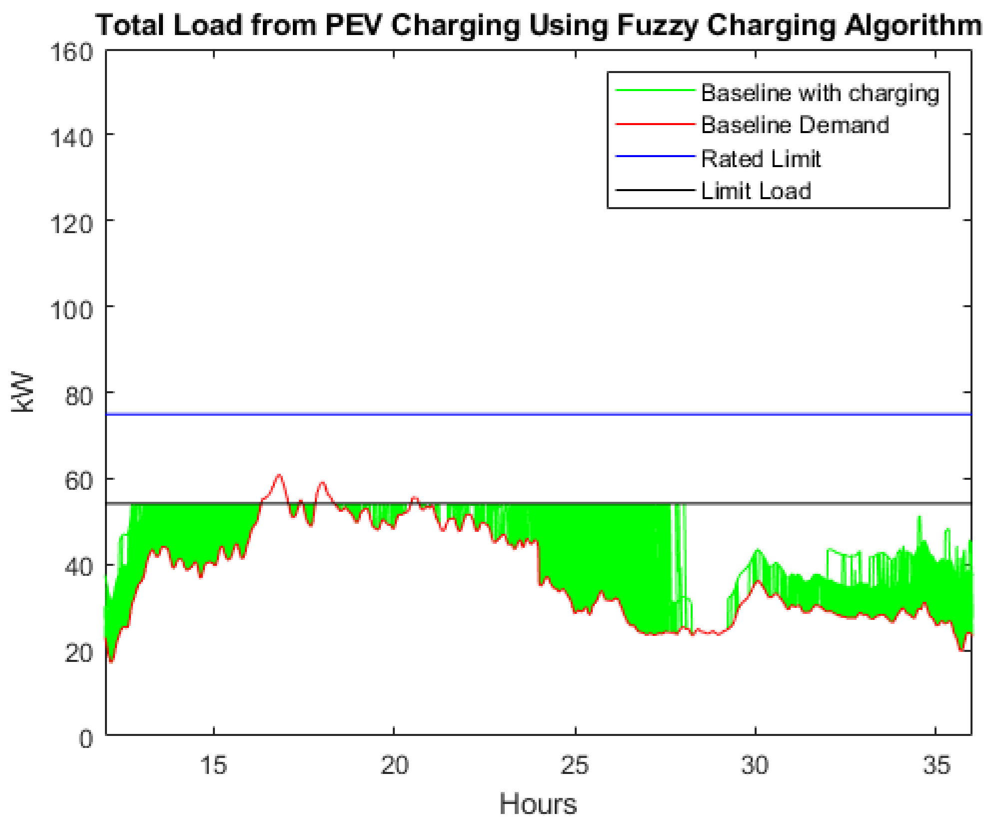

Figure 67: CVVF with fuzzy logic using the average value of the baseload plus 1.5 standard deviations (54.16 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 52.72 kW.

9.8.2 Day 2: September 16th, 2014

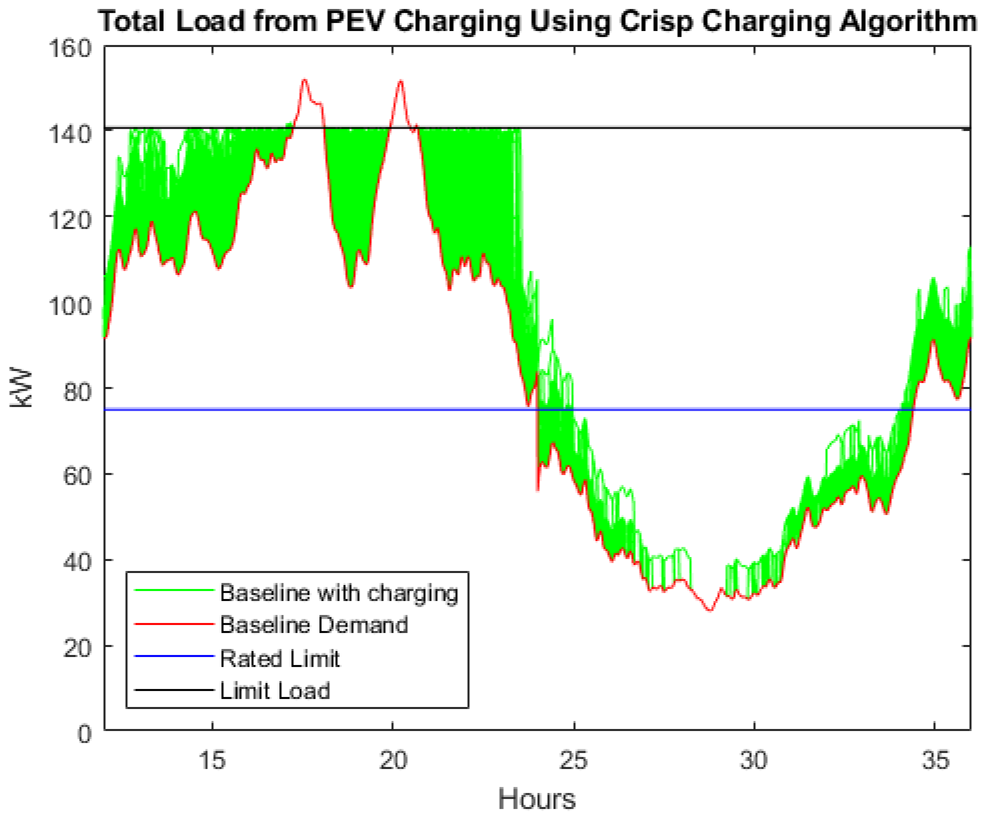

Figure 68: CVVF with crisp logic using the average value of the baseload plus 1.5 standard deviations (140.72 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 127.10 kW

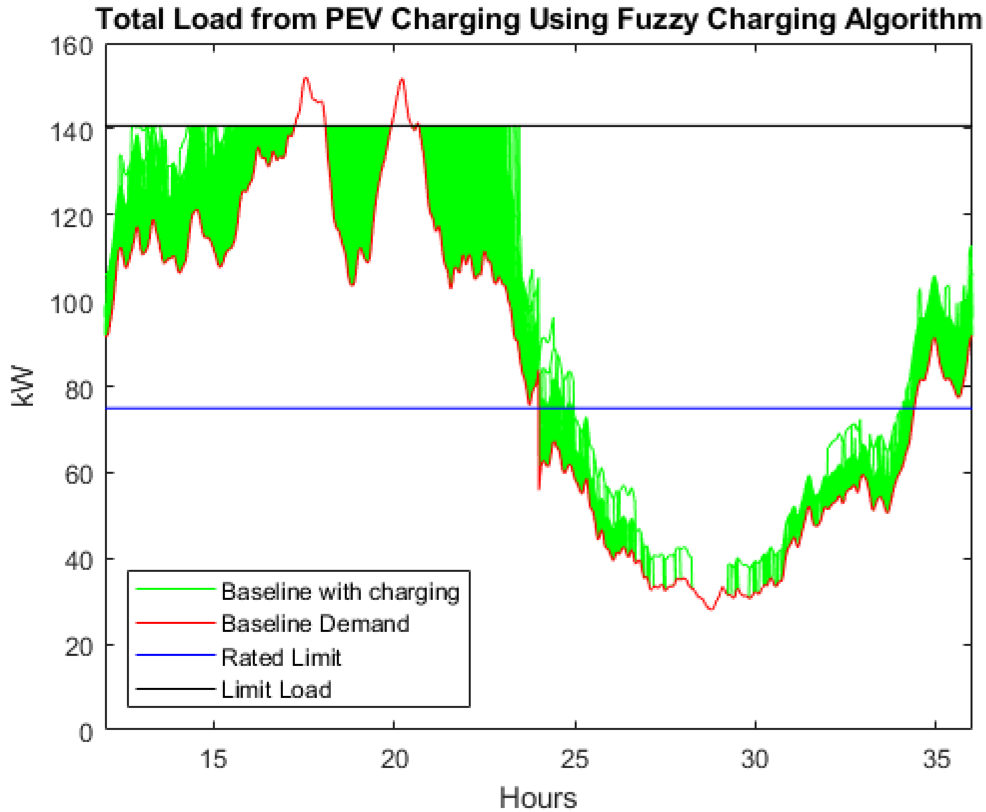

Figure 69: CVVF with fuzzy logic using the average value of the baseload plus 1.5 standard deviations (140.72 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with fuzzy logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 127.10 kW.

9.8.3 Day 3: September 25th, 2014

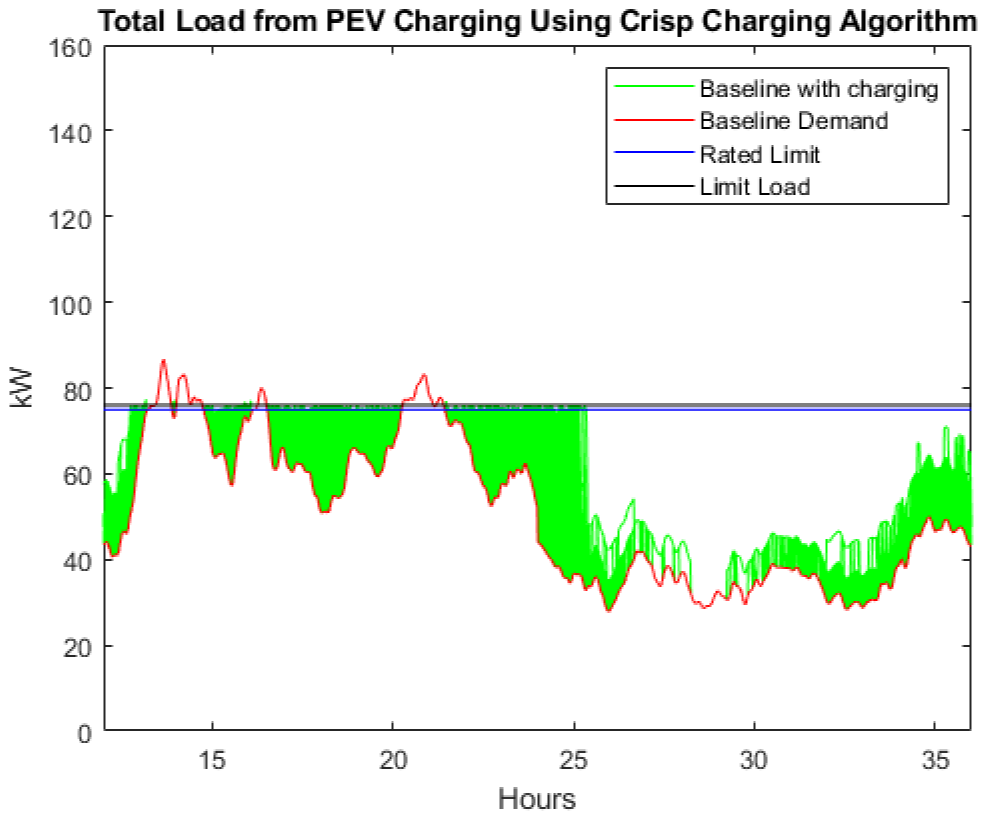

Figure 70: CVVF with crisp logic using the average value of the baseload plus 1.5 standard deviations (76.03 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any transformer is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 72.22 kW.

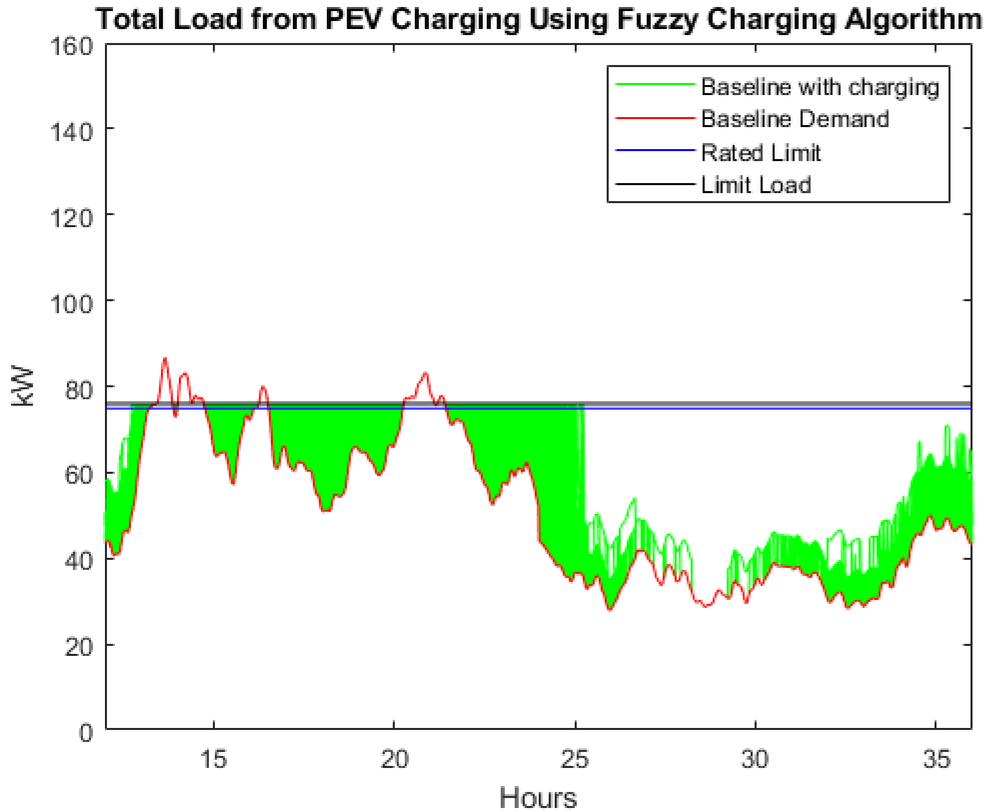

Figure 71: CVVF with fuzzy logic using the average value of the baseload plus 1.5 standard deviations (76.03 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 72.51 kW.

9.8.4 Number of Vehicles Charged

Table 22 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	0	0	20295
1	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
2	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
3	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 21: Number of cars charged using the average value of the baseload plus 1.5 standard deviations as the limit load on each day's baseload.

9.9 Case 10 – (Limit load = Mean Baseload + 2*STD)

For the purposes of this section, the limit load will be equal to the average value of the baseload plus 2 standard deviations; meaning that CVVF will fill to this value. The average value of the baseload plus 2 standard deviations on August 25th, 2014, September 16th, 2014 and September 25th, 2014 was 59.74 kW, 159.63 kW, and 84.40 kW respectively.

9.9.1 Day 1: August 25th, 2014

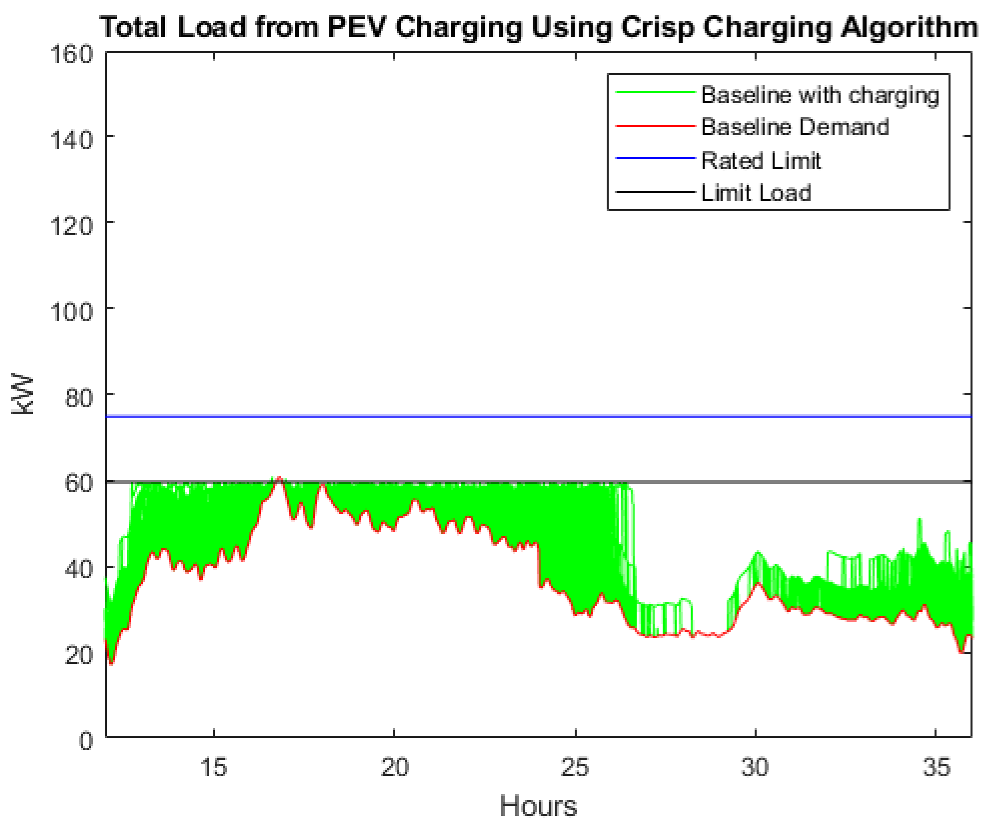

Figure 72: CVVF with crisp logic using the average value of the baseload plus 2 standard deviations (59.74 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the

baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average load during charging is 55.42 kW.

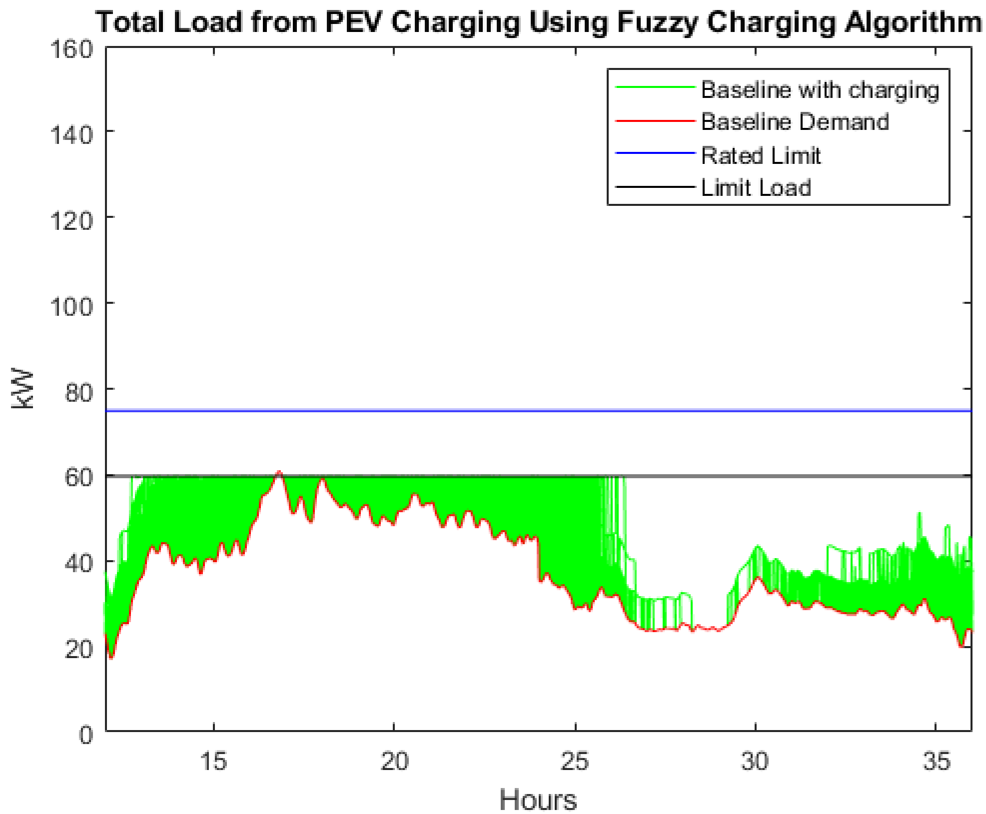

Figure 73: CVVF with fuzzy logic using the average value of the baseload plus 2 standard deviations (59.74 kW) as the load limit on August 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 60.85 kW. The average highest peak power amongst all transformers is 60.85 kW, and highest peak power from baseload is 60.85 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average baseload is 37.42 kW, and when PEV's are applied, the average load over the day is 40.77 kW, equating to a percentage difference of 8.57%. Moreover, the average load during charging is 55.85 kW.

9.9.2 Day 2: September 16th, 2014

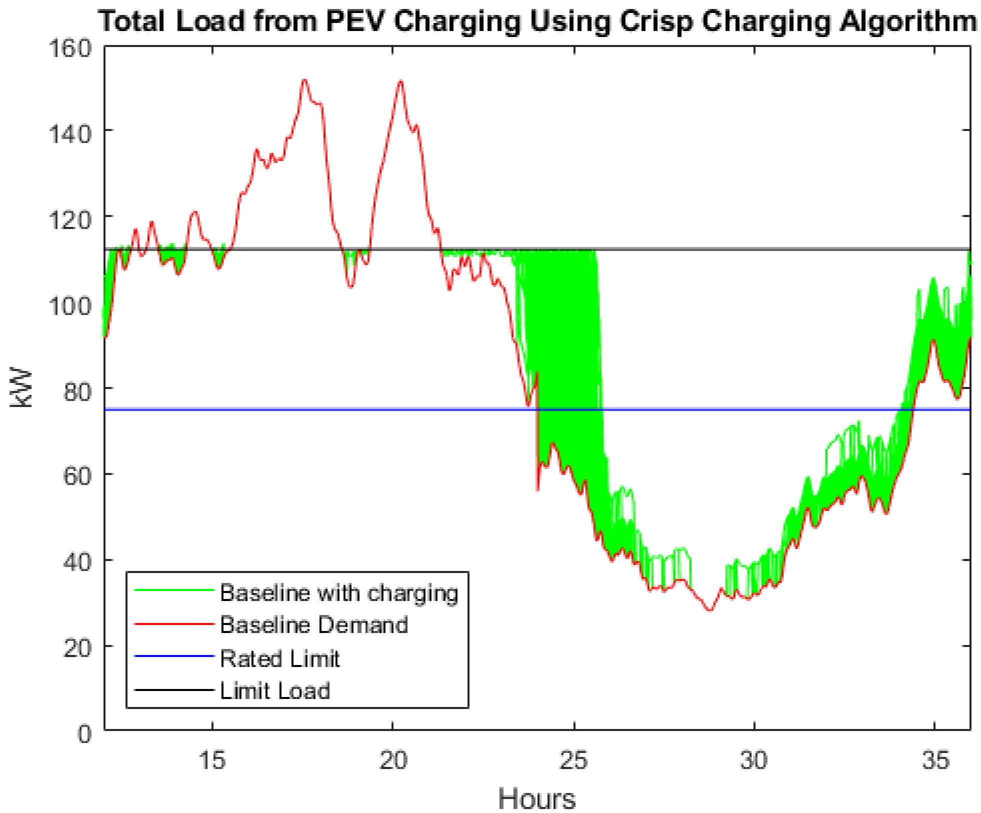

Figure 74: CVVF with crisp logic using the average value of the baseload plus 2 standard deviations (159.63 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average baseload is 83.99 kW, and when PEV's are applied, the average load over the day is 87.34 kW, equating to a percentage difference of 3.91%. Moreover, the average load during charging is 127.70 kW.

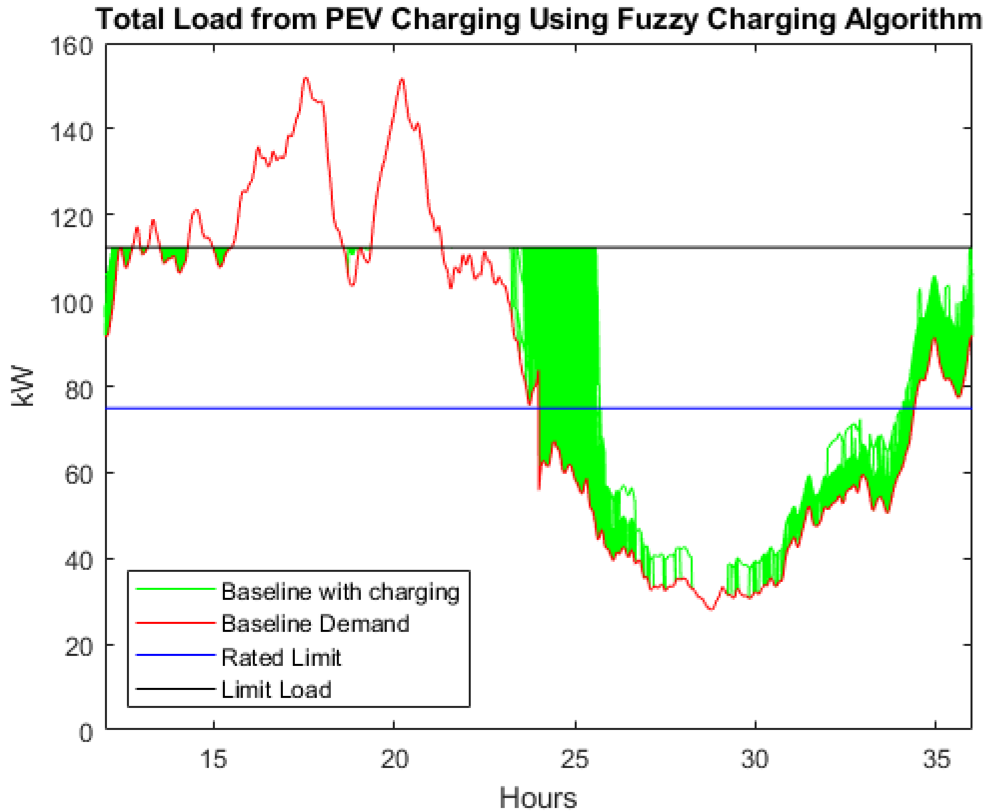

Figure 75: CVVF with fuzzy logic using the average value of the baseload plus 2 standard deviations (159.63 kW) as the load limit on September 16th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 151.93 kW. The average highest peak power amongst all transformers is 151.93 kW, and highest peak power from baseload is 151.93 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average baseload is 83.99 kW, and when PEV's are applied, the average load over the day is 87.34 kW, equating to a percentage difference of 3.91%. Moreover, the average load during charging is 127.72 kW.

9.9.3 Day 3: September 25th, 2014

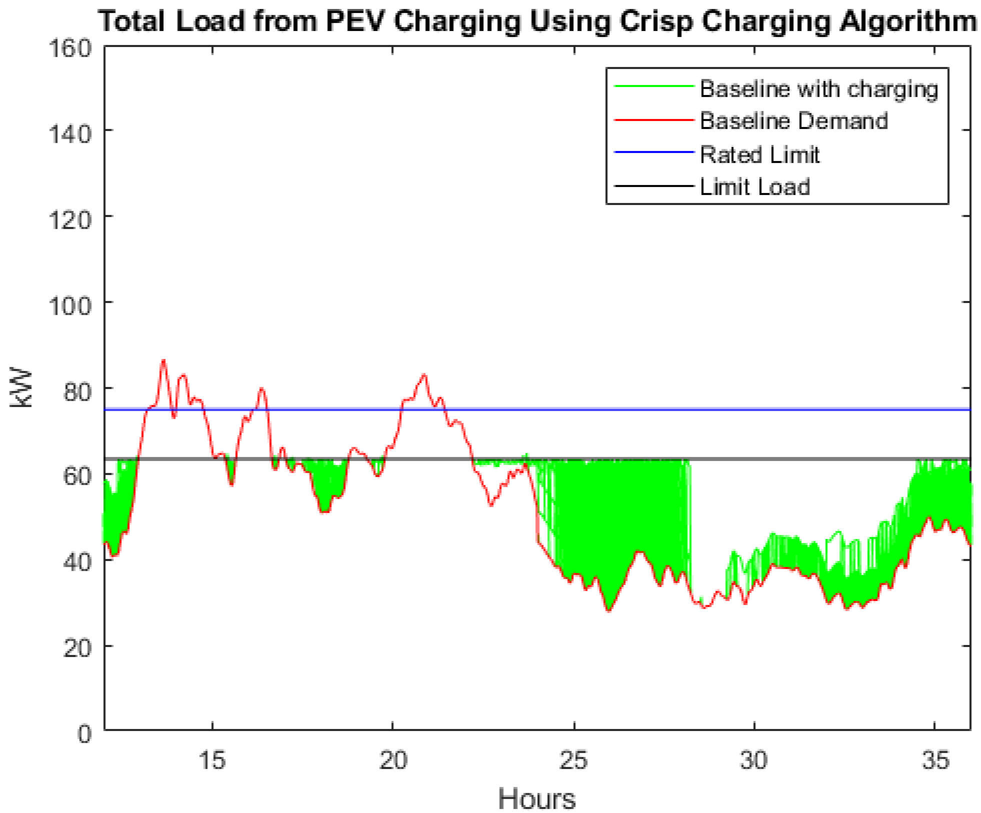

Figure 76: CVVF with crisp logic using the average value of the baseload plus 2 standard deviations (84.40 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average baseload is 50.90 kW, and when PEV's are applied, the average load over the day is 54.25 kW, equating to a percentage difference of 6.37%. Moreover, the average load during charging is 73.91 kW.

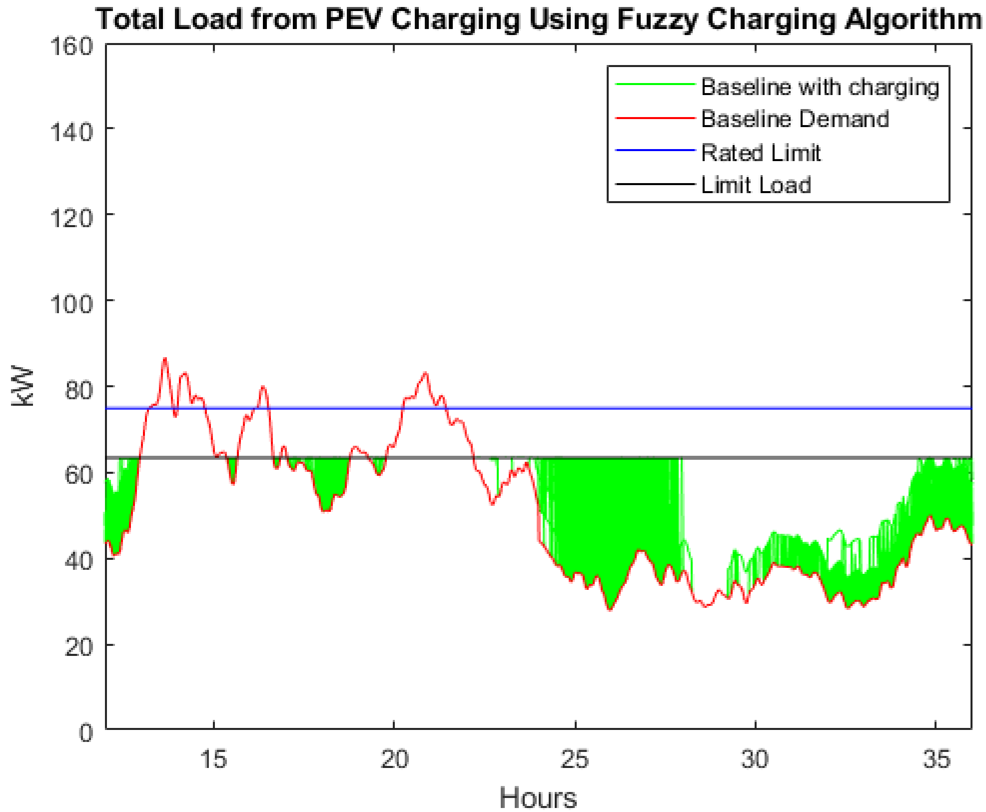

Figure 77: CVVF with fuzzy logic using the average value of the baseload plus 2 standard deviations (84.40 kW) as the load limit on September 25th, 2014 Baseload

Using CVVF with crisp logic, the highest peak power reached amongst any of the transformers is 86.58 kW. The average highest peak power amongst all transformers is 86.58 kW, and highest peak power from baseload is 86.58 kW, meaning that highest peak is produced by the baseload, not PEV charging because the algorithm restricts charging when the baseload is above CVVF limit load. The average baseload is 50.90 kW, and when PEV's are applied, the average load over the day is 54.25 kW, equating to a percentage difference of 6.37%. Moreover, the average load during charging is 74.08 kW.

9.9.4 Number of Vehicles Charged

Table 23 shows the effectiveness CVVF using both decision mechanisms, on each day's baseload by categorizing the final percent levels of all the vehicles charged.

Day	Algorithm	0-40 %	40-50%	50-60%	60-70%	70-80%	80-90%	90-100%
	Crisp	0	0	0	0	0	0	20295
1	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
2	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295
	Crisp	0	0	0	0	0	0	20295
3	Fuzzy	0	0	0	0	0	0	20295
	Uncontrolled	0	0	0	0	0	0	20295

Table 22: Number of cars charged using the average value of the baseload plus 2 standard deviations as the limit load on each day's baseload.

10 Appendix B

10.1 CVVF with Crisp Logic

```
load('FinalBaselines.mat')
choices = [FinalBaselineAug2514;FinalBaselineSep1614;FinalBaselineSep2514];

% for selection = 1:3
selection =1;
method = 1;
day = choices(selection ,:);
select = 6;

percentage_of_vehicles_charged = zeros(7,1);
transformer_limit = zeros(2255,2880);
results1 = zeros(2881,9,2255);
results2 = zeros(2880,9,2255);
actual_final_charge = zeros(2255,9);
desired_final_charge = zeros(2255,9);


forecast_with_pev = zeros(2255,2880);
load y
y_organizer = zeros(20295,3);

for i = 1:20295
    y_organizer(i,:) = y(i,2:4);
    y_organizer(i,:) = ceil(y_organizer(i,:)*(2880/48));
    if  y_organizer(i,1) == 0
        y_organizer(i,1) = 1;
    end
end

beginning_transformer = 1;
ending_transformer = 2255;

avg_point_during_charge = zeros((ending_transformer-beginning_transformer+1),1);

for transformer = beginning_transformer:ending_transformer
    %   Initialize all parameters that will research for each transformer:
    n = 9;
    desired_charge = zeros(2880,n); %How much charge each vehicle is requesting
    current_charge_of_battery = zeros(2880,n); %The current state of the battery of each car, at
each minute
    added_charge_per_minute = zeros(2880,n); %How much charge is added to the battery at
each minute
```

```
    needed_charge = zeros(2881,n); %How much charge does each vehicle need to reach desired
at each minute
    priority_ratio = zeros(2880,n); %Determines which car is in the most need of a high rate
    car_order = zeros(2880,n); %The order of the cars based on priority ratio
    plug_in_time = zeros(2880,n); %The time when vehicles plug into the transformer
    dwell_time = zeros(2880,n); %How long the vehicle will be connected to the transformer
    current_rate = zeros(2880,n); %The avaiable rates that can be given out
    actively_charging= zeros(2880,n); %Determines which vehicles are plugged in during each
minute

    %   Imports the data for APEP, which is plug in time, dwell time,
    %   requested SOC and current state of battery charge:
    plug_in_time(1,:) = y_organizer((1+(transformer-1)*9:9+(transformer-1)*9),1)';
    for lk = 1:9
        if plug_in_time(1,lk) < 720
            plug_in_time(1,lk) = 1440 + plug_in_time(1,lk);
        end
        if plug_in_time(1,lk) > 2160
            plug_in_time(1,lk) = -1440 + plug_in_time(1,lk);
        end
    end
    plug_in_time(2:2880,:) = repmat(plug_in_time(1,:),2879,1);

    dwell_time(1,:) = y_organizer((1+(transformer-1)*9:9+(transformer-1)*9),3)';
    dwell_time(2:2880,:) = repmat(dwell_time(1,:),2879,1);

    plug_out_time = plug_in_time + dwell_time;

    desired_charge(1,:) = y((1+(transformer-1)*9:9+(transformer-1)*9),5)';
    desired_charge(2:2880,:) = repmat(desired_charge(1,:),2879,1);

    %Assigning Initial States:
    current_charge_of_battery(1,:)  = [ 0 0 0 0 0 0 0 0 0];
    needed_charge(1,:)= desired_charge(1,:);


    %%  This is section assigns what will be used as the limits
    t = linspace(0,48,2880);
    forecast_without_pev = [day day];

% %     %   Option 1: Envelop Filter
%     [envHigh, envLow] = envelope(forecast_without_pev,100,'peak');
%     top_profile = envHigh;
%     limit_cap = 75;
%     top_profile(top_profile<=limit_cap)= limit_cap;
%     transformer_limit(transformer,:) = top_profile;
```

```
% %
%
   %   Option 2: Straight Line
%     running = [ 56.25 56.25 56.25 75 75 75 93.75 93.75 93.75 112.5 112.5 112.5 37.4260
83.9808 50.9069 43.0035 102.8940 59.2813 48.5810 121.8072 67.6557 54.1585 140.7204
76.0301 59.7360 159.6336 84.4045];

%     transformer_limit(transformer,:) = running(3*(loop-
1)+selection)*ones(1,length(forecast_without_pev));
 transformer_limit(transformer,:) = 48.5810*ones(1,length(forecast_without_pev));
%
% %     %   Option 3: Edgar
%     load VF_Mod757.2.mat
%     PData= flip(Data);
%     transformer_limit(transformer,:)= [PData(transformer,:) PData(transformer,:)];

   e = zeros(1,2880);
   %%  This for loop executes the charging of the vehicle

   for i = 1:2880
      %   This section determines what cars are charging
     if i == 2125
          tshoot= 1;
     end

      for k = 1:n
         if plug_in_time(i,k) == i
            actively_charging(i,k) = 1;
         end
         if (i-plug_in_time(i,k)) > (dwell_time(i,k))
            actively_charging(i,k) = 0;
         end
         if (current_charge_of_battery(i,k)) > (desired_charge(1,k))
            actively_charging(i,k) = 0;
         end
      end


      for jj = 1:n
         if i == 1
            priority_ratio(i,jj) = priority_ratio(i,jj);
         end
         if actively_charging(i,jj) == 1
            priority_ratio(i,jj) = (needed_charge(i-1,jj))/(plug_in_time(i,jj)+dwell_time(i,jj)-(i-1));
         end
```

```
        if (actively_charging(i,jj) == 1) && (((current_charge_of_battery(i,jj) +
(7.2/60)*((plug_in_time(i,jj)+dwell_time(i,jj)-(i))) < needed_charge(i-1,jj))))
            priority_ratio(i,jj) = 100;
        end
        if  actively_charging(i,jj) ~= 1
            priority_ratio(i,jj) = jj/1000000;
        end
    end

    [sorted_priority_ratio,I] = sort(priority_ratio(i,:), 'descend');
    car_order(i,:) = I;
    %%  This section assigns the values in the error membership function
    v =0;
    e(i) = round(transformer_limit(transformer,i)- forecast_without_pev((i)) - v,2);

    if e(i) < 0
        e(i) = 0;
    end

    for q = 1:n
        if (e(i)<1.9)
            mf1 = 1;
        end
        if ((e(i)>=1.9 && (e(i)<3.3)))
            mf1 = 2;
        end
        if ((e(i)>= 3.3) && (e(i)<7.2))
            mf1 = 3;
        end
        if e(i)>=7.2
            mf1 = 4;
        end

        rate= [0 1.9 3.3 7.2];
        output = rate(mf1);
        current_rate(i,q) = output;
        v = sum(current_rate(i,:));
        e(i) = round(transformer_limit(transformer,i)- forecast_without_pev((i)) - v,2);
        if e(i) < 0
            e(i) = 0;
        end
    end

    %% This section charges each vehicle

    for w = 1:n
```

```
        if (i-plug_in_time(1,car_order(i,w)) > dwell_time(1,car_order(i,w)))
           actively_charging(i,car_order(i,w)) = 0;
           added_charge_per_minute(i,car_order(i,w)) = 0;
           needed_charge(i,car_order(i,w)) = needed_charge(i,car_order(i,w));
           current_charge_of_battery(i,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w)) + added_charge_per_minute(i,car_order(i,w));
           current_charge_of_battery(i+1,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w));
        end

        if actively_charging(i,car_order(i,w)) == 1
           if needed_charge(i-1,car_order(i,w))< (7.2/60)
                 if current_rate(i,w) > 0
                    current_rate(i,1) = 3.3;
                 end
           end
           if needed_charge(i-1,car_order(i,w))< (3.3/60)
                 if current_rate(i,w) > 0
                 current_rate(i,w)= 1.9;
                 end
          end

           added_charge_per_minute(i,car_order(i,w)) = current_rate(i,w) *(1/60);
           current_charge_of_battery(i,car_order(i,w))  =
current_charge_of_battery(i,car_order(i,w)) + added_charge_per_minute(i,car_order(i,w));
           current_charge_of_battery(i+1,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w));
           if i < 2880
           actively_charging(i+1,car_order(i,w)) = 1;
           end
           needed_charge(i,car_order(i,w)) = desired_charge(1,car_order(i,w))-
current_charge_of_battery(i,car_order(i,w));
        end

%           if (actively_charging(i,car_order(i,w)) == 1) && ((current_charge_of_battery(i,w) +
(7.2/60)*((plug_in_time(i,w)+dwell_time(i,w)) - i)) < needed_charge(i,w))
%              added_charge_per_minute(i,car_order(i,w)) = 7.2 *(1/60);
%              current_charge_of_battery(i+1,car_order(i,w))  =
current_charge_of_battery(i,car_order(i,w)) + added_charge_per_minute(i,car_order(i,w));
%              current_charge_of_battery(i+1,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w));
%              actively_charging(i+1,car_order(i,w)) = 1;
%              needed_charge(i+1,car_order(i,w)) = desired_charge(1,car_order(i,w))-
current_charge_of_battery(i,car_order(i,w));
%           end
```

```
        if  actively_charging(i,car_order(i,w)) == 0
            added_charge_per_minute(i,car_order(i,w)) = 0;
            current_charge_of_battery(i,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w)) + added_charge_per_minute(i,car_order(i,w));
            current_charge_of_battery(i+1,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w));
            needed_charge(i,car_order(i,w))= desired_charge(1,car_order(i,w))-
current_charge_of_battery(i,car_order(i,w));
        end

        if (current_charge_of_battery(i,car_order(i,w)) > ((desired_charge(1,car_order(i,w)))
)*.98)
            actively_charging(i+1,car_order(i,w)) = 0;
        end

        recieved_rate = added_charge_per_minute*60;

        vv = sum(recieved_rate(i,:));
        forecast_with_pev(transformer,i) = forecast_without_pev(1,i) + vv;



        for jj = 1:n
        if priority_ratio(i,jj) == jj/1000000;
            priority_ratio(i,jj) = 0;
        end
        end
    end

  end

  actual_final_charge(transformer,:) = current_charge_of_battery(2880,:);
  desired_final_charge(transformer,:) = desired_charge(1,:);

  results1(:,:,transformer) = current_charge_of_battery;
  results2(:,:,transformer) = added_charge_per_minute*60;

    ca = sum(actively_charging,2);
    tta = find(ca>0);
    annn=0;
    for ii = 1:length((tta))
        annn = forecast_with_pev(transformer,tta(ii)) +annn;
    end
    annn = annn/length(tta);
    avg_point_during_charge(transformer-beginning_transformer+1,1) = annn;
```

```
end

carscharged = actual_final_charge./desired_final_charge;


for car = 1:9
for j = beginning_transformer:ending_transformer
if (carscharged(j,car) >= .895)
percentage_of_vehicles_charged(1,1) = percentage_of_vehicles_charged(1,1)+1;
elseif (carscharged(j,car)>=.795) && (carscharged(j,car)<.895)
percentage_of_vehicles_charged(2,1) = percentage_of_vehicles_charged(2,1)+1;
elseif (carscharged(j,car)>=.695) && (carscharged(j,car)<.795)
percentage_of_vehicles_charged(3,1) = percentage_of_vehicles_charged(3,1)+1;
elseif (carscharged(j,car)>=.595) && (carscharged(j,car)<.695)
percentage_of_vehicles_charged(4,1) = percentage_of_vehicles_charged(4,1)+1;
elseif (carscharged(j,car)>=.495) && (carscharged(j,car)<.595)
percentage_of_vehicles_charged(5,1) = percentage_of_vehicles_charged(5,1)+1;
elseif (carscharged(j,car)>=.395) && (carscharged(j,car)<.495)
percentage_of_vehicles_charged(6,1) = percentage_of_vehicles_charged(6,1)+1;
else
percentage_of_vehicles_charged(7,1) = percentage_of_vehicles_charged(7,1)+1;
end
end
end



if method < 1
figure(1)
vehicles_charged_greater_than_70c = categorical({'0-40','40-50','50-60','60-70','70-80','80-
90','90-100'});
percentage = [percentage_of_vehicles_charged(7,1) percentage_of_vehicles_charged(6,1)
percentage_of_vehicles_charged(5,1) percentage_of_vehicles_charged(4,1)
percentage_of_vehicles_charged(3,1) percentage_of_vehicles_charged(2,1)
percentage_of_vehicles_charged(1,1)];
bar(vehicles_charged_greater_than_70c,percentage)
title('Percentage of Each Car Charged Using Crisp Alogrithm ')
xlabel('Percent Level charged')
ylabel('Number of Cars')

figure(2)
plot(t,[day(1,:) day(1,:)],'r',t,transformer_limit(select,:),'b')
title(['Load on Transformer - ' num2str(select) ' Without PEV Charging'])
xlabel('Hours')
ylabel('kW')
xlim([12 36])
```

```
ylim([0 160])

figure(3)
plot(t,forecast_with_pev(select,:),'g',t,[day(1,:) day(1,:)],'r',t,transformer_limit(select,:),'b')
title(['Load on Transformer - ' num2str(select) ' With Uncontrolled Charging'])
xlabel('Hours')
ylabel('kW')
legend('Forecast with charging','Forecast w/o charging', 'Transformer Limit',
'location','southeastoutside')
xlim([12 36])
ylim([0 160])

figure(4)
for iter = 1:n
plot([1:2881],results1(:,iter,select))
hold on
end
title(['Each Vehicles Battery Level on Transformer - ' num2str(select) ' Using Crisp Algorithm'])
xlabel('Minutes')
ylabel('Battery Level (kWh)')
xlim([720 2160])
Legend=cell(n,1);
for iter1=1:n
Legend{iter1}=strcat('Car', num2str(iter1));
end
legend(Legend, 'location','southeastoutside')

figure(5)
for iter = 1:n
plot([1:2880],results2(:,iter,select))
hold on
end
title(['Each Vehicles Charging Rate on Transformer - ' num2str(select) ' Using Crisp Algorithm'])
xlabel('Minutes')
ylabel('Charge Rate (kW)')
xlim([720 2160])
Legend=cell(n,1);
for iter2=1:n
Legend{iter2}=strcat('Car', num2str(iter2));
end
legend(Legend, 'location','southeastoutside')

figure(6)
for i = 1:2255
   plot(t,forecast_with_pev(i,:),'g',t,[day(1,:) day(1,:)],'r')
   hold on
```

```
end
xlim([12 36])
ylim([0 160])
xlabel('Hours')
ylabel('kW')
title('Total Load from PEV Charging Using Crisp Charging Algorithm')
legend('Forecast with charging','Forecast w/o charging', 'location','southeastoutside')

else
transformer_limit= transformer_limit(1,1);
abolsute_max_with_pev = max(max(forecast_with_pev(:,720:2160),[],2));
average_max_with_pev = mean(max(forecast_with_pev(:,720:2160),[],2));
max_without_pev = max(forecast_without_pev(720:2160));
mean_without_pev = mean(forecast_without_pev(720:2160));
mean_mean_with_pev = mean(mean(forecast_with_pev(:,720:2160),2));
mean_percent_diff = 100*abs(mean_mean_with_pev-
mean_without_pev)/((mean_mean_with_pev+mean_without_pev)/2);
%average_max_during_charge = mean(max(forecast_with_pev(tta,:),[],2));
%abolsute_max_during_charge = max(max(forecast_with_pev(tta,:),[],2));
abosulte_mean_during_charge = mean(avg_point_during_charge);

if abolsute_max_with_pev > (max_without_pev  + .5)
   highest_peak_is_from = 'PEV Charging';
else
   highest_peak_is_from = 'Baseload';
end

baseload_above_75 = length(find(forecast_without_pev(1,720:2160) >75.1));

2 = zeros(2255,[]);
for j = 1:2255
   one = find(forecast_with_pev(j,720:2160)>75.1);
   two(j)= length(one);
end
load_above_75 = mean(two);

disp(['The transformer limit is = ', num2str(transformer_limit)])
disp(['The Highest peak power reached ed amongtst any transformer is = ',
num2str(abolsute_max_with_pev)])
disp(['The average highest peak point amongst all transformers is = ',
num2str(average_max_with_pev)])
disp(['The highest peak point from baseload is = ', num2str(max_without_pev)])
disp(['The highest peak is a result of ', highest_peak_is_from])
disp(['The average baseload is = ', num2str(mean_without_pev)])
disp(['When PEV’s are applied, the average load over the day is  = ',
num2str(mean_mean_with_pev)])
```

```
disp(['The percentage difference is = ', num2str(mean_percent_diff)])
disp(['The average load during charging is   = ', num2str(abosulte_mean_during_charge)])
disp(['The baseload exceeds the rated limit for = ', num2str(baseload_above_75)])
disp(['The average transformer exceeds the rated limit for = ', num2str(load_above_75)])

percentage_of_vehicles_charged

figure
for i = 1:2255
   plot(t,forecast_with_pev(i,:),'g',t,[day(1,:) day(1,:)],'r',t,75*ones(2880,1),'b')
   hold on
end
xlim([12 36])
ylim([0 160])
xlabel('Hours')
ylabel('kW')
title('Total Load from PEV Charging Using Crisp Charging Algorithm')
legend('Forecast with charging','Forecast w/o charging','Rated Limit',
'location','southeastoutside')
end
```

10.2 CVVF with Fuzzy Logic

```
clear
clc

load('FinalBaselines.mat')
choices = [FinalBaselineAug2514;FinalBaselineSep1614;FinalBaselineSep2514];

method = 2
selection =3;
day = choices(selection ,:);
select = 6;


percentage_of_vehicles_charged = zeros(7,1);
transformer_limit = zeros(2255,2880);
results1 = zeros(2881,9,2255);
results2 = zeros(2880,9,2255);
actual_final_charge = zeros(2255,9);
desired_final_charge = zeros(2255,9);

forecast_with_pev = zeros(2255,2880);
load y
y_organizer = zeros(20295,3);
```

```
for i = 1:20295
y_organizer(i,:) = y(i,2:4);
y_organizer(i,:) = ceil(y_organizer(i,:)*(2880/48));
if  y_organizer(i,1) == 0
y_organizer(i,1) = 1;
end
end

beginning_transformer = 1;
ending_transformer = 2255;

avg_point_during_charge = zeros((ending_transformer-beginning_transformer+1),1);

for transformer = beginning_transformer:ending_transformer
%   Initialize all parameters that will research for each transformer:
n = 9;
desired_charge = zeros(2880,n); %How much charge each vehicle is requesting
current_charge_of_battery = zeros(2880,n); %The current state of the battery of each car, at each minute
added_charge_per_minute = zeros(2880,n); %How much charge is added to the battery at each minute
needed_charge = zeros(2881,n); %How much charge does each vehicle need to reach desired at each minute
priority_ratio = zeros(2880,n); %Determines which car is in the most need of a high rate
car_order = zeros(2880,n); %The order of the cars based on priority ratio
plug_in_time = zeros(2880,n); %The time when vehicles plug into the transformer
dwell_time = zeros(2880,n); %How long the vehicle will be connected to the transformer
current_rate = zeros(2880,n); %The avaiable rates that can be given out
actively_charging= zeros(2880,n); %Determines which vehicles are plugged in during each minute

%   Imports the data for APEP, which is plug in time, dwell time,
%   requested SOC and current state of battery charge:

plug_in_time(1,:) = y_organizer((1+(transformer-1)*9:9+(transformer-1)*9),1)';
for lk = 1:9
if plug_in_time(1,lk) < 720
plug_in_time(1,lk) = 1440 + plug_in_time(1,lk);
end
if plug_in_time(1,lk) > 2160
plug_in_time(1,lk) = -1440 + plug_in_time(1,lk);
end
end
plug_in_time(2:2880,:) = repmat(plug_in_time(1,:),2879,1);

dwell_time(1,:) = y_organizer((1+(transformer-1)*9:9+(transformer-1)*9),3)';
```

```
dwell_time(2:2880,:) = repmat(dwell_time(1,:),2879,1);

plug_out_time = plug_in_time + dwell_time;

desired_charge(1,:) = y((1+(transformer-1)*9:9+(transformer-1)*9),5)';
desired_charge(2:2880,:) = repmat(desired_charge(1,:),2879,1);

%Assigning Initial States:
current_charge_of_battery(1,:)  = [ 0 0 0 0 0 0 0 0 0];
needed_charge(1,:)= desired_charge(1,:);


%%  This is section assigns what will be used as the limits
t = linspace(0,48,2880);
forecast_without_pev = [day day];

%   Option 1: Envelop Filter
%     [envHigh, envLow] = envelope(forecast_without_pev,100,'peak');
%     top_profile = envHigh;
%     limit_cap = 75;
%     top_profile(top_profile<=limit_cap)= limit_cap;
%     transformer_limit(transformer,:) = top_profile;
%

%       Option 2: Straight Line
%     running = [ 56.25 56.25 56.25 75 75 75 93.75 93.75 93.75 112.5 112.5 112.5 37.4260
83.9808 50.9069 43.0035 102.8940 59.2813 48.5810 121.8072 67.6557 54.1585 140.7204
76.0301 59.7360 159.6336 84.4045];

%     transformer_limit(transformer,:) = running(3*(loop-
1)+selection)*ones(1,length(forecast_without_pev));
transformer_limit(transformer,:) = 59.2813*ones(1,length(forecast_without_pev));
%
% %     %   Option 3: Edgar
%     load VF_Mod757.2.mat
%     PData= flip(Data);
%     transformer_limit(transformer,:)= [PData(transformer,:) PData(transformer,:)];

e = zeros(1,2880);
%%  This for loop executes the charging of the vehicle

for i = 1:2880
%   This section determines what cars are charging
if i == 1280
tshoot= 1;
end
```

```
for k = 1:n
if plug_in_time(i,k) == i
actively_charging(i,k) = 1;
end
if (i-plug_in_time(i,k)) > (dwell_time(i,k))
actively_charging(i,k) = 0;
end
if (current_charge_of_battery(i,k)) > (desired_charge(1,k))
actively_charging(i,k) = 0;
end
end


for jj = 1:n
if i == 1
priority_ratio(i,jj) = priority_ratio(i,jj);
end
if actively_charging(i,jj) == 1
priority_ratio(i,jj) = (needed_charge(i-1,jj))/(plug_in_time(i,jj)+dwell_time(i,jj)-(i-1));
end
if (actively_charging(i,jj) == 1) && (((current_charge_of_battery(i,jj) +
(7.2/60)*((plug_in_time(i,jj)+dwell_time(i,jj)-(i))) < needed_charge(i-1,jj))))
priority_ratio(i,jj) = 100;
end
if  actively_charging(i,jj) ~= 1
priority_ratio(i,jj) = jj/1000000;
end
end

[sorted_priority_ratio,I] = sort(priority_ratio(i,:), 'descend');
car_order(i,:) = I;

%%  This section assigns the values in the error membership function
v =0;

e(i) = round(transformer_limit(transformer,i)- forecast_without_pev((i)) - v,2);
if e(i) < 0
e(i) = 0;
end

for q = 1:sum( actively_charging(i,:))

if (( (e(i)<= 0 )))
mf1 = 4;
mf2 = 4;
```

```
certainty1 = 1;
certainty2 = 1;
end
if ((e(i)>0 && (e(i)<1.9)))
mf1 = 1;
mf2 = 4;
certainty1 = 1;
certainty2 = 0;
end
if ((e(i)>=1.9 && (e(i)<3.3)))
mf1 = 1;
mf2 = 2;
certainty1 =  -1/(3.8-1.9)*(e(i)-1.9)+1;
certainty2 = 1/(3.3-1.9)*(e(i)-1.9);
end
if ((e(i)>=3.3 && (e(i)<3.8)))
mf1 = 1;
mf2 = 2;
certainty1 =  -1/(3.8-1.9)*(e(i)-1.9)+1;
certainty2 = -1/(4.7-3.3)*(e(i)-4.7);
end
if ((e(i)>= 3.8) && (e(i)<4.7))
mf1 = 2;
mf2 = 3;
certainty1 = -1/(4.7-3.3)*(e(i)-4.7);
certainty2 = 1/(7.2-3.8)*(e(i)-3.8);
end
if ((e(i)>= 4.7) && (e(i)<7.2))
mf1 = 3;
mf2 = 3;
certainty1 = 1/(7.2-3.8)*(e(i)-3.8);
certainty2 = 0;
end
if e(i)>=7.2
mf1 = 3;
mf2 = 4;
certainty1 = 1;
certainty2 = 0;
end

% Below are the ratio membership function
if (priority_ratio(i,car_order(i,q))< .016)
mf3 = 1;
mf4 = 4;
certainty3 = 1;
certainty4 = 0;
```

```
end
if ((priority_ratio(i,car_order(i,q))>=.016 && (priority_ratio(i,car_order(i,q))<.033)))
mf3 = 1;
mf4 = 2;
certainty3 = -60*(priority_ratio(i,car_order(i,q))-.033);
certainty4 = 60*(priority_ratio(i,car_order(i,q))-.016);
end
if ((priority_ratio(i,car_order(i,q))>=.033 && (priority_ratio(i,car_order(i,q))<.05)))
mf3 = 2;
mf4 = 3;
certainty3 = 60*(priority_ratio(i,car_order(i,q))-.033);
certainty4 = -60*(priority_ratio(i,car_order(i,q))-.05);
end
if priority_ratio(i,car_order(i,q))>=.05
mf3 = 3;
mf4 = 4;
certainty3 = 1;
certainty4 = 0;
end

u1 = min(certainty1,certainty3);
u2 = min(certainty2,certainty3);
u3 = min(certainty1,certainty4);
u4 = min(certainty2,certainty4);
u = [u1 u2 u3 u4];
%% This section creates the inference table and the determines the output

X = zeros(3); %X is the inference table
X(1,1:4) = [1 2 3 0];
X(2,1:4) = [2 3 3 0];
X(3,1:4) = [2 3 3 0];
X(4,1:4) = [0 0 0 0];

output_mf = [ X(mf3, mf1) X(mf3, mf2) X(mf4, mf1) X(mf4, mf2)];
base_mf  = [ 0 0 0 0];
mid_mf  = [ 0 0 0 0];

for pp = 1:4
if output_mf(pp) == 0
base_mf(pp) = 0;
mid_mf(pp) = 0;
end

if output_mf(pp) == 1
base_mf(pp) = 3.8;
mid_mf(pp) = 1.9;
```

```
end

if output_mf(pp) == 2
base_mf(pp) = 2.8;
mid_mf(pp) = 3.3;
end

if output_mf(pp) == 3
base_mf(pp) = 6.8;
mid_mf(pp) = 7.2;
end
end

num = sum((u1*base_mf(1)*mid_mf(1)) + (u2*base_mf(2)*mid_mf(2)) +
(u3*base_mf(3)*mid_mf(3)) + (u4*base_mf(4)*mid_mf(4)));
dom = sum((u1*base_mf(1)) + (u2*base_mf(2)) + (u3*base_mf(3)) + (u4*base_mf(4)));
if dom == 0
output = 0;
else
output = num/dom;
end

if output > e(i)
output = e(i);
end

current_rate(i,q) = output;

v = sum(current_rate(i,:));

e(i) = round(transformer_limit(transformer,i)- forecast_without_pev((i)) - v,2);
if e(i) < 0
e(i) = 0;
end

end

%% This section charges each vehicle

for w = 1:n
if (i-plug_in_time(1,car_order(i,w)) > dwell_time(1,car_order(i,w)))
actively_charging(i,car_order(i,w)) = 0;
added_charge_per_minute(i,car_order(i,w)) = 0;
needed_charge(i,car_order(i,w)) = needed_charge(i,car_order(i,w));
current_charge_of_battery(i,car_order(i,w)) = current_charge_of_battery(i,car_order(i,w)) +
added_charge_per_minute(i,car_order(i,w));
```

```
current_charge_of_battery(i+1,car_order(i,w)) = current_charge_of_battery(i,car_order(i,w));
end

if actively_charging(i,car_order(i,w)) == 1
if needed_charge(i-1,car_order(i,w)) < current_rate(i,w)*(1/60)
current_rate(i,w)= (needed_charge(i-1,car_order(i,w))*60);
end

added_charge_per_minute(i,car_order(i,w)) = current_rate(i,w) *(1/60);
current_charge_of_battery(i,car_order(i,w))  = current_charge_of_battery(i,car_order(i,w)) +
added_charge_per_minute(i,car_order(i,w));
current_charge_of_battery(i+1,car_order(i,w)) = current_charge_of_battery(i,car_order(i,w));
if i < 2880
actively_charging(i+1,car_order(i,w)) = 1;
end
needed_charge(i,car_order(i,w)) = desired_charge(1,car_order(i,w))-
current_charge_of_battery(i,car_order(i,w));
end

%           if (actively_charging(i,car_order(i,w)) == 1) && ((current_charge_of_battery(i,w) +
(7.2/60)*((plug_in_time(i,w)+dwell_time(i,w)) - i)) < needed_charge(i,w))
%               added_charge_per_minute(i,car_order(i,w)) = 7.2 *(1/60);
%               current_charge_of_battery(i+1,car_order(i,w))  =
current_charge_of_battery(i,car_order(i,w)) + added_charge_per_minute(i,car_order(i,w));
%               current_charge_of_battery(i+1,car_order(i,w)) =
current_charge_of_battery(i,car_order(i,w));
%               actively_charging(i+1,car_order(i,w)) = 1;
%               needed_charge(i+1,car_order(i,w)) = desired_charge(1,car_order(i,w))-
current_charge_of_battery(i,car_order(i,w));
%           end

if  actively_charging(i,car_order(i,w)) == 0
added_charge_per_minute(i,car_order(i,w)) = 0;
current_charge_of_battery(i,car_order(i,w)) = current_charge_of_battery(i,car_order(i,w)) +
added_charge_per_minute(i,car_order(i,w));
current_charge_of_battery(i+1,car_order(i,w)) = current_charge_of_battery(i,car_order(i,w));
needed_charge(i,car_order(i,w))= desired_charge(1,car_order(i,w))-
current_charge_of_battery(i,car_order(i,w));
end

if (current_charge_of_battery(i,car_order(i,w)) > ((desired_charge(1,car_order(i,w))))*.98)
actively_charging(i+1,car_order(i,w)) = 0;
end

recieved_rate = added_charge_per_minute*60;
```

```
vv = sum(recieved_rate(i,:));
forecast_with_pev(transformer,i) = forecast_without_pev(1,i) + vv;



for jj = 1:n
if priority_ratio(i,jj) == jj/1000000;
priority_ratio(i,jj) = 0;
end
end
end

end

actual_final_charge(transformer,:) = current_charge_of_battery(2880,:);
desired_final_charge(transformer,:) = desired_charge(1,:);

results1(:,:,transformer) = current_charge_of_battery;
results2(:,:,transformer) = added_charge_per_minute*60;

ca = sum(actively_charging,2);
tta = find(ca>0);
annn=0;
for ii = 1:length((tta))
annn = forecast_with_pev(transformer,tta(ii)) +annn;
end
annn = annn/length(tta);
avg_point_during_charge(transformer-beginning_transformer+1,1) = annn;

end

carscharged = actual_final_charge./desired_final_charge;


for car = 1:9
for j = beginning_transformer:ending_transformer
if (carscharged(j,car) >= .895)
percentage_of_vehicles_charged(1,1) = percentage_of_vehicles_charged(1,1)+1;
elseif (carscharged(j,car)>=.795) && (carscharged(j,car)<.895)
percentage_of_vehicles_charged(2,1) = percentage_of_vehicles_charged(2,1)+1;
elseif (carscharged(j,car)>=.695) && (carscharged(j,car)<.795)
percentage_of_vehicles_charged(3,1) = percentage_of_vehicles_charged(3,1)+1;
elseif (carscharged(j,car)>=.595) && (carscharged(j,car)<.695)
percentage_of_vehicles_charged(4,1) = percentage_of_vehicles_charged(4,1)+1;
elseif (carscharged(j,car)>=.495) && (carscharged(j,car)<.595)
percentage_of_vehicles_charged(5,1) = percentage_of_vehicles_charged(5,1)+1;
```

```
elseif (carscharged(j,car)>=.395) && (carscharged(j,car)<.495)
percentage_of_vehicles_charged(6,1) = percentage_of_vehicles_charged(6,1)+1;
else
percentage_of_vehicles_charged(7,1) = percentage_of_vehicles_charged(7,1)+1;
end
end
end

if method < 1
figure
vehicles_charged_greater_than_70c = categorical({'0-40','40-50','50-60','60-70','70-80','80-
90','90-100'});
percentage = [percentage_of_vehicles_charged(7,1) percentage_of_vehicles_charged(6,1)
percentage_of_vehicles_charged(5,1) percentage_of_vehicles_charged(4,1)
percentage_of_vehicles_charged(3,1) percentage_of_vehicles_charged(2,1)
percentage_of_vehicles_charged(1,1)];
bar(vehicles_charged_greater_than_70c,percentage)
title('Percentage of Each Car Charged Using Fuzzy Algorithm ')
xlabel('Percent Level charged')
ylabel('Number of Cars')

figure
plot(t,[day(1,:) day(1,:)],'r',t,transformer_limit(select,:),'b')
title(['Load on Transformer - ' num2str(select) ' Without PEV Charging'])
xlabel('Hours')
ylabel('kW')
xlim([12 36])
ylim([0 160])

figure
plot(t,forecast_with_pev(select,:),'g',t,[day(1,:) day(1,:)],'r',t,transformer_limit(select,:),'b')
title(['Load on Transformer - ' num2str(select) ' With PEV Charging Using Fuzzy Algorithm'])
xlabel('Hours')
ylabel('kW')
legend('Forecast with charging','Forecast w/o charging', 'Transformer Limit',
'location','southeastoutside')
xlim([12 36])
ylim([0 160])

figure
for iter = 1:n
plot([1:2881],results1(:,iter,select))
hold on
end
title(['Each Vehicles Battery Level on Transformer - ' num2str(select) ' Using Fuzzy Algorithm'])
xlabel('Minutes')
```

```
ylabel('Battery Level (kWh)')
xlim([720 2160])
Legend=cell(n,1);
for iter1=1:n
Legend{iter1}=strcat('Car', num2str(iter1));
end
legend(Legend, 'location','southeastoutside')

figure
for iter = 1:n
plot([1:2880],results2(:,iter,select))
hold on
end
title(['Each Vehicles Charging Rate on Transformer - ' num2str(select) ' Using Fuzzy
Algorithm'])
xlabel('Minutes')
ylabel('Charge Rate (kW)')
xlim([720 2160])
Legend=cell(n,1);
for iter2=1:n
Legend{iter2}=strcat('Car', num2str(iter2));
end
legend(Legend, 'location','southeastoutside')


figure
for i = 1:2255
plot(t,forecast_with_pev(i,:),'g',t,[day(1,:) day(1,:)],'r')
hold on
end
title('Total Load from PEV Charging Using Fuzzy Algorithm')
xlabel('Hours')
ylabel('kW')
legend('Forecast with charging','Forecast w/o charging', 'location','southeastoutside')
xlim([12 36])
ylim([0 160])

else

transformer_limit= transformer_limit(1,1);
abolsute_max_with_pev = max(max(forecast_with_pev(:,720:2160),[],2));
average_max_with_pev = mean(max(forecast_with_pev(:,720:2160),[],2));
max_without_pev = max(forecast_without_pev(720:2160));
mean_without_pev = mean(forecast_without_pev(720:2160));
mean_mean_with_pev = mean(mean(forecast_with_pev(:,720:2160),2));
```

```
mean_percent_diff = 100*abs(mean_mean_with_pev-
mean_without_pev)/((mean_mean_with_pev+mean_without_pev)/2);
%average_max_during_charge = mean(max(forecast_with_pev(tta,:),[],2));
%abolsute_max_during_charge = max(max(forecast_with_pev(tta,:),[],2));
abosulte_mean_during_charge = mean(avg_point_during_charge);

if abolsute_max_with_pev > (max_without_pev  + .5)
highest_peak_is_from = 'PEV Charging';
else
highest_peak_is_from = 'Baseload';
end

baseload_above_75 = length(find(forecast_without_pev(1,720:2160) >75.1));

two = zeros(2255,[]);
for j = 1:2255
one = find(forecast_with_pev(j,720:2160)>75.1);
two(j)= length(one);
end
load_above_75 = mean(two);

disp(['The transformer limit is = ',  num2str(transformer_limit)])
disp(['The Highest peak power reached ed amongtst any transformer is = ',
num2str(abolsute_max_with_pev)])
disp(['The average highest peak point amongst all transformers is = ',
num2str(average_max_with_pev)])
disp(['The highest peak point from baseload is = ', num2str(max_without_pev)])
disp(['The highest peak is a result of ', highest_peak_is_from])
disp(['The average baseload is = ', num2str(mean_without_pev)])
disp(['When PEV’s are applied, the average load over the day is  = ',
num2str(mean_mean_with_pev)])
disp(['The percentage difference is = ', num2str(mean_percent_diff)])
disp(['The average load during charging is   = ', num2str(abosulte_mean_during_charge)])
disp(['The baseload exceeds the rated limit for = ', num2str(baseload_above_75)])
disp(['The average transformer exceeds the rated limit for = ', num2str(load_above_75)])


percentage_of_vehicles_charged


figure
for i = 1:2255
plot(t,forecast_with_pev(i,:),'g',t,[day(1,:) day(1,:)],'r',t,75*ones(2880,1),'b')
hold on
end
xlim([12 36])
```

```
ylim([0 160])
xlabel('Hours')
ylabel('kW')
title('Total Load from PEV Charging Using Fuzzy Charging Algorithm')
legend('Forecast with charging','Forecast w/o charging','Rated Limit',
'location','southeastoutside')
end
```