Intelligent controller based on pattern recognition

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Abstract

Due to the increase in the number of household electrical appliances, electricity consumption accordingly increases. Therefore, there must be a reasonable way to reduce electricity consumption to minimize electrical problems that occur during high demand periods on the grid without compromising user's comfort. The basic aim of this project is to design a real-time controller to organize electricity consuming in households. This controller gets its feedback from an artificial neural network (ANN) that classify devices according to their profiles. This research will reduce the number of sensors to single current sensor attached to the main electrical unit and appliances can be categorized accordingly. The ANN gives very accurate results to recognize appliances that have different current consumption pattern .

الملخص

تعد الكهرباء عنصر اساسي ومقوم من مقومات الحياه التي لا يمكن الاستغناء عنها ، ففي الاعمال البيتيه والمستشفيات والمصانع والشركات جل الاعتماد على الطاقه الكهربائيه. انقطاع التيار الكهربائي نتيجة لزيادة الطاقه الاستهلاكيه للاحمال الذي يولد ضغط شديد على الشبكه مما يعرض الكهرباء للانقطاع ،يسبب ذلك من تقليل مستوى تطور الحياة الاجتماعية كما يسبب انزعاج مستخدمي الكهرباء. علاوة على انقطاع الكهرباء المتكرر في فلسطين بسبب محدودية حصتها من الكهرباء كذلك تواجه فلسطين المزيد من التحديات المفروضه من قبل سلطات الاحتلال. يمكن حل مشكلة انقطاع الكهرباء المتكرر بسبب زيادة الاحمال، عن طريق ترشيد وادارة استهلاك الطاقه الكهربائيه في القطاعات السكنية والتجارية وغيرها من القطاعات.من هنا ولدت الحاجه لوجود متحكم ذكي يقوم بتنظيم عمل الاجهزه الكهربائيه على مستوى كل منزل في القطاع السكني في وقت الذروه ، ووظيفته الاساسيه تجنب تشغيل جميع الاجهزه الكهربائيه معا في وقت واحد خاصه في ساعات الذروه فيقوم بنقل عمل ما يمكن الاستغناء عنه من الاحمال وتشغيله اثناء الوقت الذي لا يكون فيه استهلاك عالي للكهرباء. شرط عمل هذه المتحكمات هو المحافظه التامه على عدم مساس راحة المستخدمين. ونظرا لان مثل هذه المتحكمات تحتاج الى مجسات للاستعلام عن حالة كل جهاز منزلي، ونظرا للتكلفة العالية لمثل هذه المجسات . لهذا تم خفض تكلفة هذه المتحكمات ليتمكن الجميع من استعماله فعوضاً عن استعمال مجس لكل جهاز في المنزل لتحديد الاجهزه الكهربائيه الشغاله والتحكم بها تم استخدام خوارزمية neural network pattern recognition للتعرف على حالة الاجهزه الحالية من خلال مجس واحد فقط يتم ربطه على اللوحة الرئيسية للمنزل.

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Chapter1

1 Introduction

1.1 Introduction

Energy has been recognized as important factors for economic, sustainable, and social development and improving quality of life[1]. It constitutes a major threat to the environment and sustainable development of countries worldwide. Therefore, energy must be maintained even for irresponsible consumption.

There are many reasons for the increased consumption in electricity; mainly due to high growth of population and thus the demands increase rapidly. For example in our case study in Palestine, the consumption of electricity increased at an annual average rate of 6.4% between 1999 and 2005[1] . In addition to the high population growth in Palestine, there are many issues in this sector that are exclusive for Palestine such as the limitation imposed by the Israeli occupation and the monopoly role it provokes. In addition, the country does not have sufficient distribution system a problem that leads to constraints on electricity efficiency[2] .

Currently, electricity is used every minute of every day, therefore, the demand for electricity in the residential sector is very large and constitute about one-third of total electricity consumption in most countries. These reasons are enough to work toward a more permanent solutions or intelligent system of energy distribution in residential sector. Electricity in some areas of the country is unavailable or interrupted for certain periods during day. As a result, demand-side management through controlling the operation of some electric home appliances is a reasonable short-term solution for redistribution the electric consumption. This can be achieved by designing a suitable intelligent demand-side management controller that can deal relatively with all type of electricity usage. However, to implement such controllers there is a need for identifying which electric load is in operation in real time. Though, the houses need to be prepared by a suitable indoor electrical distribution grid and communication between the electric loads' statuses and the controller. For example, one of the popular systems used for this purpose is the costly because its based on communication protocol for building application (KNX/EIB) systems. One part of KNX system structure is the sensor provided for each electrical load.

This research aims to achieve a maximum efficiency of electricity usage at certain power capacity with sensible cost and at the same time preserving the comfort level for end-users. This study aspires to create a low-cost system that can identify names of appliances contributing in total current consumption in real time depending on a single current sensor attached to the main house electrical distribution unit. It depends on intelligent recognition through machine learning technique which is an input for demand-side management controller.

1.2 Problem definition

Generally, the income, age, and behavior of an individual as well as the physical characteristics of the environment affect the total energy consumed at a certain location. Inefficient electricity consumption caused by the use of improper domestic electrical appliances that lead to increased power needed especially during peak hours. The peak hour demand creates many problems including reduction in power grid efficiency and intermittent supply, which depletes the capacity of power stations to meet the demand and causes various technical and economic challenges to the electricity providers.

Particularly in Palestine, electricity faces many problems; the first is the constraints imposed by Israel policies and actions on the ability of the Palestinian authority to operate and develop its own energy system. Secondly, the high cost of electricity due to the high prices imposed by the Israel electric corporation. Finally, the inefficient use of electricity. Therefore, it is necessary to manage the residential sector consumption to improve the overall energy efficiency and reduce peak hour demand. This can be achieved by using techniques for managing energy consumption using more energy efficient home appliances and behavioral changes in daily lifestyles.

1.3 Recognition of need

According to aforementioned, this project will implement a system in order to control the electrical current consumption while maintain a comfortable condition for individuals in order to increase the efficiency and reduce demand. This system must be able to cope with all possible scenarios. The research hopes to develop a system to recognize electrical appliances through single current sensor attached to main electrical unit. Pattern recognition and the output from this algorithm are used as input for Stateflow controller.

1.4 Project aim and methodology

The main aim of this project is to improve the energy efficiency in homes without compromising comfort. This can be achieved by using smart techniques for managing energy consumption with using more energy efficient home appliances and behavioral changes in daily life in order to reduce peaks hour demand. Intelligent techniques control is introduced here for that purpose. This work is to develop a low-cost system to determine names to appliances contributing to each of the total currents in real-time with a single current sensor. This system will be able to provide very accurate recognition of appliances in real-time based on one current sensor attached to the main electrical unit. To this end, machine-learning techniques are required to adopt and understand the unpredictable consumption pattern using the Artificial Neural Network for pattern recognition and for the controller using logic-based Stateflow control. A logical system imitates human thinking. The importance of this project can be summarized in the following bullet points:

1. Measuring the current pattern consumption for the whole house using single current sensor. This sensor provided a sample of appliances using data loggers, which measure the current with sampling frequency one-value per second.

2. Design controller to manage load shifting from peak hour to off-peak hour.

3. Building a prototype for the purpose of control of power pattern consumption for homes.

Project aims: To make load shifting from peak hour to off-peak hour, and classify electric load by using single current sensor.

Conceptual design

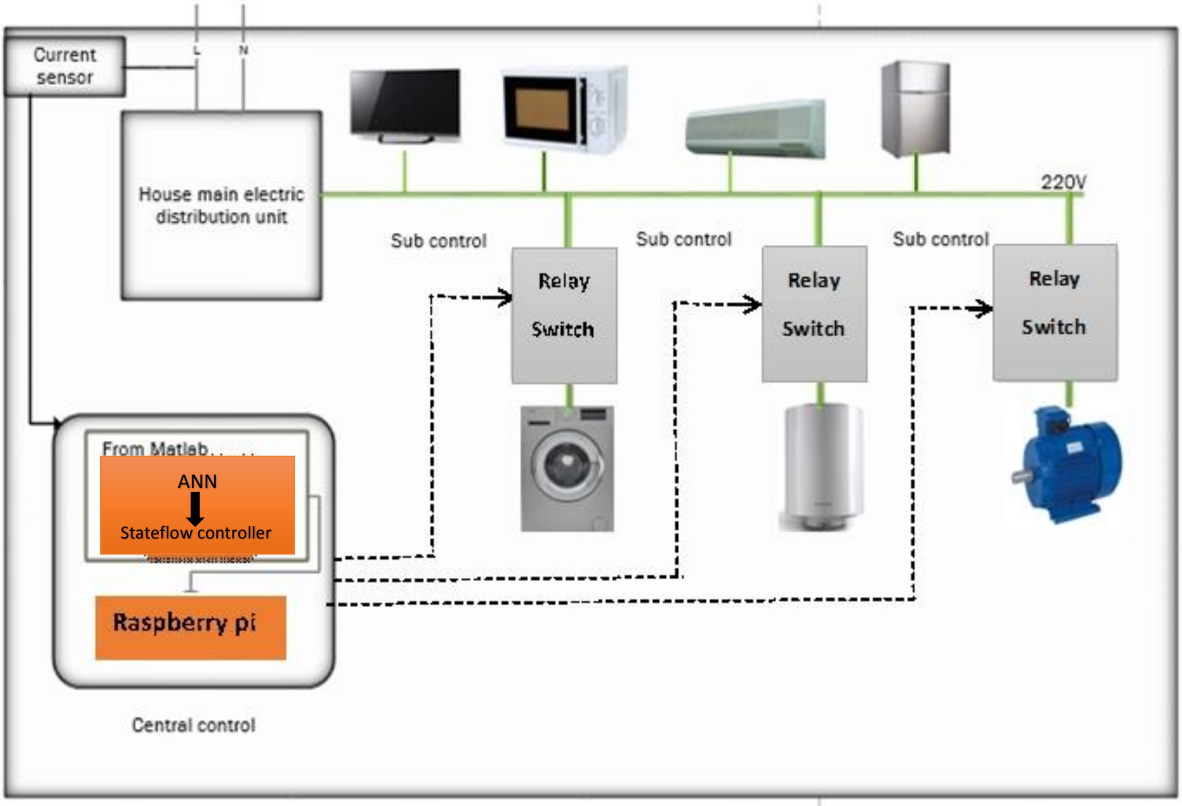


Figure 1-1:Conceptual Design

The figure (1-1) shows an example of a simple home receiving electricity from the main grid with various electrical appliances (TV, boiler, microwave, refrigerator, water pump, washing machine and air conditioner). The project will focus on controlling certain appliances mainly washing machine, boiler, and water pump. The use of such appliances is shifted to off-peak hour without affecting user comfortable condition. To receive current consumption information in real-time, a current sensor is used and clipped around the live wire of the main electrical unit. This data used to train Neural Network Pattern recognition(NNPR) to recognize and understand appliances activity. Numerous measurements were taken and a database of appliances consumption profile is then created. The real time data measurement will allow the system to recognize when an appliance is active or not and then record this information for later use. The output of NNPR is used as an input for a Stateflow controller. The advantage of this system is that it learns human behavior without influencing it.

1.5 Related work

ViridiScope, Kim et Al. [3] used indirect sensing to evaluate the power consumption of home appliances. Ambient signals placed near appliances estimate power consumption by measuring sound and magnetic field variations when appliances are on or off.

Farinaccio [4] implemented a pattern recognition approach to distribute the electricity consumption in a house into end-uses. This work doesn’t need profiling or addressing the appliances instead it only assumes constant appliance signature which is variable according to the house load and the way it is plugged in. this technique by solutions wires so it is need for a new structures.

Patel [5] implement similar method by detecting the electrical noise on house power lines using the disrupt switching of the appliances where noise is evident when an appliance is running. This approach depends on the fact that abruptly switching electrical loads produce broad-band electrical noise either continues or transit. The application of this phase collect and record noise signals in the states on/off and previous cases of variable power drown by some devices regarding this approach.

Zufferey [6] used a system able to recognize home appliances based on single current sensor attached on the main electrical panel using PCA & K-NN algorithms which are not very accurate.

Ruzzelli [7] research presents an intelligent system for recognition of electrical appliances activity in real-time by implementing Neural Network Technique to recognize the appliances. However, this system is applicable to resistive loads only.

This research will provide an intelligent system to monitor the electrical appliances in real-time. The demand side management controller is based on neural network to recognize appliances from single current sensor attached on the live wire on main electrical panel. This system can deal with all types of loads (resistive, inductive, and capacitive). The output from NNPR is then used as an input for the Stateflow controller. The controller will be able to shift the operating of home appliances, based on Stateflow rules and other conditions.

1.6 Conclusion of the chapter

Electricity sector suffer from many problems that require urgent solutions. the need for an intelligent system to provide and rationalize electricity consumption at a reasonable cost is therefore a logical step forward. The main aim of this project is to create an intelligent controller to shift electrical loads from peak hours to off-peak hours while keeping the same level of comfort for the user.

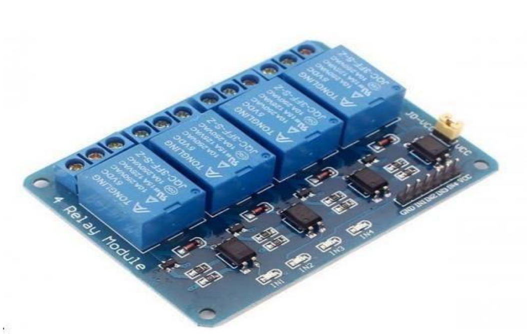
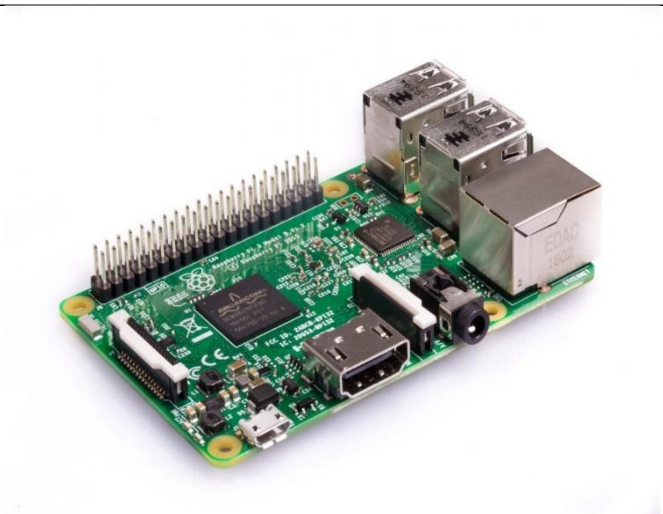
1.7 Time Table

Table 1-1:Time table

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selection Of project idea																
Collecting of the data																
Conceptual design																
Implement neural network																
Week	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Implement the controller																
Build prototype																
Write documentation																

1.8 Cost table:

Table 1.1-2:Cost Table

	Name	Picture	Details	Price
1	Switch: four slots		Switch On /Off	4x3= 12
2	Relays: two slots		4 Channel 5V Relay Module 10A	2x45= 90
3	Raspberry pi 3: one slot		Memory: 1GB Connectivity: 1)4 × USB 2.0 ports 2) 2.4 GHz and 5 GHz 802.11.b/g/n/ac wireless Access: Extended 40-pin Input power: 5 V/2.5 A DC via micro USB connector	1x250 =250
4	Leds: 8 slots		Power:12v/2A	8x8= 64
5	Current sensor			1x65= 65
6	Total price			481

Chapter2

2 Measurement

2.1 Introduction

The increasing in population and lifestyle standards present a pressing issue to the governments to meet that demand especially in the residential sector which is one of the largest sector for electricity consumption [8]. In Palestine as mentioned above, the Israeli occupation contribute to the problem and hinder the energy development in Palestine. Through demand side management research, such as this project, the supply shortage can be avoided without the need for power stations. This is done simply by shifting some loads from peak time to off-peak time in an automated control system. Through this process, the energy imported from Israel will also be significantly lower. Intelligent control systems approach uses Stateflow controller in order to find the optimal time to operate certain appliances. The use of cost effective system components will reduce the cost of implementation of these system for users. For example, the use of pattern recognition based on neural network requires a single current sensor to recognize total current consumption to determine appliances status instead of expensive KNX systems.

2.2 Measurement tools

This section explains how to take measurements, tools and software used for this purpose. The current consumption pattern will be studied and analyzed of single house.

- Current sensor:
  CTV-C HOBO current sensor was used to measure current (0-50A) which used with HOBO U12 data logger device to sense the current every second. Accuracy of these devices is about ±4.5% at full scale (includes logger `accuracy) [9].

Figure 2-1:Current Sensor

- **Data Logger:**

A data logger was used to record and analyze the obtained current data over time. It uses digital processor and battery powered.

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Figure 2-2:Data Logger

HOBO U12 (channel logger with 12-bit resolution) Data Logger was used here and it operates in an indoor environment and can record up to 43,000 measurements or events. The logger uses a direct USB interface for fast data exchange which was record every 1 second to obtain high resolution.

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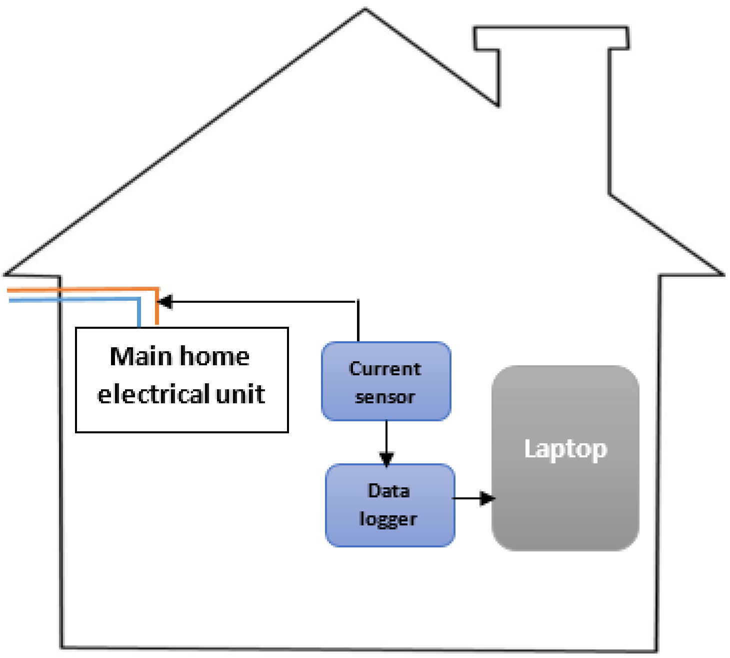


Figure 2-3:Home Measurements Process

The figure (2-3) shows simple diagram illustrates the process of taking measurements.

2.3 Software’s

In this project three-computer software ware used to collect and analyze data.

- HOBOWARE Software:

HOBOWARE Software is Used for launching, reading and plotting data collected from data logger. This software can set defined parameters such as sample interval and start type (immediate, delayed, interval or triggered) and synchronize logger clocks to computer clock. It can display real-time sensor reading and can easily convert data format to excel.

Figure 2-4:HOBO ware Software

- Microsoft Excel program:

A software program produced by Microsoft that allows users to organize, format and calculate data; in this case it used to store the obtained data from HOBO ware.

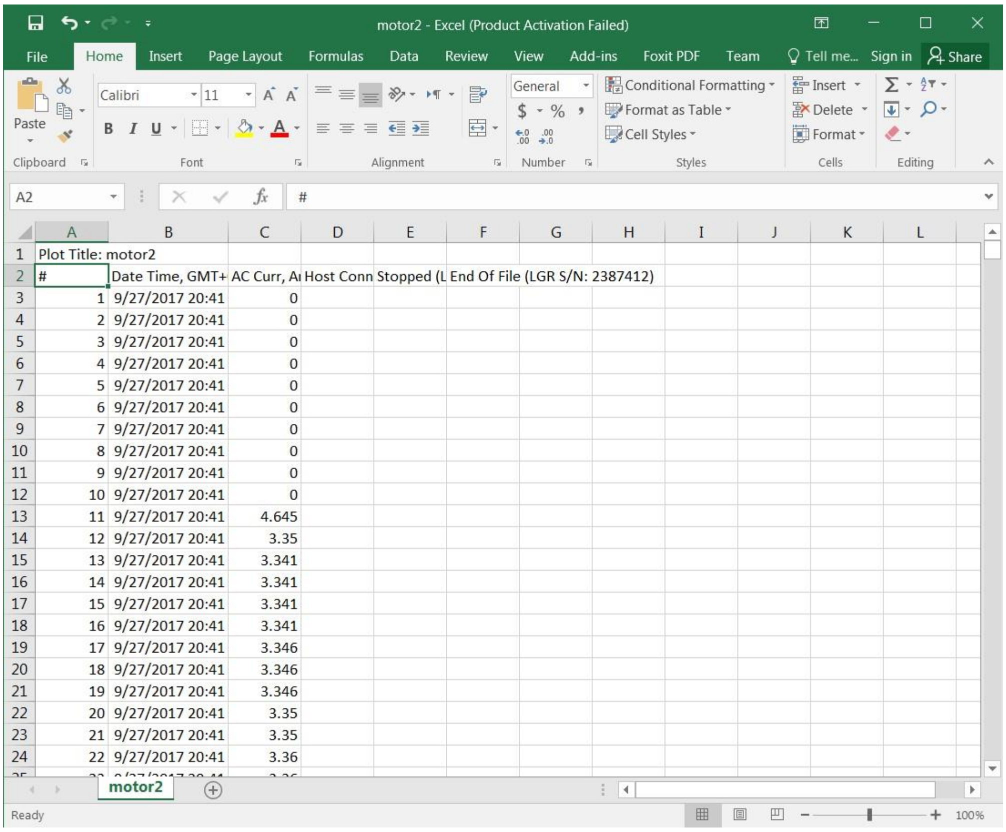


Figure 2-5:Excel Software

Matlab Software:

Matlab is a high-performance language software for fast technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include [9]:

1. Math and computation
2. Algorithm development
3. Modeling, simulation, and prototyping
4. Data analysis, exploration, and visualization
5. Scientific and engineering graphics
6. Application development, including Graphical User Interface building.

An important tool in Matlab is Simulink which contains sim-power library that used to build the model for verification as well as building Stateflow controller. Another important tool is Matlab Application Program Interface (API) which is useful to implement neural network pattern recognition.

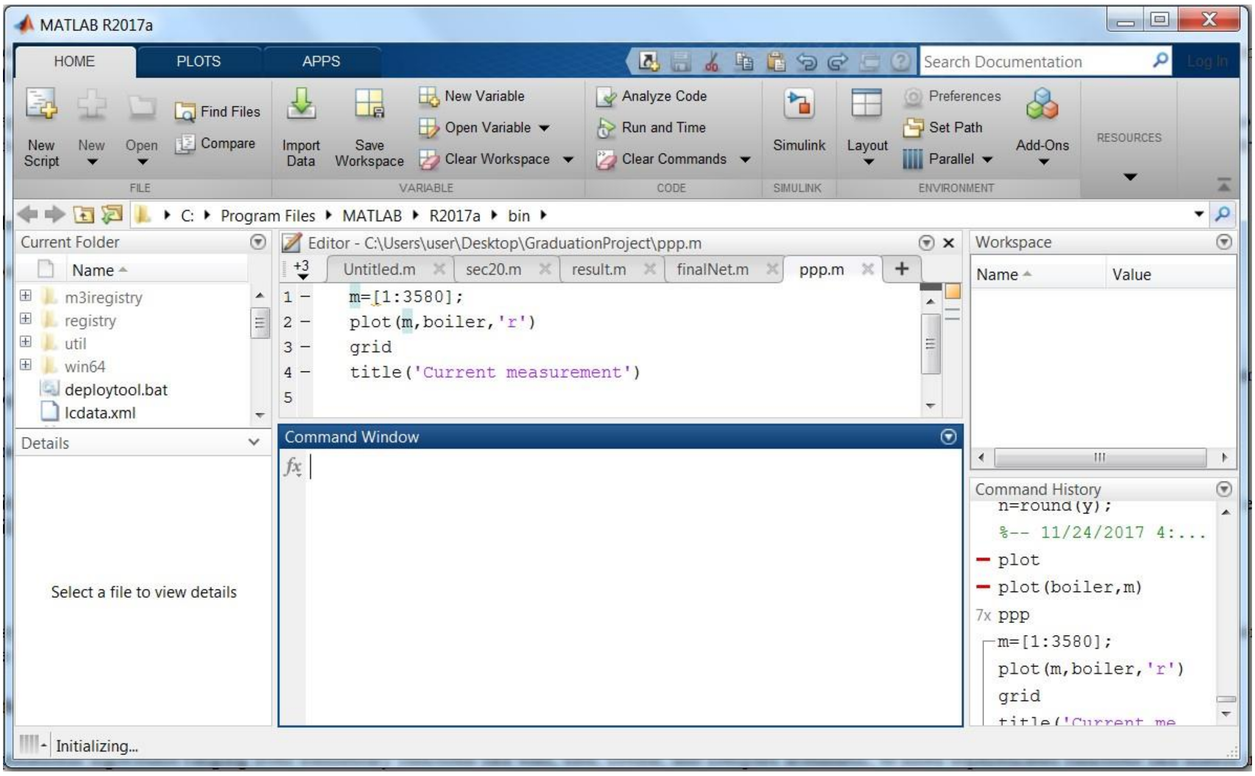


Figure 2-6:Matlab Software

2.4 Patterns

This section will discuss the current consumption patterns for controllable appliances. The measurements taken for a 24-hour in a given house will be shown for a further analysis in term of how each appliance effect total current consumption. The selected house for this study is located in Yatta, a village in the south of Hebron, which faces electricity problems and high population growth. The surface area of the house is 170 m and its physical locations is shown in the figure

(2-7).

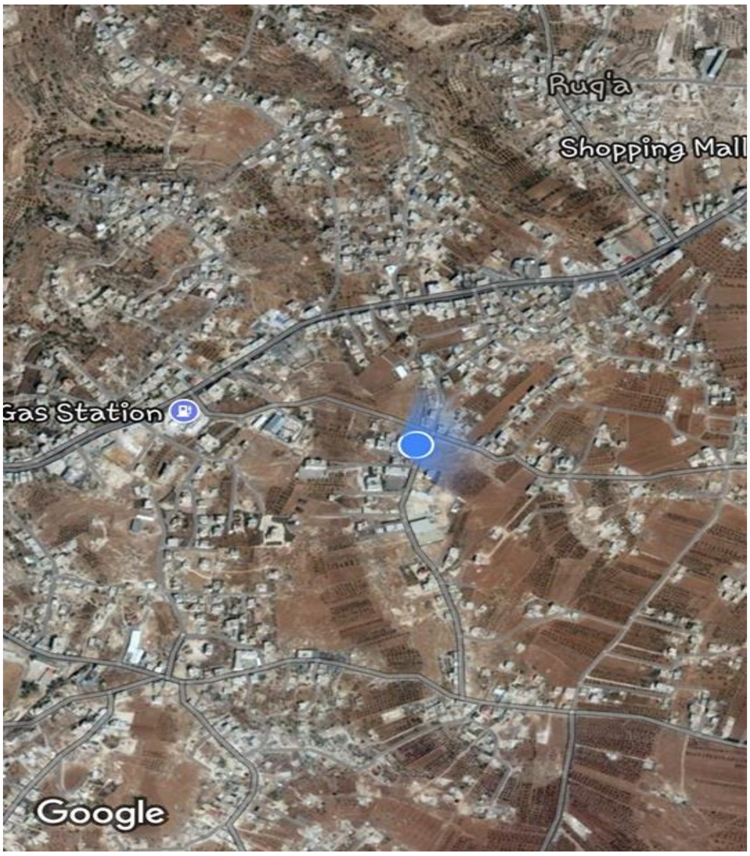
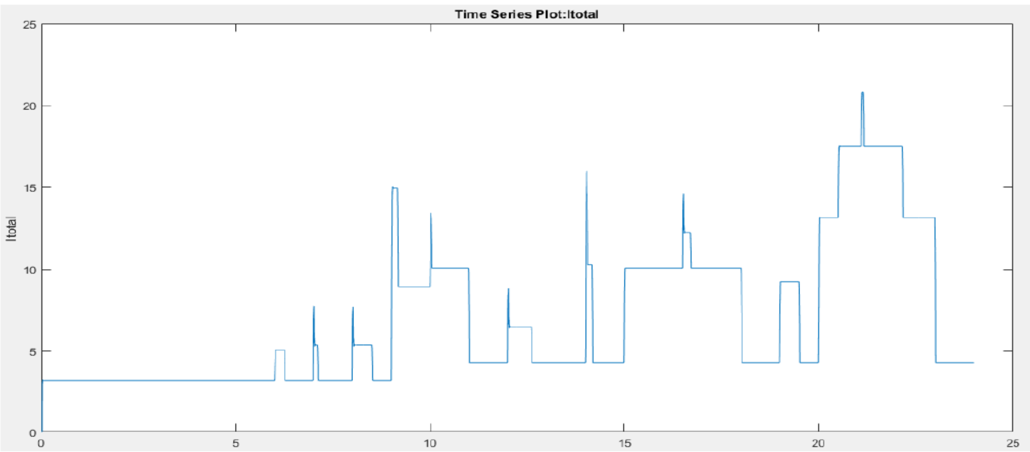


Figure 2-7:Home Location



The figure (2.7) shows the current measurements at house mainly displaying the total consumption pattern of running household appliances throughout the day. The house contains many appliances that can be summarized in the following table:

Table 2-1:Appliances type

Resistive loads	Inductive loads	Capacitive loads
Boiler (2800w)	Washing machine (2100w)	TV (125W)
Heater (2000w)	Water Pump (1200w)	-
Hair dryer (2000w)	Fridge (800w)	-
Others: mobile chargers, iron (2200w)	Microwave (1450w)	-

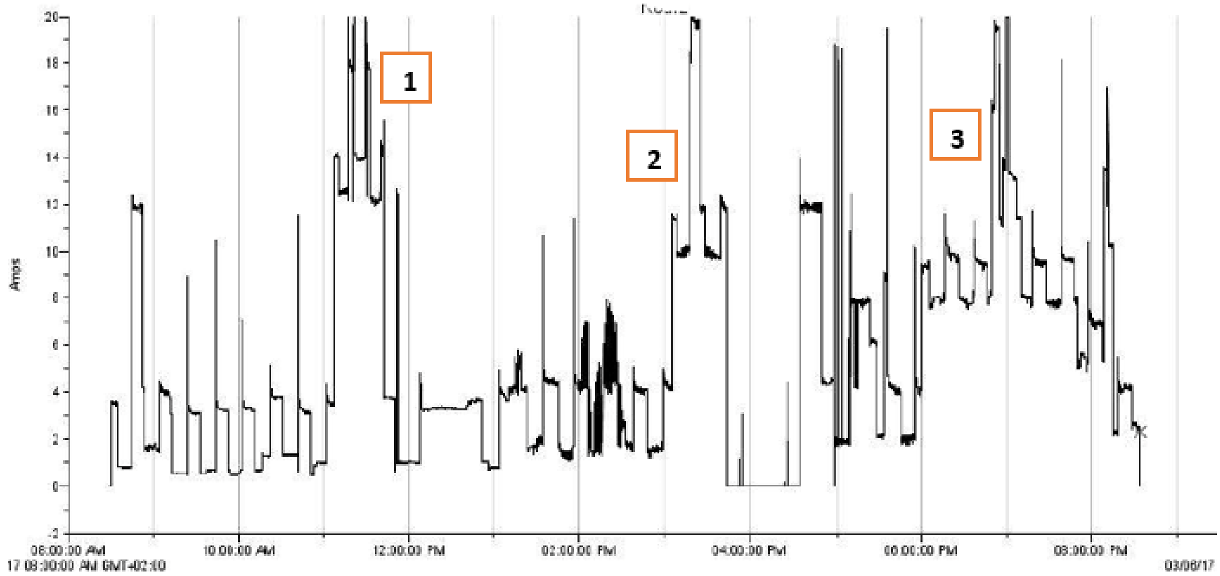


Figure 2-8:Current measurement about 24 hours

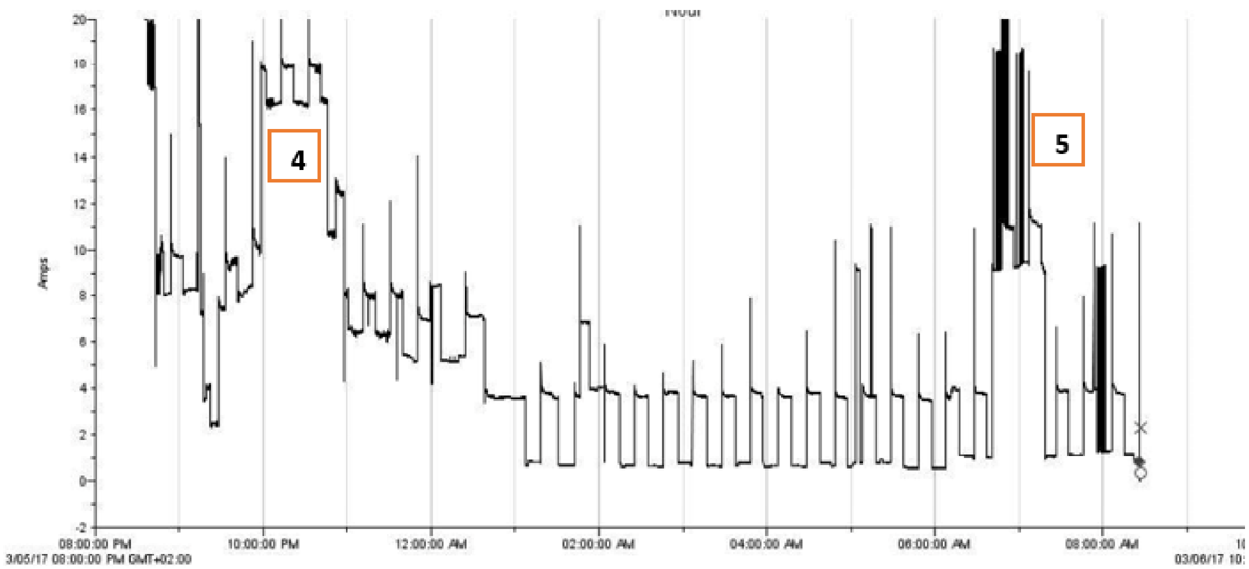


Figure 2-9:Current measurement about 24 hours

Table 2-2:The operation hours of home appliances during a day

Boiler	Pump	Micro-Wave	Vacuum Cleaner	Washing Machine	Heater	Fridge	Iron	TV	Others
9-11 AM	20-23 PM	10-10:03 AM	9-9:10 AM	20:30-22:15 PM	20-23 PM	All day	19-19:30 PM	10AM-23:59 PM	6-6:25 AM
15-18 PM		14-14:04 PM	2-2:10 PM		--				7-7:10 AM
									8-8:30 AM

These measurements show that the behavior of using the electricity make peaks in a pattern at different times in every day (as shown in points 1-5) and this is normal for home consumption. These peaks affect efficiency and reduces the ability of power station to meet demand, thus the electricity company will be forced to build new energy stations. This research try to help mitigate this issue by developing an intelligent controller to achieve the maximum efficiency of electricity at a given capacity. However, the challenge here is to find the optimal schedule for shifting some of the appliances to off-peak hours. For this purpose, the Stateflow controller was the optimal choice.

The current consumption pattern will be displayed for selected appliances to be shifted to off peak hours

Boiler:

A heat transfer process to heat water with the help of an energy source and the final results is comfortable water to the user. Boilers do not provide a continuous hot water but rather water is heated based on demand. Hot water temperature varies with the consumption and flow rate. Figure (2-10) below shows the current behavior for 2800-watt boiler.

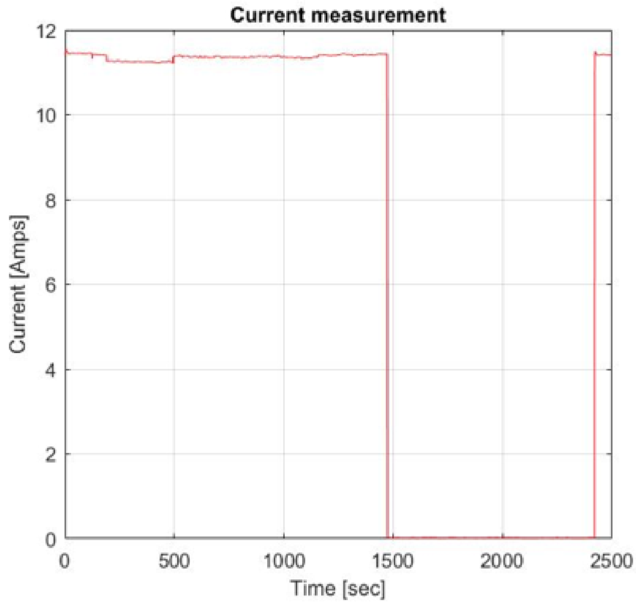


Figure 2-10:Boiler measurement current

Washing machine:

In an automated machine, there are three cycle included in the process which are:

- Washing: It has a heating element to heat the water which is an essential step in cleaning. Running the machine at different water temperatures provide efficient cleaning; however, higher temperature for washing means more energy consumption.
- Rinsing: The washing machine performs several rinses cycles after the main wash to remove most of the detergent.
- Spinning: Higher spin speeds to remove water from clothes for faster drying.

The figure (2-11) shows the current behavior for 2100 watt washing machine pattern.

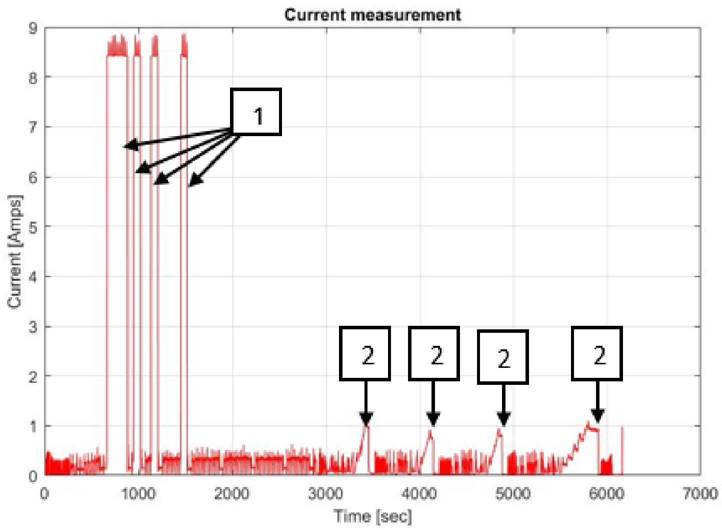


Figure 2-11:Pattern of washing machine

Water pump:

This widely used in Palestine. It pumps the water from common wells to main water tanks. Figure(2-12) below shows the current behavior for 1200 watt boiler pattern.

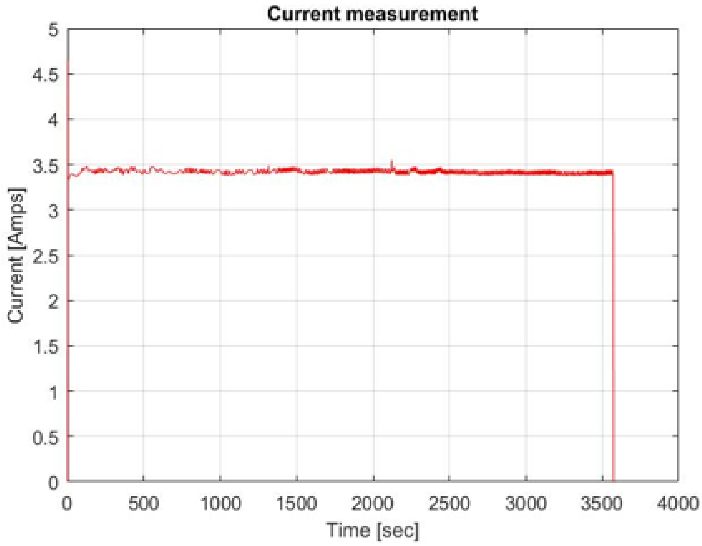


Figure 2-12:current pattern of water pump

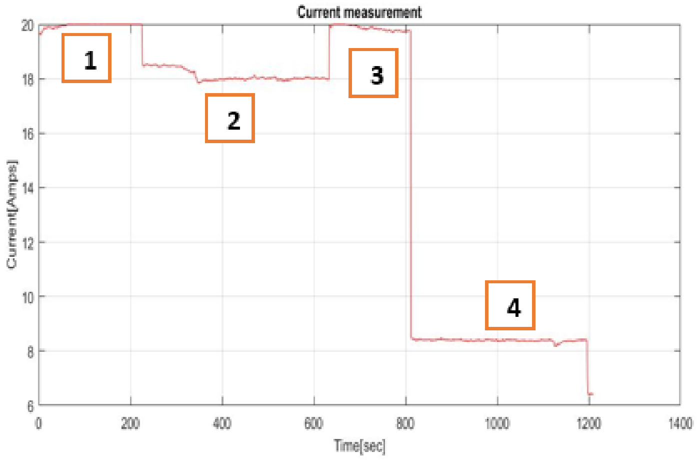


Figure 2-13:Pattern of multiple loads

As shown in figure (2-13), point 1 and 3 show the appliances (boiler, motor, and refrigerator) running at the time interval. At point 2 the refrigerator was turned off while at point 4 it was turned on again and the boiler was turned off.

2.5 Conclusion of the chapter

Devices such as boiler, washing machines, iron draw high current and consume more energy. By shifting the running time of these appliances to off-peak hour will reduce the pressure experienced by the grid during peak hours. By shifting these appliances to different time will not noticeably affect the comfort of users.

Chapter3

3 Neural network

3.1 What is neural network

Natural network can be defined as a way of thinking based on a human brain. The brain consists of a densely interconnected group of basic information processing units, called neurons. It incorporates nearly 10 billion neurons and 60 trillion connections, and synapses (Shepherd and Koch, 1990). The brain can perform its operations faster than the fastest computers of today. Data transfer from neurons by using connections between neurons; those leading to the 'right answer' are strengthened while the ones leading to the 'wrong answer' weaken. Therefore, the neural networks have the ability to learn from experience.

Nowadays, artificial neural network (ANN) is similar to human brain. It consists of a number of very simple and highly interconnected processors also called neurons; the neurons are connected by weighted links that passing signals from one neurons to another. ANNs are capable of learning; they use the experience to improve their performance when sufficient samples are taken. ANNs results can be generalized to cases they have not previously encountered. Artificial neural networks can be used to recognize hand-written characters, and identify human faces.

3.2 How does an artificial neural network learn?

The neurons are connected by links that have a numerical weight associated with it. They express the strength of each neuron input. A neural network learns through repeated adjustments of these weights. As shown in figure (3-1) below, ANN is made up of a hierarchy of layers in which the neurons in the networks are arranged. Input and output layers are connected to the external environment. The weights are modified to bring the network input/output behavior into line with that of the environment.

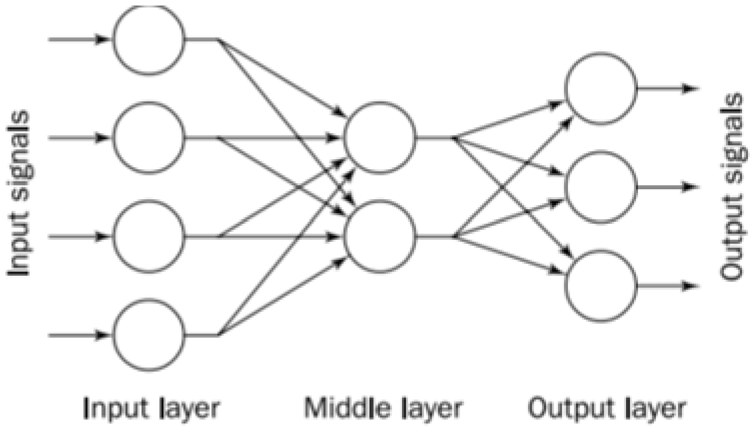


Figure 3-1:Feed forward network

Each neuron is an elementary information-processing unit. It has a means of computing its activation level given the inputs and numerical weights. To build an artificial neural network, the first step is to decide how many neurons are to be used and how the neurons are to be connected to form a network. Then, we decide which learning algorithm to use. And final, we train the neural network. That is, we initialize the weights of the network and update the weights from a set of training examples.

3.3 Multilayer neural networks

A multilayer is a feedforward neural network with one or more hidden layers. Typically, the network consists of an input layer of source neurons, with at least one middle or hidden layer of computational neurons, and an output layer of computational neurons. The input signals are propagated in a forward direction on a layer-by-layer basis.

Each layer in a multilayer neural network has its own specific function. The input layer accepts input signals from the outside world and redistributes these signals to all neurons in the hidden layer. Actually, the input layer rarely includes computing neurons, and thus does not process input patterns. The output layer accepts output signals. In other words, a stimulus pattern, from the hidden layer establishes the output pattern of the entire network. Neurons in the hidden layer detect the features; the weights of the neurons represent the features hidden in the input patterns. These features are then used by the output layer in determining the output pattern. With one hidden layer, we can represent any continuous function of the input signals, and with two hidden layers even discontinuous functions can be represented. Each layer in a neural network has its own specific function. The input layer accepts.

Input signals from the outside world redistribute these signals to all neurons in the hidden layer. Actually, the input layer rarely includes computing neurons, and thus does not process input patterns. The output layer accepts output signals from the hidden layer and establishes the output pattern of the entire network. Neurons in the hidden layer detect the features; the weights of the neurons represent the features hidden in the input patterns. These features are then used by the output layer in determining the output pattern with one hidden layer.

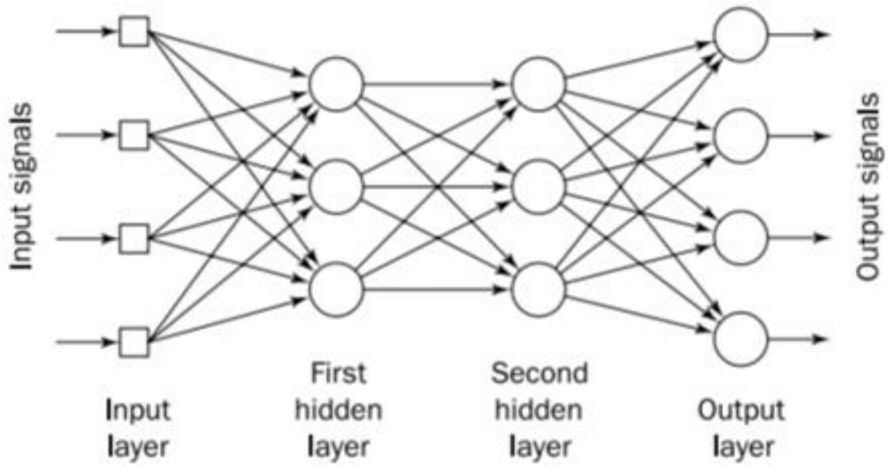


Figure 3-2:Nueral network with multiple layer

Learning in multilayer network proceeds the same way as for a perceptron; but the different is in a perceptron that there is only one weight for each input and only one output. However, in the multilayer network, there are many weights; each of which contributes to more than one output. Therefore, a training set of input patterns is presented to the network. The network computes its output pattern, and if there is a difference between actual and desired output patterns, the weights are adjusted to reduce this error.

3.4 Training algorithm 'Back-propagation'

More than a hundred different learning algorithms are available, but the most popular method is back-propagation. In a back-propagation neural network, a training input pattern is presented to the network input layer. The network then propagates the input pattern from layer to layer until the output layer generates the output pattern. If this pattern is different from the desired output, an error is calculated and then propagated backward through the network from the output layer to the input layer. The weights are modified as the error is propagated until reached the desired output.

As shown in the figure (3-3), input signals are propagated through the network from left to right, and error signals are from right to left.

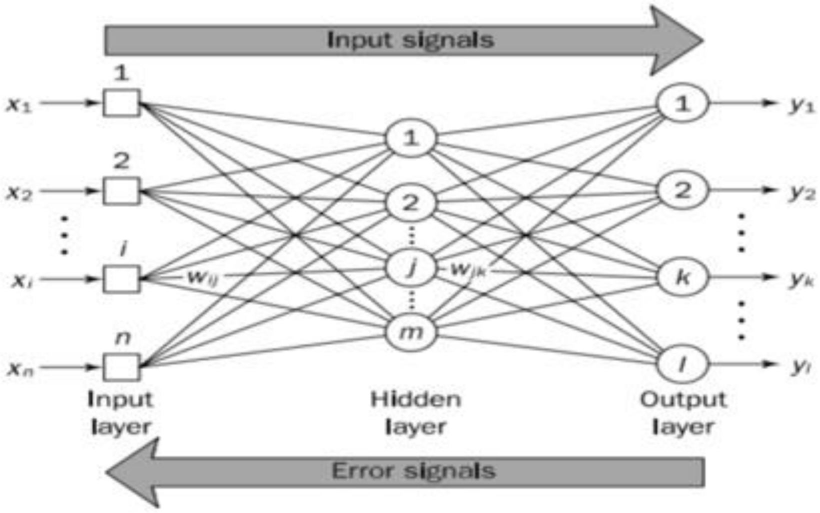


Figure 3-3:Back-propagation operation

3.5 Neural network principle

1. Neural Network Recessives N-inputs.
2. Multiplies each input by its weight; activation function could be:
   I. Threshold function outputs 1 when input is positive and 0 otherwise.
   II. Sigmoid function= $\frac{1}{(1+e^{-x})}$
3. Applies activation function to the sum of results.
4. Output results.

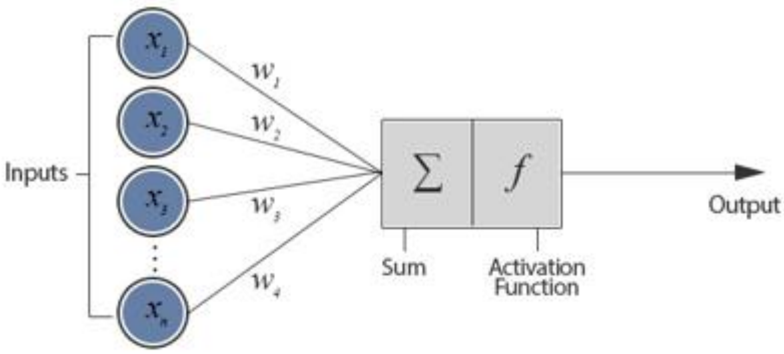


Figure 3-4:Nueral network principle

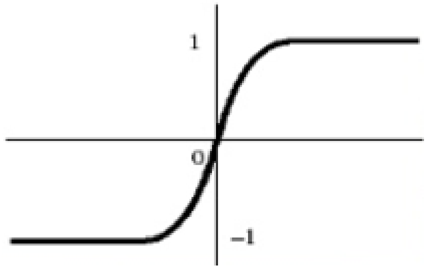


Figure 3-5:Sigmod activation function

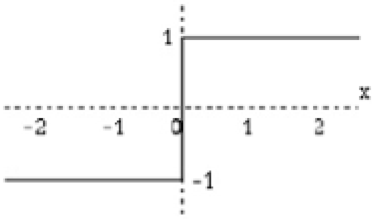


Figure 3-6:Threshold activation function

3.6 Using neural network

For using ANN, a sample of measured data was taken as follows: each case was measured five times; each time consisted of one-third hour and then divided into five minutes. However, we decided that it would be better to divide it into one minute because we need to have a real-time system and to detect the devices every minute then after five minutes give the decision is more accurate.

This research has not been dealing with the equations to implement neural networks; the tool is just used to implement ANN which was an MATLAB software. One of the important tools in Matlab is neural network toolbox; which provides algorithms, realistic example that contains training data with an explanation to show how this tool is work, and apps to create train, validation, test, and simulate the neural network. It is used to perform classification, regression, and reduction. There are two ways to use the neural network toolbox software. The first way, by using “nnstart” command, while the second way is built in application by matlab, and by selecting suitable application for the task.

3.7 Pattern recognition neural network

Neural networks are efficient in recognizing patterns. In this research, home appliances have been classified according to their current consumption. For this object and for each controllable device, all expected cases are measured (96 example cases for 3 items of data, keeping in mind if all the data entered to the neural network may be correct or wrong). This is approved by experiment. The best way to be familiar with this tool is to start with neural network application (GUI). However, before using any method, the first step is to select data set to define a pattern recognition problem. A set of N input vectors consisted columns in an input matrix. Then, the second step is to arrange another set of N target vectors so that they indicate the classes which the input vectors are assigned.

The following example shows a small part of the measured data to explain how to set data. The size of input matrix is 60x10 and the size of target matrix is 4x10. This means that when the input is to be classified into N different classes, the target matrix should have N elements; the target can consist 1 or 0. The first and second vectors in the input matrix represent the situation when the boiler is turned on while the third and fourth vectors represent the case when the iron is turned on. The fifth and sixth vectors represent the case when a heater-mode is turned on while the seventh and sixth vectors serve when spin-mode, boiler and iron are turned on. Finally, the rest vectors are when motor is turned on. These cases are represented in the target matrix; respectively as follows: [1 0 0 0 1], [0 1 0 0 1], [0 0 1 0 1], [1 1 1 0 1] and [0 0 0 1 1]. It is important to mention that in all cases that have been shown the refrigerator is turned on.

$$\text{Target} = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$$

Input=

19.507	19.643	18.134	9.001	14.022	16.234	23.56	23.809	5.544	5.768
19.614	19.639	18.134	8.996	16.234	16.259	25.744	25.866	5.47	5.758
19.565	19.639	18.164	8.987	16.269	16.249	25.768	26.061	5.499	5.719
19.59	19.619	18.129	8.977	16.264	16.341	25.724	25.915	5.504	5.748
19.629	19.639	18.129	8.987	16.279	16.381	25.72	25.925	5.524	5.744
19.595	19.595	18.1	8.952	16.258	16.533	25.709	25.992	5.529	5.768
19.619	19.595	18.11	8.972	16.263	14.339	25.719	26.046	5.572	5.821
19.546	19.59	18.09	8.972	16.249	14.31	25.734	25.988	5.588	5.842
19.565	19.653	18.11	8.977	16.244	14.149	25.866	26.061	5.597	5.87
19.58	19.639	18.115	8.982	16.264	14.154	25.866	26.095	5.626	5.87
19.565	19.648	18.081	8.977	16.244	14.149	26.061	25.939	5.705	5.934
19.57	19.673	18.105	8.991	16.268	14.164	25.929	25.944	5.675	5.904
19.58	19.692	18.071	8.996	16.273	14.144	25.953	26.036	5.744	5.964
19.634	19.692	18.071	8.977	16.283	14.159	25.939	25.943	5.763	5.983
19.585	19.707	18.09	9.011	16.278	14.149	25.929	25.836	5.802	6.032
19.614	19.678	18.085	9.026	16.273	14.139	25.914	26.022	5.773	5.983
19.59	19.673	18.046	9.011	16.303	14.139	25.914	25.919	5.837	6.008
19.595	19.663	18.056	9.006	16.317	14.12	25.91	25.875	5.851	6.017
19.629	19.673	9.241	9.016	16.434	14.124	25.983	26.026	5.895	6.032
19.57	19.678	9.05	8.987	16.44	14.12	26.046	26.037	5.827	5.993
19.609	19.658	9.045	9.045	16.61	14.129	26.217	26.256	5.797	5.978
19.59	19.687	9.055	9.031	16.439	14.144	26.071	26.105	5.768	5.934
19.575	19.707	9.026	9.021	16.42	14.134	25.851	26.134	5.788	5.944
19.58	19.707	9.016	9.001	16.307	14.125	25.685	25.983	5.783	5.993
19.57	19.726	9.016	9.016	16.283	14.119	25.675	25.914	5.504	5.719
19.58	19.741	9.035	9.001	16.289	14.134	25.661	25.915	5.48	5.69
19.595	19.751	9.065	9.016	16.298	14.246	25.694	25.968	5.528	5.738
19.565	19.741	9.035	9.001	16.273	14.412	25.66	25.924	5.514	5.734
19.565	19.751	9.035	8.991	16.308	14.344	25.734	25.919	5.504	5.734
19.59	19.751	9.04	8.977	16.293	14.237	25.709	25.905	5.499	5.763
19.565	19.697	9.031	8.991	16.293	14.271	25.739	25.885	5.494	5.748
19.58	19.678	9.035	8.991	16.293	14.129	25.763	25.885	5.475	5.719
19.556	19.653	9.016	9.006	16.283	14.134	25.866	25.919	5.49	5.705
19.531	19.687	9.006	9.031	16.318	14.12	25.954	25.9	5.524	5.739
19.531	19.687	9.074	9.035	16.283	14.12	25.998	25.929	5.504	5.714
19.516	19.683	9.026	16.2	16.264	14.134	25.939	25.983	5.494	5.719
19.521	19.697	9.021	18.085	16.259	14.134	25.904	25.944	5.48	5.768
19.521	19.678	9.021	18.105	16.254	14.139	25.865	25.895	5.509	5.709
19.458	19.707	9.031	18.095	16.278	14.149	25.914	25.919	5.514	5.754
19.453	19.702	9.035	18.105	16.259	14.119	25.87	25.944	5.524	5.685
19.531	19.702	9.04	14.178	16.298	14.115	25.954	25.851	5.543	5.704
19.482	19.731	9.026	9.055	16.405	14.119	26.027	25.963	5.528	5.709
19.536	19.722	9.026	9.006	16.679	14.124	26.345	26.232	5.582	5.709
19.487	19.678	9.021	9.006	16.577	14.129	26.208	26.105	5.567	5.758
19.477	19.683	9.006	9.011	16.362	14.124	25.983	25.964	5.543	5.753
19.482	19.726	8.991	9.016	16.385	14.125	25.963	25.978	5.588	5.729
19.492	19.731	9.006	9.006	16.298	14.124	25.724	25.9	5.593	5.783
19.473	19.814	8.987	8.991	16.273	14.119	25.734	25.905	5.558	5.759
19.556	19.81	8.987	9.045	16.269	14.188	25.748	25.963	5.588	5.788
19.536	19.834	9.011	9.016	16.254	14.252	25.734	25.949	5.597	5.817
19.551	19.829	9.026	8.991	16.273	14.54	25.748	25.953	5.597	5.812
19.526	19.785	9.021	9.016	16.268	14.496	28.283	25.822	5.626	5.866
19.575	19.795	9.031	8.982	16.268	14.193	28.283	25.802	5.645	5.831
19.595	19.79	9.026	8.987	16.273	14.149	28.283	25.836	5.719	5.929
19.59	19.814	8.977	9.001	16.283	14.134	28.283	25.836	5.729	5.939
19.629	19.814	9.031	8.972	16.259	14.129	28.283	25.846	5.724	5.988
19.639	19.805	9.006	8.991	16.268	14.125	28.283	25.856	5.734	6.022
19.629	19.814	8.996	8.982	16.249	14.12	28.278	25.856	5.758	5.997
19.643	19.819	8.996	9.001	16.244	14.129	28.278	25.851	5.782	6.036
19.629	19.805	8.991	9.026	16.239	14.149	26.315	26.022	5.836	6.017

After setting data, the next step is to use the neural network pattern recognition (NNPR) application. The most important point is to select input and target matrices then select samples mode as (matrix columns).

- The input vectors and output vector must be divided into three set as follows:

- Training: (70% from original data) is used to train neural network.

- Validation: is to measure network generalizing and to stop training before overfitting (15% from original data), where the overfitting in case occurs when test error increases with iterations, and when the performance in the test set is much lower than the performance on train set.

- Testing: is used as a completely independent test of network generalization (15% from original data). One of the major benefits of neural network is their ability to be generalize that means network could classify data that it has never seen before.

After training, to check if the result was good, under plots pane, click on confusion. The next figure (3-7) shows the confusion matrices for training, testing, and validation. It provides a summary of prediction results on classification problem; it gives insight not only into the errors being made by classifier but more importantly the types of errors that are being made. The response will appear as follows: the number of correct response in the green squares and numbers of incorrect response in red squares. The blue squares illustrate the overall accuracies.

The next figure (3-8) shows performance plot that represents mean square error dynamics for all datasets in logarithmic scale. Training MSE is always decreasing.

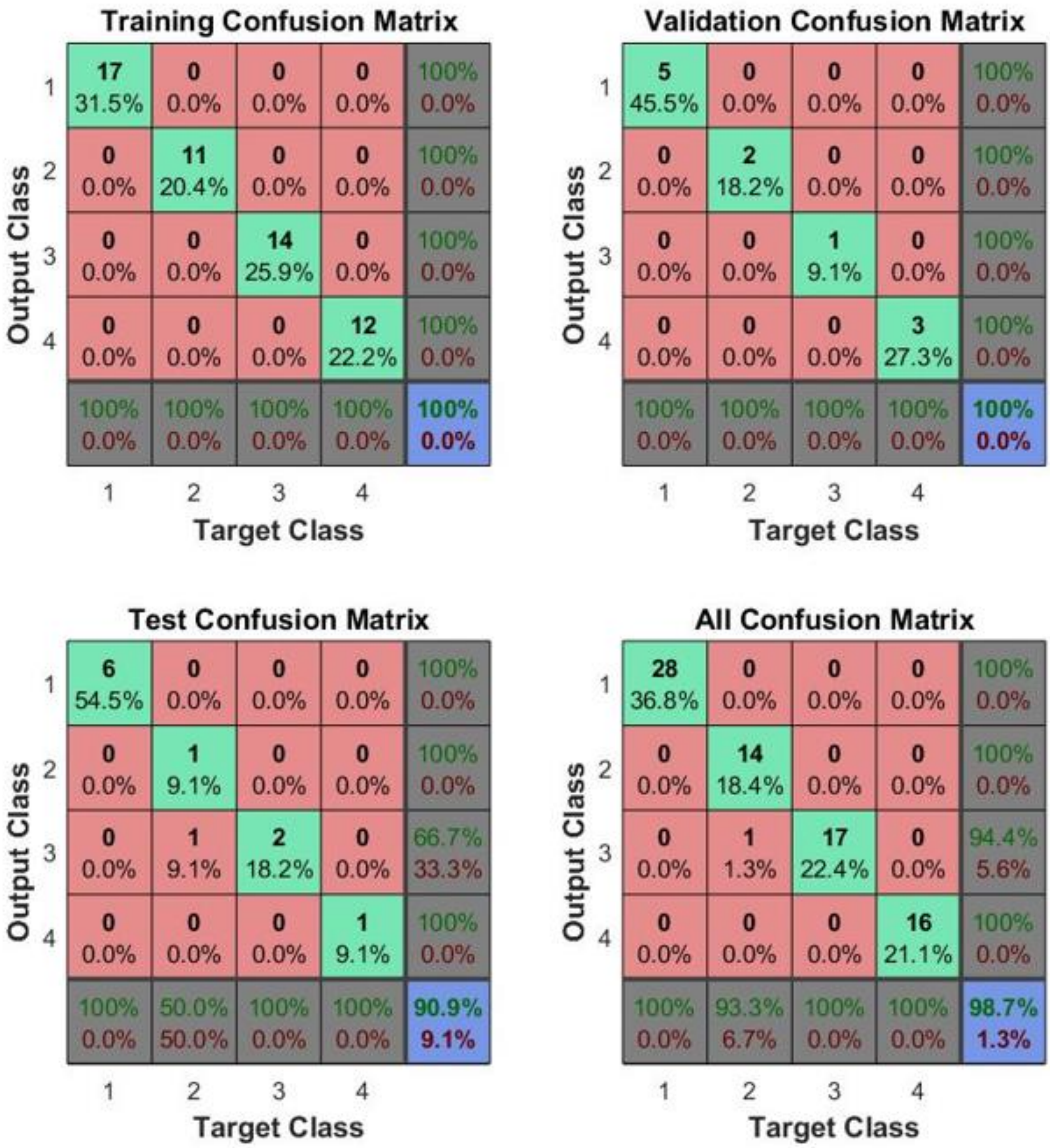


Figure 3-7:Confusion matrices

The confusion matrices showing that the results are acceptable there is very small error ratio. The data selected were for devices that have dissimilarity in the current consumption profile. When all the measured data are taken, the error percentage increases significantly. The reason is due to the similarity in current profile consumption. After evaluating the network, there is the capability to test network against new data and if the network performance was unsatisfactory, there is ability to train it again, increase the number of neurons, or to get a larger dataset.

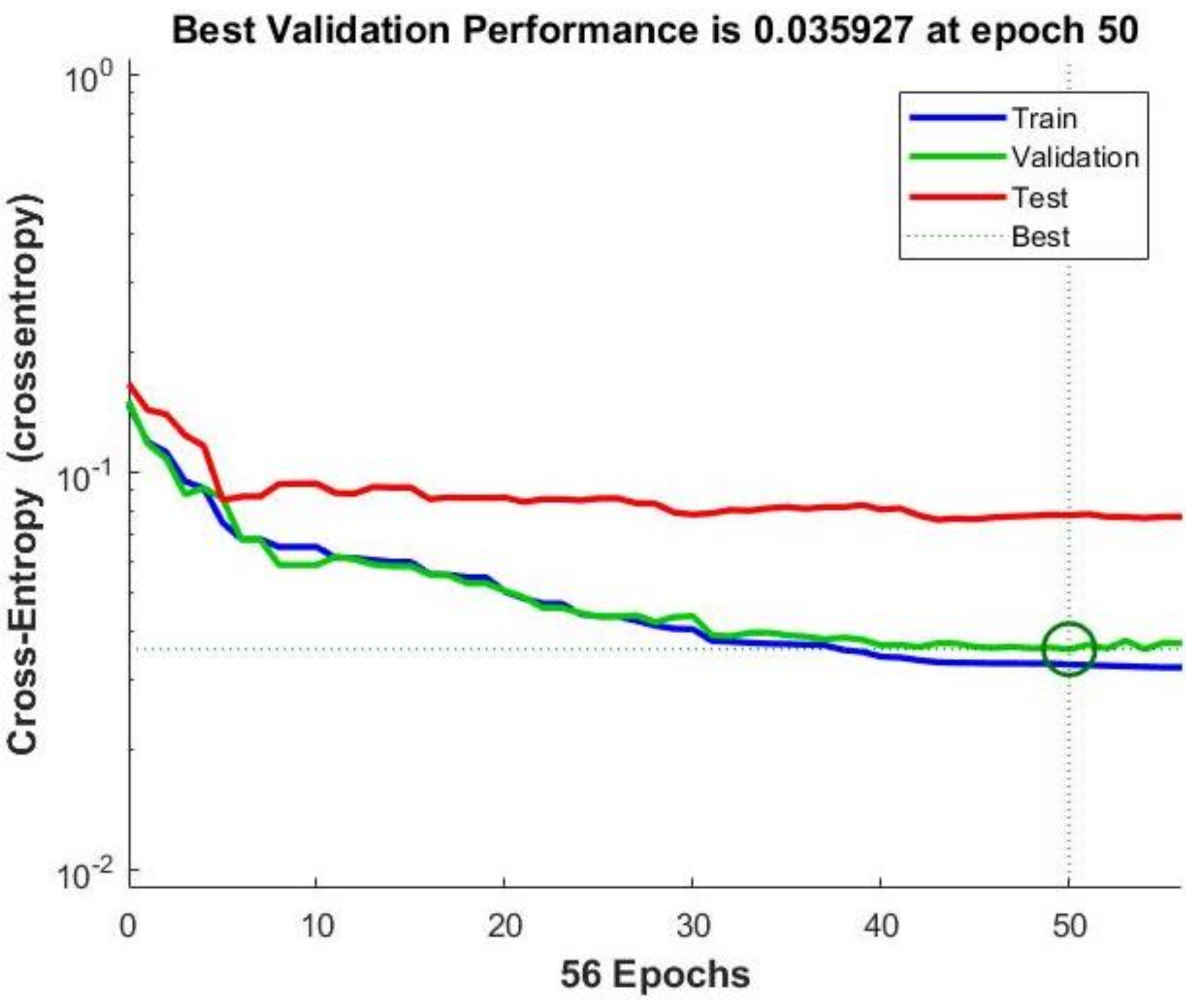


Figure 3-8:Performance Plot

3.8 Conclusion of the chapter

Artificial neural network can give amazing results to pattern recognition problems if the input data is clear. However, in this case, where the challenge has been discovered after the experiment is those appliances with the same current consumption pattern. For dissimilarity, the identified accuracy was excellent as shown. It is also the expected results after resolving the problem of similarity cases.

Chapter four

4 Mathematical model

4.1 Introduction:

Electric loads are categorized as resistive, capacitive, or inductive loads for mathematical modelling. Each load is modeled as RLC circuit with a variable magnitude for each category (resistor, capacitor, inductor) based on the load component. For example, the boiler is a resistive load, television is a capacitive load, and washing machine is an inductive load.

4.2 Building the mathematical model:

To implement the mathematical model, Matlab (Simulink) was used especially with Simpower library. The main component used from this library is:

1. Series RLC load: (R: resistor, L: inductor, and C: capacitor)

   This block implements a linear load as a single inductor, capacitor, or resistor, or combination of those. At specified frequency (F) and voltage (Vrms), any electric load can be modeled as RLC circuit depending on load type. The main parameters for this block:

   - Nominal voltage(Vn): Electric loads were designed with one nominal voltage (Vn) at a value of 220 Vrms.
   - Nominal Frequency (Fn): The standard frequency of supply in Palestine is 50 Hz.
   - Active Power (P), Inductive reactive power (QL), and Capacitive reactive power (QC)

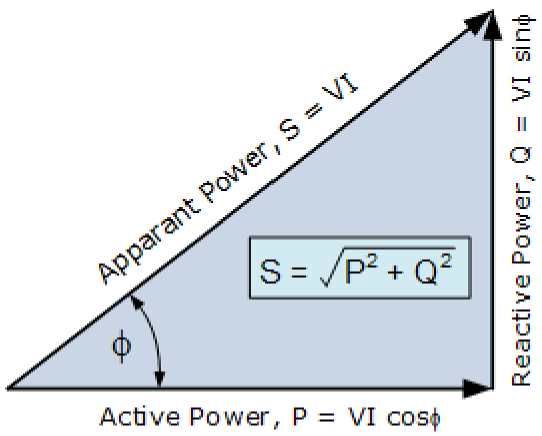


Figure 4-1 Power triangle

2. RMS: Calculate true root mean square (RMS) value of the input signal. Here it's important to set the fundamental frequency to 50 Hz.
3. Current measurement: used to measure the current in any electrical block.
4. Ideal switch.

5. AC voltage source: this block implements an ideal AC voltage source (sinusoidal voltage).

$V(t) = A.sin(wt + theta),\ w = 2 * pi * f$, theta= Phase in radians.

The following circuits explain how the mathematical model was build:

- Television: capacitive load.

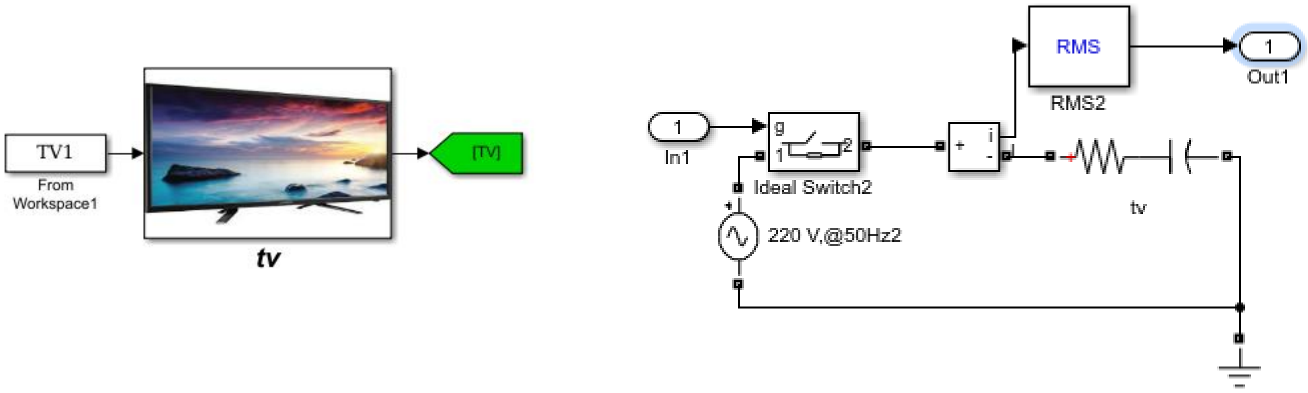


Figure 4-2 TV model

- Boiler: resistive load.

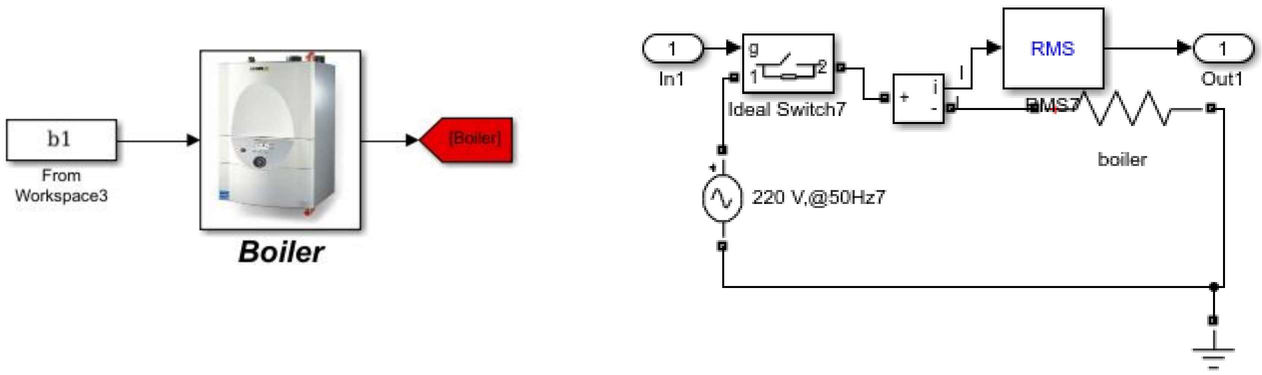


Figure 4-3 Boiler model

- Washing machine: inductive load.

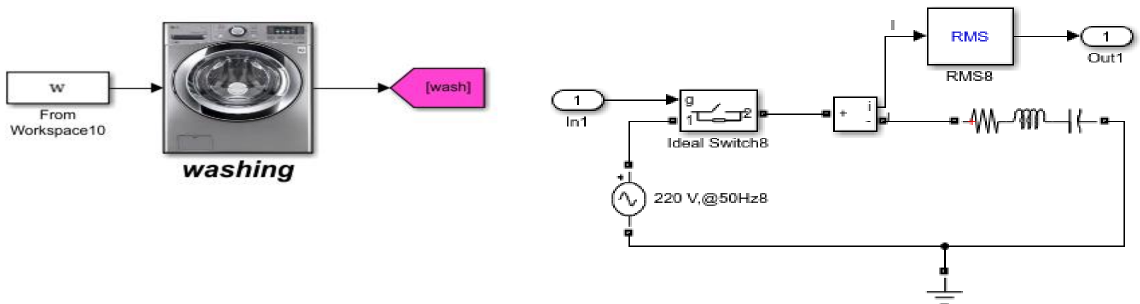


Figure 4-4 Washing machine

The remaining appliances were also modeled using the same method and libraries. Total current pattern can be found when all output ports of current measurement blocks are connected with summation block. The mathematical model is verified using simulation and validated by the actual measurements. the figure (4-5) below illustrates the mathematical model for a home using in Matlab (Simulink) library.

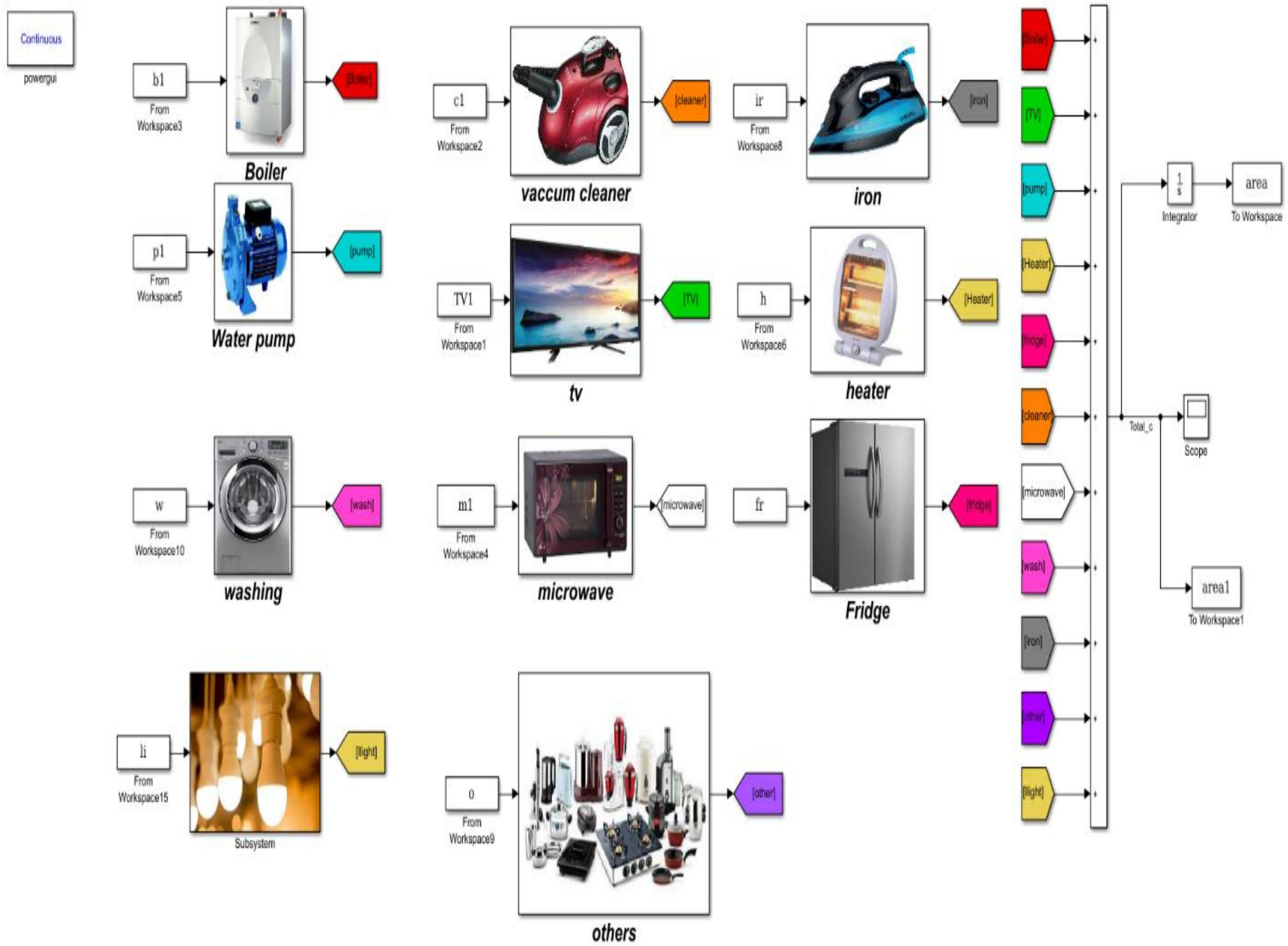


Figure 4-5 Mathematical model

Table (4-1) shows the operation hours of home appliances during a given day. This was the original scenario for running appliances at that particular day. The figure (4-6) below shows the current consumption pattern for home where these measurements were recorded for 24 hours' period as mentioned in (ch.2). In Simulink, however, each hour of the day was represented by one second.

Table 4-1 Original Scenario

Boiler	Pump	Vacuum Cleaner	Microwave	Wash Machine	Heater	Fridge	Iron	Other home appliances	TV	Dish Washer
9-11	20-23	9-9.10	10-10:03	20.5-22.15	20-23	All the day	19-19:3	6-6:25	10-23:5	10:30-11:20
15-18	-	2-2:10	14-14:04	-	-	-	-	7-7:10	-	14-14:30
-	-	-	-	-	-	-	-	8-8:30	-	18-18:13

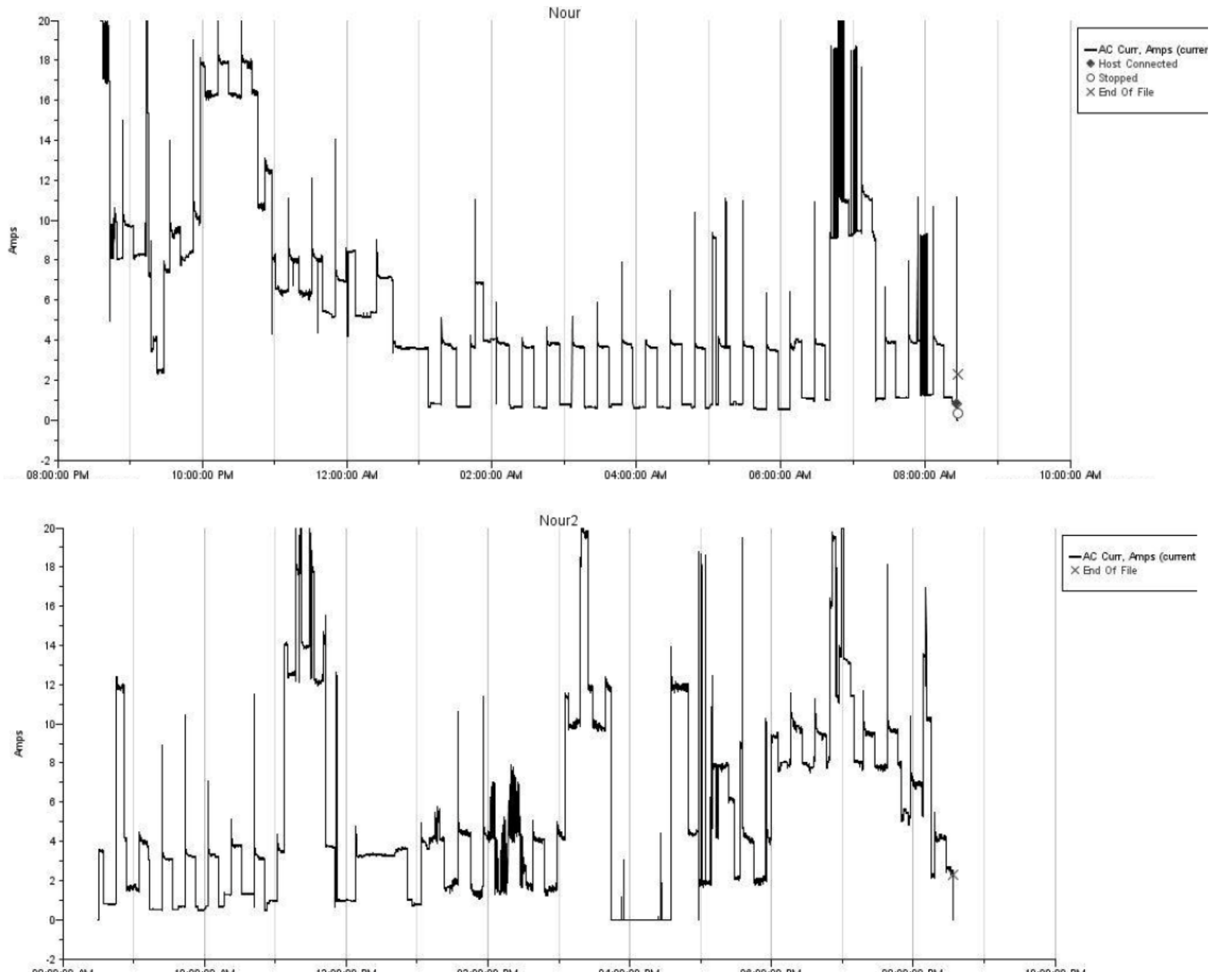


Figure 4-6 Current Measurements

4.3 Results:

The figure (4-7) below shows the total current consumption in the whole house:-

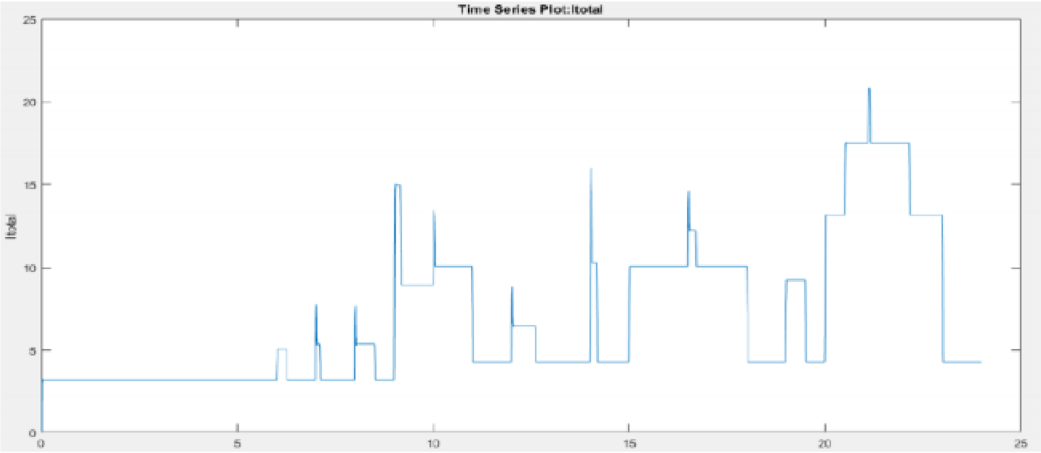


Figure 4-7 Simulation results

It should be mentioned that the graph matches the experimented results done before perfectly, which leads to the conclusion that the mathematical model fits and satisfies the desired design and expresses the system in it's optimal way.

4.4 Conclusion:

A mathematical modelling procedure was done to express the parameters of the system and ease the implementation of the intelligent controller without any neglected terms left behind which may cause diversity in the final output of the controller or differ the expected efficiency from the actual one. Never the less, the modelling procedure included all the taken variables into account, from the nominal voltage frequency and the appliance power in order to achieve an optimal output and performance for the system, allowing it to be valid for the implementation process for any desired system- house.

Chapter five

5 The Controller

5.1 Stateflow design to control home consumption [9]:

Stateflow is a modeling and simulation environment for combinatorial and sequential decision logic based on state machines and flow charts. Stateflow lets you combine graphical and tabular representations including state transition diagrams, flow charts, state transition tables, and truth tables in order to understand how a system reacts to events, time-based conditions, and external input signals.

The advantages of Stateflow

• Serve as a high-level starting point for a complex software design process.

• Allows focusing on the operating modes and the conditions required to pass from one mode to another.

• Help to design models that remain clear and concise despite their complexities.

The Stateflow chart communicate with the other blocks in the Simulink model by sharing data through input and output connections, parameters, and data stores.

The appliances that assumed to be controlled by the Stateflow are (Washing machine, Boiler, and Water bump). The reason to choose these particular appliances is that they can be shifted to off peak hours without affecting the end-user comfort. According to the measurements, it is clear that these loads can contribute largely to increase in demand during peak hours.

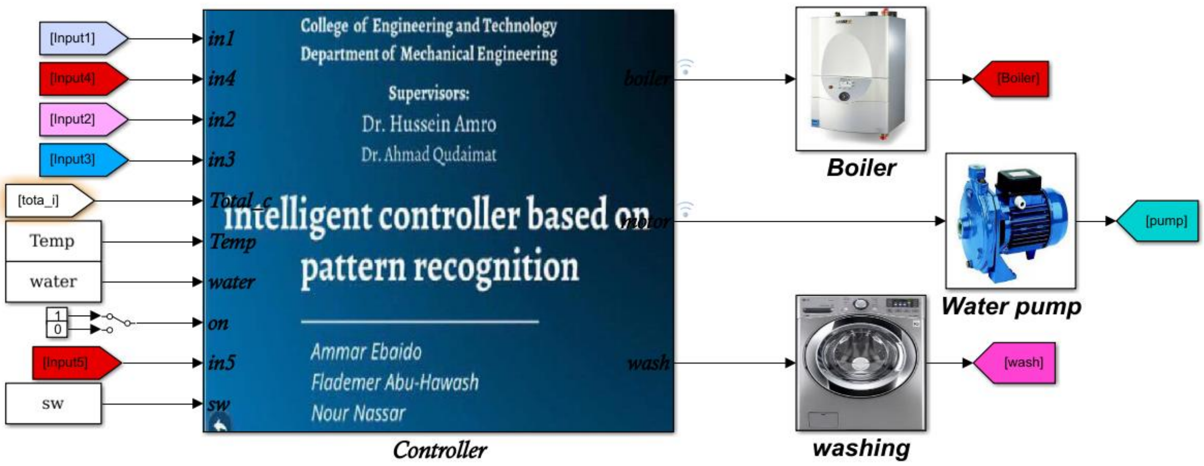


Figure 5-1 DMS controller

As shown in the figure (5-1) above the controller has ten inputs (five input from the artificial neural network, a sensor to detect the water level in the tank, a sensor to measure water temperature, on/off switch for washing machine, on/off switch for the controller, and feedback from total current consumption), and three outputs. Inside the controller, there are three sub states working in parallel see figure (5-2).

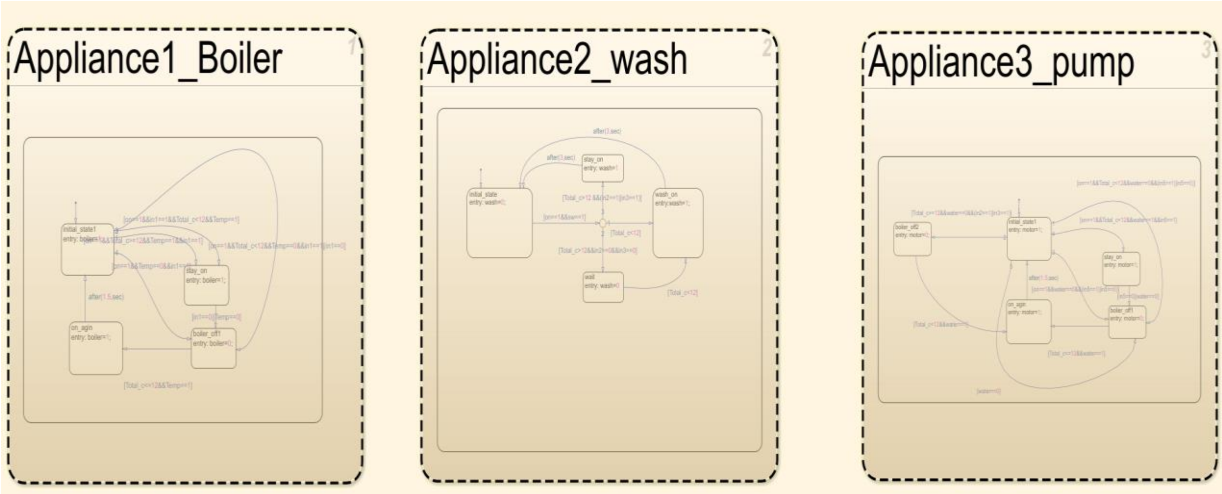


Figure 5-2 Controller Substate

The figure (5-2) below is a sub state for control the washing machine working principle; this sub-state contains many states and transitions. One state only is active at the time.

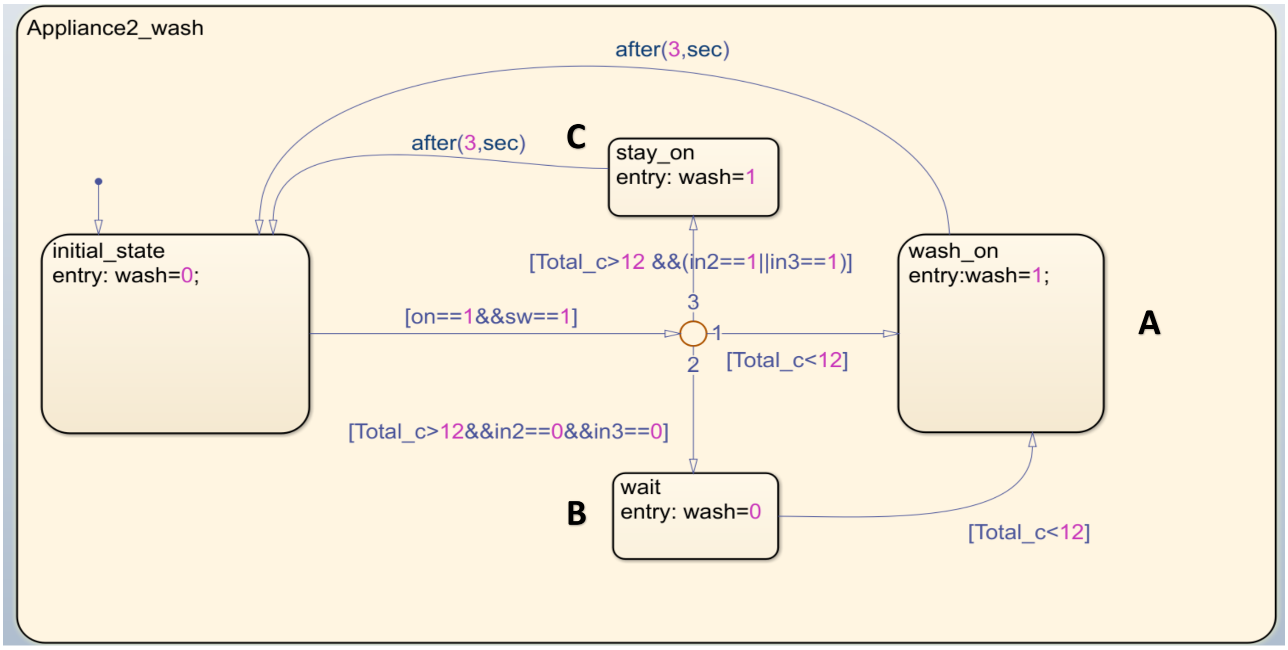


Figure 5-3 Washing machine Substate

which works as following: initially the washing machine is turned off, it requires the user to manually turn it on, then the state flow loop checks if the following conditions are satisfied:

- The controller is ON.
- The washing machine is manually turned on.

Meanwhile, if both of the two conditions were satisfied at the same time, then the controller will follow the three states: -

A. Turn the washing machine ON.
B. Delaying the operation process.
C. Keeping the washing machine in its pervious state (wash=1).

In state A, the condition is satisfied when the total current consumption is less than 12 [A], where the machine still operating for 30 [minutes] (the time of the total washing cycle).

In state B, delaying the machine running time happens when the following three conditions are satisfied together.

1. The total current consumption is less than 12 Ampere.
2. The spin mode is not operating (as an input form the NNPR).
3. The heater mode is not operating (as an input form the NNPR).

In state C, washing machine will still be operating based on the state of the following two conditions together: -

1. The total current consumption is more than 12 Ampere.
2. The spin mode or heater mode is operated (as an input form the NNPR).

The figure (5-4) below is a sub state for control the Boiler working principle

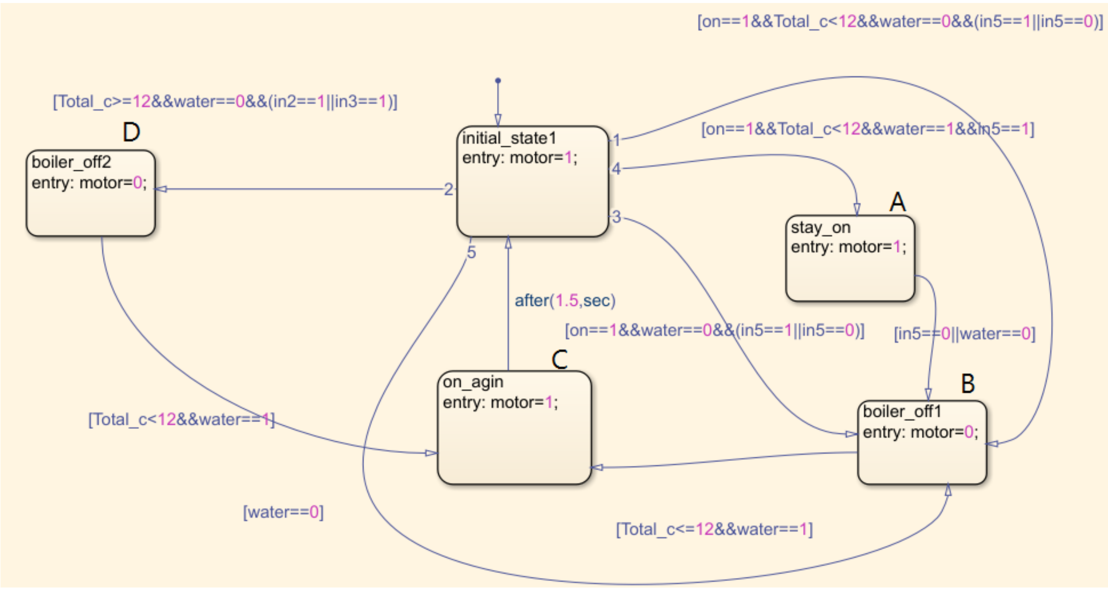


Figure 5-4 Motor Substate

initially the pump is on; it is required to observe several conditions in order to decide whether to turn itself on or off, according to the following states:

A. Turn the pump ON.

B. Turn the pump OFF.

C. Keeping the pump on for 15 min (the time needed to rise the water level in the water tank).

D.Turn the pump OFF.

Firstly, in the case of (state B), which is turning the pump off, is based on the state of the following four conditions together:

1- The controller ON.
2- The total current consumption is less than 12 Ampere.
3- The water level is low.
4- The pump is ON (as an input form the NNPR).

Then the path continues to (state C) based on the state of the following two conditions together:

1. The water level is low.
2. The total current consumption is less than or equal 12 Ampere.

Then it gets back to the initial state after 15 minutes.

Secondly, in case of (state D), which's turning off the pump, is based on the state of the following three conditions together:

1- The total current consumption is more than or equal 12 Ampere.
2- The water level is high.
3- The spin mode or heater mode is ON (as an input form the NNPR).

Then the path continues to (state C) based on the state of the following two conditions together:

1. The water level is low.
2. The total current consumption is less than 12 Ampere.

Then it gets back to the initial state after 15 minutes.

Thirdly, in case of (state B), which's turning the pump off, is based on the state of the following three conditions together:

1. The controller is ON.
2. The water level is high.
3. The pump is ON or OFF (as an input form the NNPR).

Then the path continues to (state C) based on the state of the following two conditions together:

1. The water level is low.
2. The total current consumption is less than or equal 12 Ampere.

Then it gets back to the initial state after 15 minutes.

Fourthly, in case of (state A), which's turning the pump off, is based on the state of the following four conditions together:

1. The controller is ON.
2. The total current consumption is less than 12 Ampere.
3. The water level is low.
4. The pump is ON (as an input form the NNPR).

Then the path continues to (state B) based on the state of one of the following two conditions:

1. The pump is OFF (as an input form the NNPR).
2. The water level is high.

Then it gets back to the initial state throw (state C).

Fifthly, in case of (state B), which's turning the pump off, is based on the state of the following condition:

1. The water level is high.

2.The pump is OFF (as an input form the NNPR).

The figure (5-5) below is a sub state for control the Boiler working principle

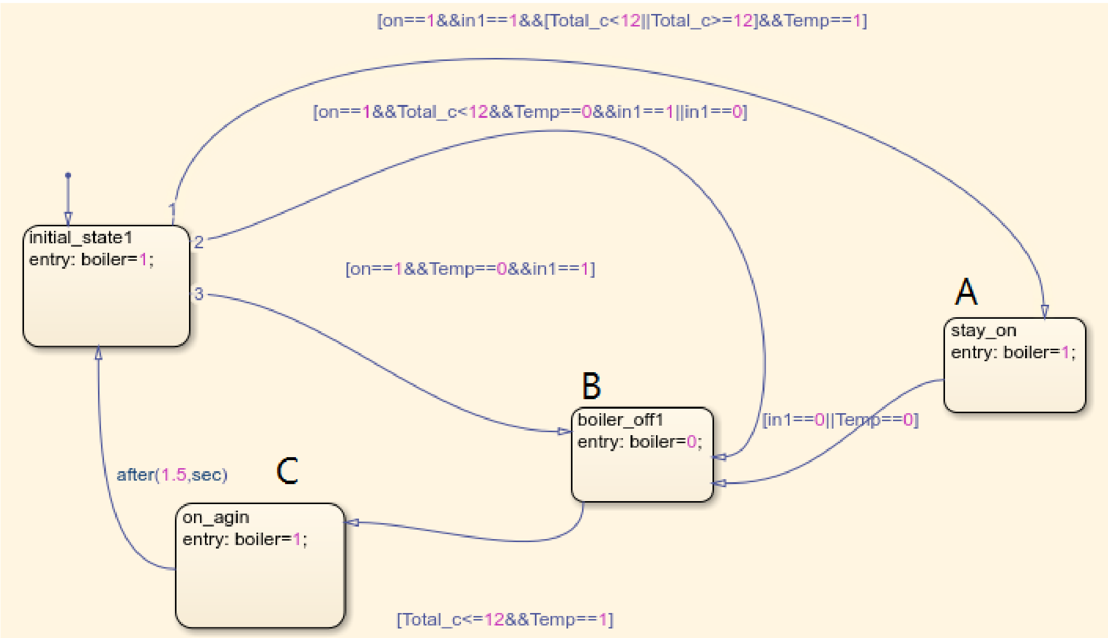


Figure 5-5 Boiler Substate

Initially, when the boiler is on, it is required to observe several conditions in order to decide whether to turn itself on or off, according to the following states:

A. Turn the boiler ON.
B. Turn the boiler OFF.
C. Keeping the boiler on for 15 min (the time needed to rise the water temperature in the tank).

Firstly, in the case of (state A), which's turning the boiler on, is based on the state of the following three conditions together:

1. The controller is ON.
2. The total current consumption is less than 12 Ampere OR (the total current consumption more than or equal 12 Ampere).
3. The temperature is low.

Then the path continues to (state B) based on the state of one of the following two conditions:

1- The temperature is high.
2- The boiler is OFF.

Then the path continues to (state C) based on the state of one of the following two conditions:

1. The temperature is low.
2. The total current consumption is less than or equal 12 Ampere.

Then it gets back to the initial state after 15 minutes.

Secondly, in case of (state B), which is turning off the boiler, is based on the state of the following four conditions together:

1. The controller is ON.
2. The total current consumption is less than 12 Ampere.
3. The temperature is high.
4. The boiler is ON or OFF (as an input form the NNPR).

Then the path continues to (state C) based on the state of one of the following two conditions:

1. The temperature is low.
2. The total current consumption is less than or equal 12 Ampere.

Then it gets back to the initial state after 15 minutes.

Thirdly, in case of (state B), which's turning the boiler off, is based on the state of the following three conditions together:

1. The controller is ON.
2. The temperature is high.
3. The boiler is ON (as an input form the NNPR).

Then it gets back to the initial state throw (state C).

5.2 The mathematical model with the controller:

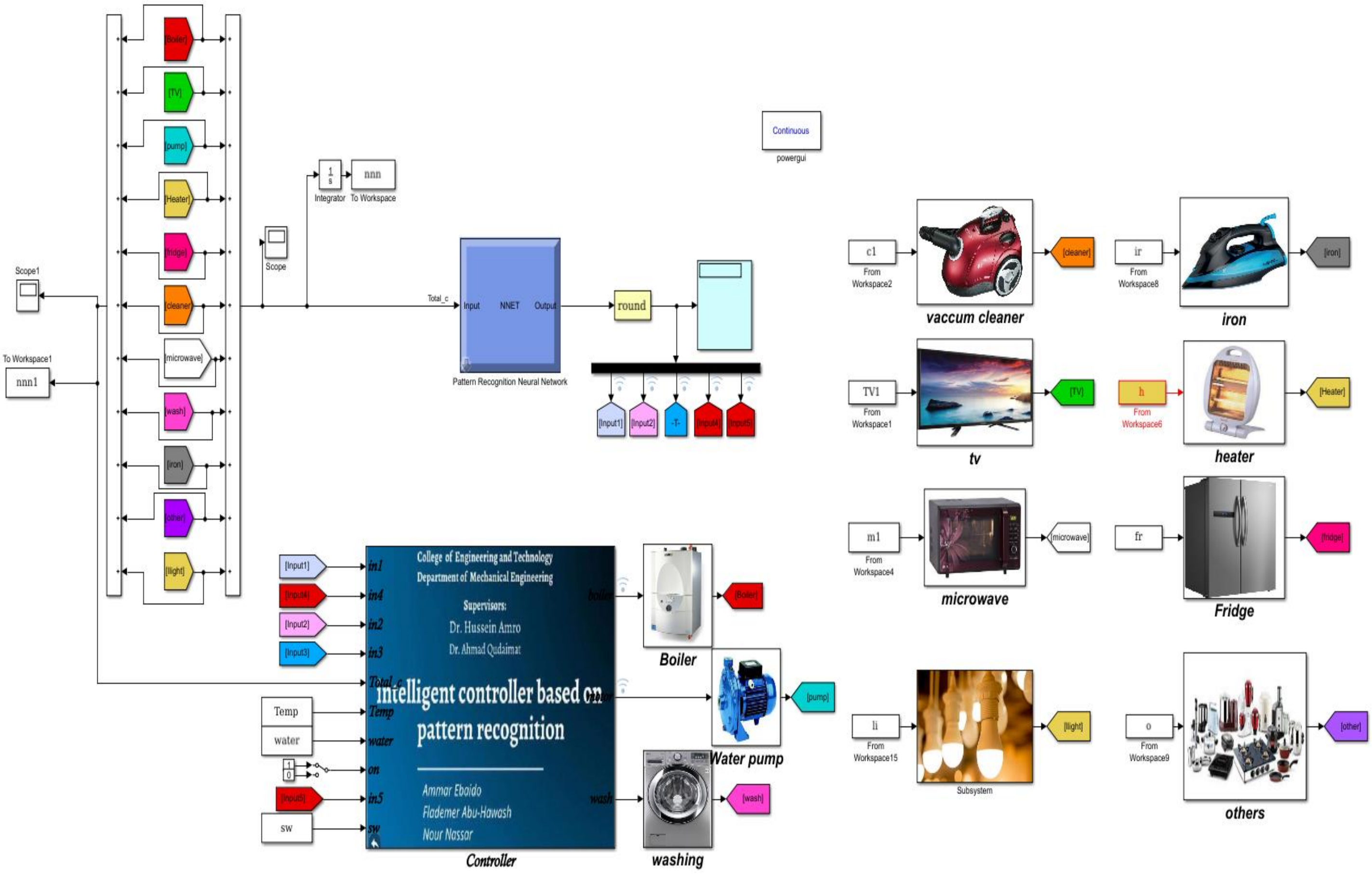


Figure 5-6 Mathematical model & controller

5.3 Result:

To examine the work of the designed controller, it has to be simulated in scenarios of tuning the loads on/off manually and then monitoring the real output of the controllable loads from the controller. To test the controller control. Here are two scenarios:

The First Scenario

Table 5-1 First Scenario

Boiler	TV	Motor	Cleaner	Micro	Wash	Heater	Iron	Others
9-11	10-23.9	20-23	9-9.15	10-10.03	20.5-22.15	20-23	19-19.5	7-7.10
15-18	-	-	14-14.13	14-14.04	-	-	-	6-6.25& 8-8.5

-	-	-	-	12.10-12.15	-	-	-	12-12.6&16.5-16.7

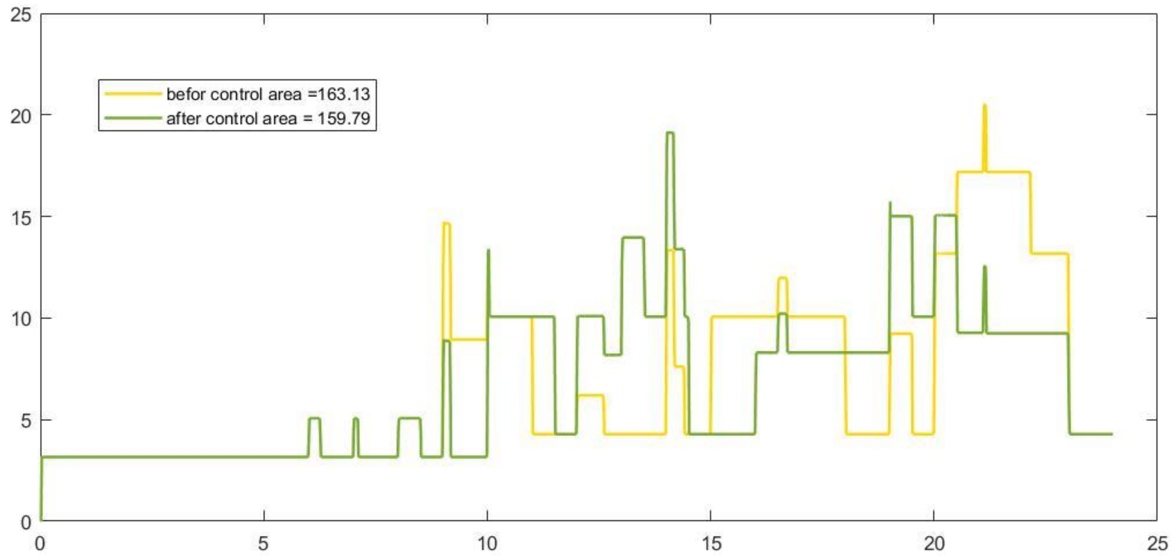


Figure 5-7 result (scenario 1)

The yellow curve represents the current consumption pattern in the house for 24 hours, which reaches 20 amperes; the green curve is the consumption pattern after installing the controller the current only reached 15 amperes. As shown in the figure (5-7) above, the area under two curves were calculated. For the first curve, the area is 163.13, while for the second curve, the area is 160. The difference between areas is due to starting current for the inductive load; this indicates that after the installation, the tendency of using the appliances was not affected but the work of electric devices was distributed around the clock. So, they didn't work in the same time. As a result, there is no peak in the current consumption curve.

The Second Scenario:

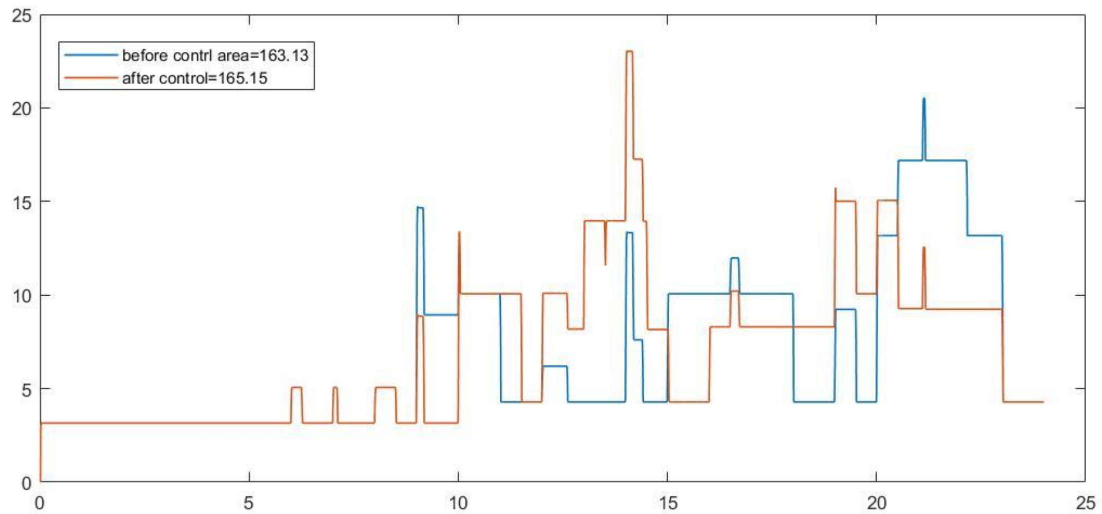


Figure 5-8 result (scenario 2)

The blue curve represents the current consumption pattern in the house for 24 hours, which reaches 20 amperes; the brown curve is the consumption pattern after installing the controller the current only reached 15 amperes. As shown in the figure (5-8) above, the area under two curves were calculated. For the first curve, the area is 163.13, while for the second curve, the area is 165. The difference between areas is due to starting current for the inductive load; this indicates that after the installation, the tendency of using the appliances was not affected but the work of electric devices was distributed around the clock. So, they didn't work in the same time. As a result, there is no peak in the current consumption curve.

Table 5-2 Second Scenario

Boiler	TV	Motor	Cleaner	Micro	Wash	Heater	Iron	Others
11-13.7	12-23.9	9-10	7.5-7.6	12.5-12.59	13.5-15	19-20	20-20.5	5-5.25
-	-	13.5-14.5	13.5-13.6	13.5-15	-	-	-	7-7.10&16.5-16.7
-	-	-	-	-	-	-	-	12-12.6&16.5-16.7

5.4 User interface:

A graphical user interface (GUI) was built using Matlab shown in figure (5-9) to allow the user to test the controller before using this system. This GUI allows the user to enter any operation scenario for appliances, and the apparent power for each device then plot the current consumption pattern for home before and after implementing the controller. GUI can access the block inside the Simulink model and make a change in its parameter value based on user input data.

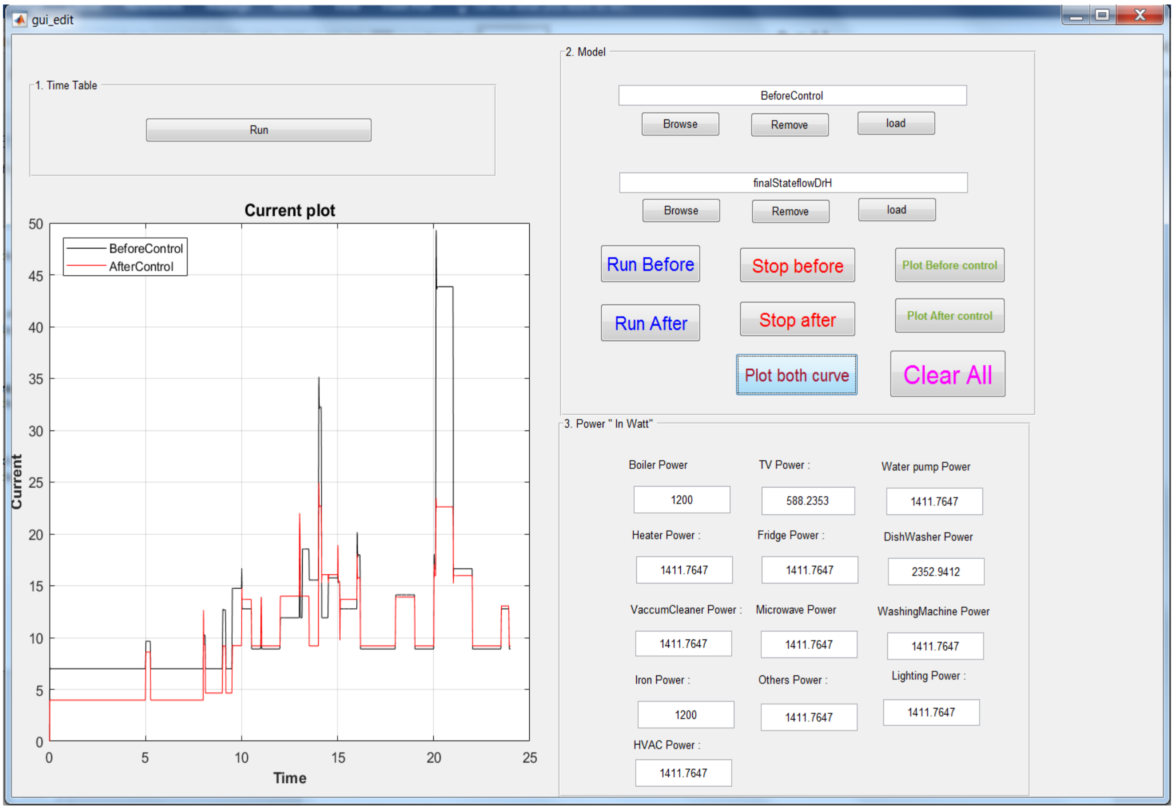


Figure 5-9 GUI

5.5 Prototype Results:

1.Proteus program:

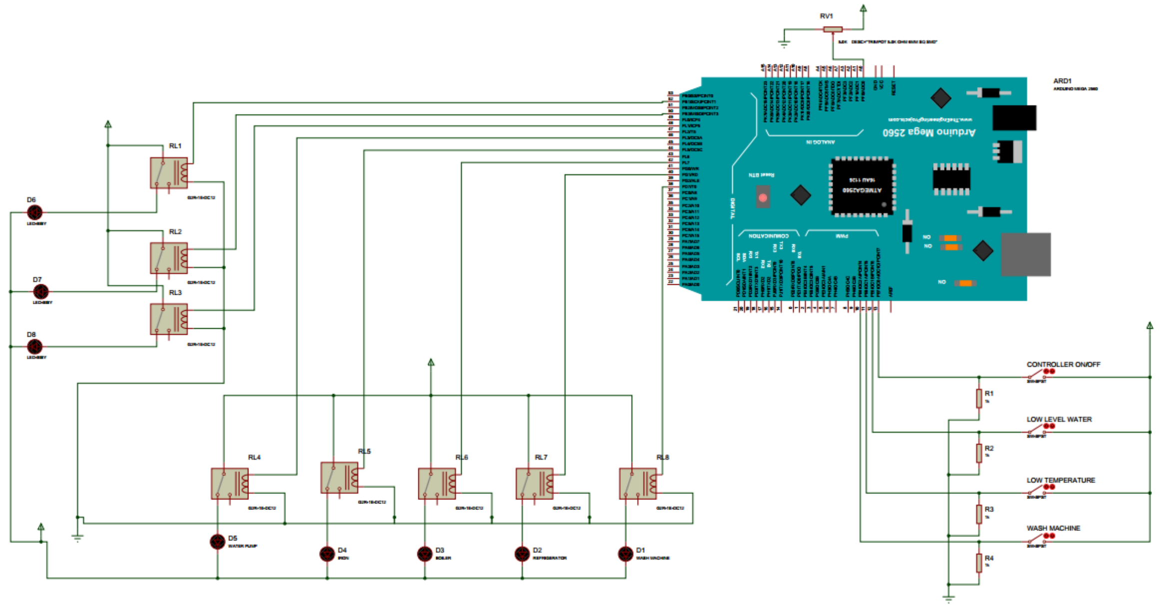


Figure 5-10 proteus simulation wiring

2. Prototype:

The project was practically represented as a prototype, the electrical devices and NNPR were represented by LEDs . The figure(5-11) below shows the prototype.

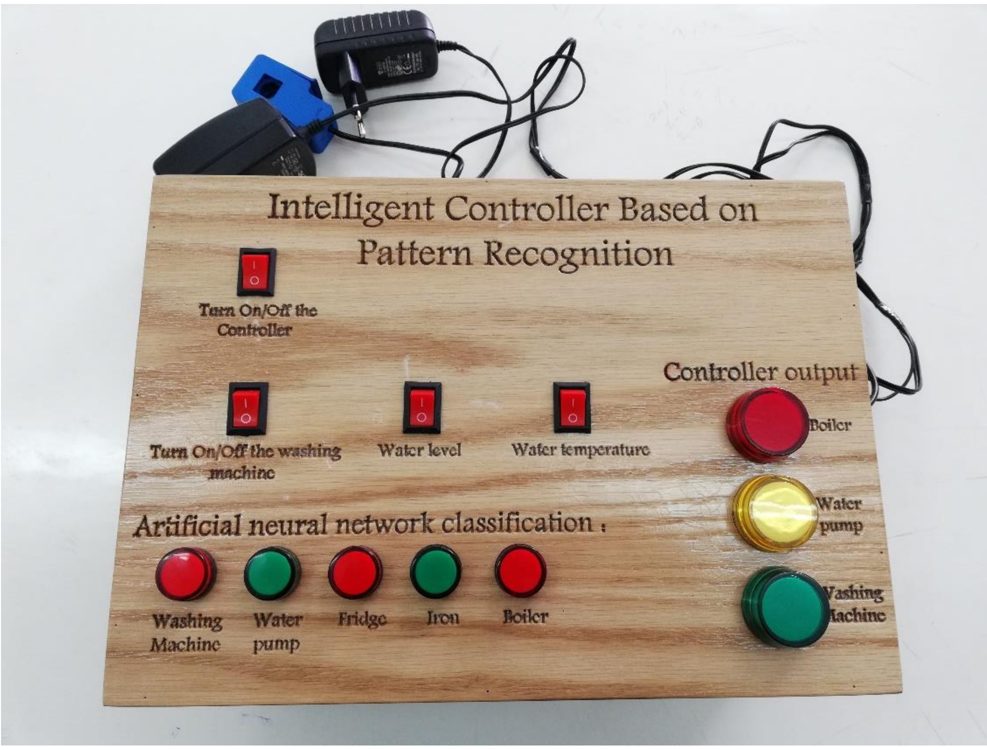


Figure 5-11 System prototype

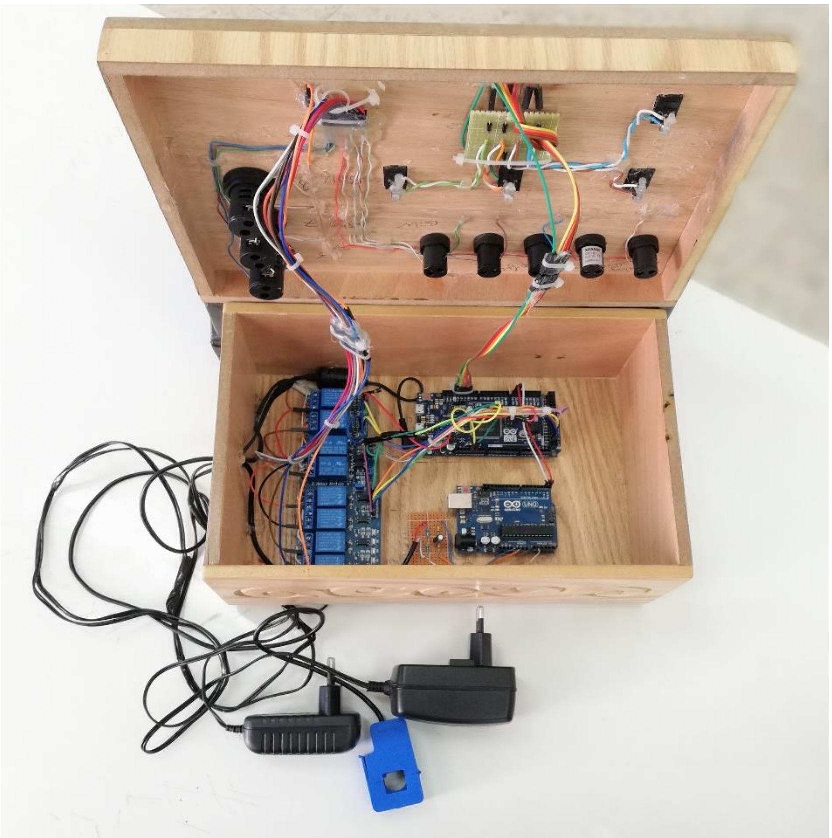


Figure 5-12 Wiring connection

All cases that tested in NNPR mentioned in chapter 3 were represented in real time. The figures from figure (5-13) to figure (5-17) verification NNPR output.

Case 1:

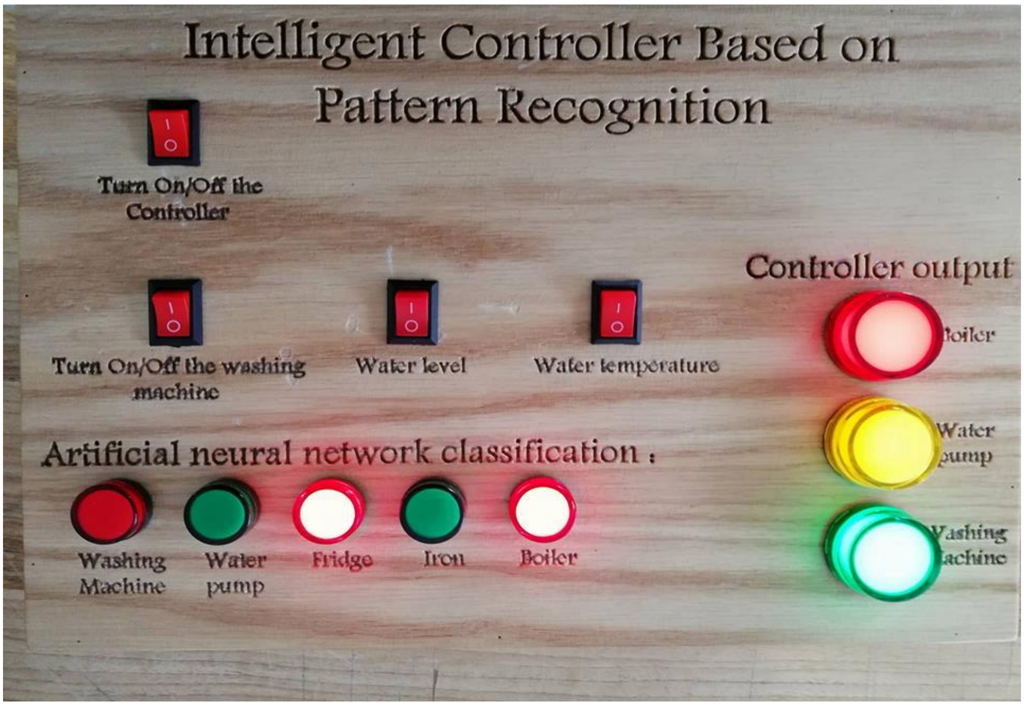


Figure 5-13 Boiler and fridge

Case2:

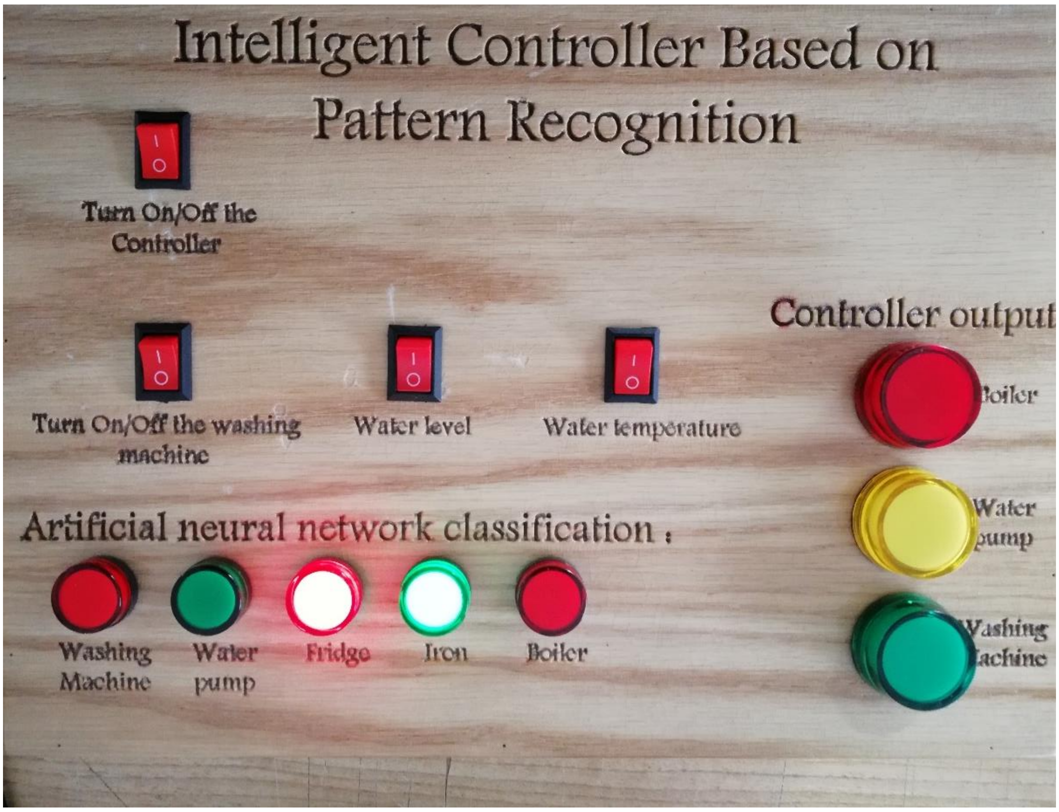


Figure 5-14 fridge and Iron

Case3: In this case washing machine in heater-mode was on.

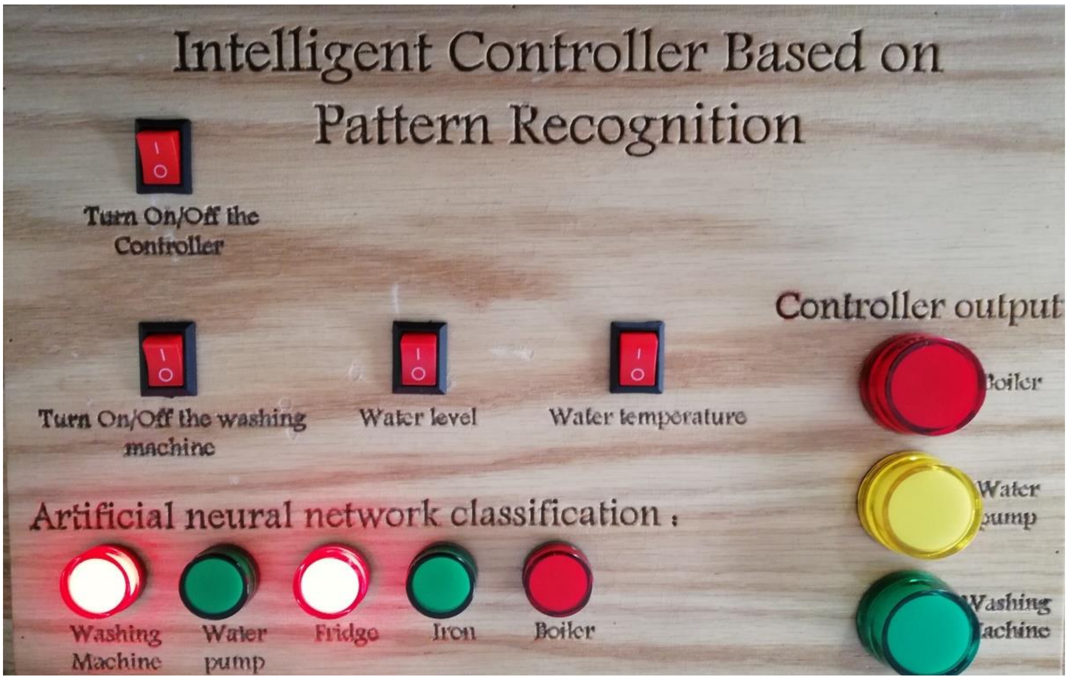


Figure 5-15 washing machine and fridge

Case4:In this case washing machine in spin mode was on.

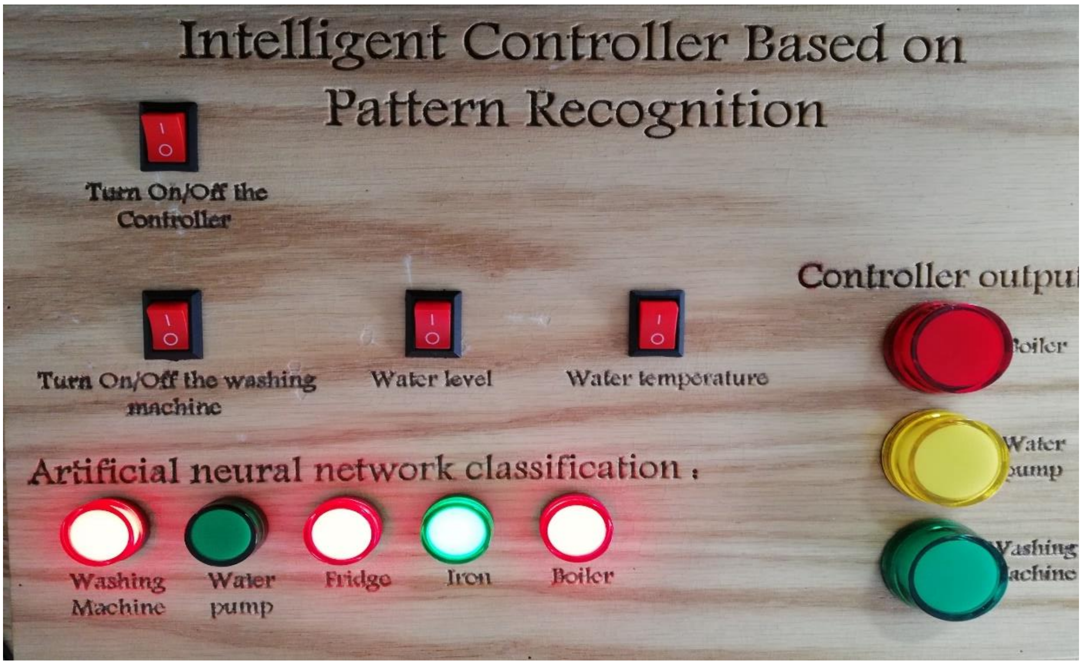


Figure 5-16 washing machine, fridge, and Iron

Case5:

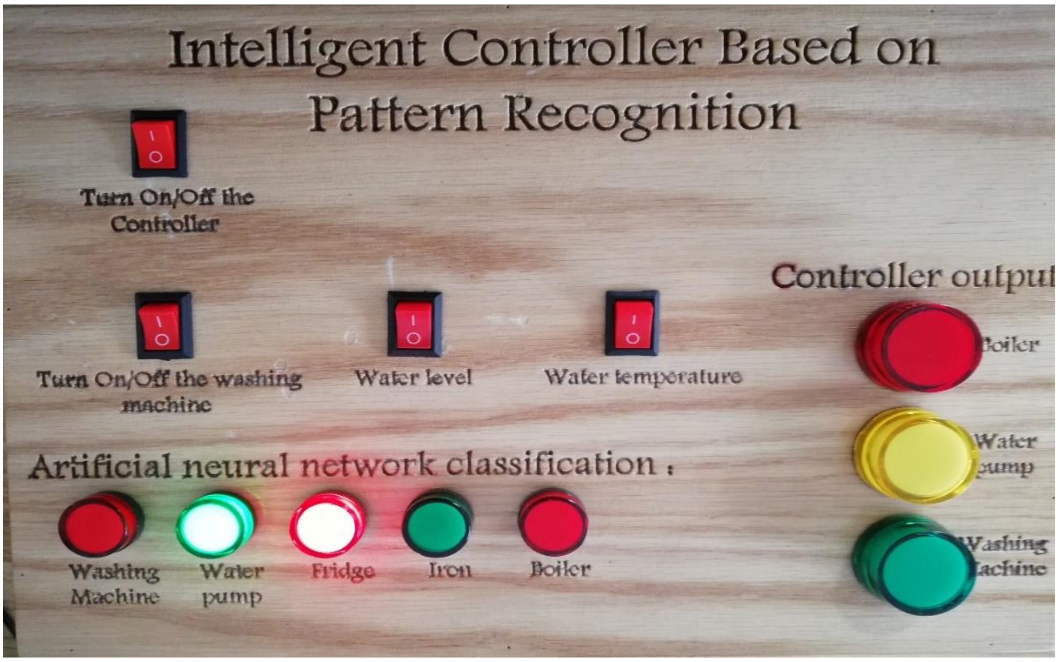


Figure 5-17 water pump and fridge

5.6 Conclusion:

After implementing the controller according to the designed procedure, it was able to load shifting. One of the main difficulties in building the prototype was the large size of code so the suitable microcontroller to implement this system was Arduino Due or Raspberry pi3. The suggests features

5.7 Project conclusion:

An intelligent system has been built, to monitor and control the electric loads in real-time. The controller is based on neural network to recognize electric loads from single current sensor attached on the live wire on main electrical panel. This system was able to recognize all types of loads by using NNPR in the cases where there are no similarity in current consumption. The output from NNPR is then used as an input for the Stateflow controller. The controller was able to shift the operating of electric loads from peak-on hour to peak-off hours, based on Stateflow rules and other conditions.

References:

[1] W. Bank, "Gaza Energy Sector Review," *World Bank report, Report*, no. 39695-GZ, 2007.

[2] B. T. Q. Yaseen, "Energy efficiency improvement and cost saving measures in some different industries in Palestine," 2008.

[3] Y. Kim, T. Schmid, Z. M. Charbiwala, and M. B. Srivastava, "ViridiScope: design and implementation of a fine grained power monitoring system for homes," in *Proceedings of the 11th international conference on Ubiquitous computing*, 2009, pp. 245-254: ACM.

[4] L. Farinaccio and R. Zmeureanu, "Using a pattern recognition approach to disaggregate the total electricity consumption in a house into the major end-uses," *Energy and Buildings*, vol. 30, no. 3, pp. 245-259, 1999.

[5] S. N. Patel, T. Robertson, J. A. Kientz, M. S. Reynolds, and G. D. Abowd, "At the flick of a switch: Detecting and classifying unique electrical events on the residential power line," *Lecture Notes in Computer Science*, vol. 4717, pp. 271-288, 2007.

[6] D. Zufferey, C. Gisler, O. A. Khaled, and J. Hennebert, "Machine learning approaches for electric appliance classification," in *Information Science, Signal Processing and their Applications (ISSPA), 2012 11th International Conference on*, 2012, pp. 740-745: IEEE.

[7] A. G. Ruzzelli, C. Nicolas, A. Schoofs, and G. M. O'Hare, "Real-time recognition and profiling of appliances through a single electricity sensor," in *Sensor Mesh and Ad Hoc Communications and Networks (SECON), 2010 7th Annual IEEE Communications Society Conference on*, 2010, pp. 1-9: IEEE.

[8] L. Pérez-Lombard, J. Ortiz, and C. Pout, "A review on buildings energy consumption information," Energy and buildings, vol. 40, no. 3, pp. 394-398, 2008.

[9] https://www.mathworks.com/products/matlab.html.

[10] http://www.onsetcomp.com/products/sensors/ctv-c.

Appendix A

Neural network pattern recognition Code

```
% Solve a Pattern Recognition Problem with a Neural Network
% Script generated by Neural Pattern Recognition app
% Created 15-Dec-2017 18:16:49
%
% This script assumes these variables are defined:
%
%   nm - input data.
%   n - target data.

x = input;
t = output;

% Choose a Training Function
% For a list of all training functions type: help nntrain
% 'trainlm' is usually fastest.
% 'trainbr' takes longer but may be better for challenging problems.
% 'trainscg' uses less memory. Suitable in low memory situations.
trainFcn = 'trainscg';  % Scaled conjugate gradient backpropagation.

% Create a Pattern Recognition Network
hiddenLayerSize = 10;
net = patternnet(hiddenLayerSize, trainFcn);

% Choose Input and Output Pre/Post-Processing Functions
% For a list of all processing functions type: help nnprocess
net.input.processFcns = {'removeconstantrows','mapminmax'};
net.output.processFcns = {'removeconstantrows','mapminmax'};

% Setup Division of Data for Training, Validation, Testing
% For a list of all data division functions type: help nndivide
net.divideFcn = 'dividerand';  % Divide data randomly
net.divideMode = 'sample';  % Divide up every sample
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;

% Choose a Performance Function
% For a list of all performance functions type: help nnperformance
net.performFcn = 'crossentropy';  % Cross-Entropy

% Choose Plot Functions
% For a list of all plot functions type: help nnplot
net.plotFcns = {'plotperform','plottrainstate','ploterrhist', ...
```

```
    'plotconfusion', 'plotroc'};

% Train the Network
[net,tr] = train(net,x,t);

% Test the Network
y = net(x);
e = gsubtract(t,y);
performance = perform(net,t,y)
tind = vec2ind(t);
yind = vec2ind(y);
percentErrors = sum(tind ~= yind)/numel(tind);

% Recalculate Training, Validation and Test Performance
trainTargets = t .* tr.trainMask{1};
valTargets = t .* tr.valMask{1};
testTargets = t .* tr.testMask{1};
trainPerformance = perform(net,trainTargets,y)
valPerformance = perform(net,valTargets,y)
testPerformance = perform(net,testTargets,y)

% View the Network
view(net)

% Plots
% Uncomment these lines to enable various plots.
%figure, plotperform(tr)
%figure, plottrainstate(tr)
%figure, ploterrhist(e)
%figure, plotconfusion(t,y)
%figure, plotroc(t,y)

% Deployment
% Change the (false) values to (true) to enable the following code blocks.
% See the help for each generation function for more information.
if (false)
    % Generate MATLAB function for neural network for application
    % deployment in MATLAB scripts or with MATLAB Compiler and Builder
    % tools, or simply to examine the calculations your trained neural
    % network performs.
    genFunction(net,'myNeuralNetworkFunction');
    y = myNeuralNetworkFunction(x);
end
if (false)
    % Generate a matrix-only MATLAB function for neural network code
    % generation with MATLAB Coder tools.
    genFunction(net,'myNeuralNetworkFunction','MatrixOnly','yes');
```

```
    y = myNeuralNetworkFunction(x);
end
if (false)
    % Generate a Simulink diagram for simulation or deployment with.
    % Simulink Coder tools.
    gensim(net);
end
```

Appendix B

Arduino code for current sensor

```
void loop()
{
  int current = 0;
  int maxCurrent = 0;
  int minCurrent = 1000;
  for (int i=0 ; i<=200 ; i++)  //Monitors and logs the current input for 200 cycles to determine max and min
current
  {
    current = analogRead(currentPin);    //Reads current input
    if(current >= maxCurrent)
      maxCurrent = current;
    else if(current <= minCurrent)
      minCurrent = current;
  }
  if (maxCurrent <= 517)
  {
    maxCurrent = 516;
  }
  double RMSCurrent = ((maxCurrent - 516)*0.707)/5.9;    //Calculates RMS current based on maximum
value
 itoa(RMSCurrent, str, 10); //Turn value into a character array
 Serial.write(str,4);
 Serial.println(RMSCurrent);
}
```

Appendix C

A measurement of the current pattern consumption of Home appliances

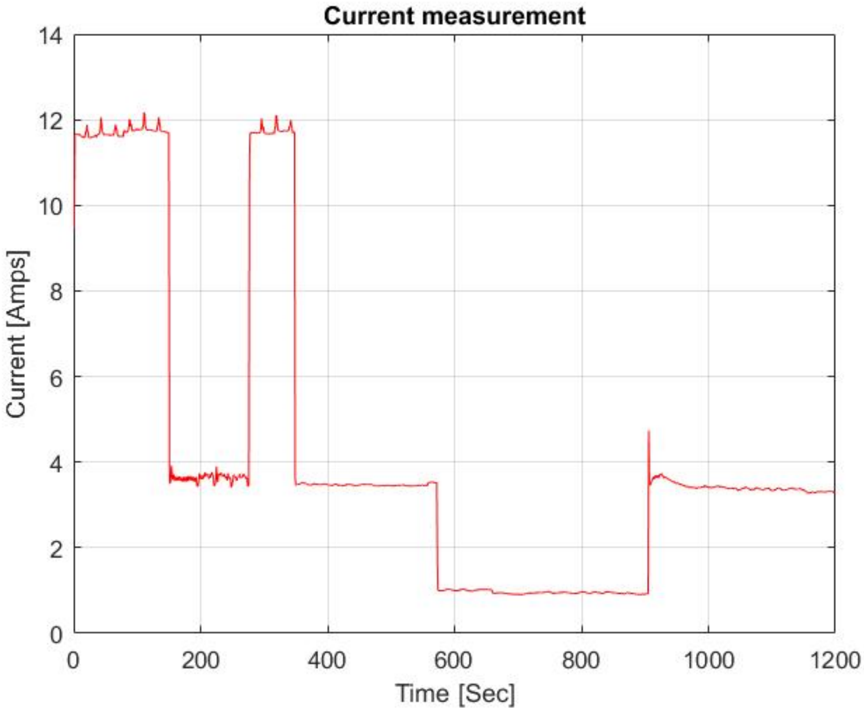


Figure 0-1 Heater-mode

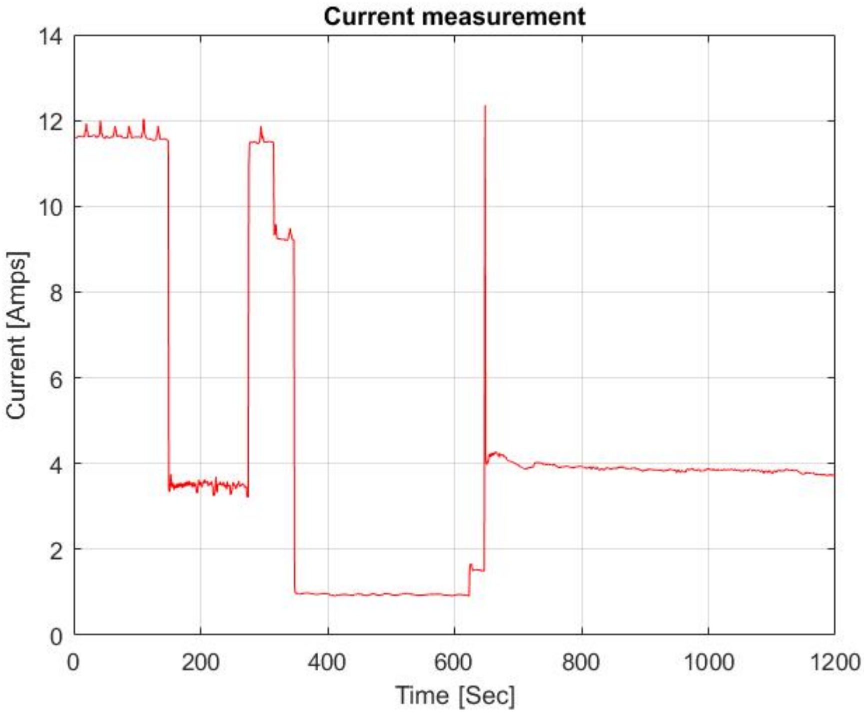


Figure 0-2 Heater-mode

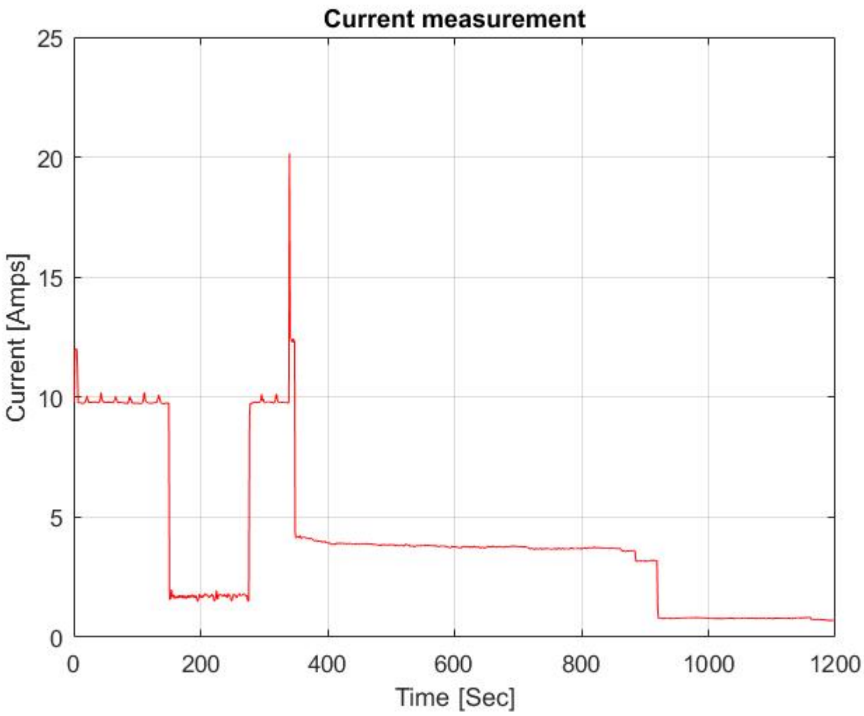


Figure 0-3 Heater-mode

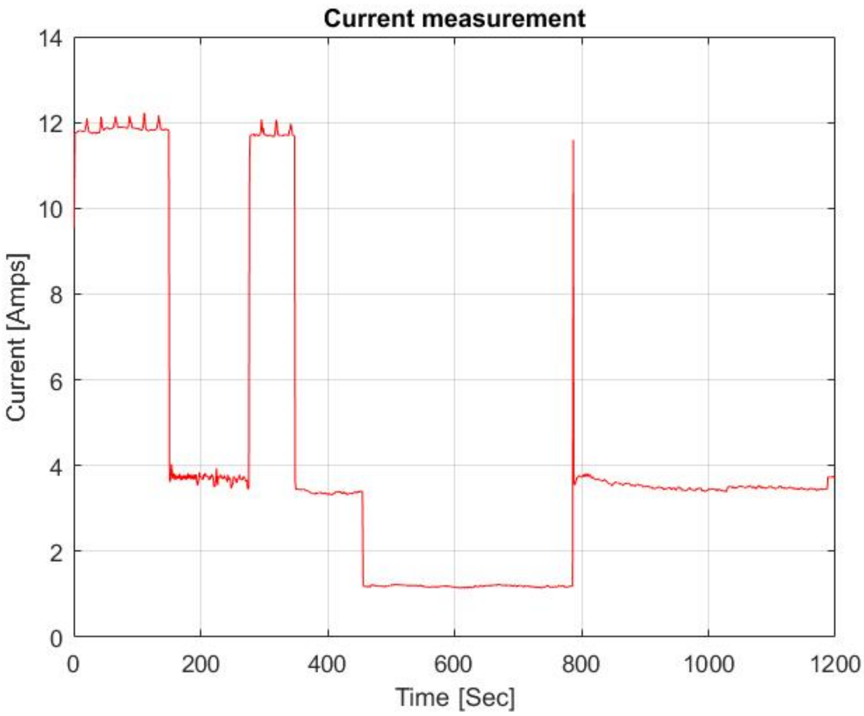


Figure 0-4 Heater-mode

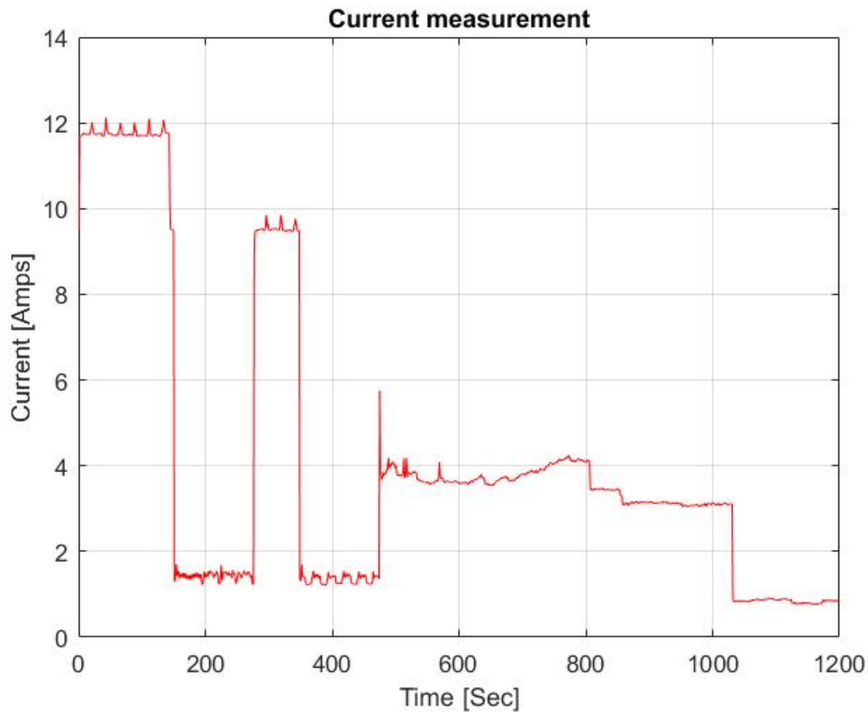


Figure 0-5 Heater-mode

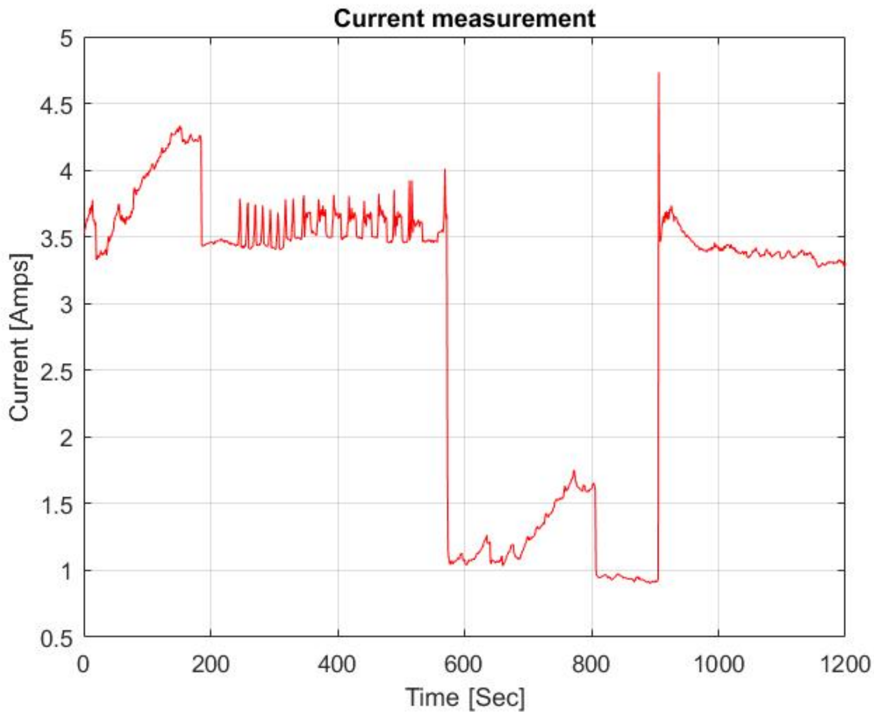


Figure 0-6 Rinse-mode

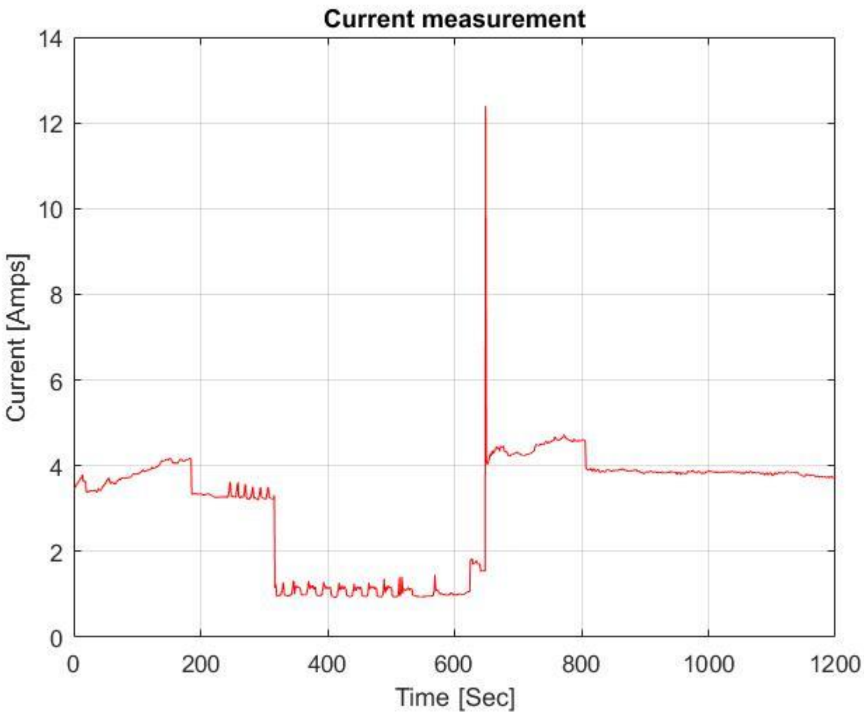


Figure 0-7 Rinse-mode

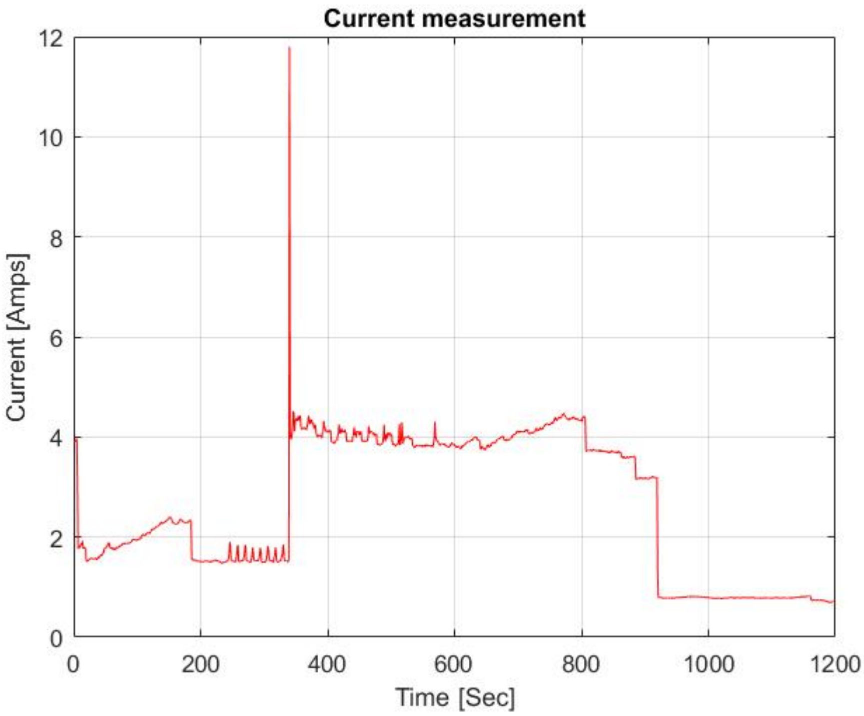


Figure 0-8 Rinse-mode

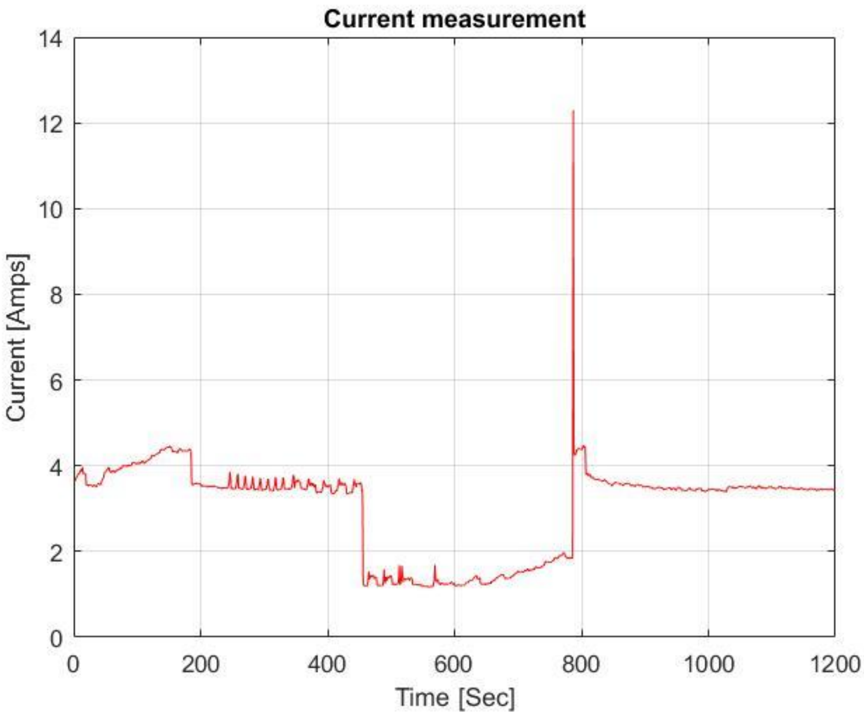


Figure 0-9 Rinse-mode

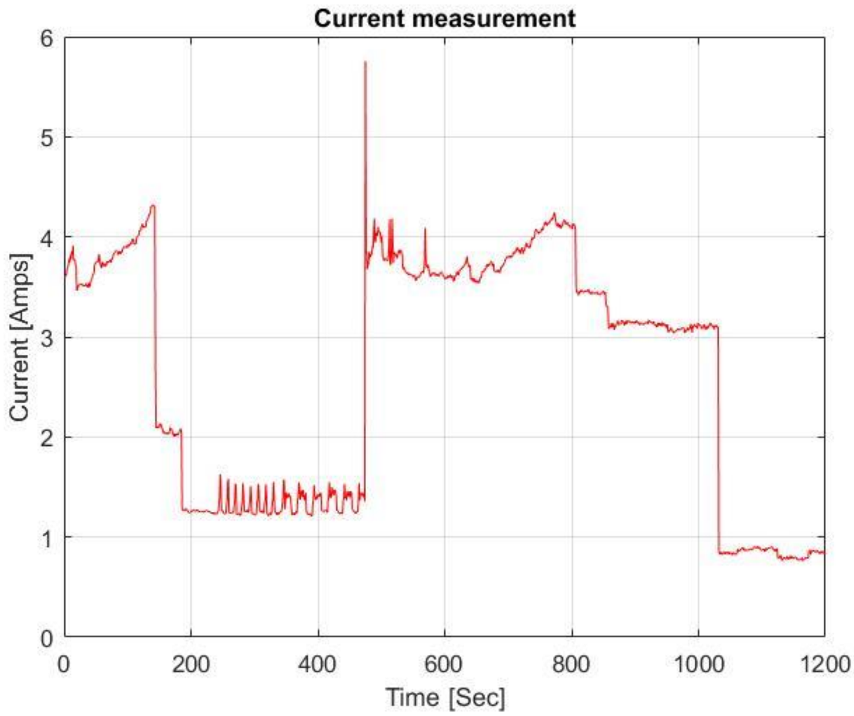


Figure 0-10 Rinse-mode

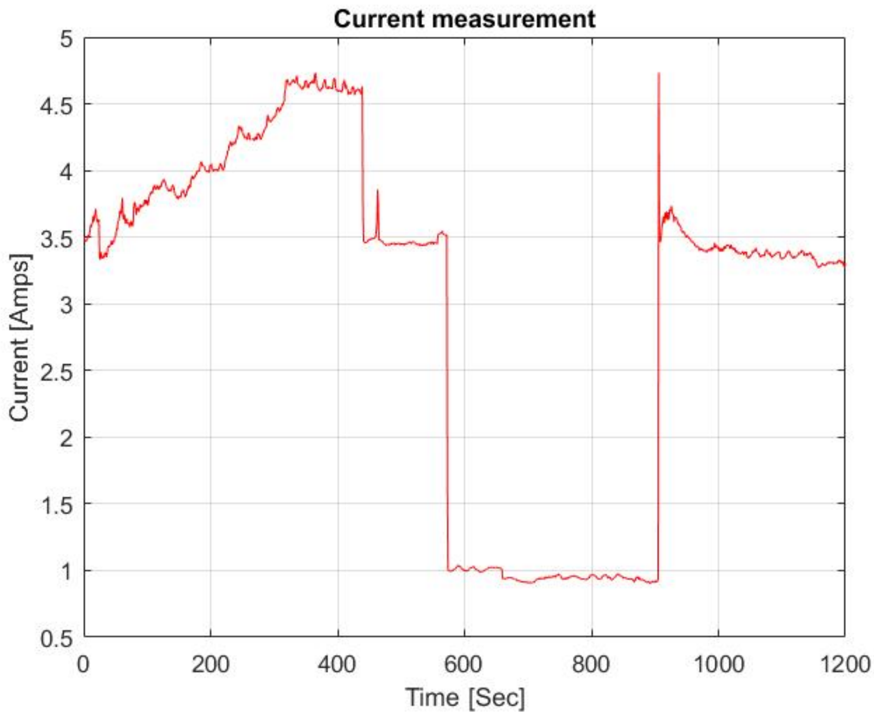


Figure 0-11 Spin-mode

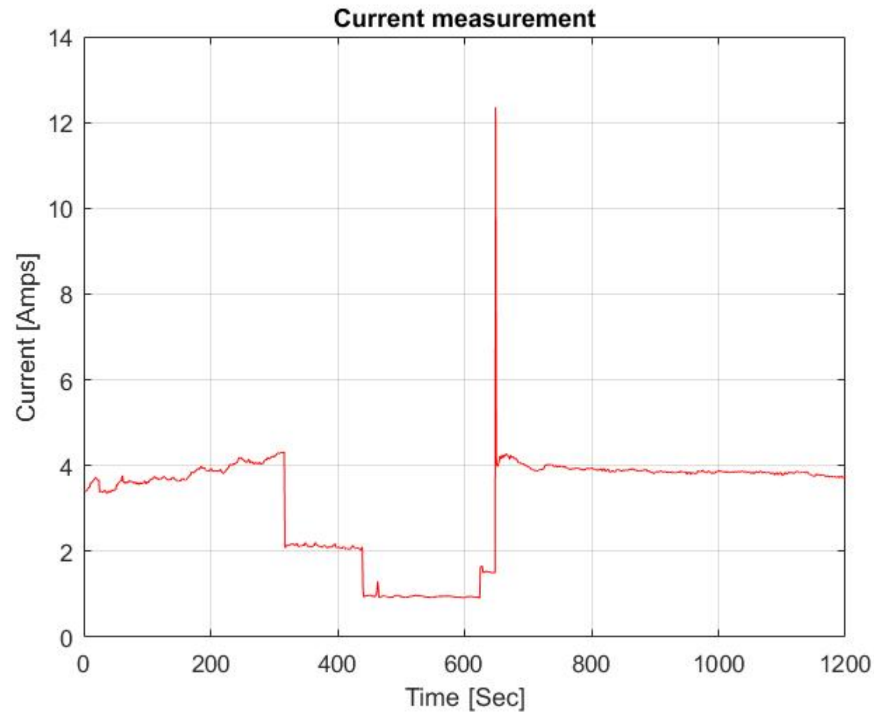


Figure 0-12 Spin-mode

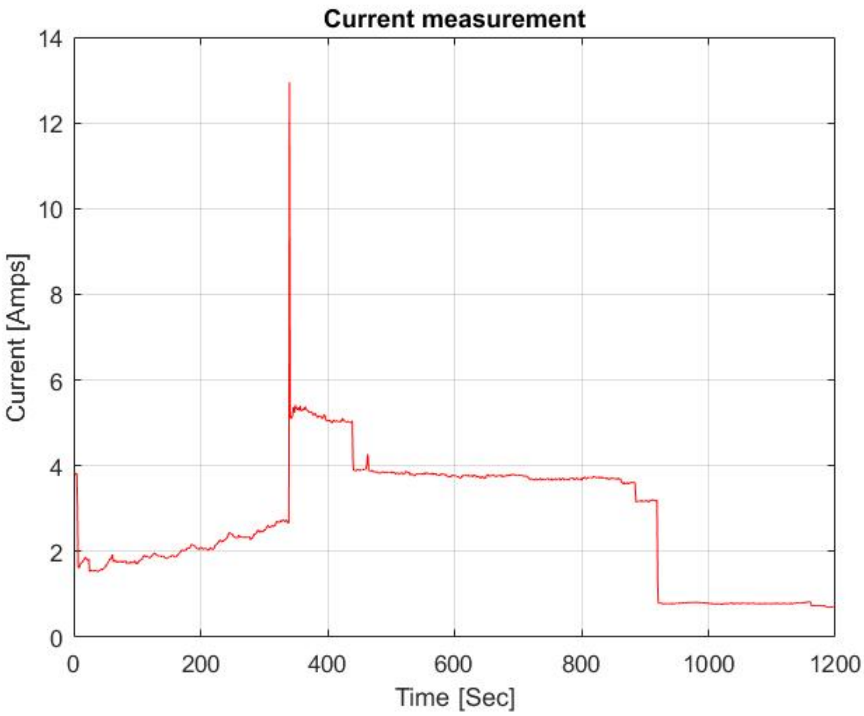


Figure 0-13 Spin-mode

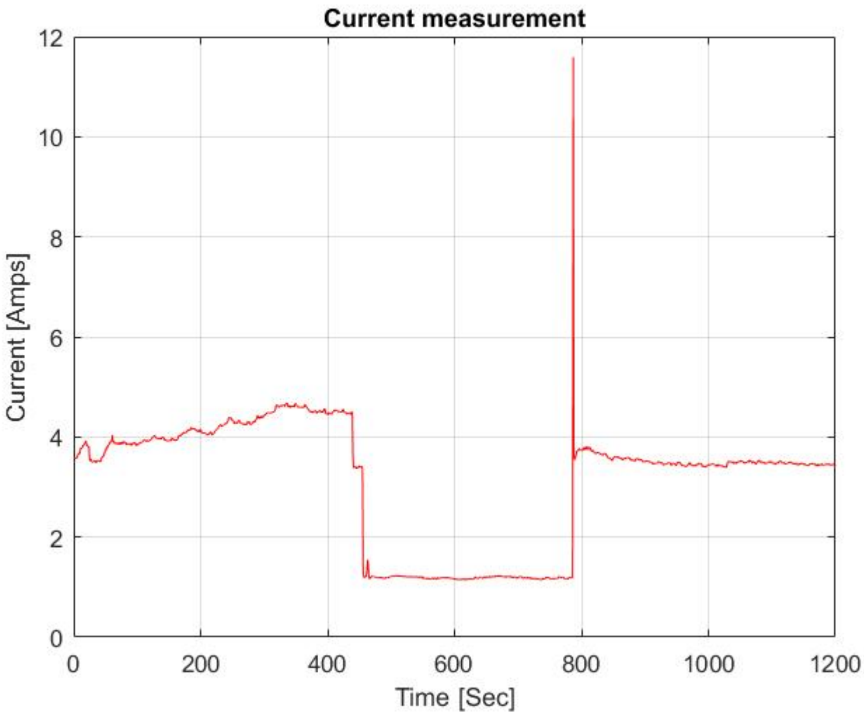


Figure 0-14 Spin-mode

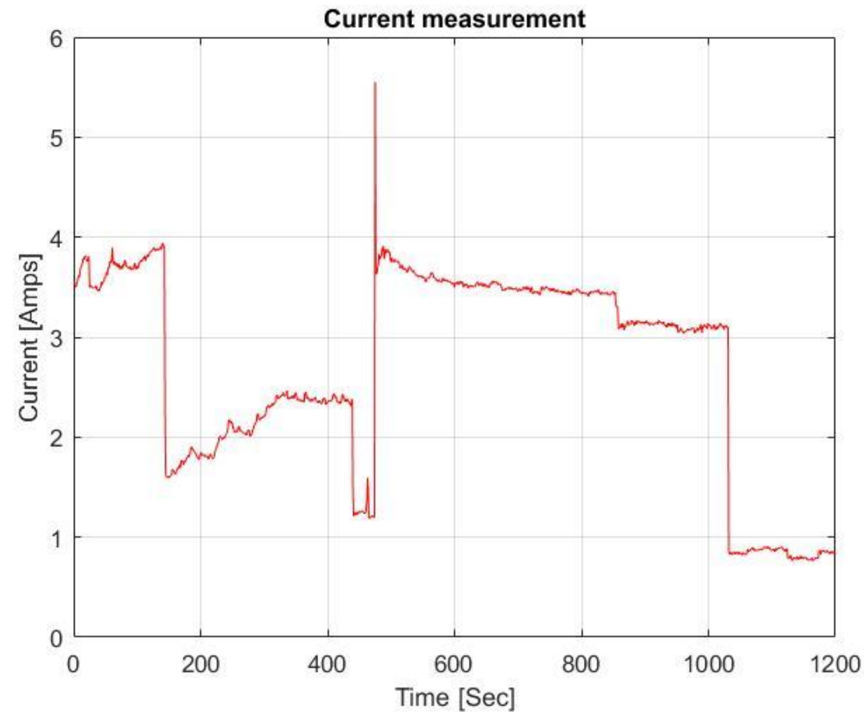


Figure 0-15 Spin-mode

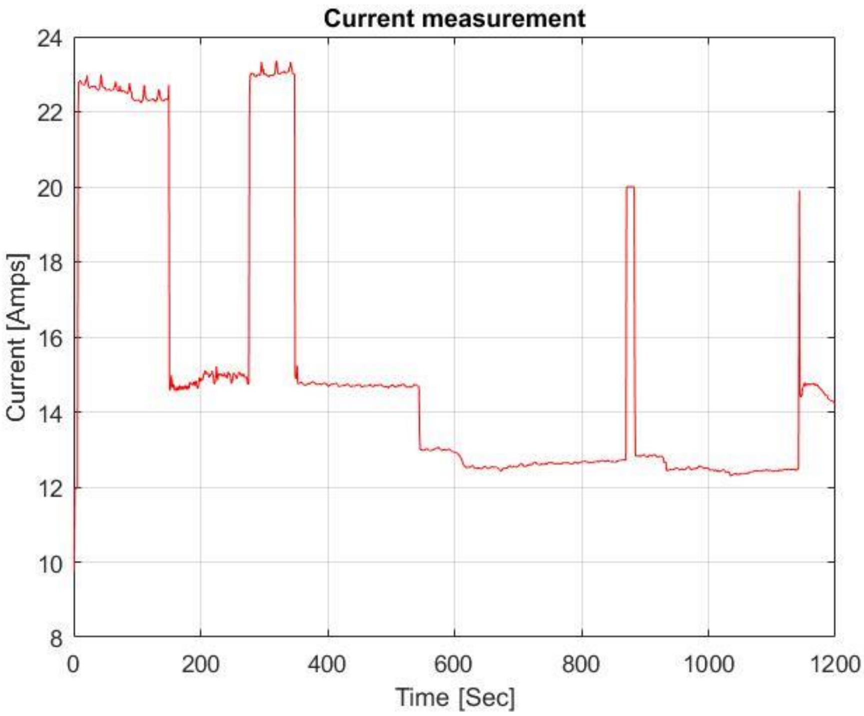


Figure 0-16 Heater-mode & boiler

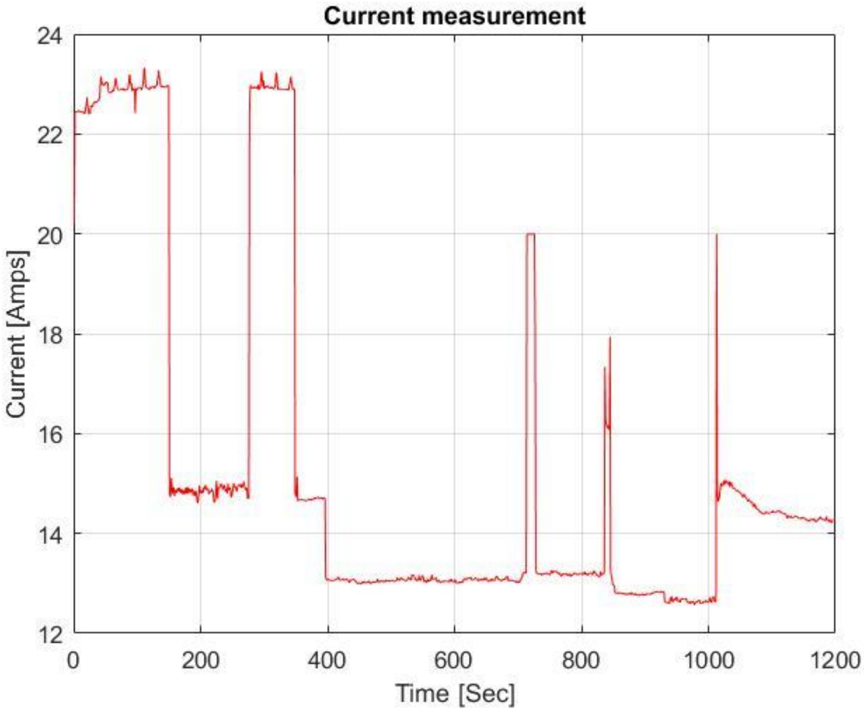


Figure 0-17 Heater-mode & boiler

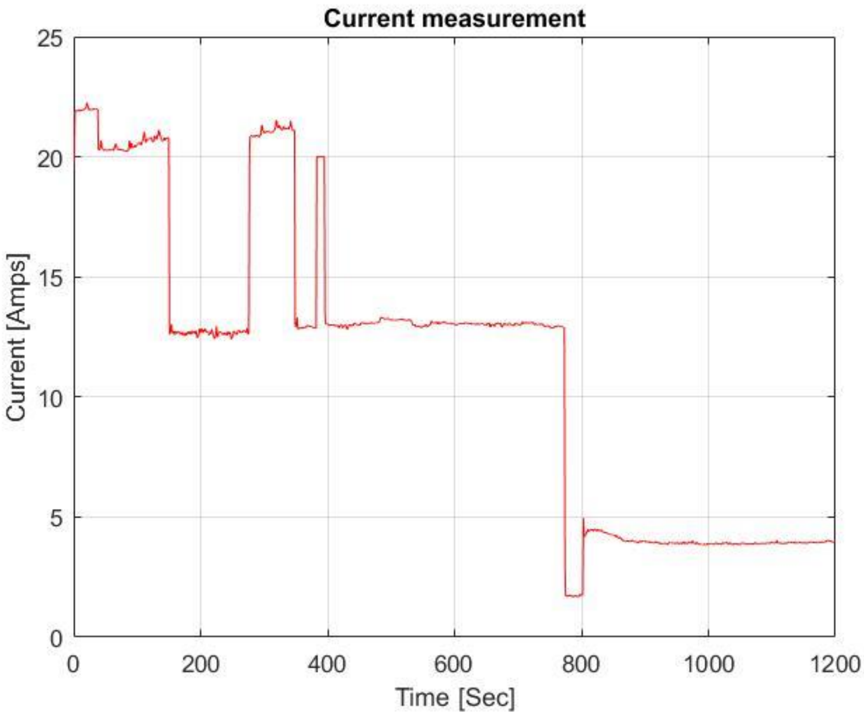


Figure 0-18 Heater-mode & boiler

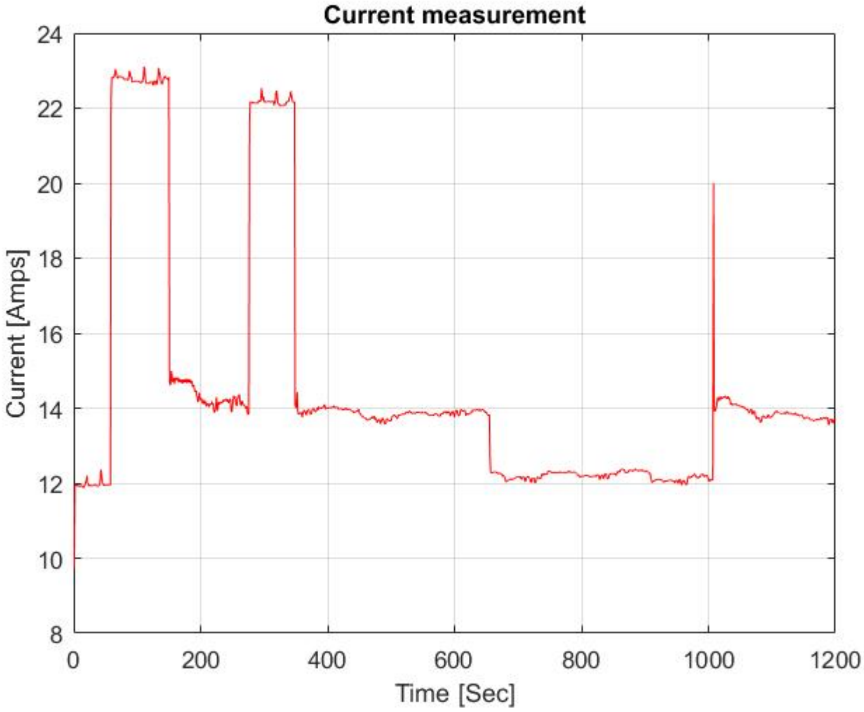


Figure 0-19 Heater-mode & boiler

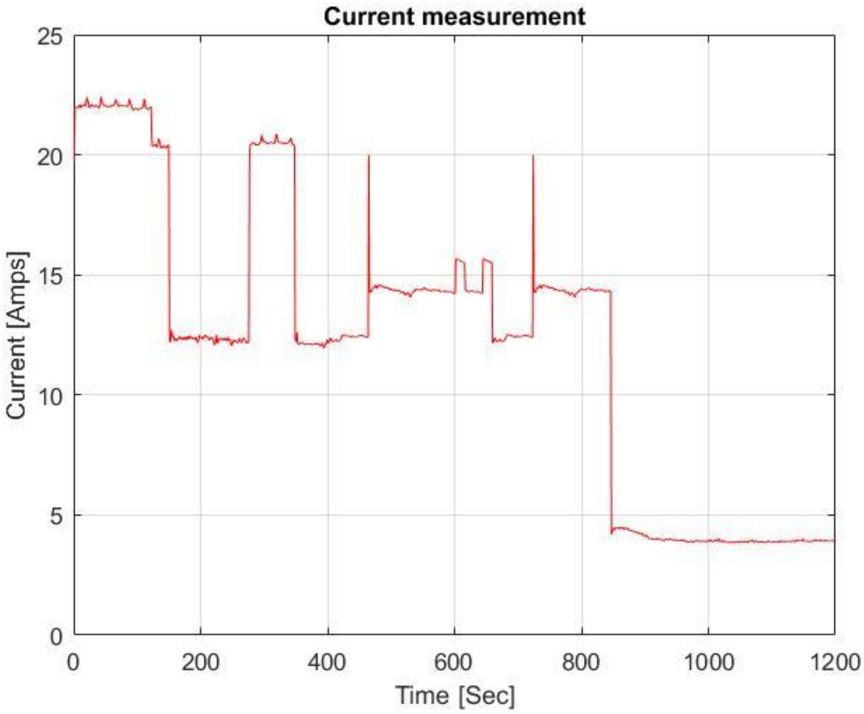


Figure 0-20 Heater-mode & boiler

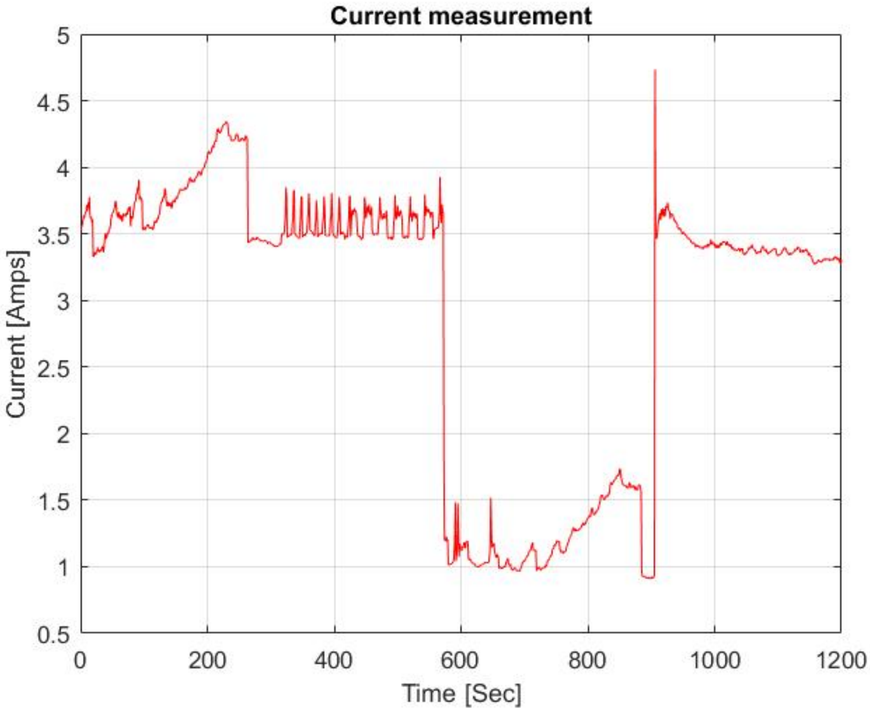


Figure 0-21 Rinse-mode & boiler

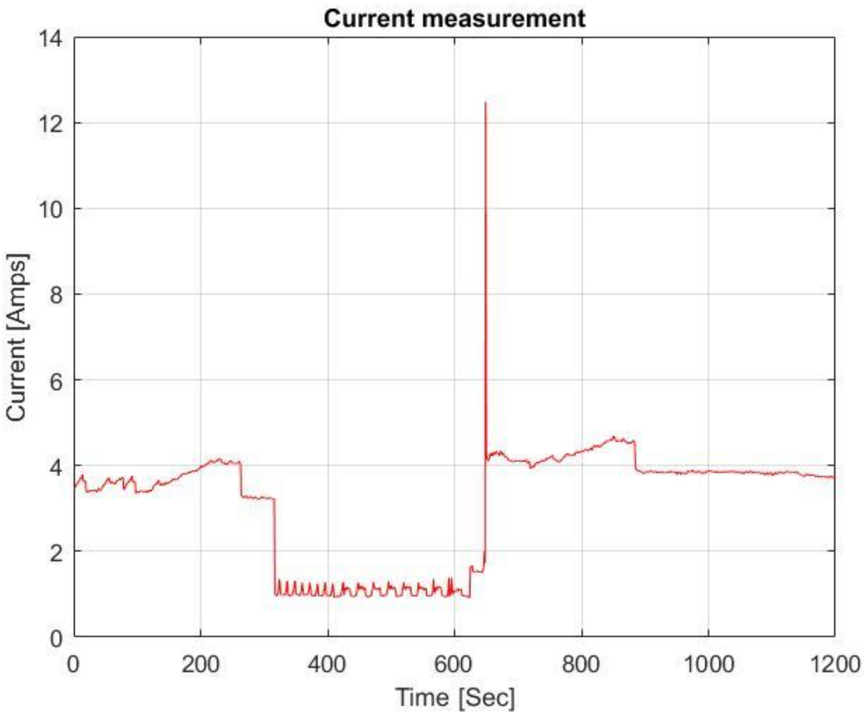


Figure 0-22 Rinse-mode & boiler

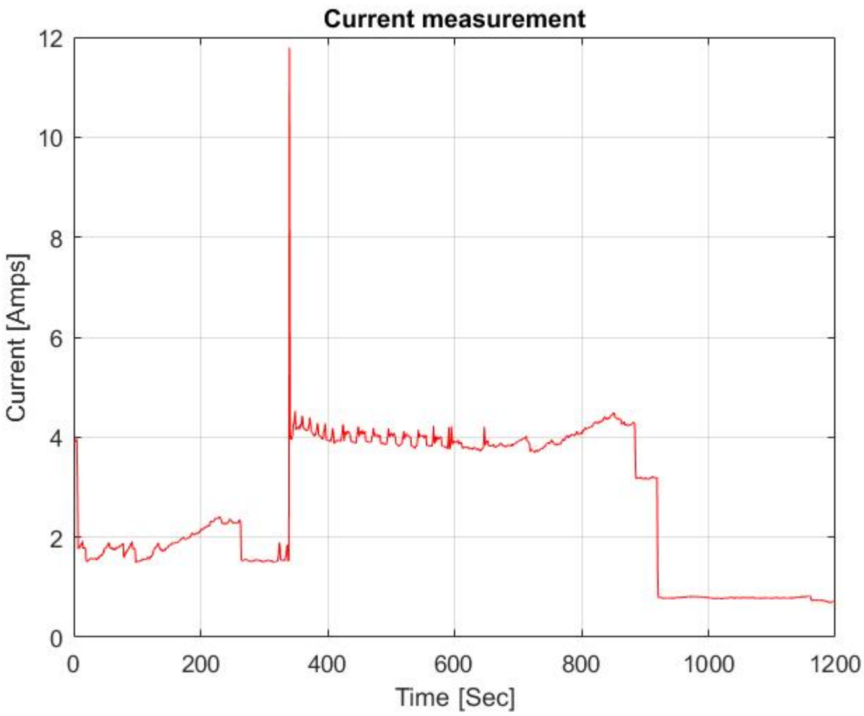


Figure 0-23 Rinse-mode & boiler

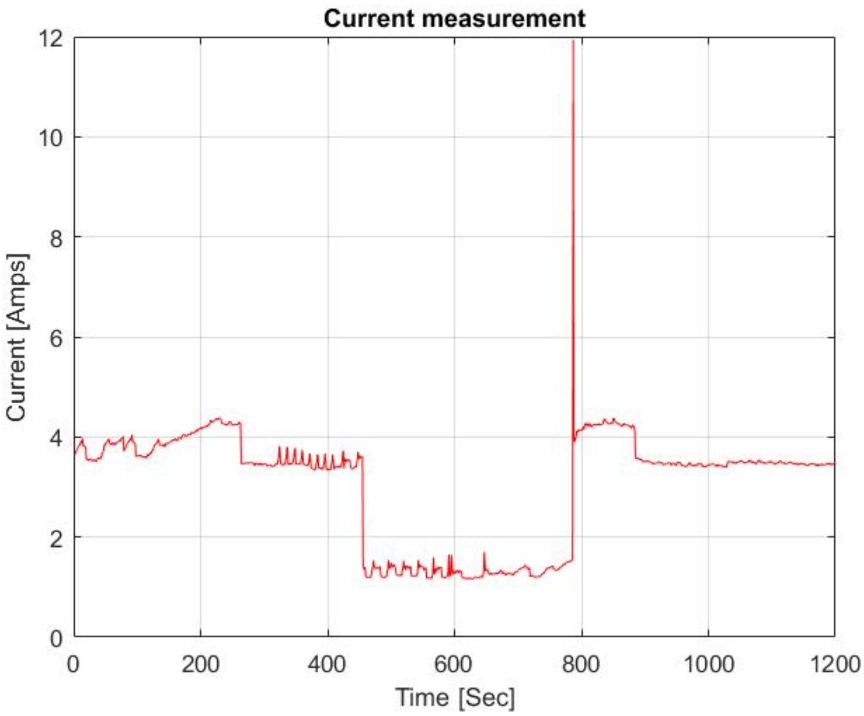


Figure 0-24 Rinse-mode & boiler

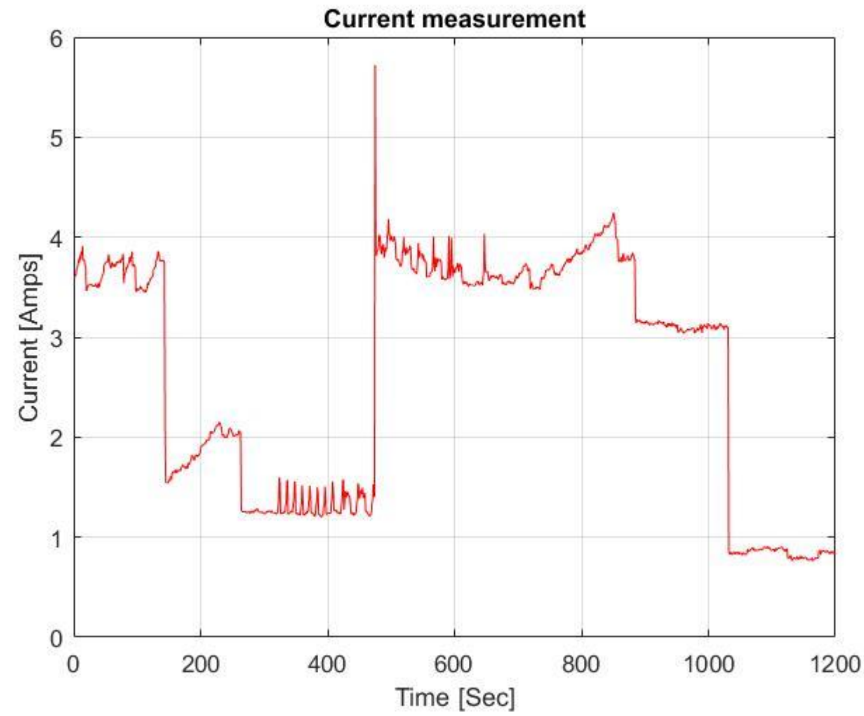


Figure 0-25 Rinse-mode & boiler

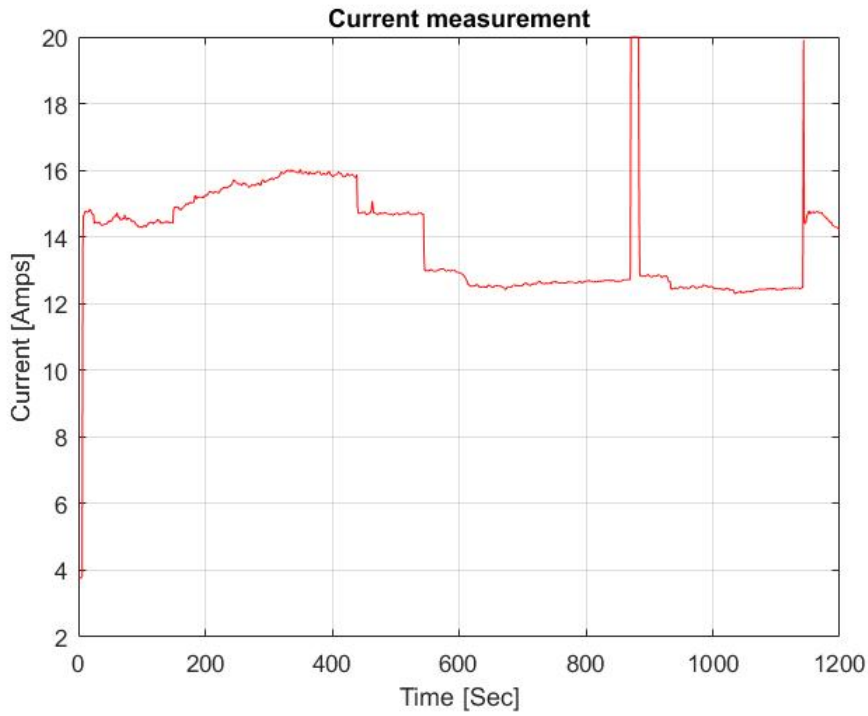


Figure 0-26 Spin-mode & boiler

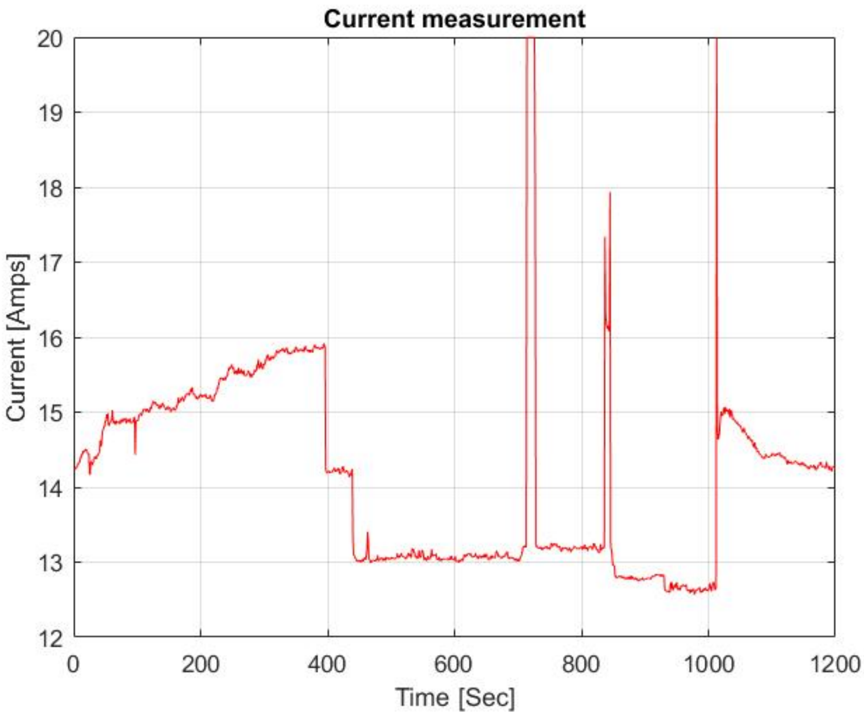


Figure 0-27 Spin-mode & boiler

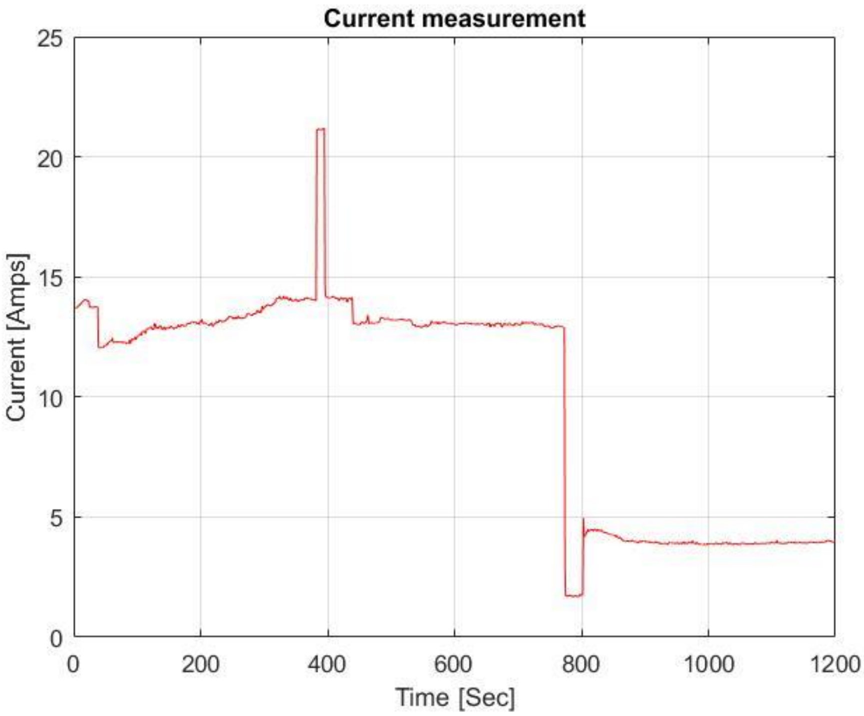


Figure 0-28 Spin-mode & boiler

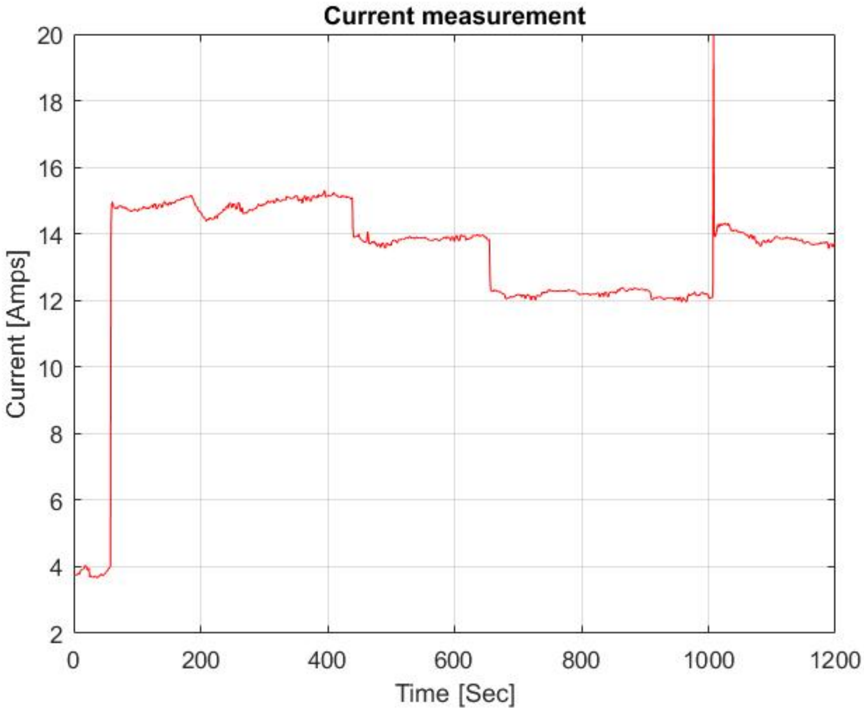


Figure 0-29 Spin-mode & boiler

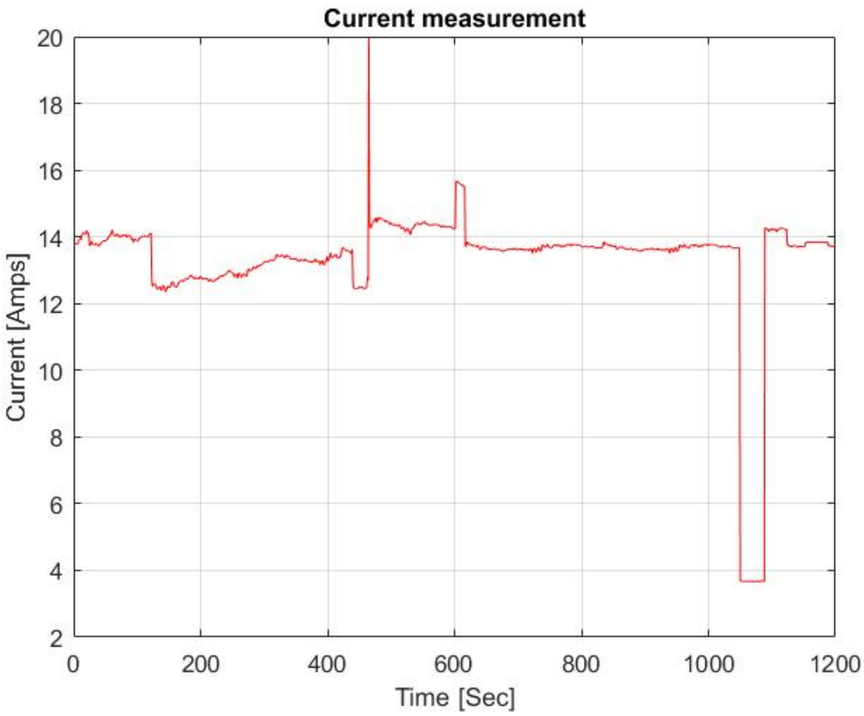


Figure 0-30 Spin-mode & boiler

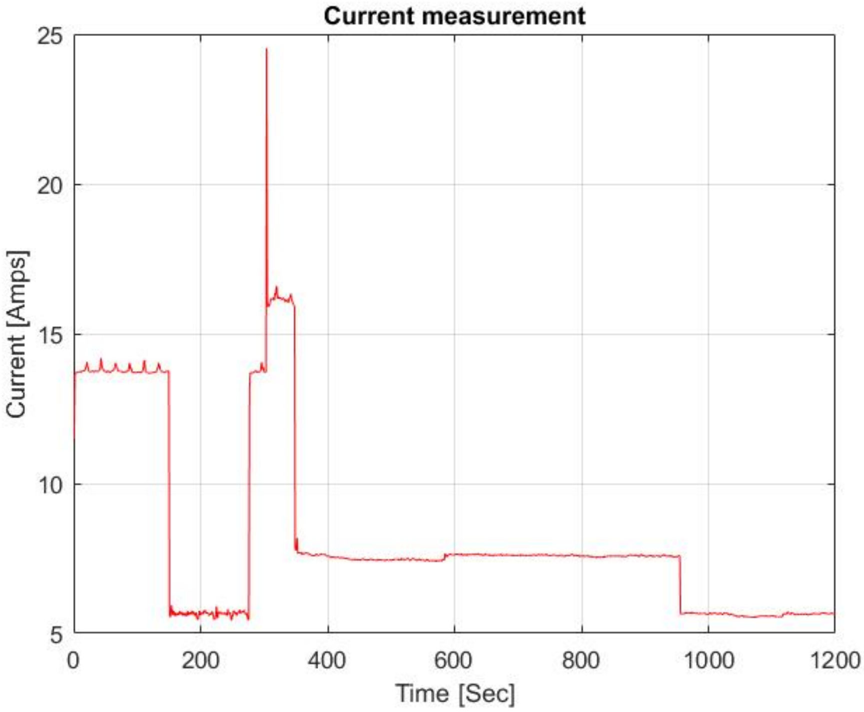


Figure 0-31 Heater-mode & motor

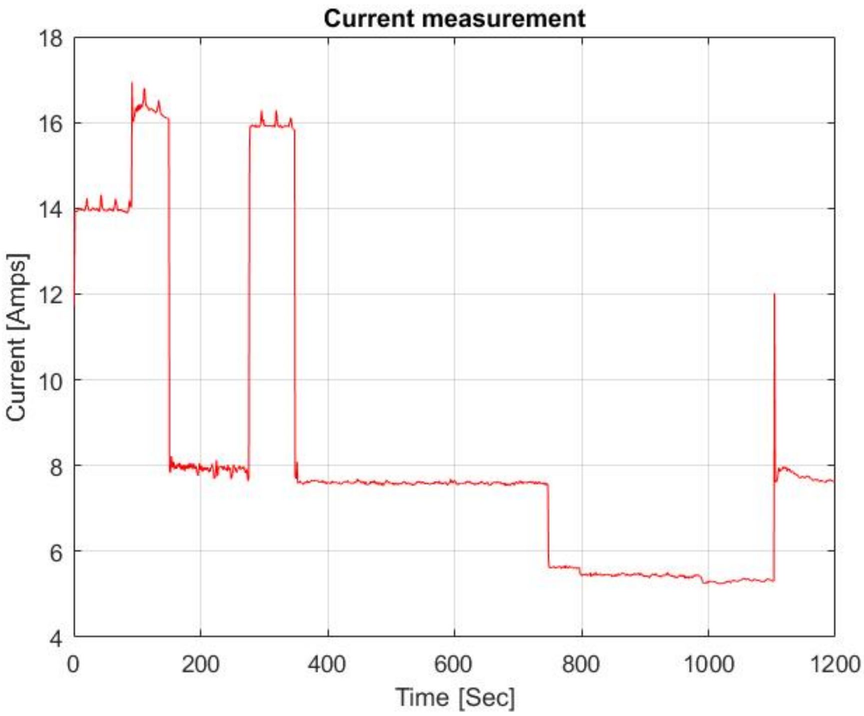


Figure 0-32 Heater-mode & motor

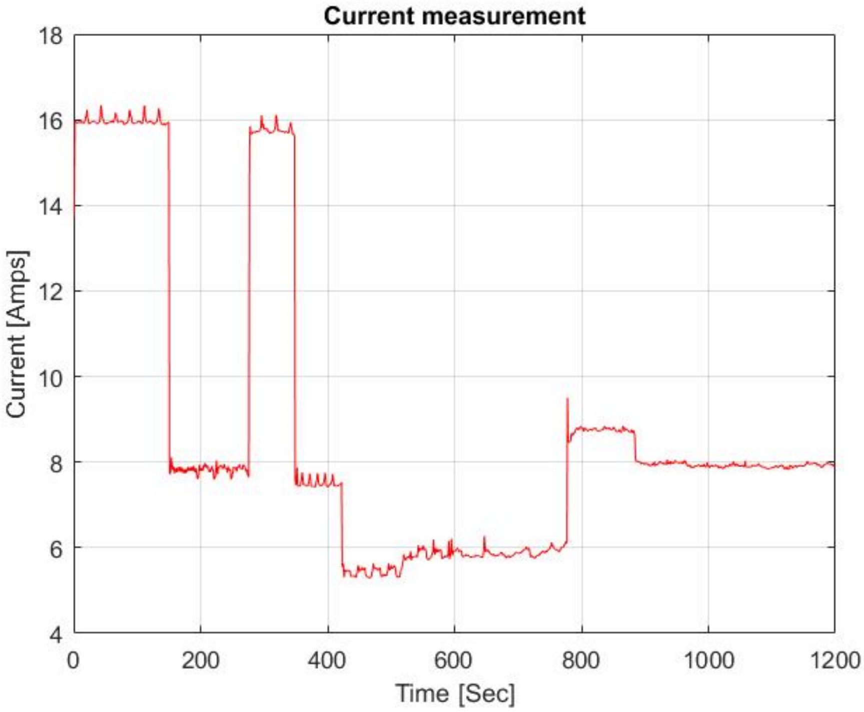


Figure 0-33 Heater-mode & motor

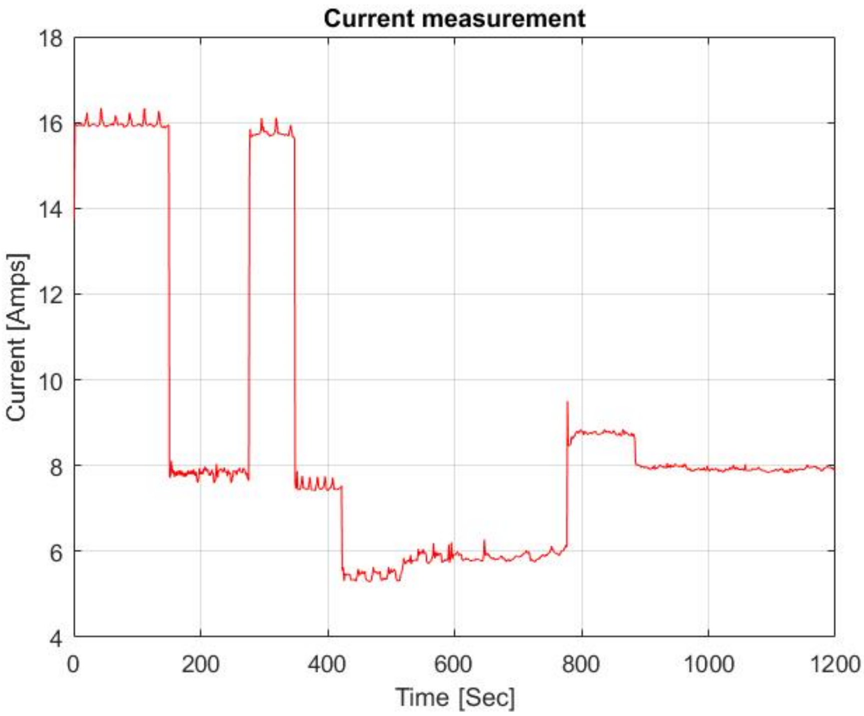


Figure 0-34 Heater-mode & motor

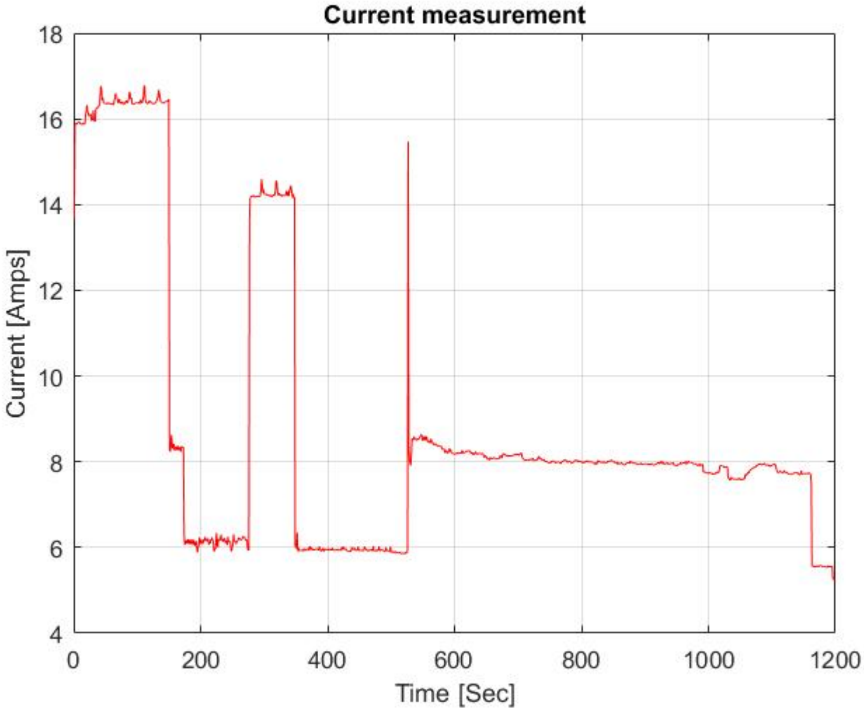


Figure 0-35 Heater-mode & motor

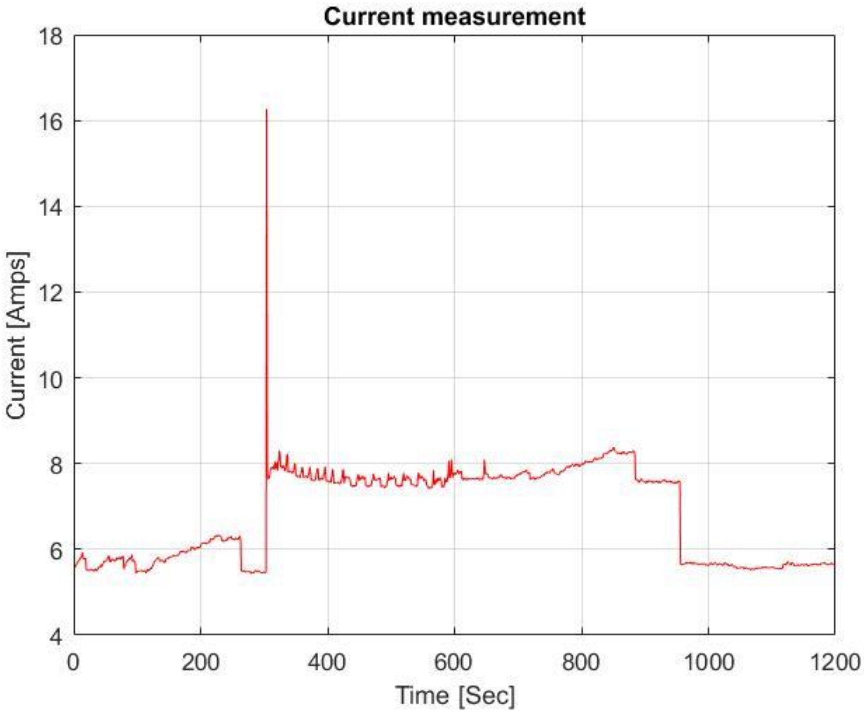


Figure 0-36 Rinse-mode & motor

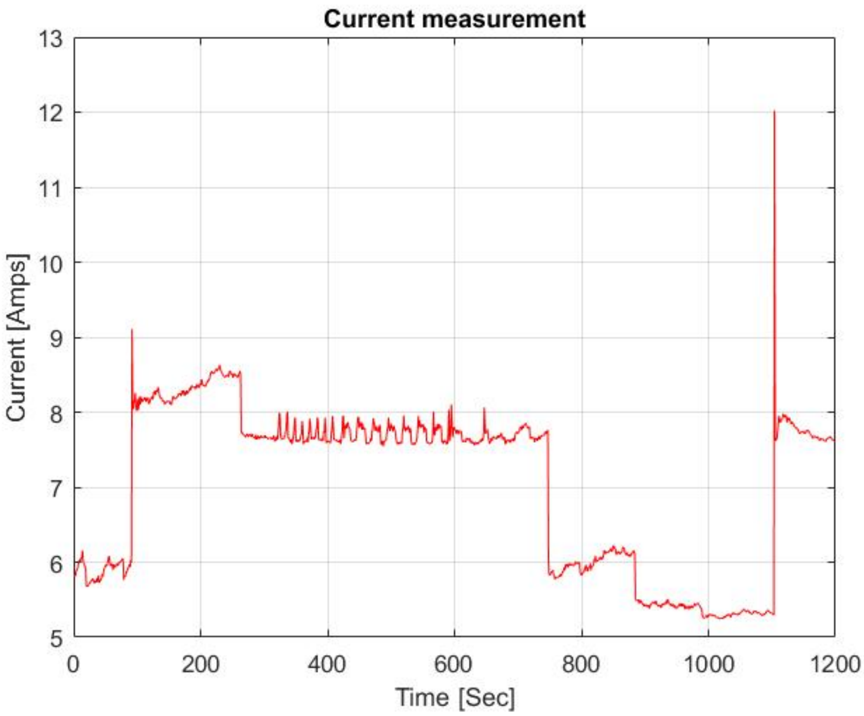


Figure 0-37 Rinse-mode & motor

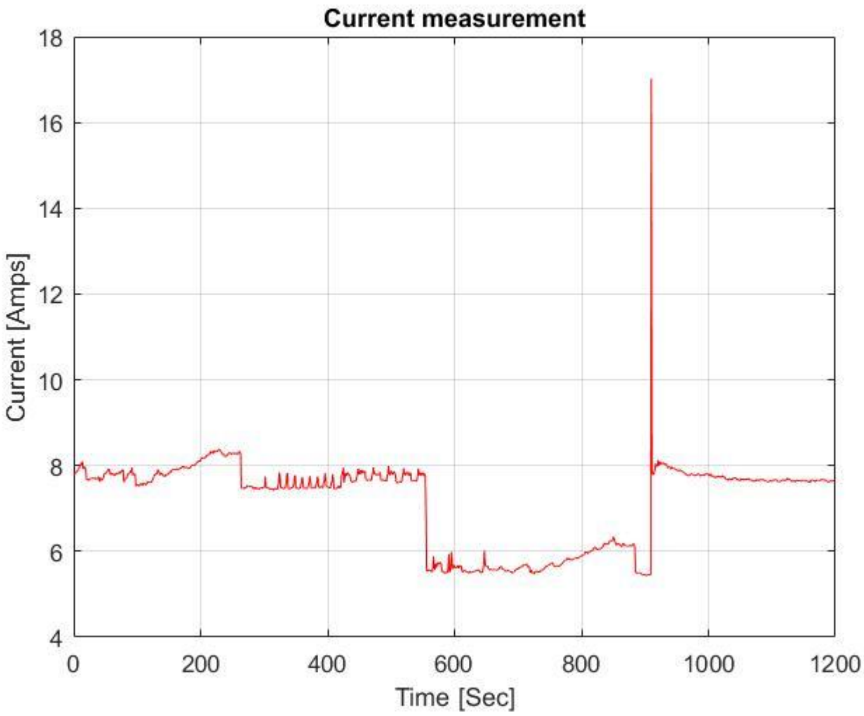


Figure 0-38 Rinse-mode & motor

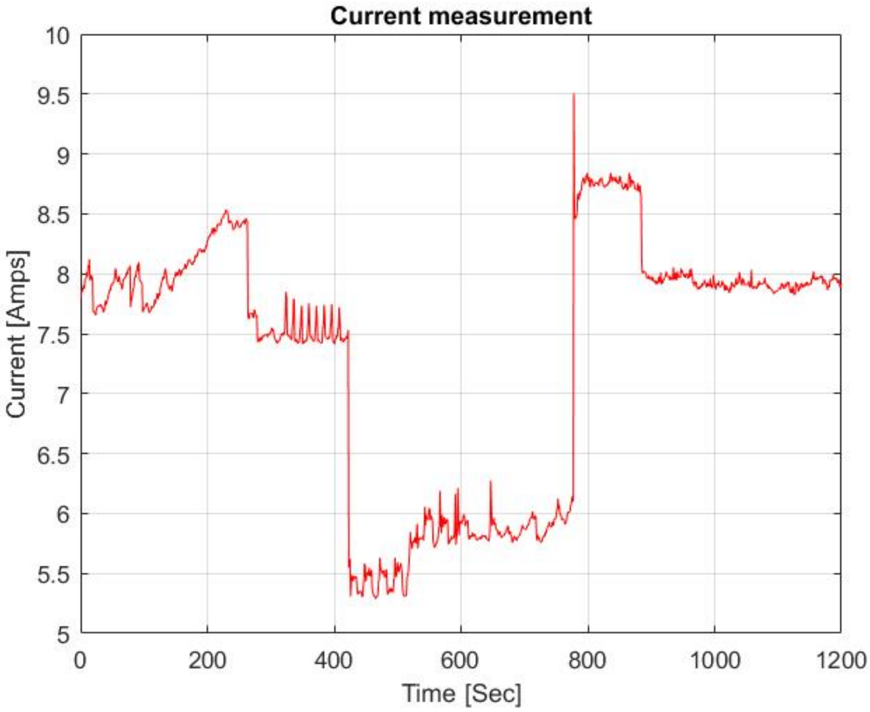


Figure 0-39 Rinse-mode & motor

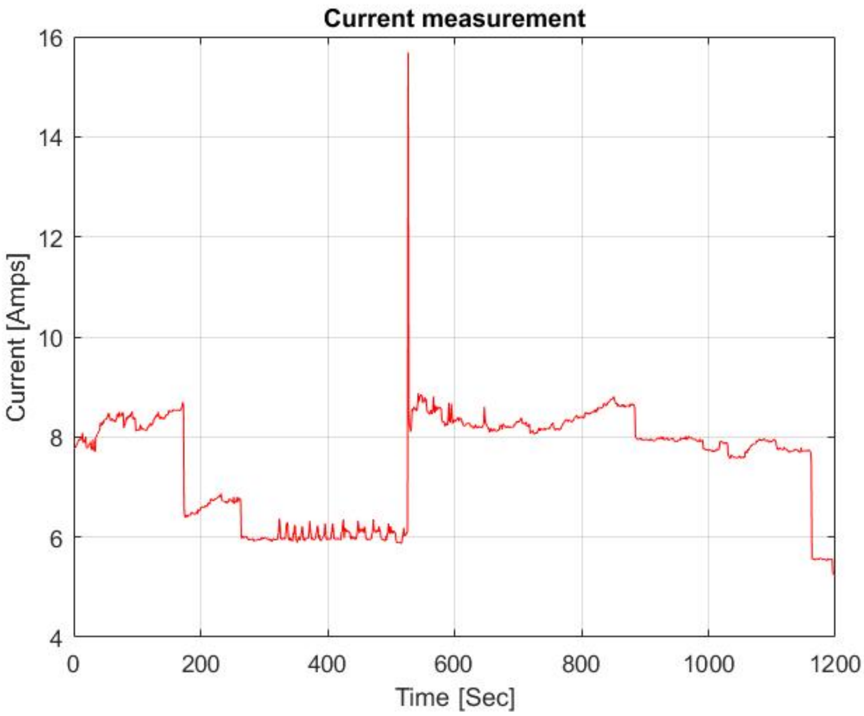


Figure 0-40 Rinse-mode & motor

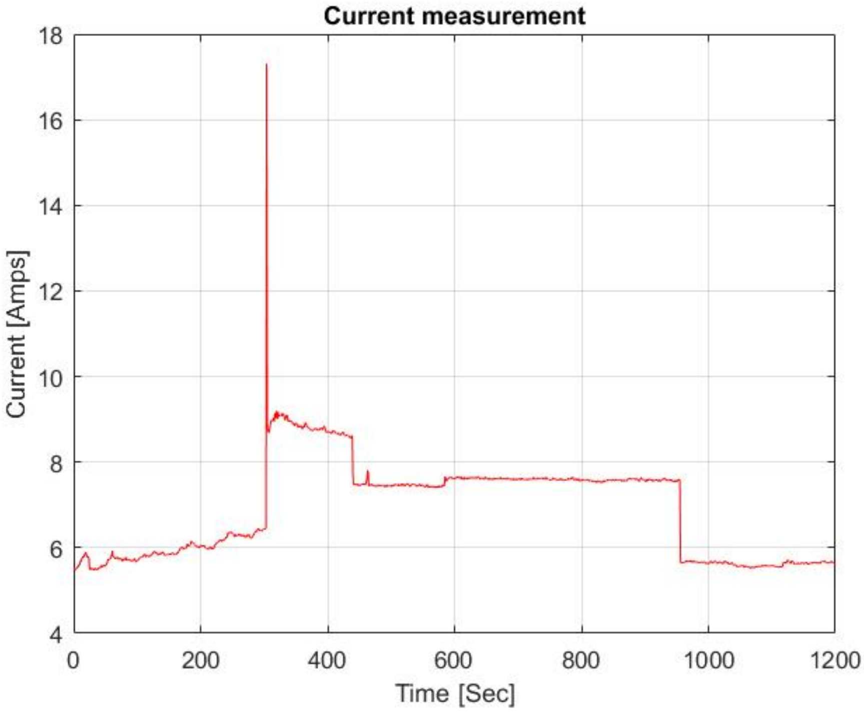


Figure 0-41 Spin-mode & motor

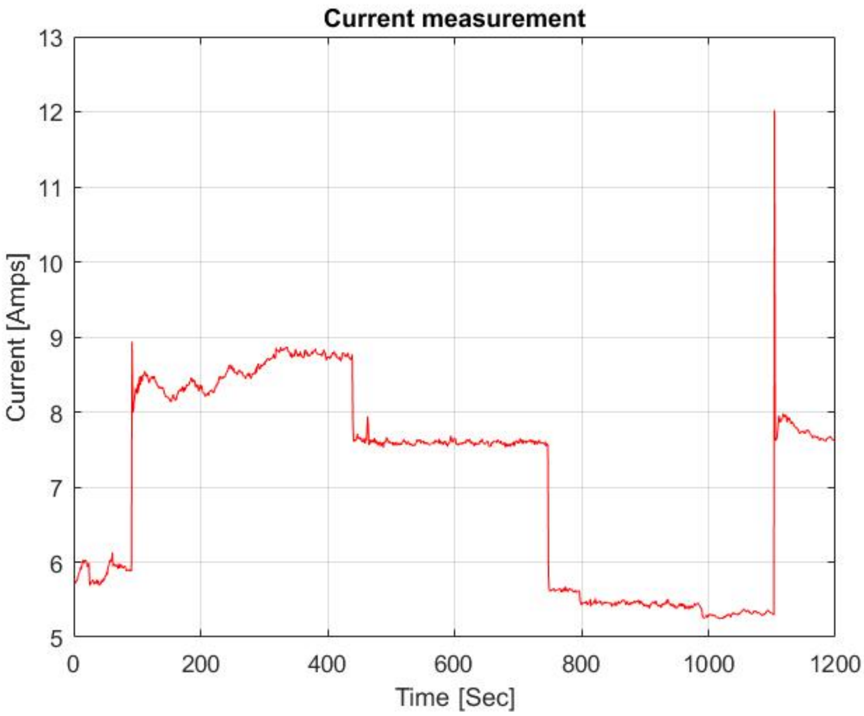


Figure 0-42 Spin-mode & motor

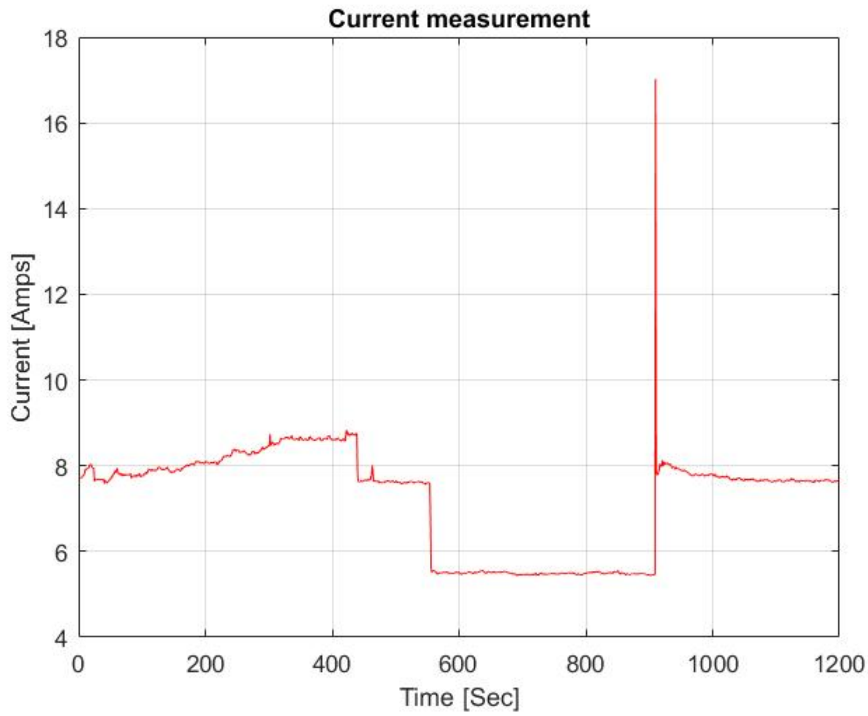


Figure 0-43 Spin-mode & motor

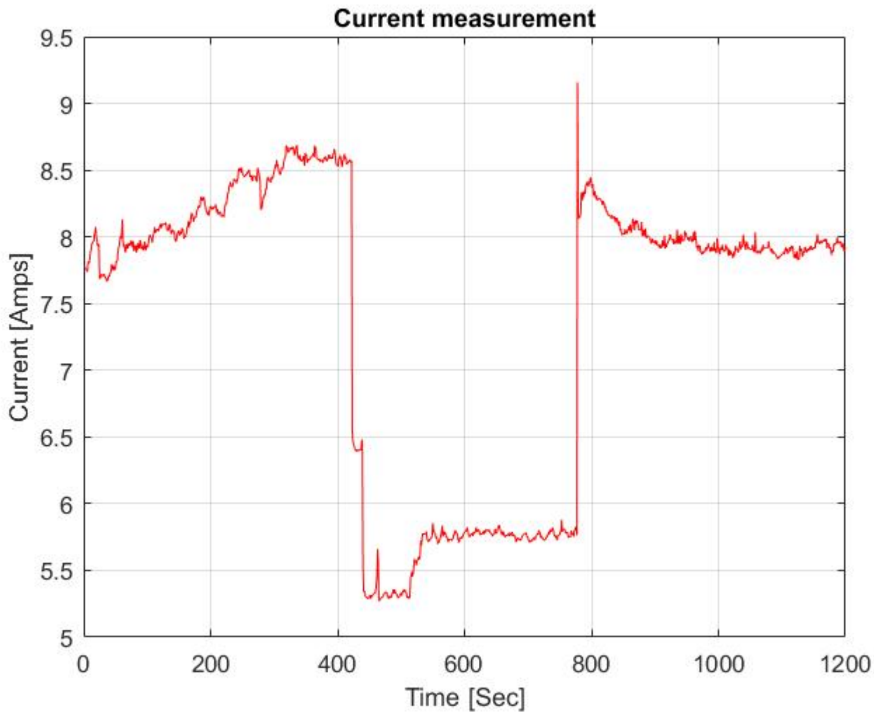


Figure 0-44 Spin-mode & motor

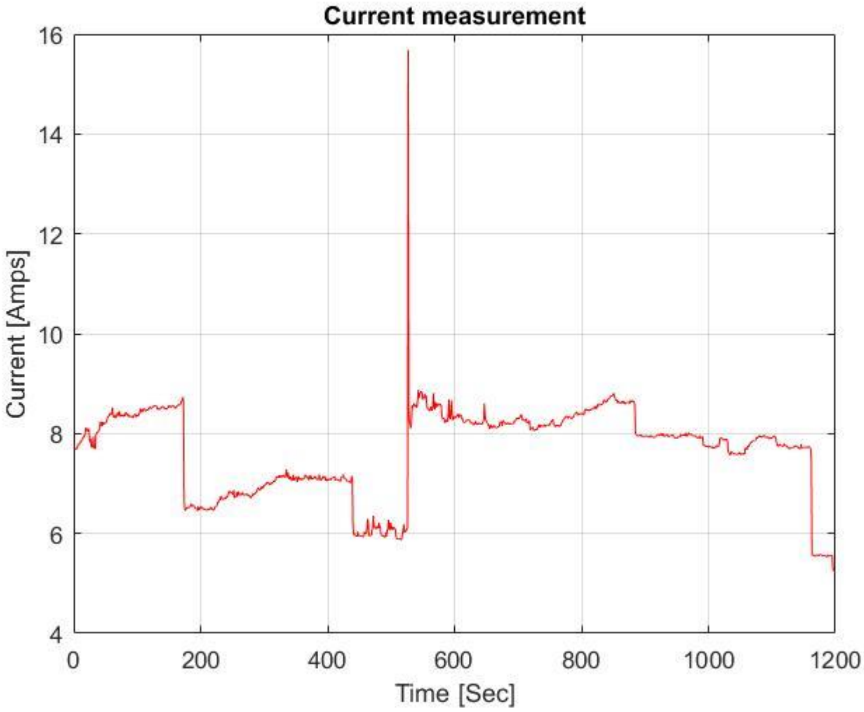


Figure 0-45 Spin-mode & motor

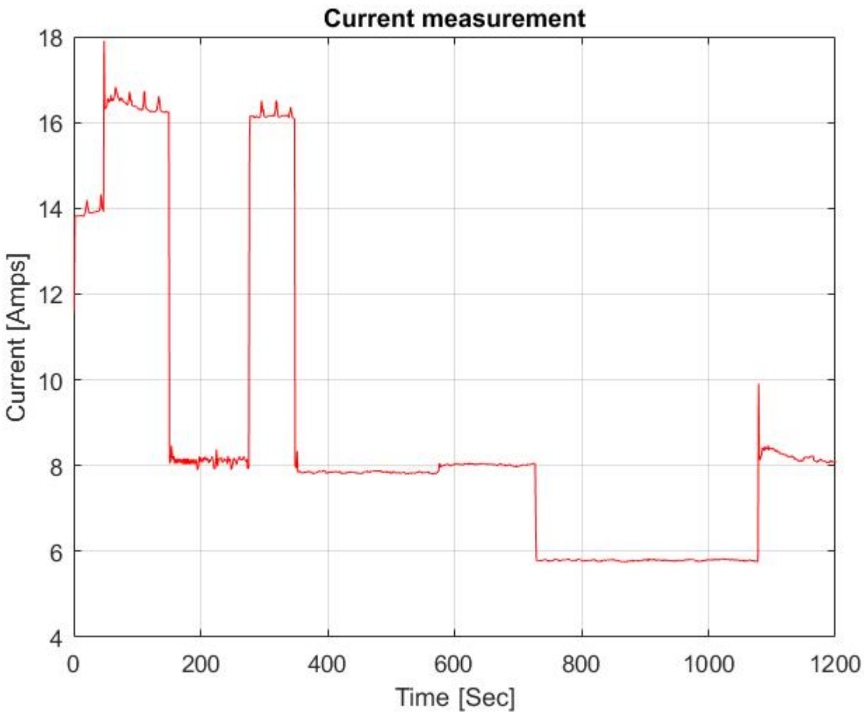


Figure 0-46   Heater-mode, motor and TV

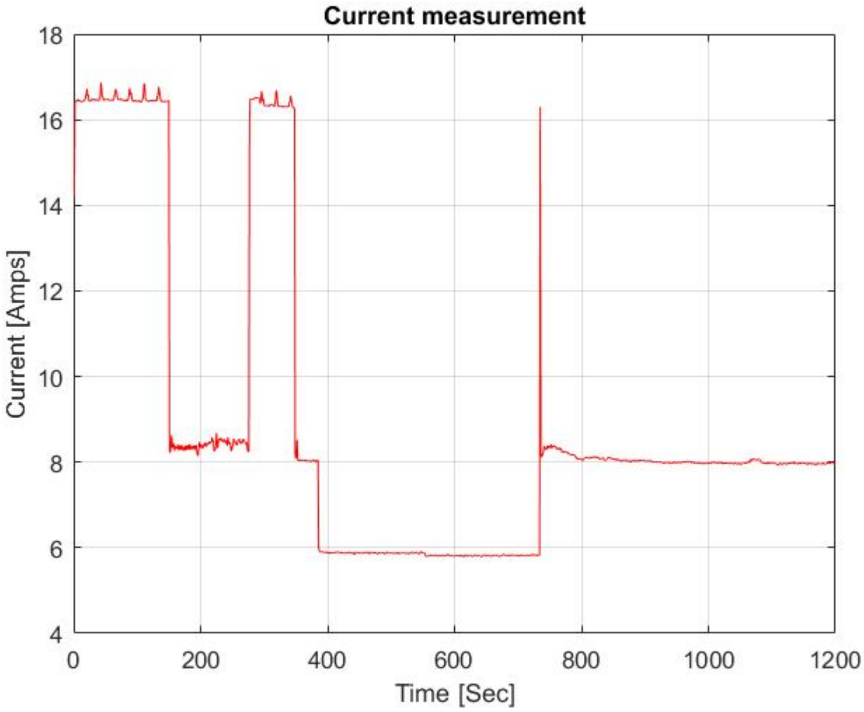


Figure 0-47 Heater-mode, motor and TV

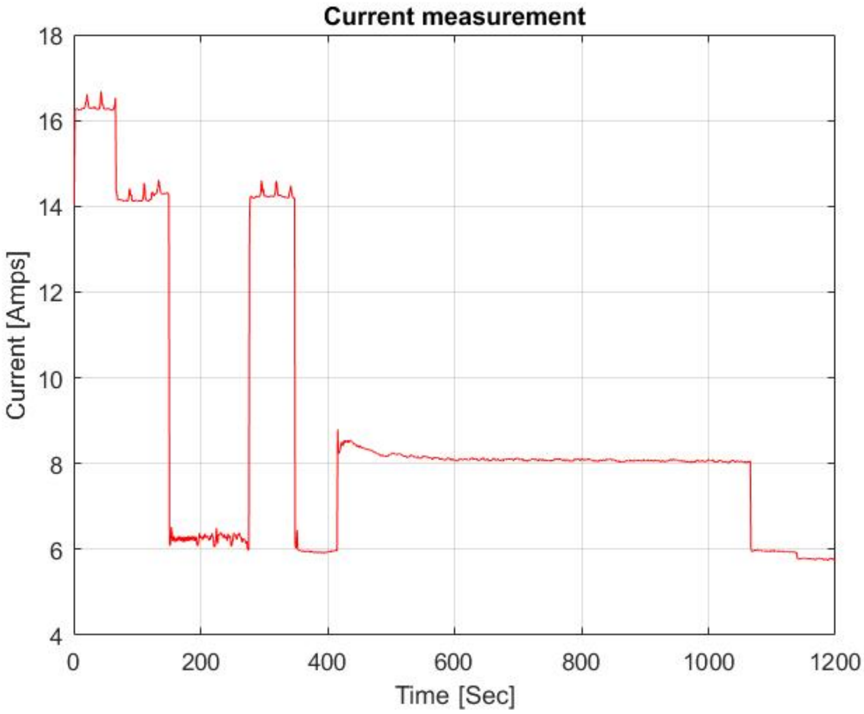


Figure 0-48 Heater-mode, motor and TV

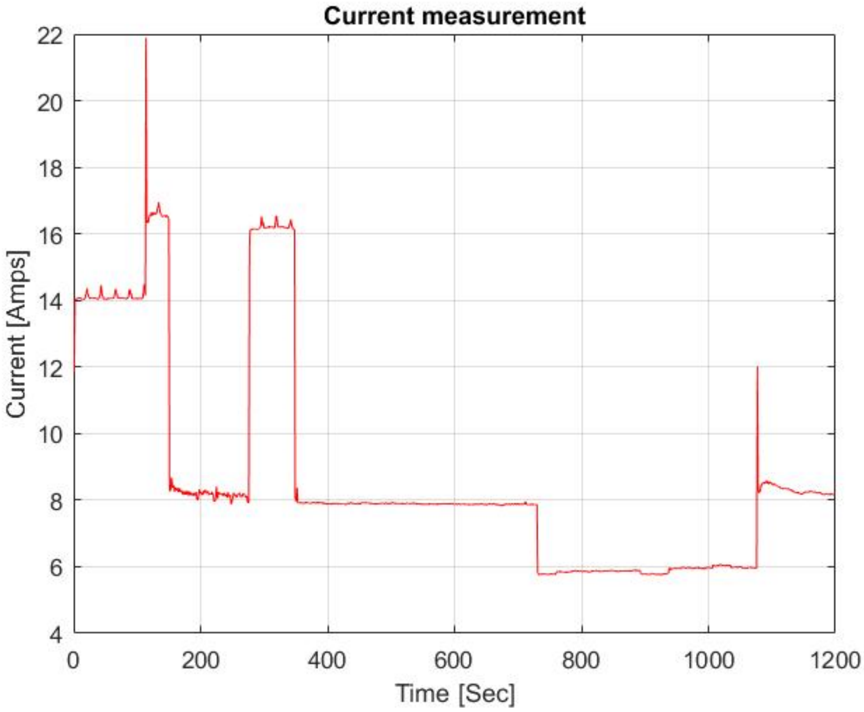


Figure 0-49 Heater-mode, motor and TV

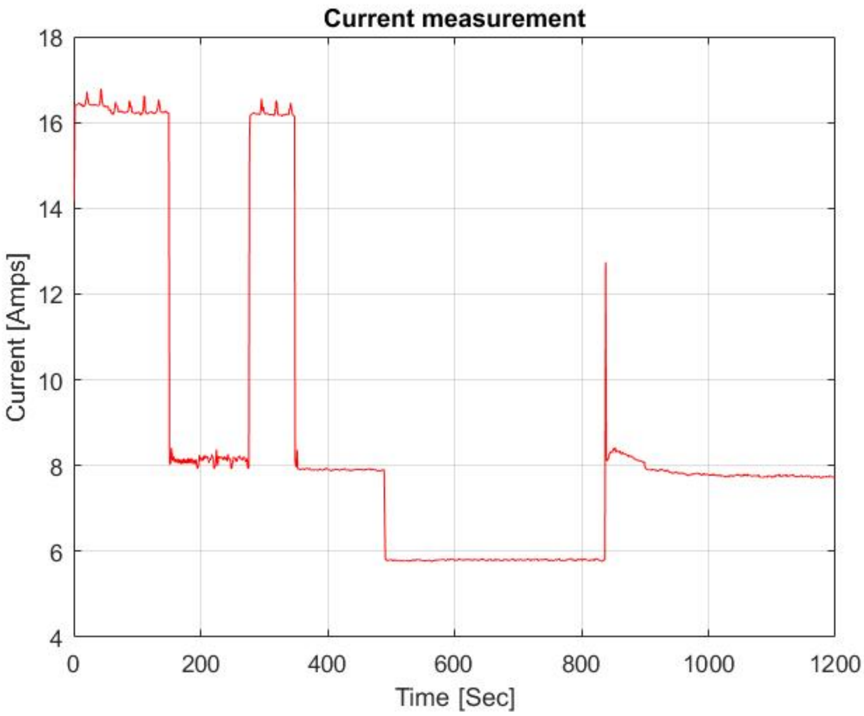


Figure 0-50 Heater-mode, motor and TV

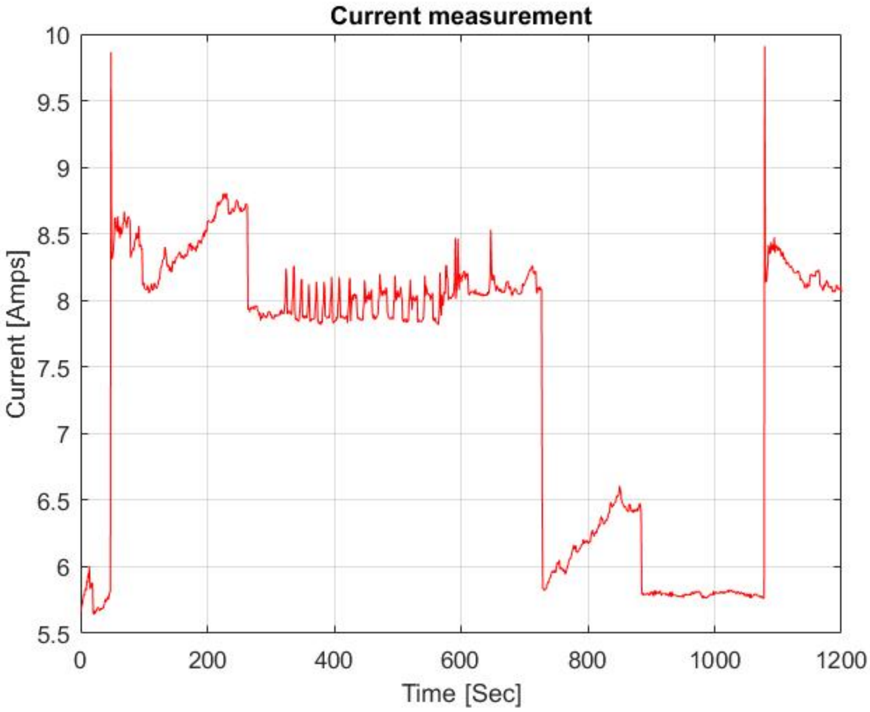


Figure 0-51 Rinse-mode, motor and TV

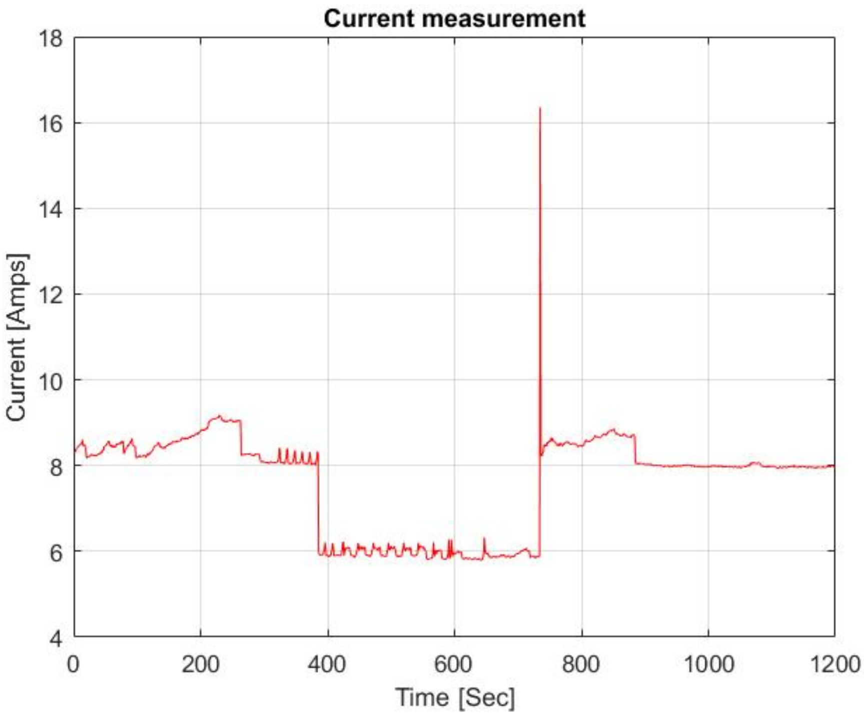


Figure 0-52 Rinse-mode, motor and TV

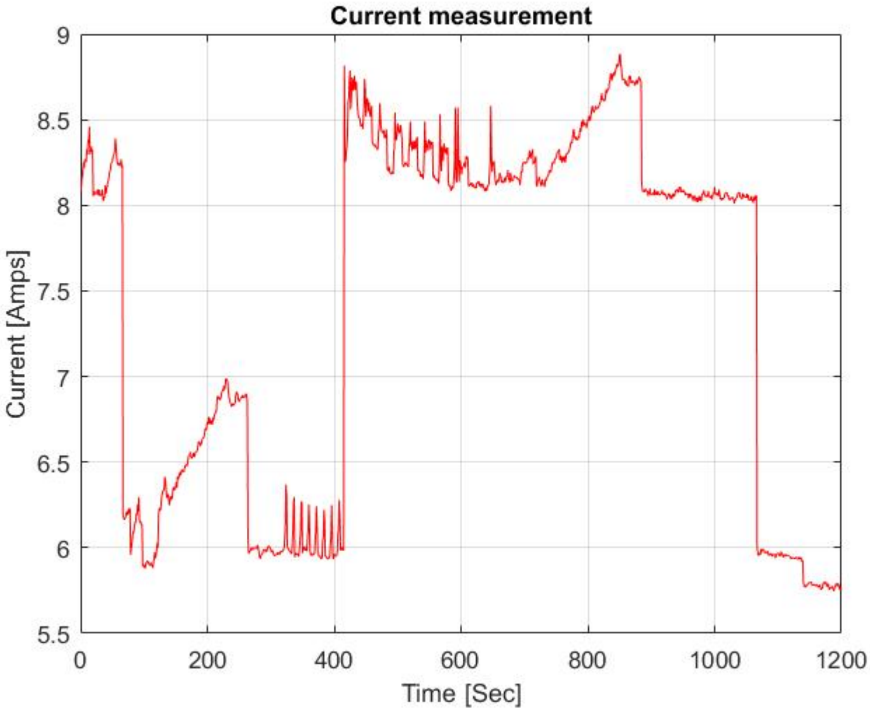


Figure 0-53 Rinse-mode, motor and TV

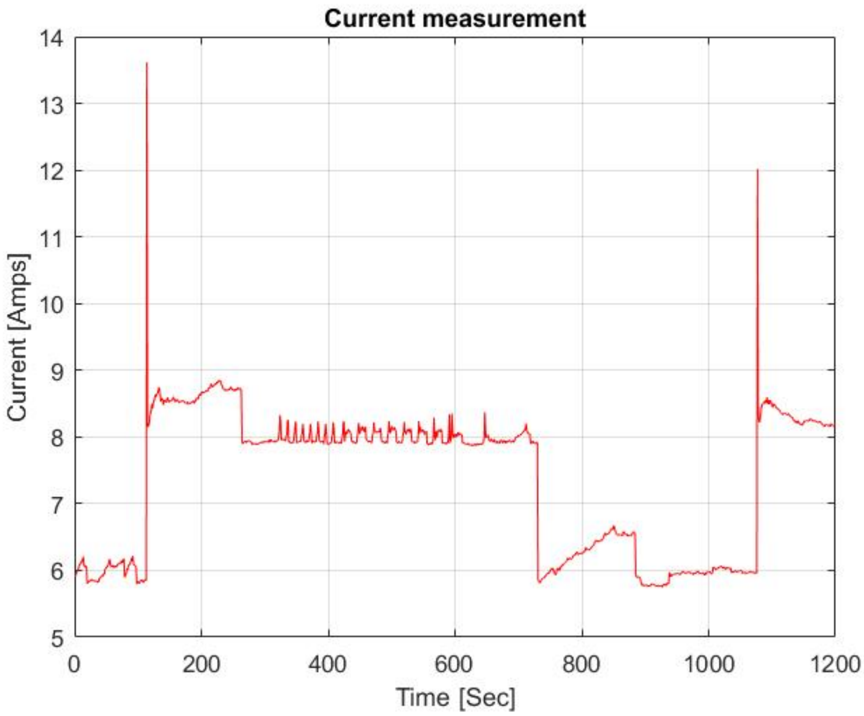


Figure 0-54 Rinse-mode, motor and TV

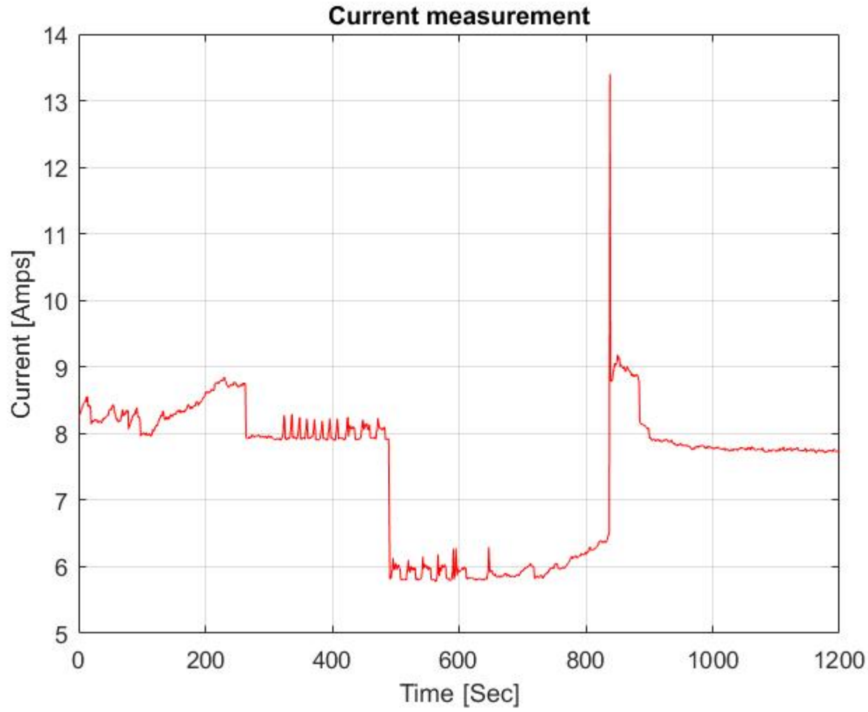


Figure 0-55 Rinse-mode, motor and TV

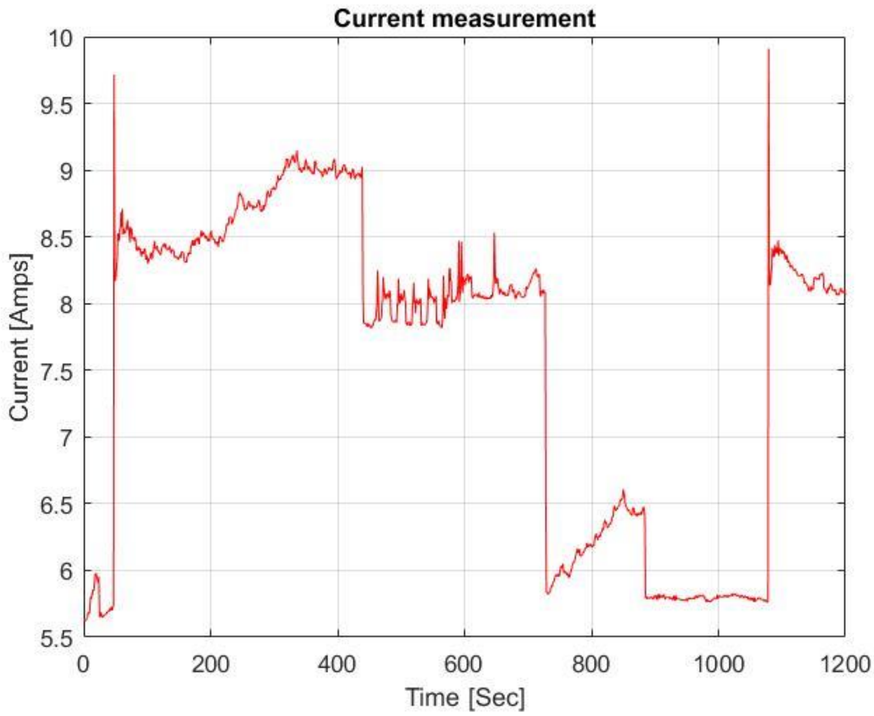


Figure 0-56 Spin-mode, motor and TV

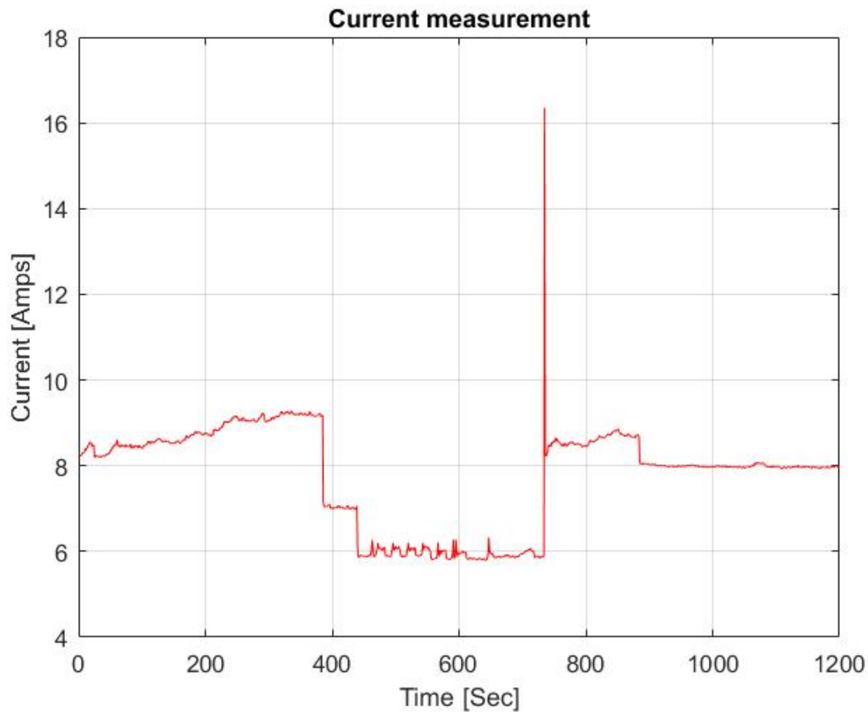


Figure 0-57 Spin-mode, motor and TV

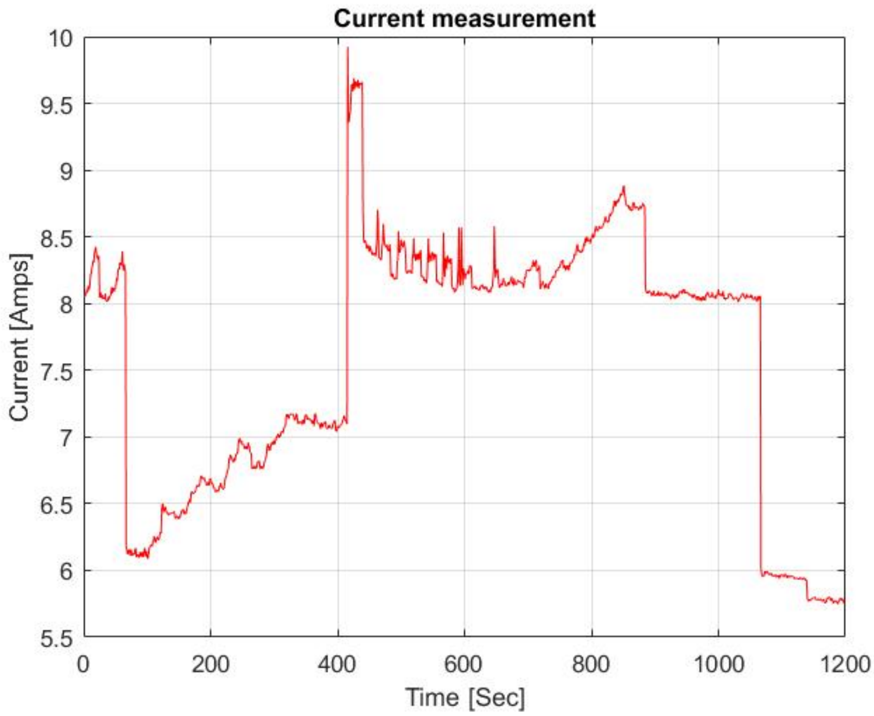


Figure 0-58 Spin-mode, motor and TV

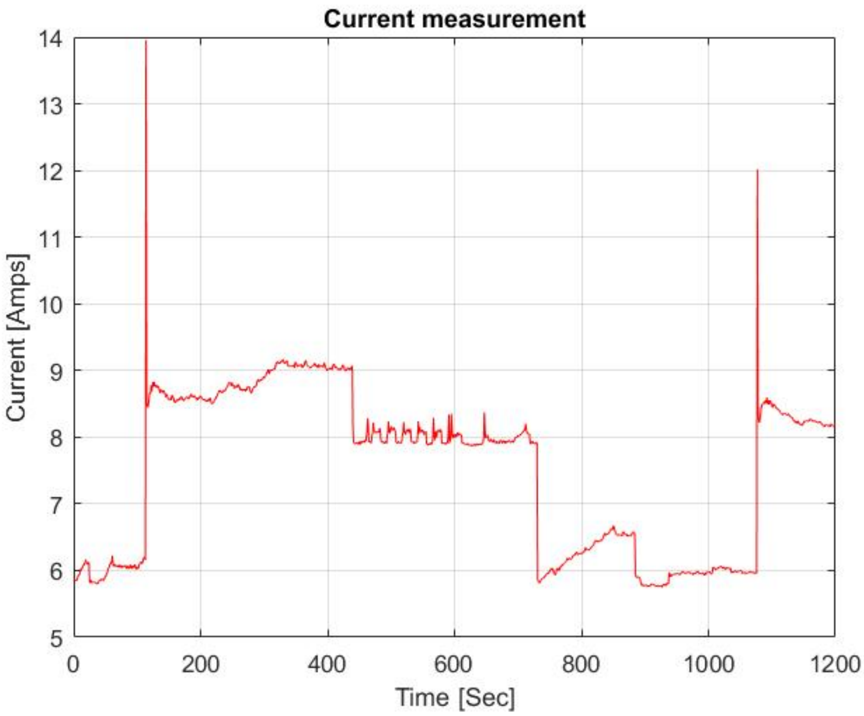


Figure 0-59 Spin-mode, motor and TV

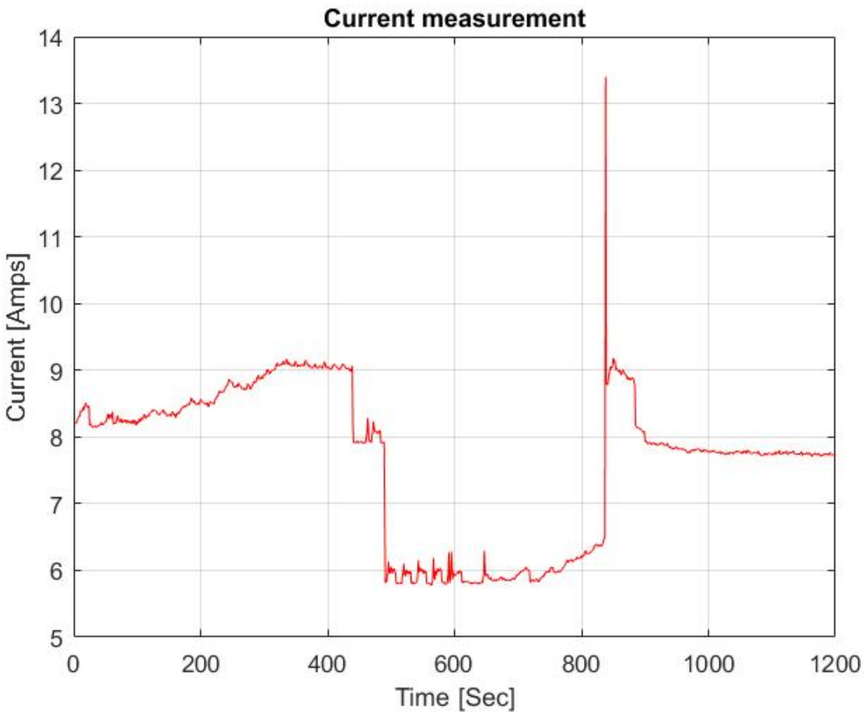


Figure 0-60 Spin-mode, motor and TV

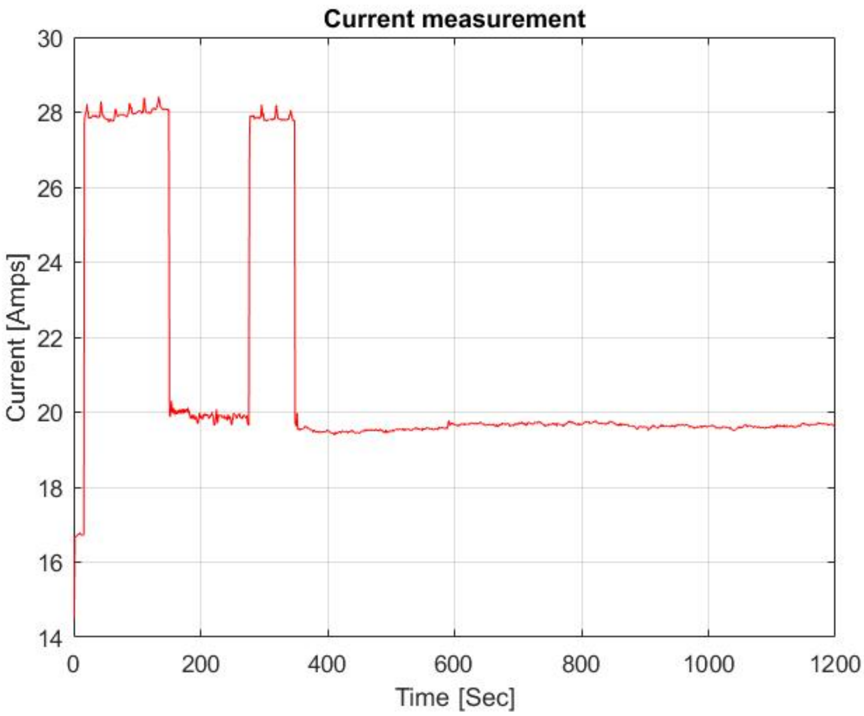


Figure 0-61 Heater-mode, motor, TV and boiler.

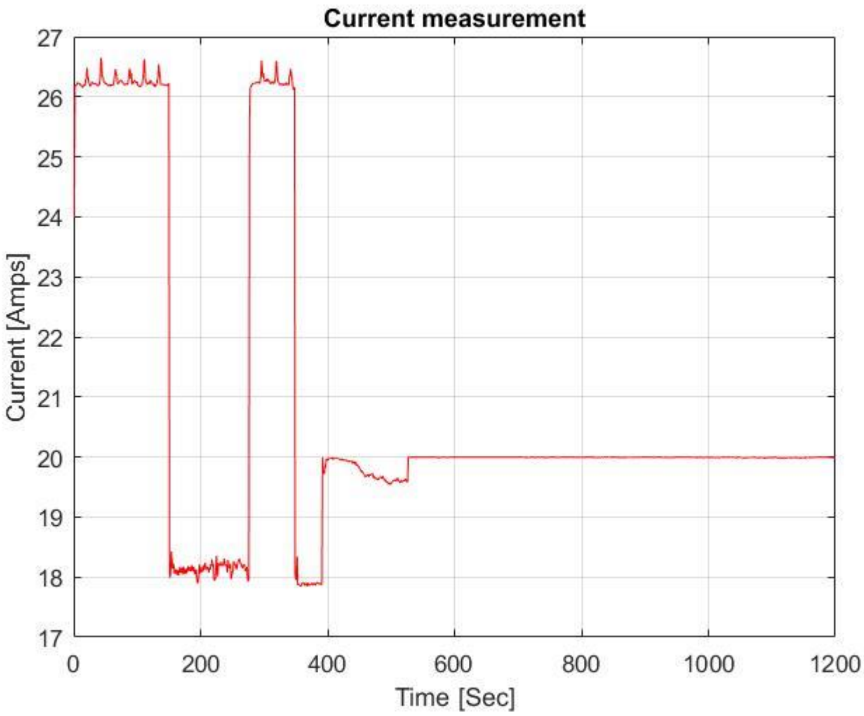


Figure 0-62 Heater-mode, motor, TV and boiler.

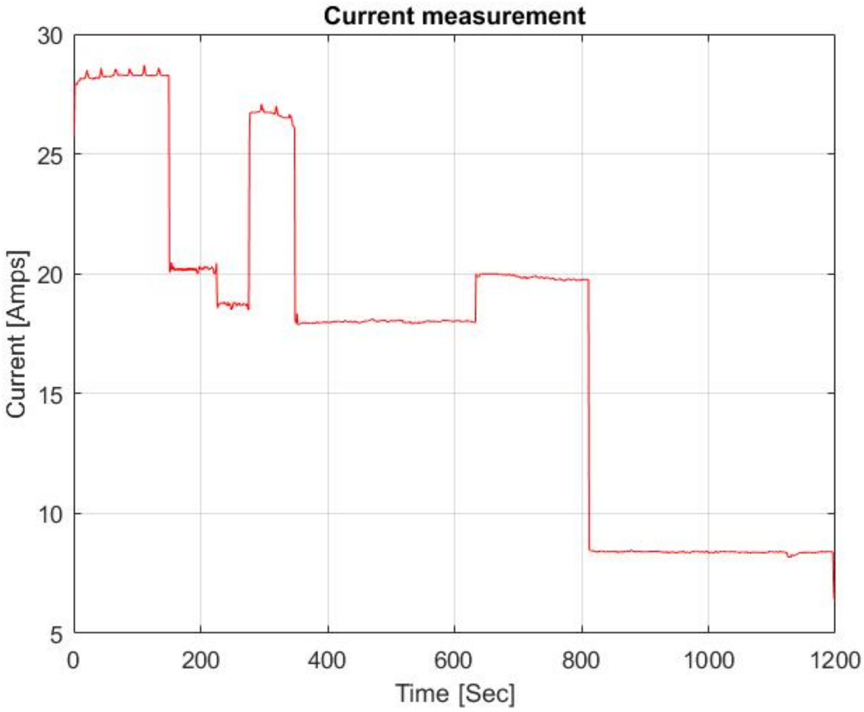


Figure 0-63 Heater-mode, motor, TV and boiler.

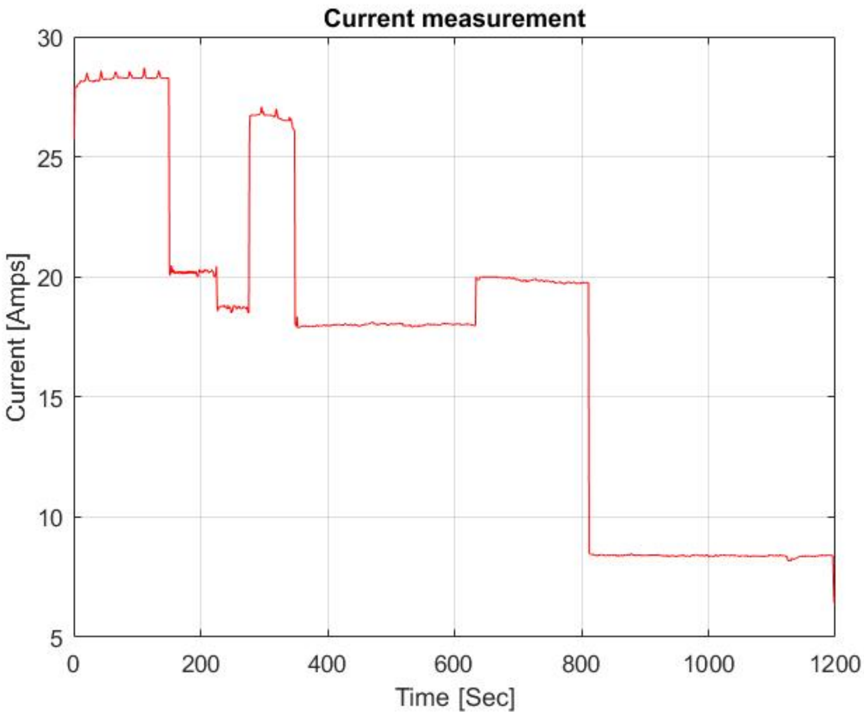


Figure 0-64 Heater-mode, motor, TV and boiler.

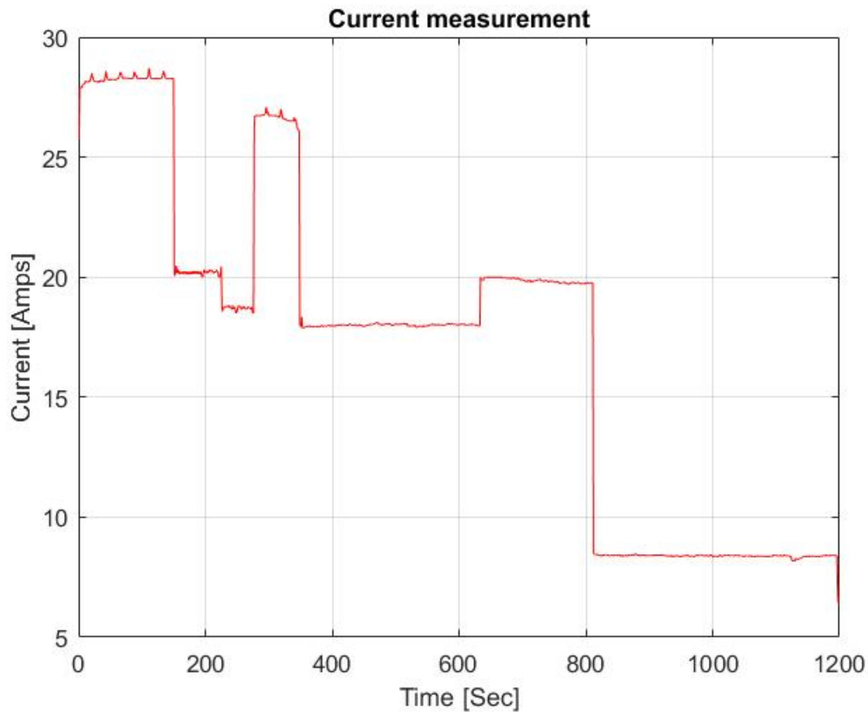


Figure 0-65 Heater-mode, motor, TV and boiler.

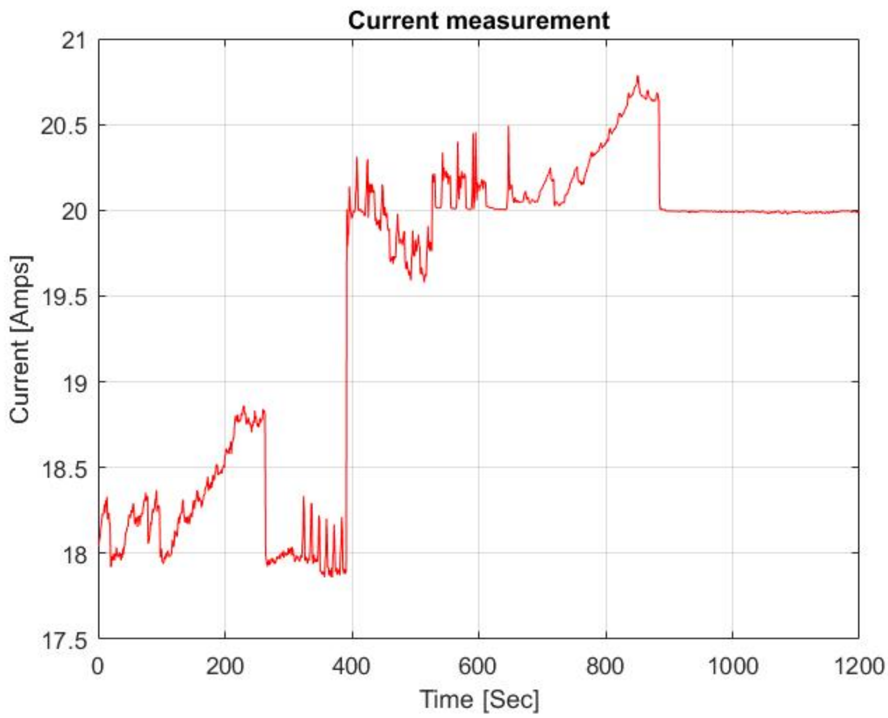


Figure 0-66 Rinse-mode, motor, TV and boiler.

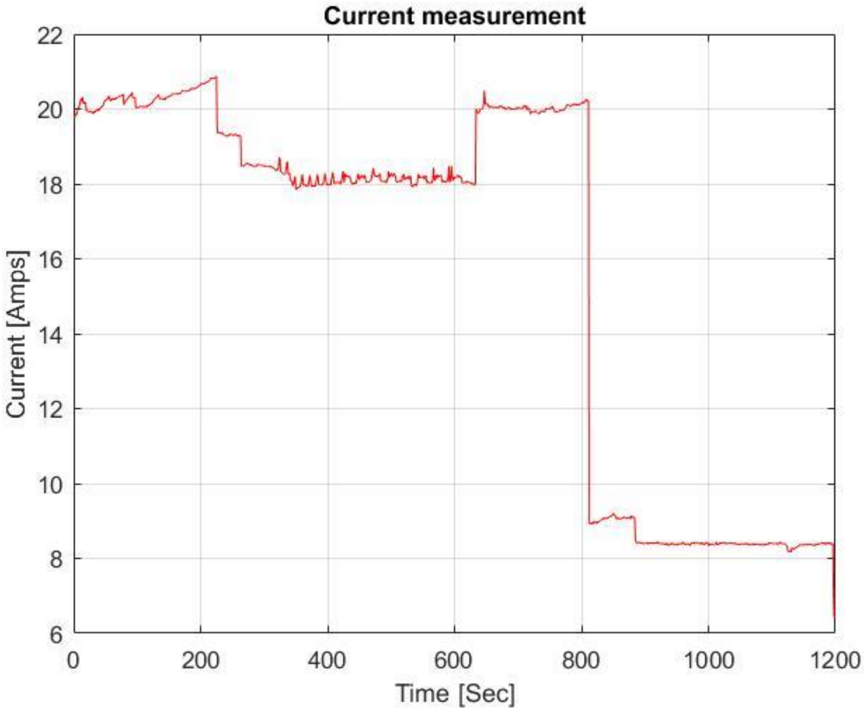


Figure 0-67 Rinse-mode, motor, TV and boiler.

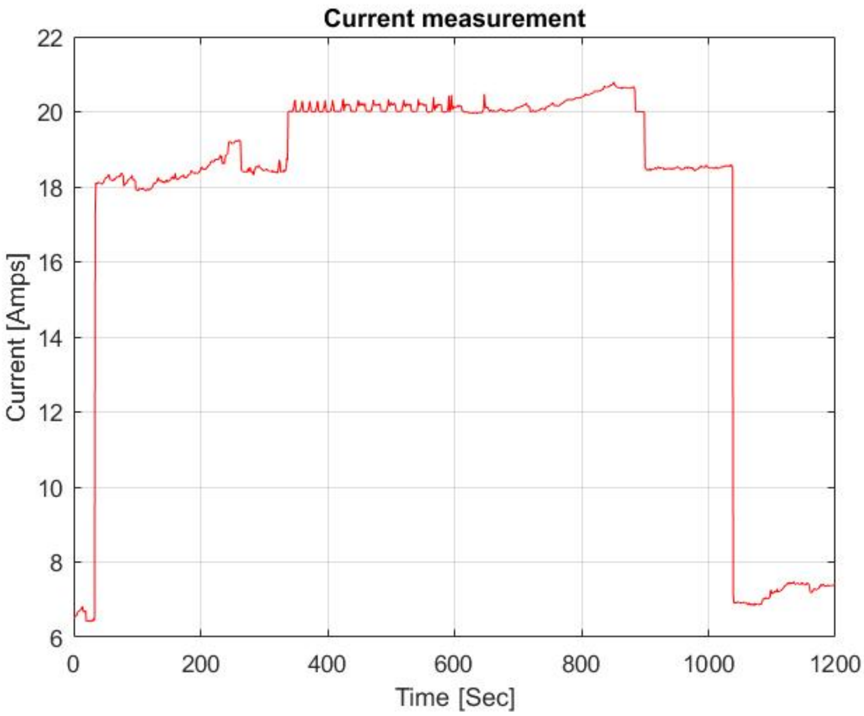


Figure 0-68 Rinse-mode, motor, TV and boiler.

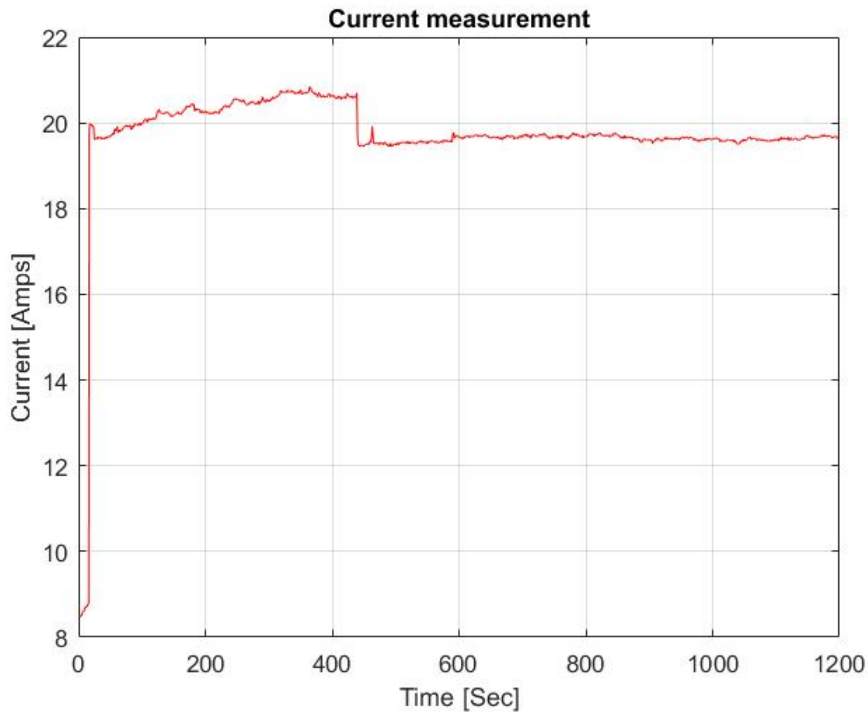


Figure 0-69 Rinse-mode, motor, TV and boiler.

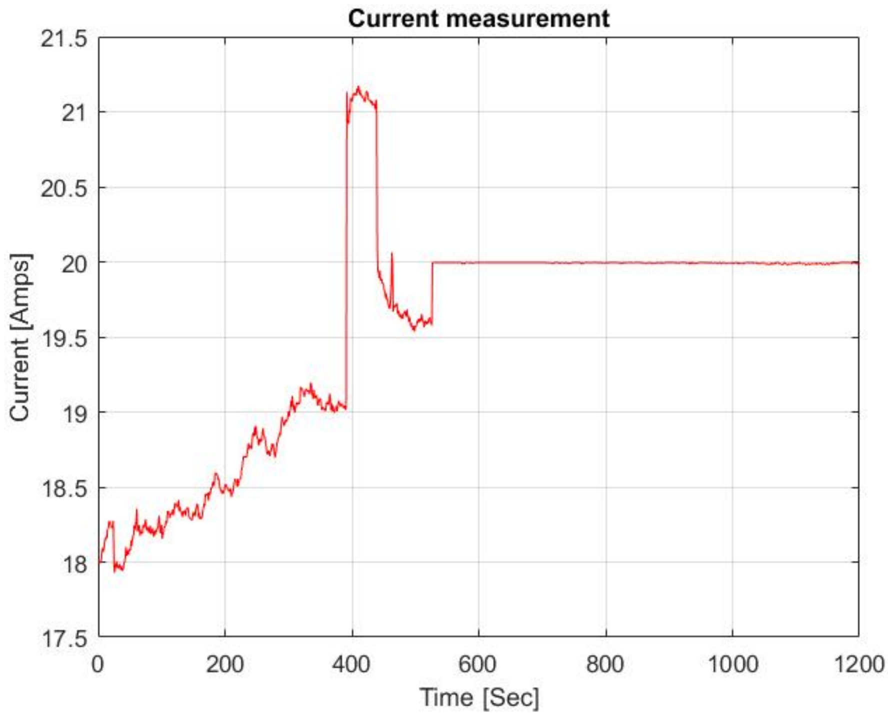


Figure 0-70 Spin-mode, motor, TV and boiler.

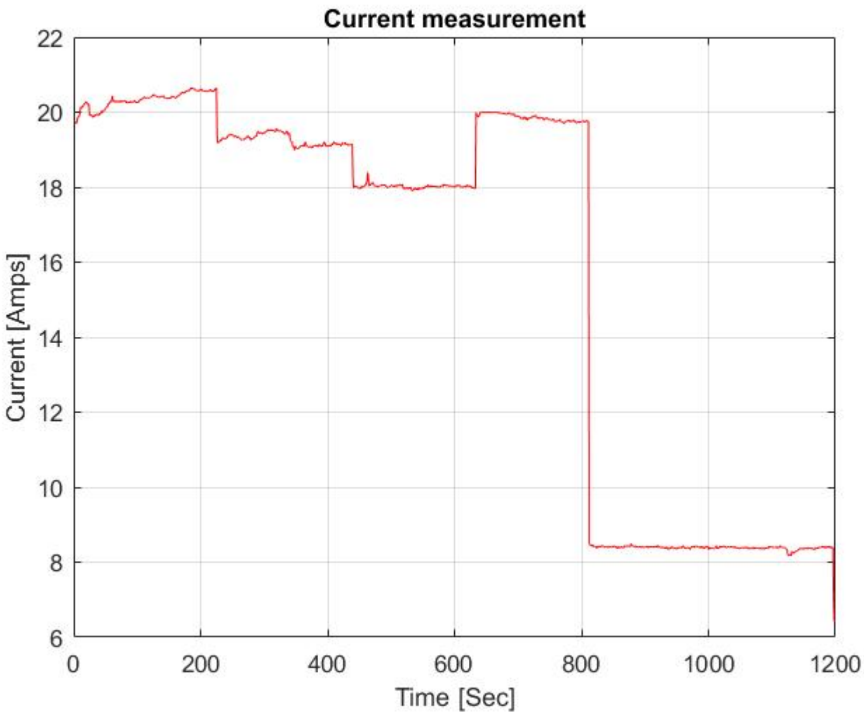


Figure 0-71 Spin-mode, motor, TV and boiler.

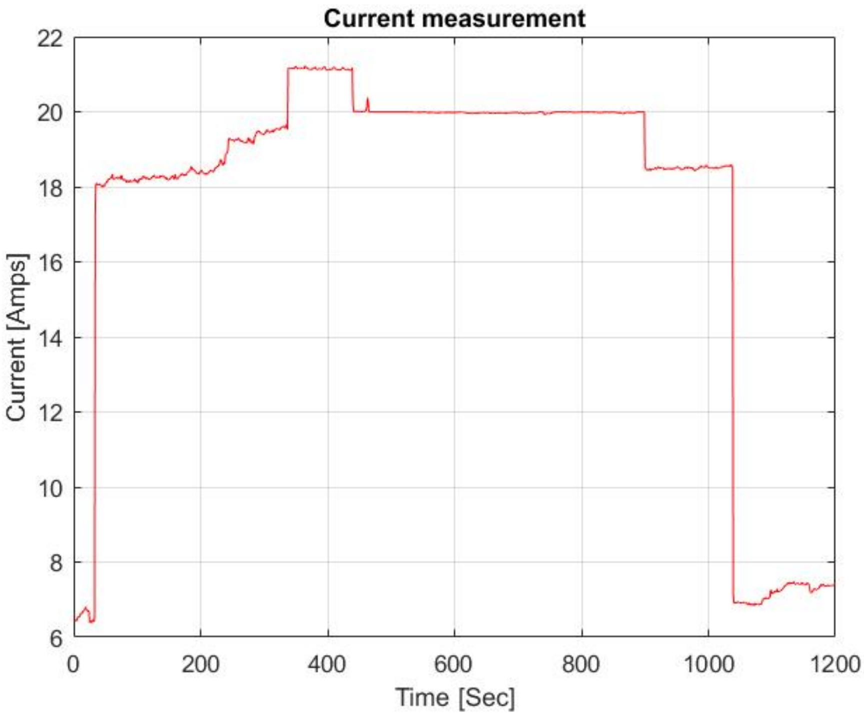


Figure 0-72 Spin-mode, motor, TV and boiler.

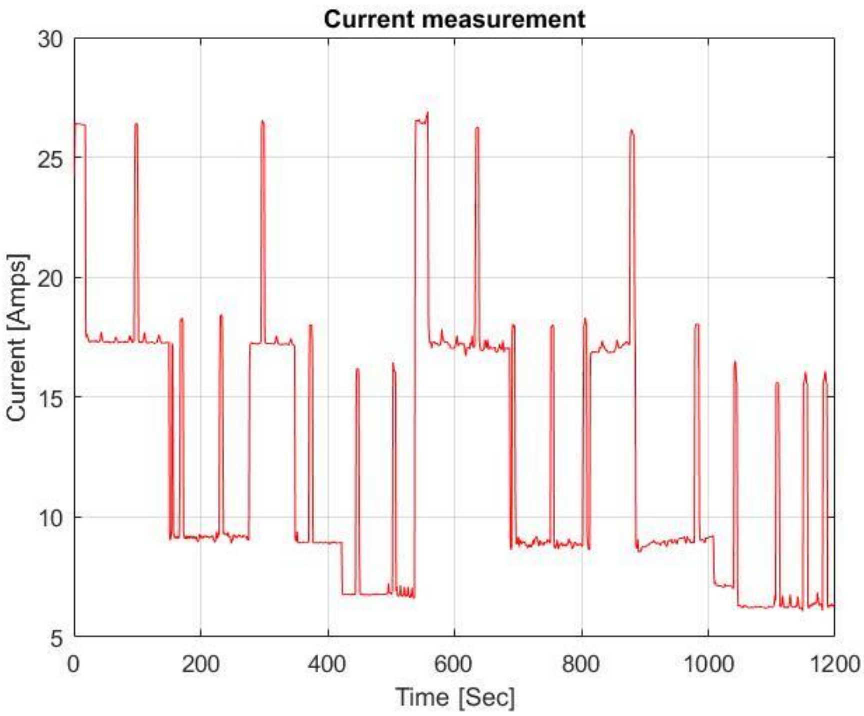


Figure 0-73 Spin-mode, motor, TV and boiler.

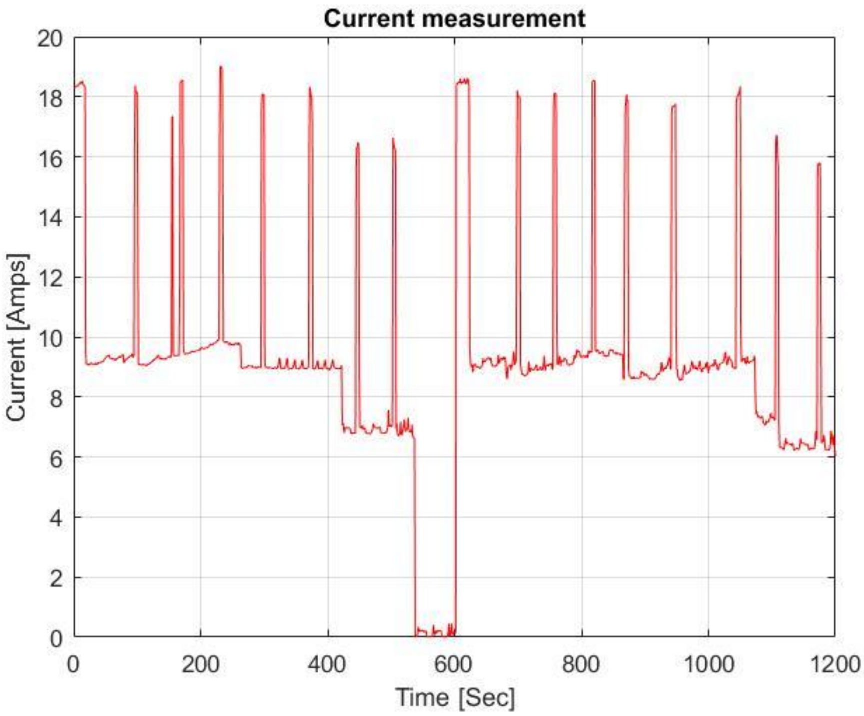


Figure 0-74 Heater-mode, TV and Iron

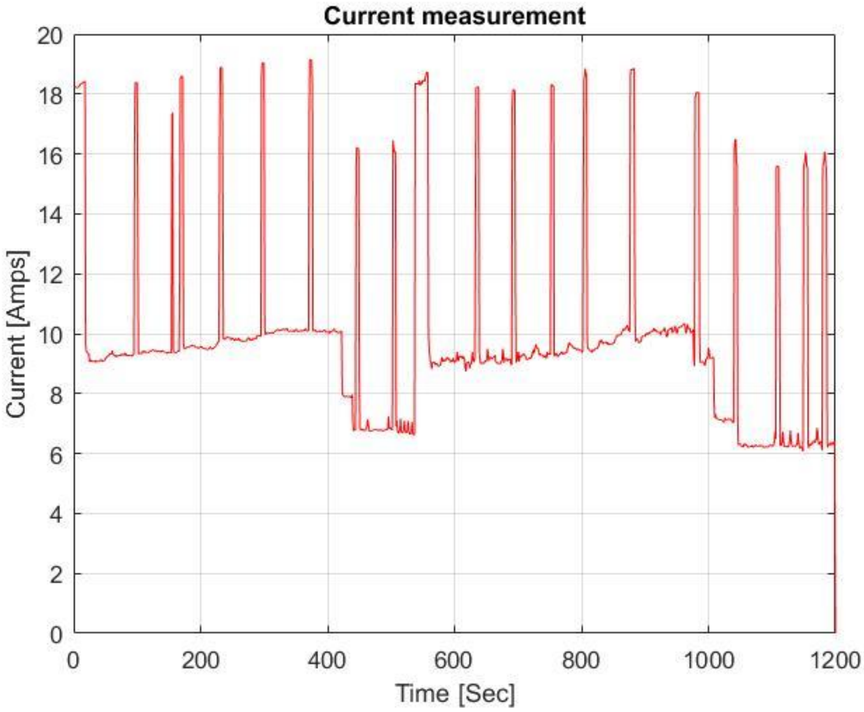


Figure 0-75 Rinse-mode, TV and Iron

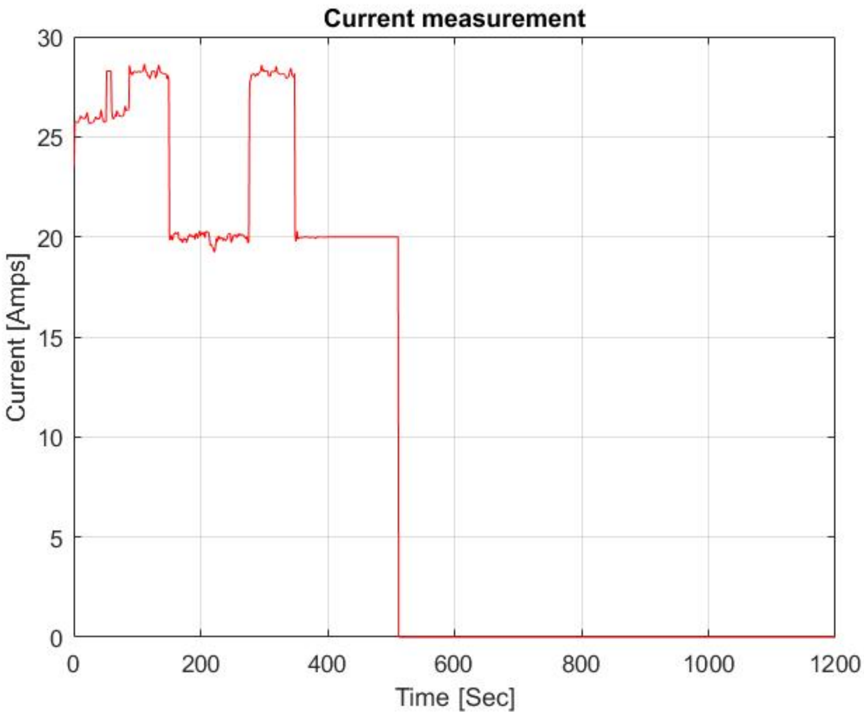


Figure 0-76 Heater-mode, TV and Iron

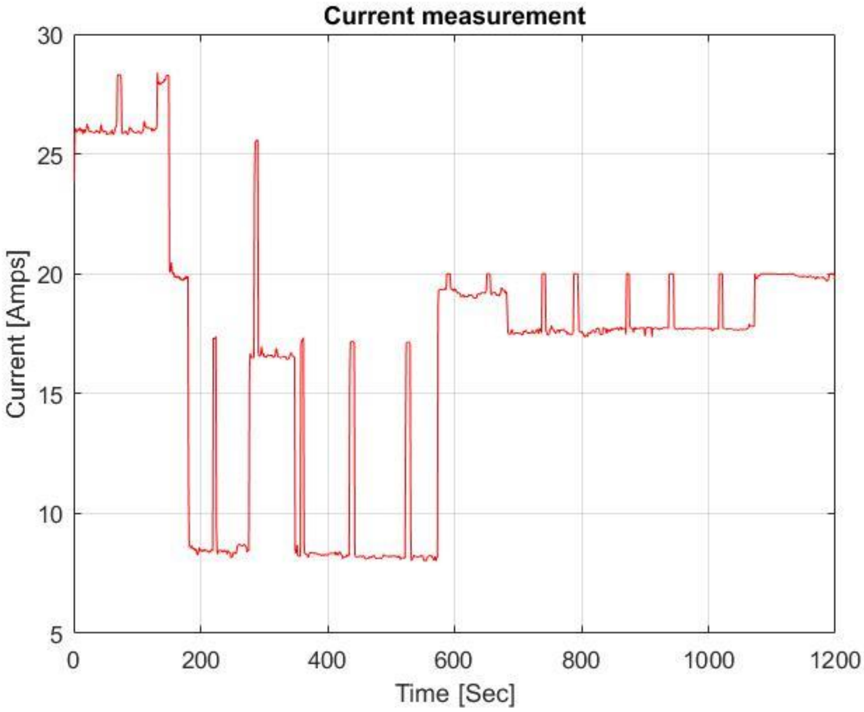


Figure 0-77 Heater-mode, TV, iron and boiler.

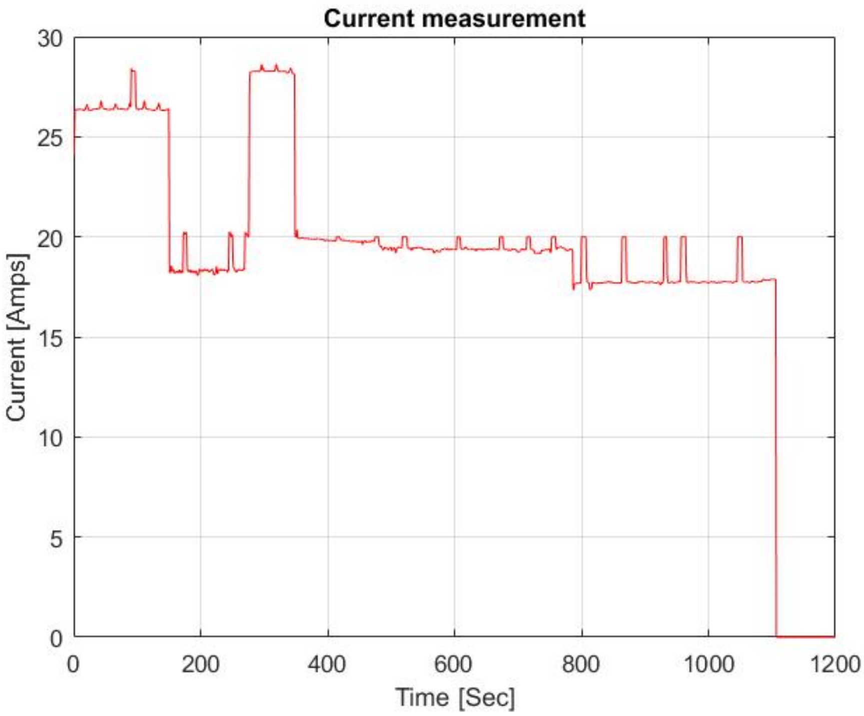


Figure 0-78 Heater-mode, TV, iron and boiler.

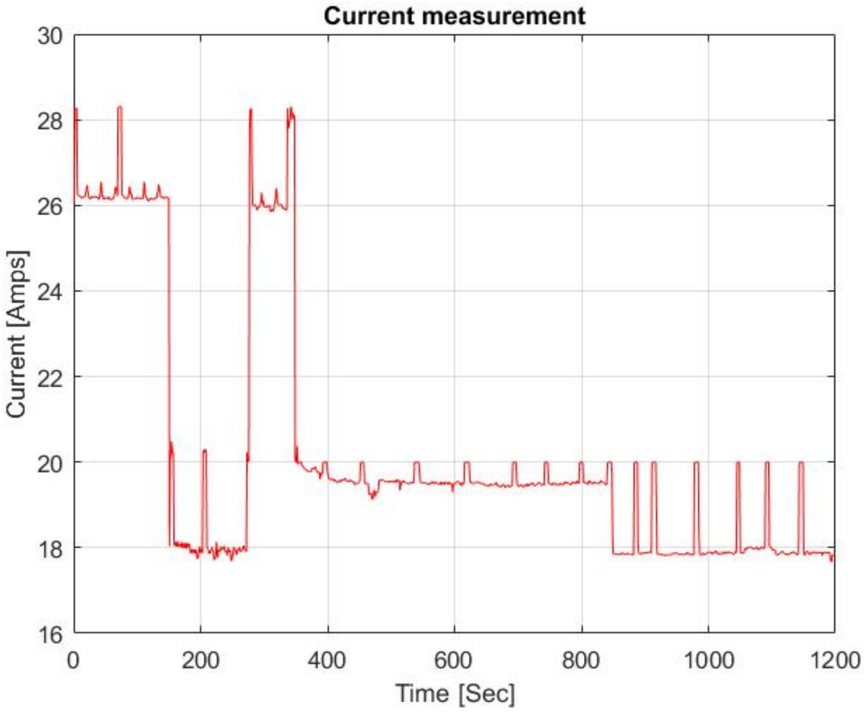


Figure 0-79 Heater-mode, TV, iron and boiler.

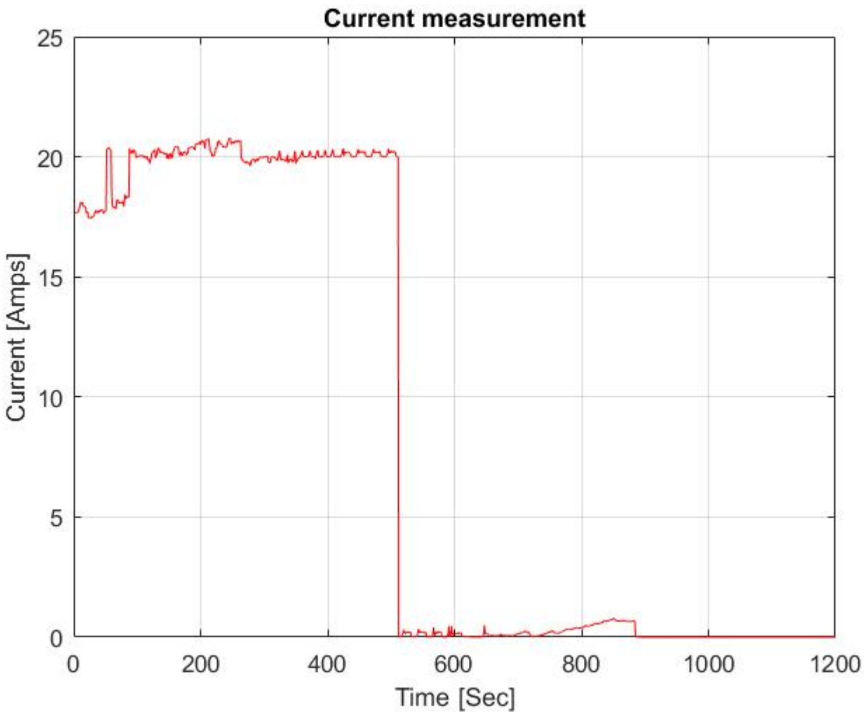


Figure 0-80 Rinse-mode, TV, iron and boiler.

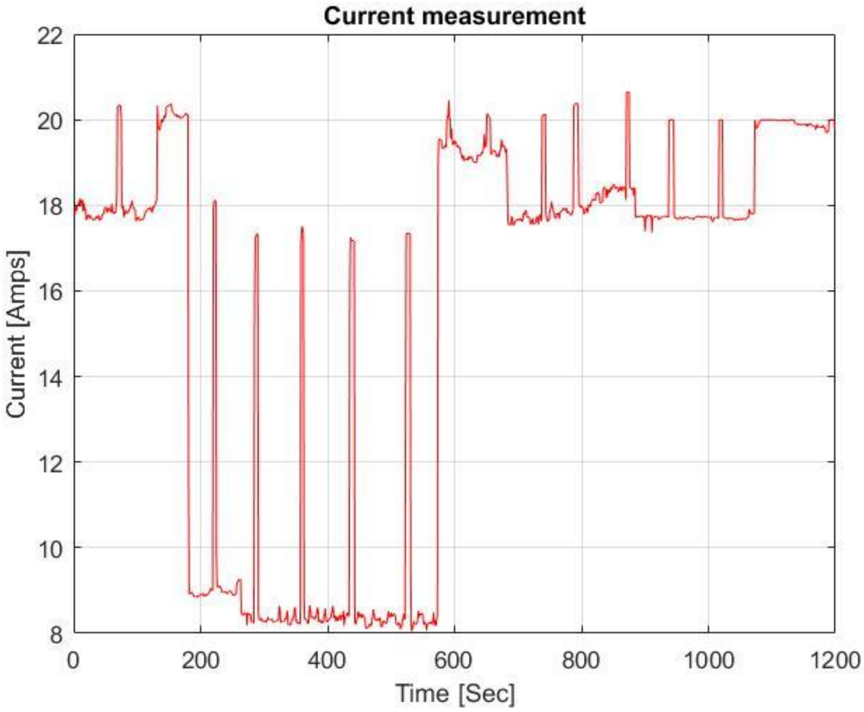


Figure 0-81 Rinse-mode, TV, iron and boiler.

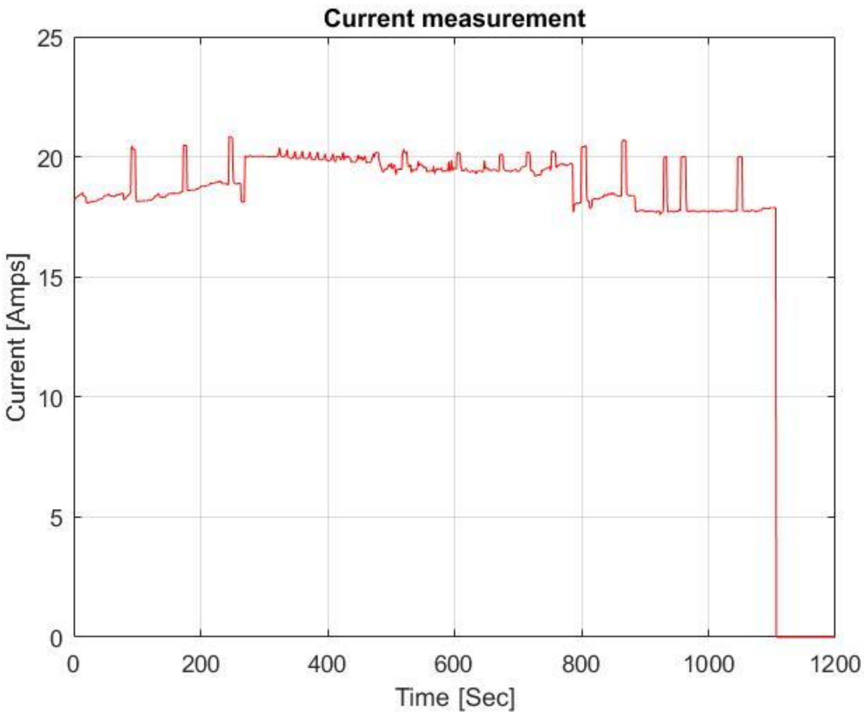


Figure 0-82 Rinse-mode, TV, iron and boiler.

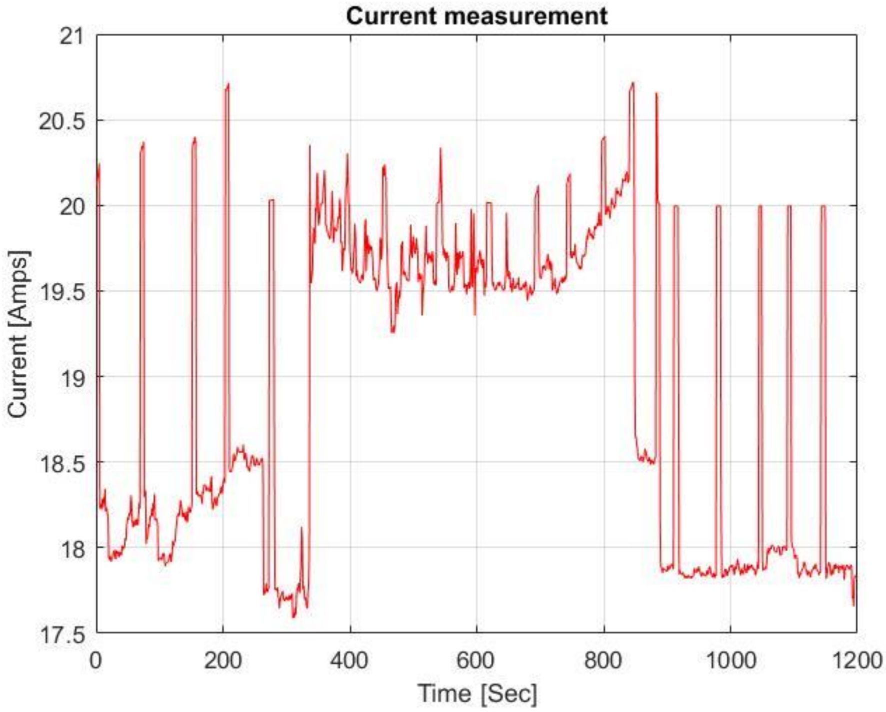


Figure 0-83 Rinse-mode, TV, iron and boiler.

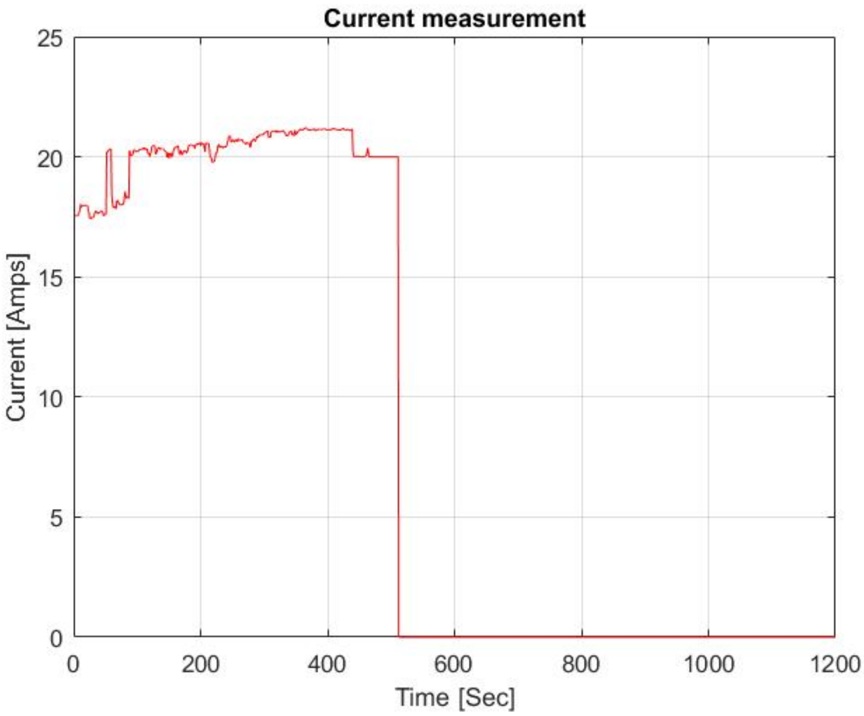


Figure 0-84 Spin-mode, TV, iron and boiler.

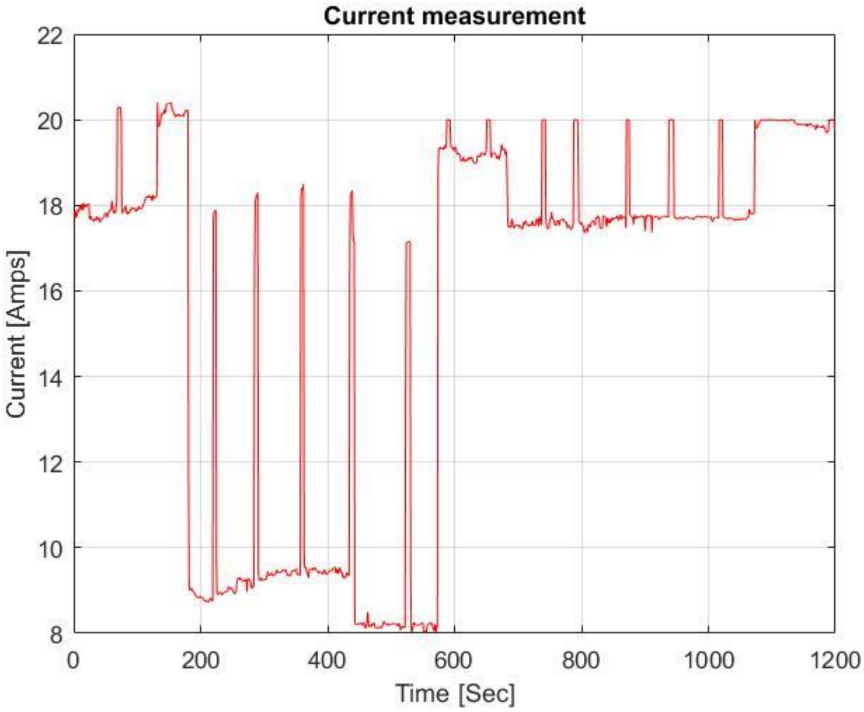


Figure 0-85 Spin-mode, TV, iron and boiler.

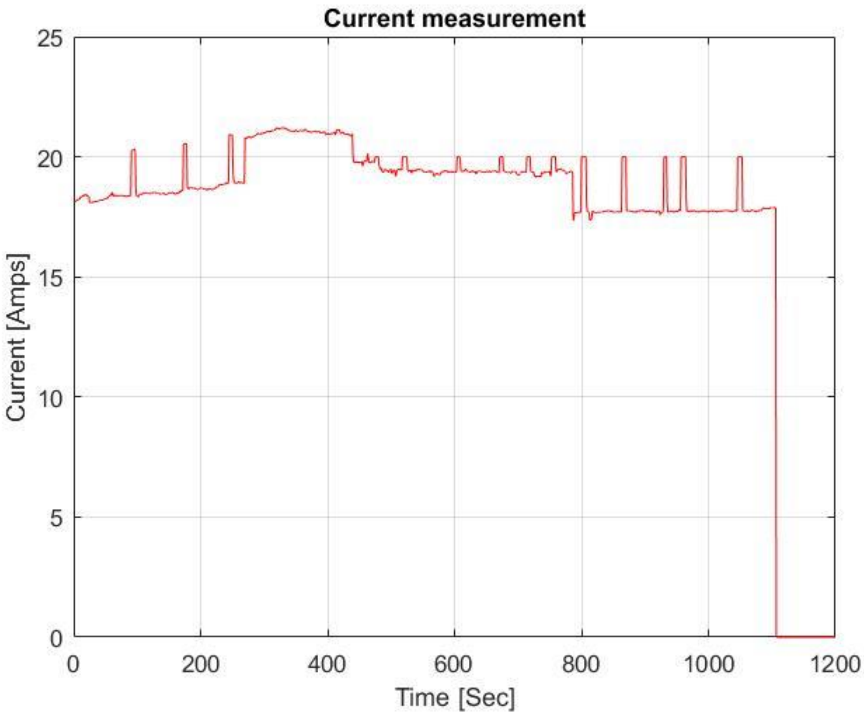


Figure 0-86 Spin-mode, TV, iron and boiler.

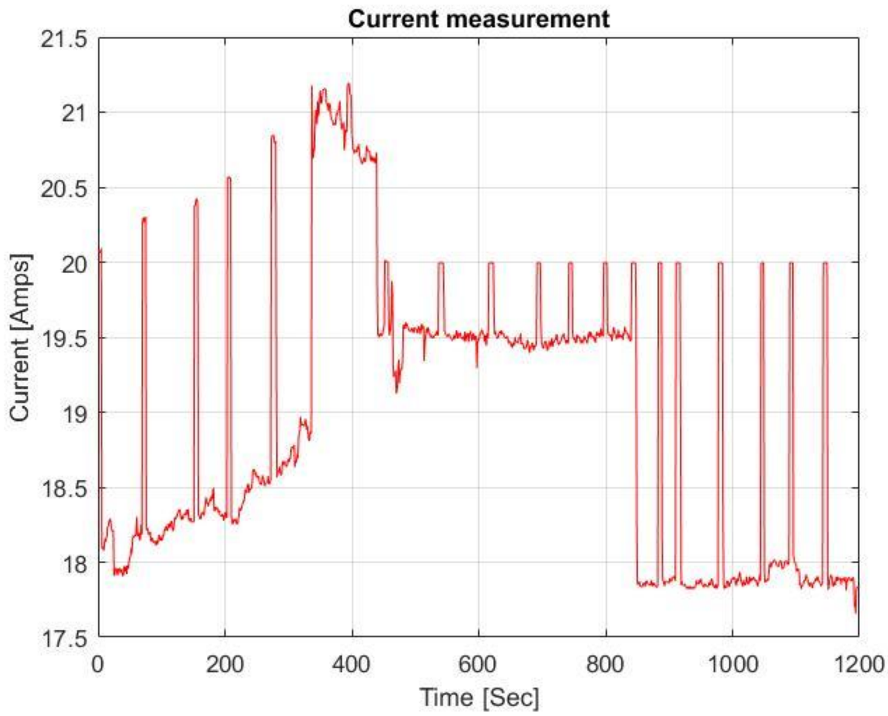


Figure 0-87 Spin-mode, TV, iron and boiler.

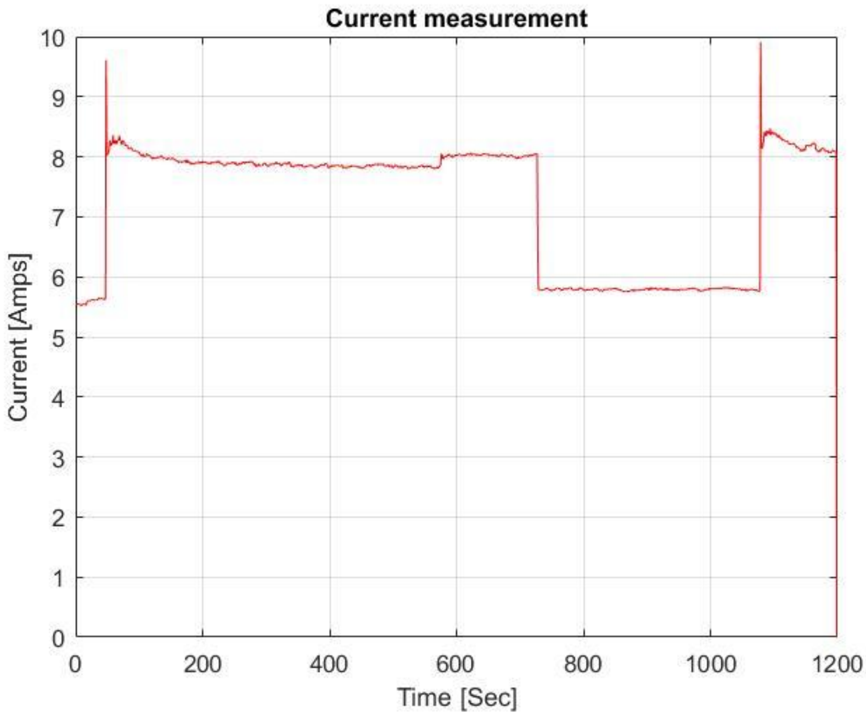


Figure 0-88 Motor and TV.

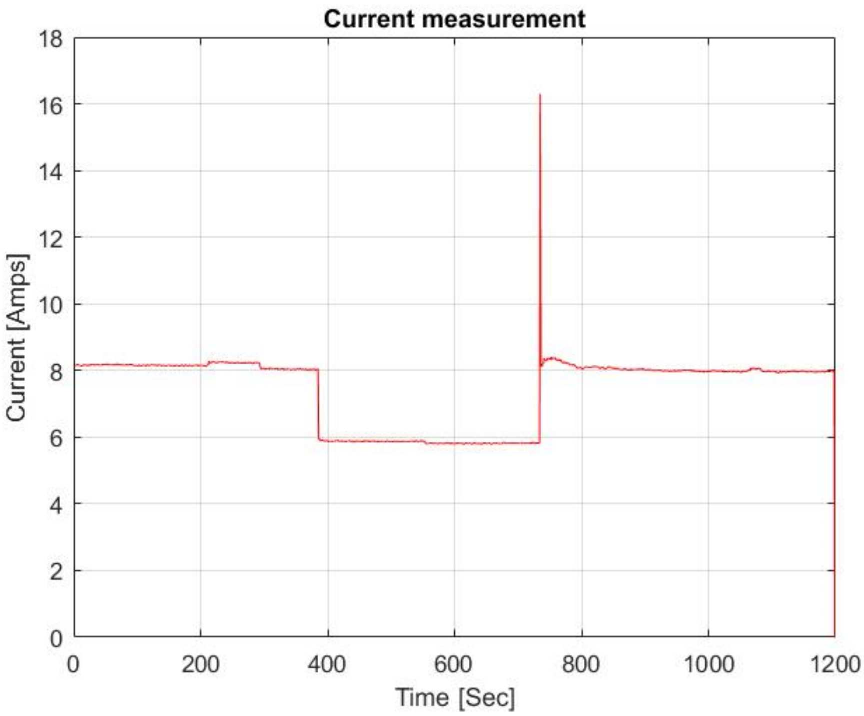
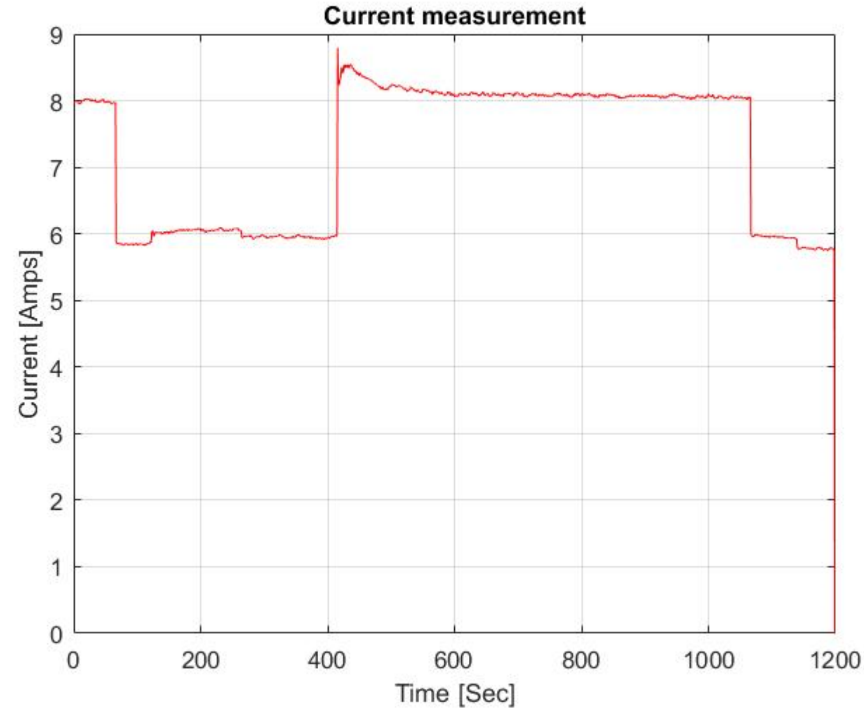


Figure 0-89 Motor and TV.



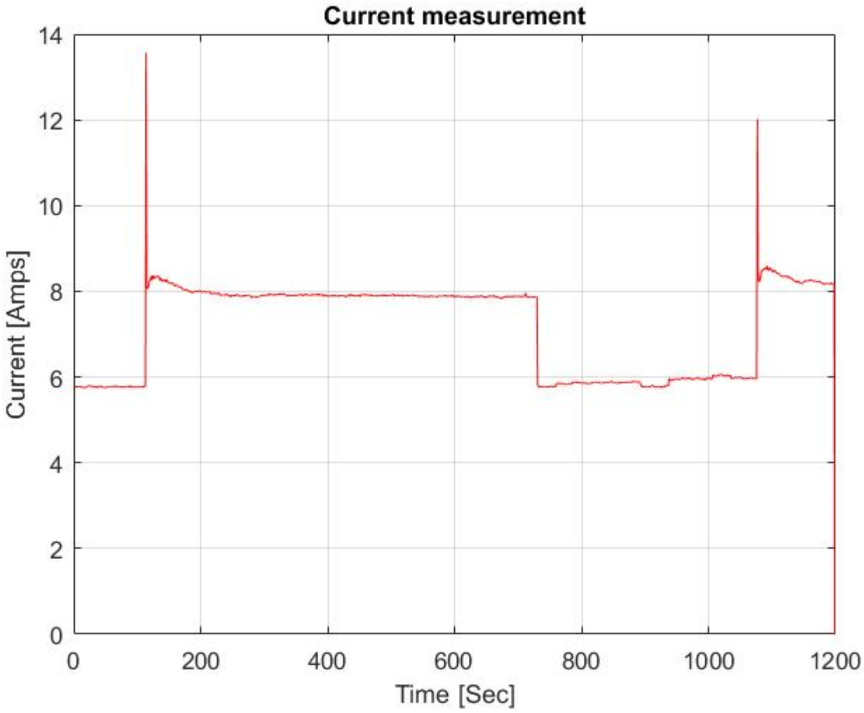


Figure 0-90 Motor and TV.

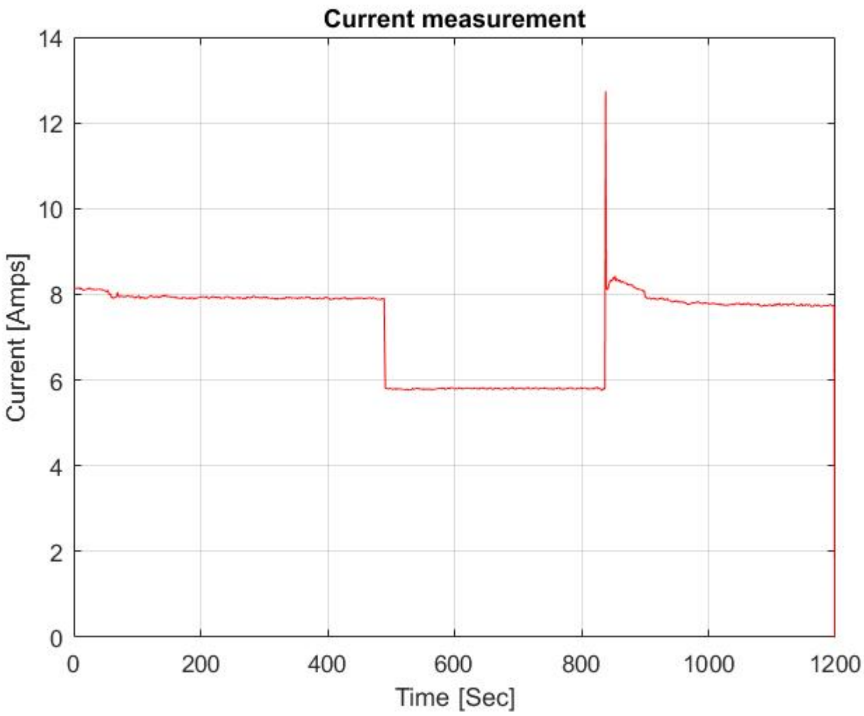


Figure 0-91 Motor and TV.

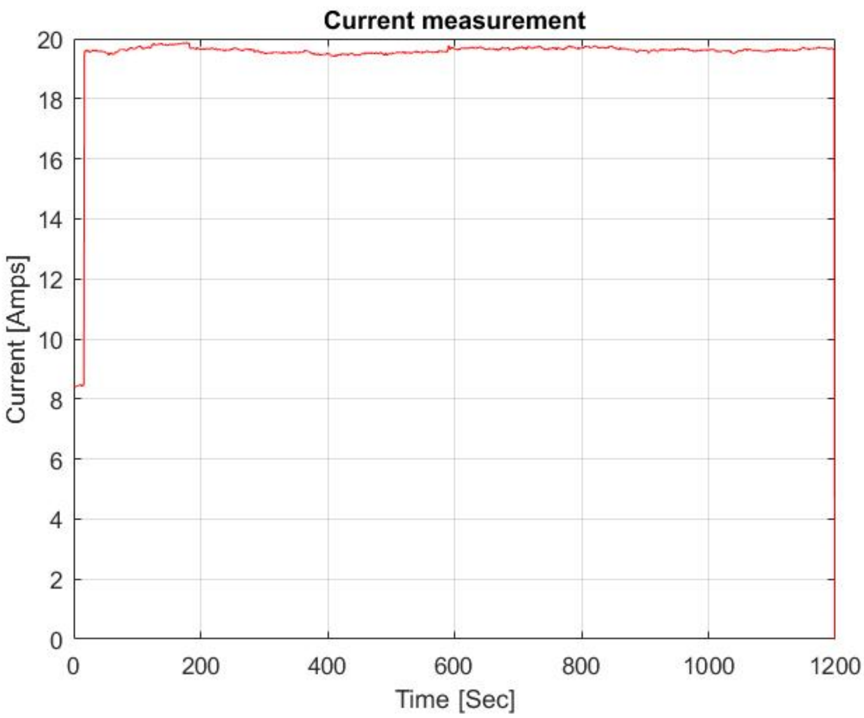


Figure 0-92 Motor, TV and boiler.

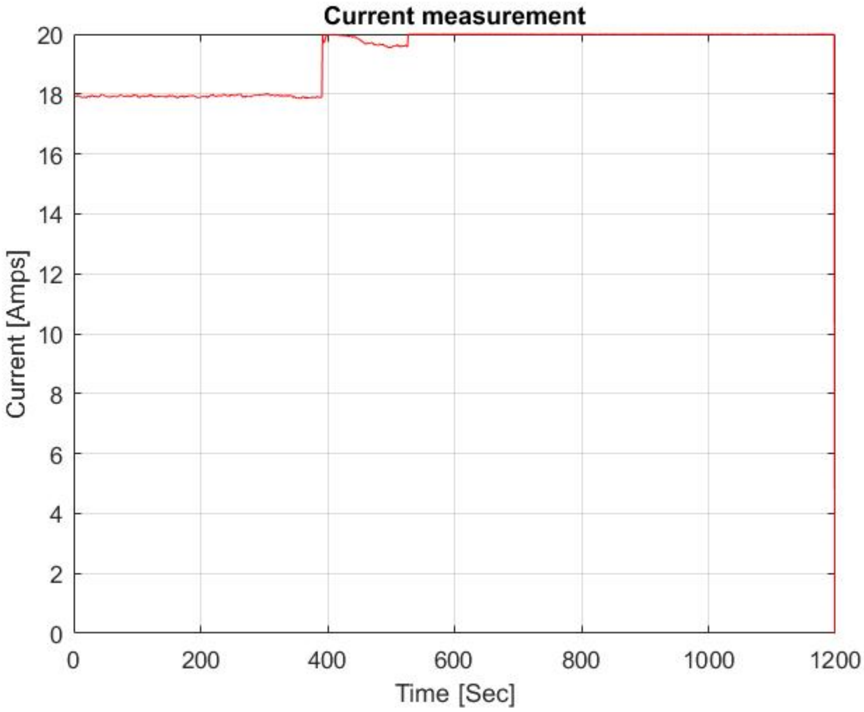


Figure 0-93 Motor, TV and boiler.

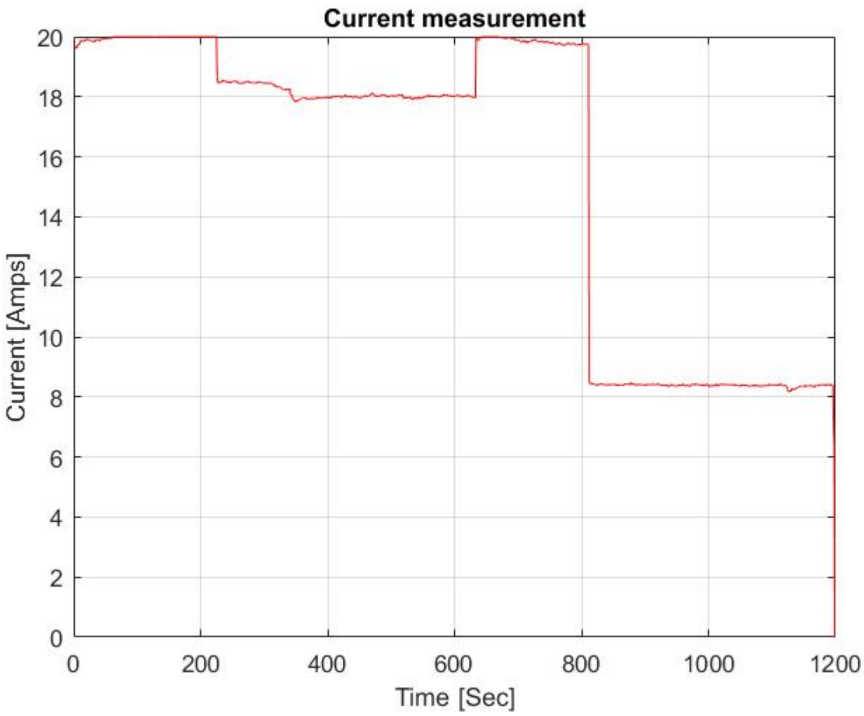


Figure 0-94 Motor, TV and boiler.

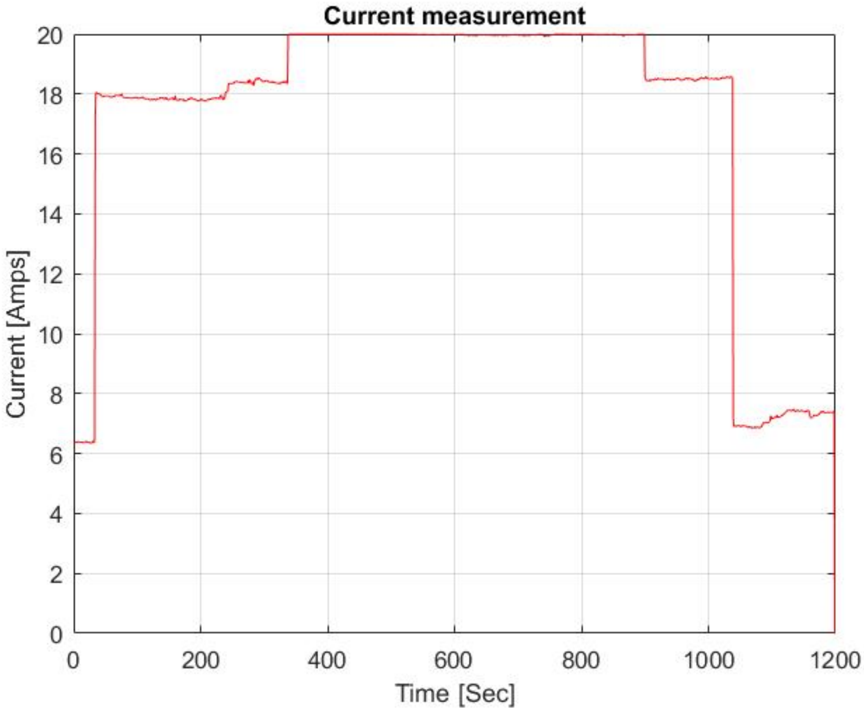


Figure 0-95 Motor, TV and boiler.

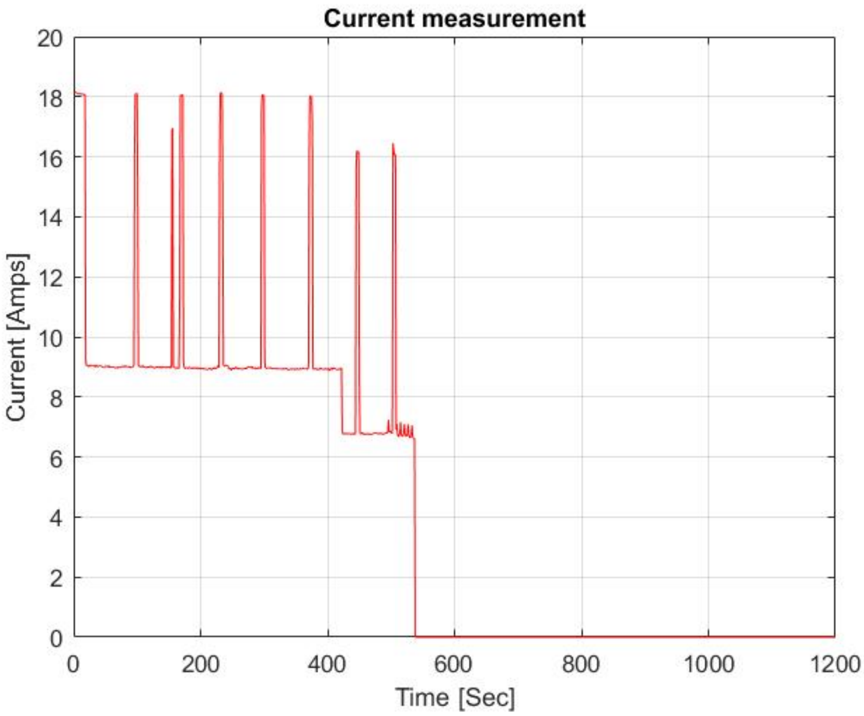


Figure 0-96 Motor, TV and iron.

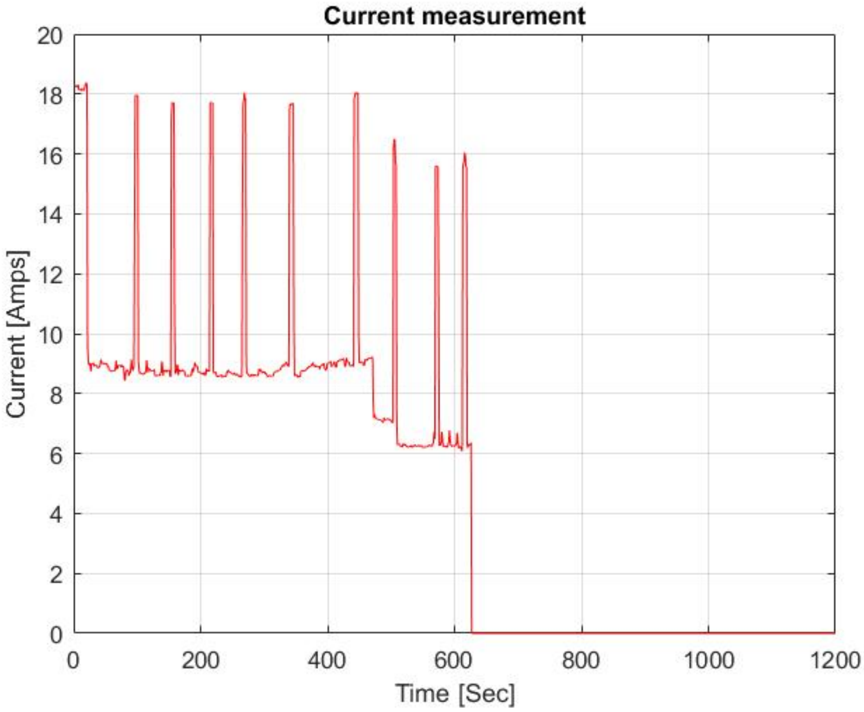


Figure 0-97 Motor, TV and iron.

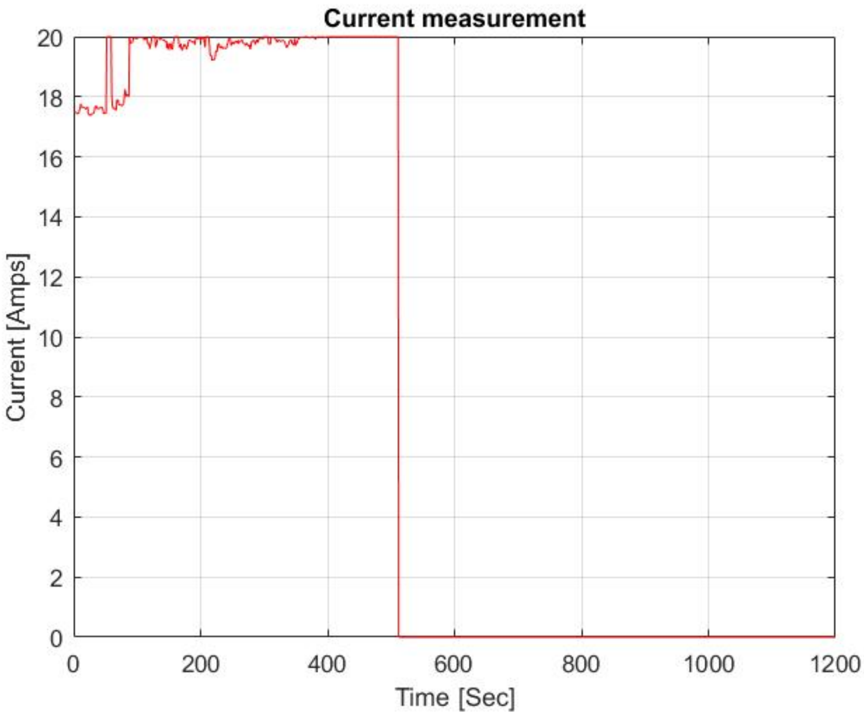


Figure 0-98 Motor, TV ,iron and boiler

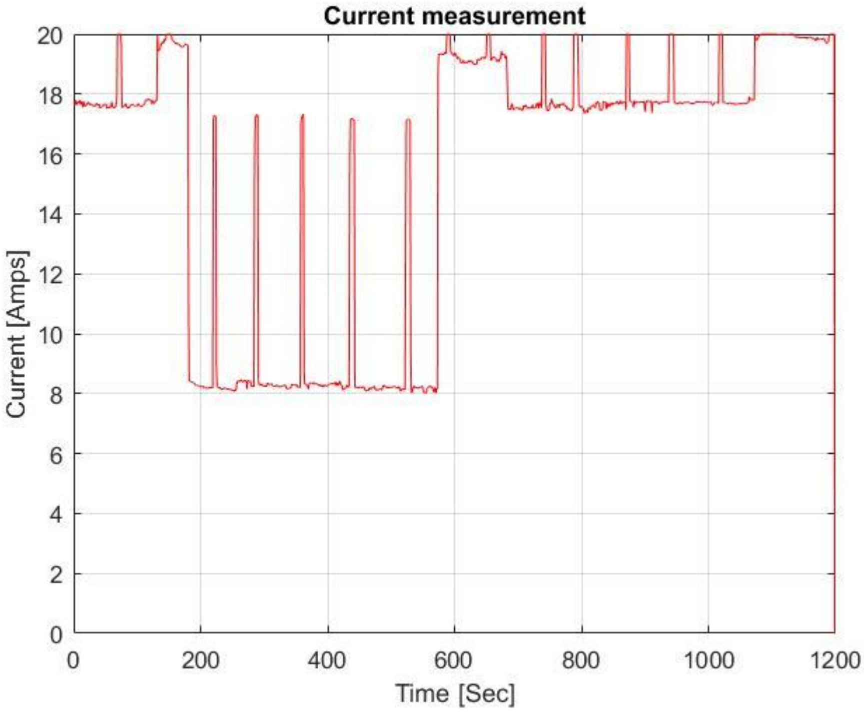


Figure 0-99 Motor, TV and iron.

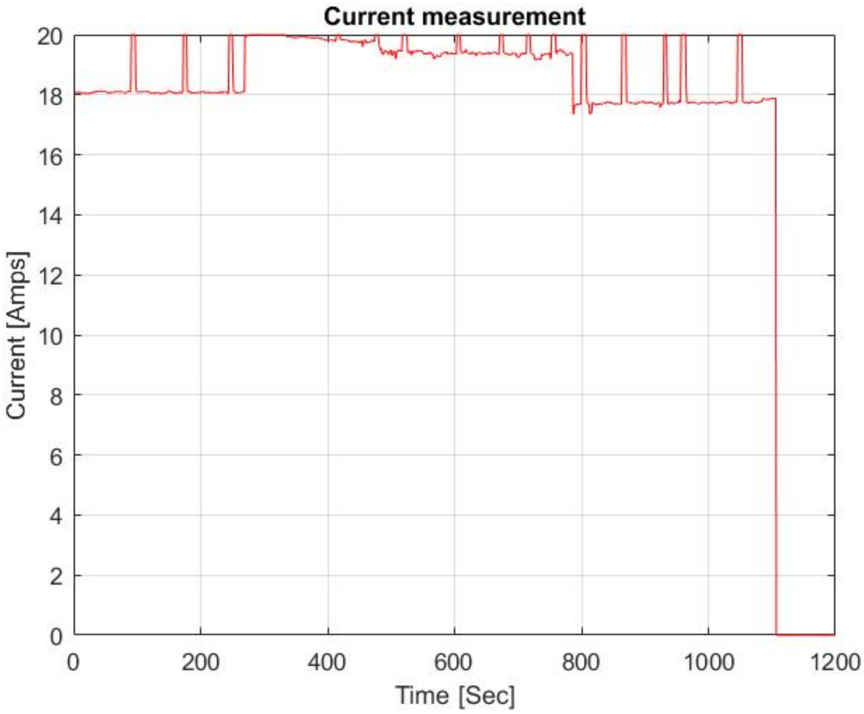


Figure 0-100 Motor, TV and iron.

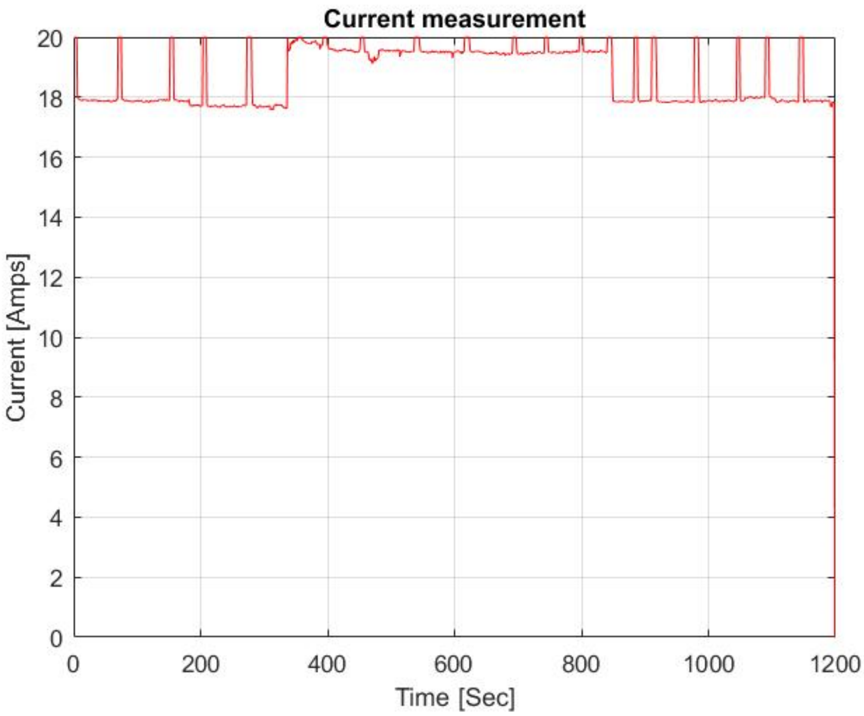


Figure 0-101 Motor, TV, iron and boiler

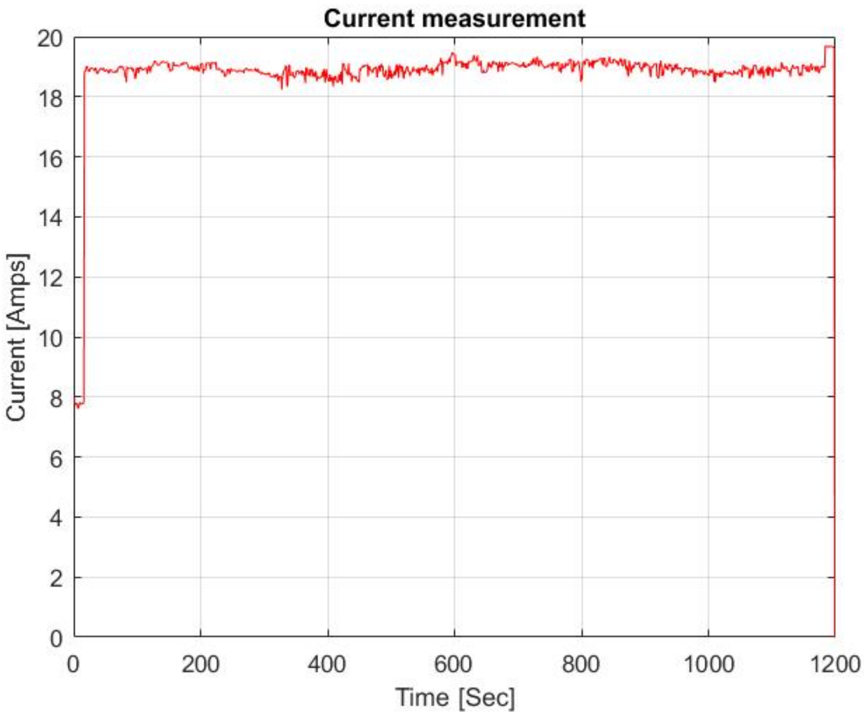


Figure 0-102 Motor, boiler and iron.

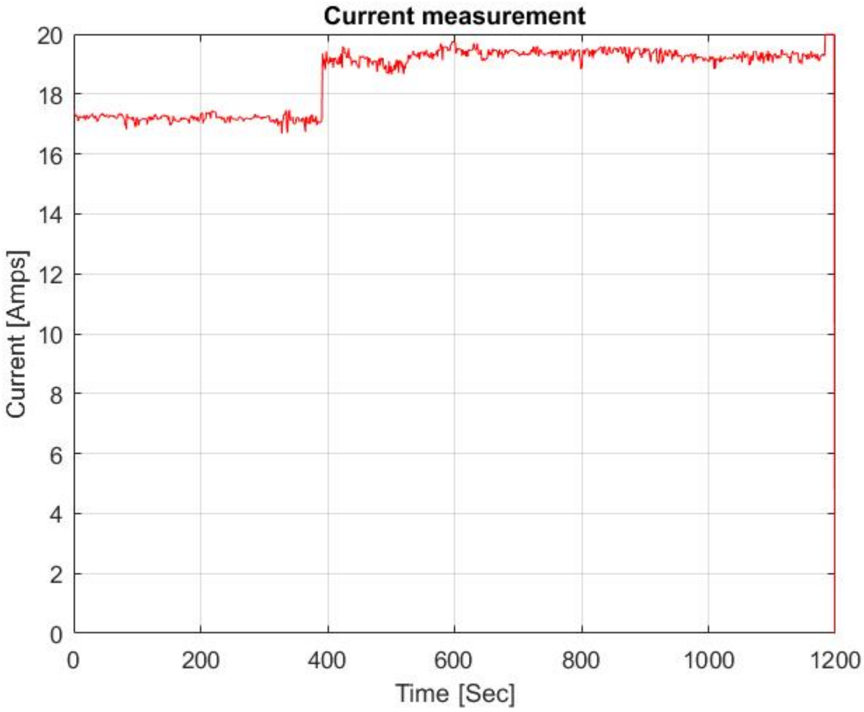


Figure 0-103 Motor, boiler and iron.

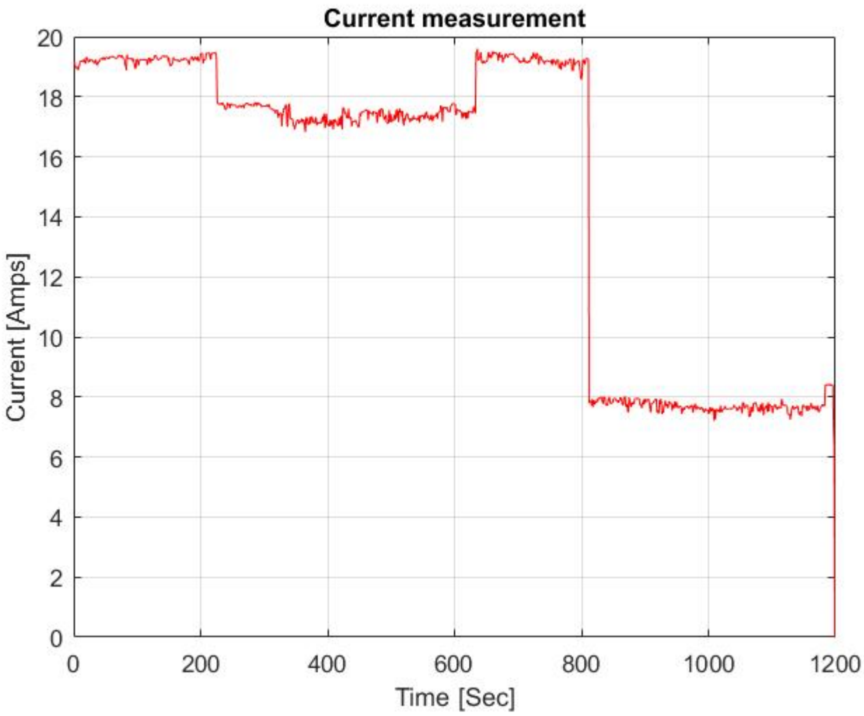


Figure 0-104 Motor, boiler and iron.

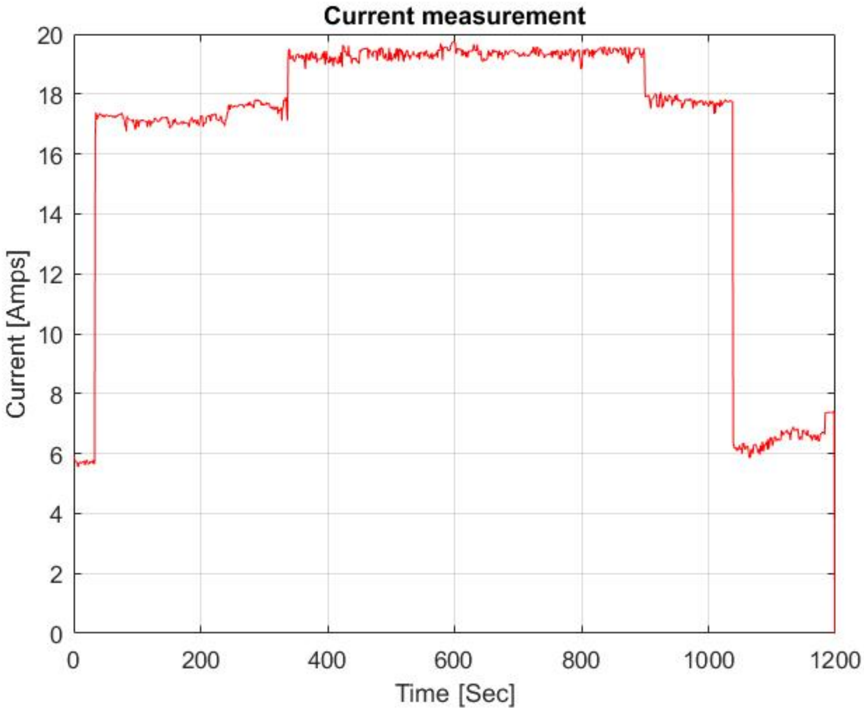


Figure 0-105   Motor, boiler and iron.

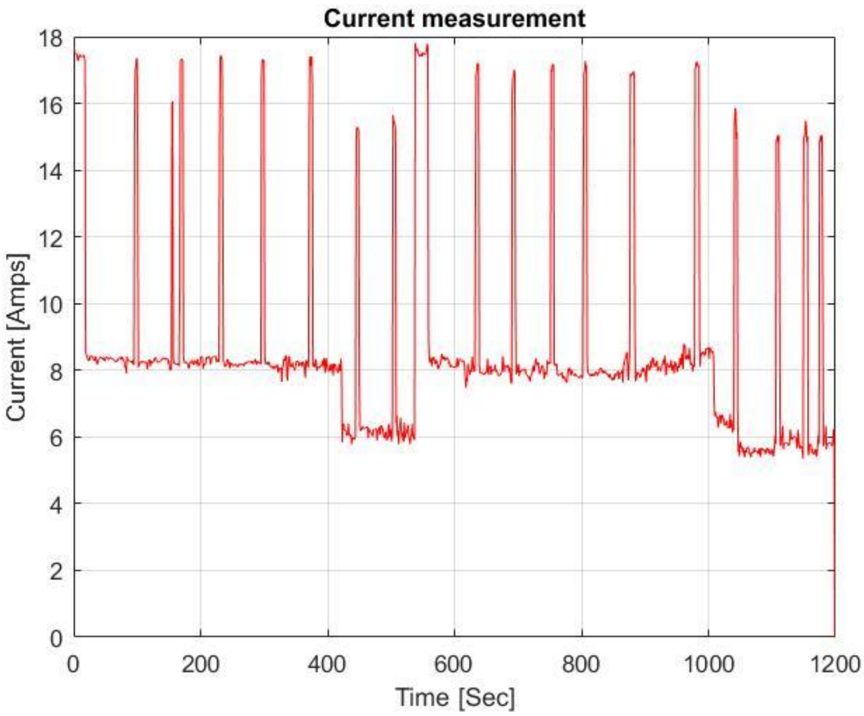
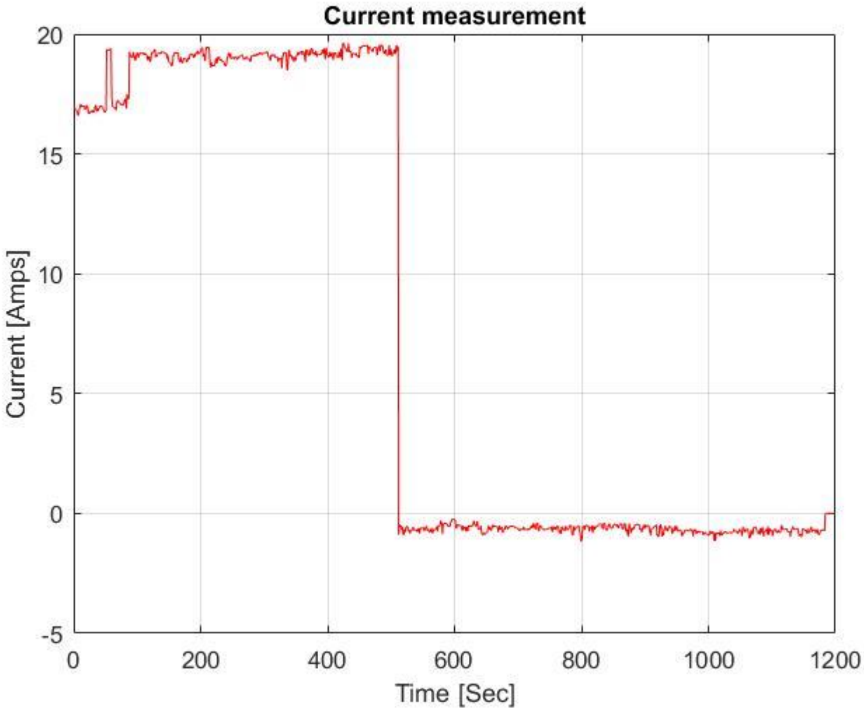


Figure 0-106   Motor, iron and I.


Current measurement
20
15
10
5
0
-5
Current [Amps]
0
200
400
600
800
1000
1200
Time [Sec]