School of Engineering
Integrated Design Project 2
Assignment 2
Individual Detail Design
2020/21

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Plastic Recycling Stream of a Recycling Plant of the Future in Santiago, Chile

Word count:1599

TECHNICAL SUMMARY

What part of the facility is simulated by your detailed design?	The plastic recycling stream including: • A three-phase power generation and conversion system. • A general light-duty DC motor model (e.g., conveyor). • A general heavy-duty AC motor model (e.g., shredder). • A water heater with tank (with water taken from the plastic cooler to save power) and a plastic washer. • The plastic melting furnace only requires constant power, and it is mainly a resistive load, therefore it is modelled only with a thermal resistor.
What are the key features of your simulation?	• Melted plastic is cooled with water which will be directed to the heater tank and heated for the washing process. • The power generation system includes a backup power storage system using battery packs which can ensure a proper shut down of the factory in case of a blackout and one of the battery array stores excessive energy generated by the solar panels.
How realistic is your simulation, and how could it be made more realistic?	• Most of the system parameters were obtained on their manufactures datasheets. It resembles about 60% of the real design. • However, there were difficulties integrating the load design with the power generation and conversion systems in the main template. Thus, the load section in the main template is only for demonstration.
What did you find were the best approaches to modelling to improve power efficiency?	• Apply some load and use gearbox to ensure the motor is running a little below (around 10%) its nominal speed. • To retrieve energy from parts of the system and use it on the modules that need it. • Theoretically, a brushless DC motor would be more efficient, but I could not run the simulation after around 0.5 s (time when the motor reaches the desired rotational speed).
What obstacles did you encounter and spend the longest time getting to work?	• I wanted to model a brushless DC motor and its control system for the conveyor system. However, after the motor reaches the desired rotational speed and the controller reduces its input voltage using the Buck convertor which causes problem with the three-phase rectifier. The problem persists after I added a resistive load in between the three-phase rectifier and the Buck convertor. • I had to abandon the model as I could not resolve the problem in time and went for a general DC motor model. It is still a valuable experience as I learned the basics of controlling a brushless DC motor.
How would you tackle the simulation differently if you could start again?	• Start with systems that I understand well, not something hefty like a BLDC motor. • Start with the power supply and conversion and a simple load. Make sure when trying to model the load to be more realistic, choose components that need external electrical power supply.

SIMULATION

Qualitative Description:

The plastic recycling stream consists of a conveyor system, a shredder, a plastic washer, and a furnace. Design and modelling of the conveyor system and the shredder mainly involve choosing the right motors and model them. Plastic washer and the furnace are modelled mainly in the Thermal Liquid domain of Simulink. The goal of the modelling process is to achieve a stable closed-loop control of the equipment set while optimise its efficiency. Note that the purpose load section in the main template is only to demonstrate power from the utility grid can be converted to power the generalised load.

Quantitative Description: Specification Table

Table 1. General Properties

Property	Quantity
Indoor Temperature (°C)	20
Indoor Relative Humidity (%)	30
Daily (8h) Plastic Intake Capacity (ton)	200
Processed Single-piece Plastic Dimensions (cm)	100*100*1
Processed Plastic per Package (Number of Sheets)	100

Table 2. Power Characteristics

Property	Quantity
Number of Phase	3
Phase-to-phase Voltage (V)	380
Frequency (Hz)	50
Phase Shift (°)	0
Harmonics	None
Parasitics	None
*Overall Rated Steady-state Power Consumption (GWh)**	11.48
*Overall Rated Steady-state Power Efficiency (%)**	6.1

Table 3. Light-duty DC Motor Used for Conveyor Systems - Characteristics

Property	Quantity
*Model Name***	250 W, Maxon RE 65 Ø65 mm, Graphite Brushes, 388991
Number of Units	20

Table 4. Heavy-duty AC Motor for Shredder - Characteristics

Property	Quantity
*Model Name***	Three-phase Squirrel-Cage-Motors SIMOTICS Motor type: 1CV2282D SIMOTICS SD - 280 M - IM V35 - 8p
Number of Units	1

Table 5. Constant Temperature Plastic Washer Characteristics

Property	Quantity
Heater/Washer Tank Dimension (m)	3.5*3.5*3.5
Melted Plastic Cooler Pipe Dimension (m)	100*0.03*0.03
Volume of Plastic Washed Simultaneously (m^3)	10
Water Intake (kg/s)	1

Steady-state Power Consumption (MW)	2.84
Steady-state Power Received by the Tank (kW)	163
Steady-state Heater Efficiency (%)	5.763
Steady-state Overall Efficiency (%)	5.766

*Table 6. Plastic Melting Furnace Characteristics****

Property	Quantity
Power Consumption (MW)	2.84
Furnace Dimension (m)	3.5*3.5*3.5
Volume of Plastic Melted Simultaneously (m^3)	5

*Design concept data from Table 6 are not included in the calculation.

**Copies of datasheets [1][2] provided in the Appendix section.

***This part was not modelled due to time constrain; the quantities listed are only design concepts.

Model: The Simulation model diagram(s)

Overall Model

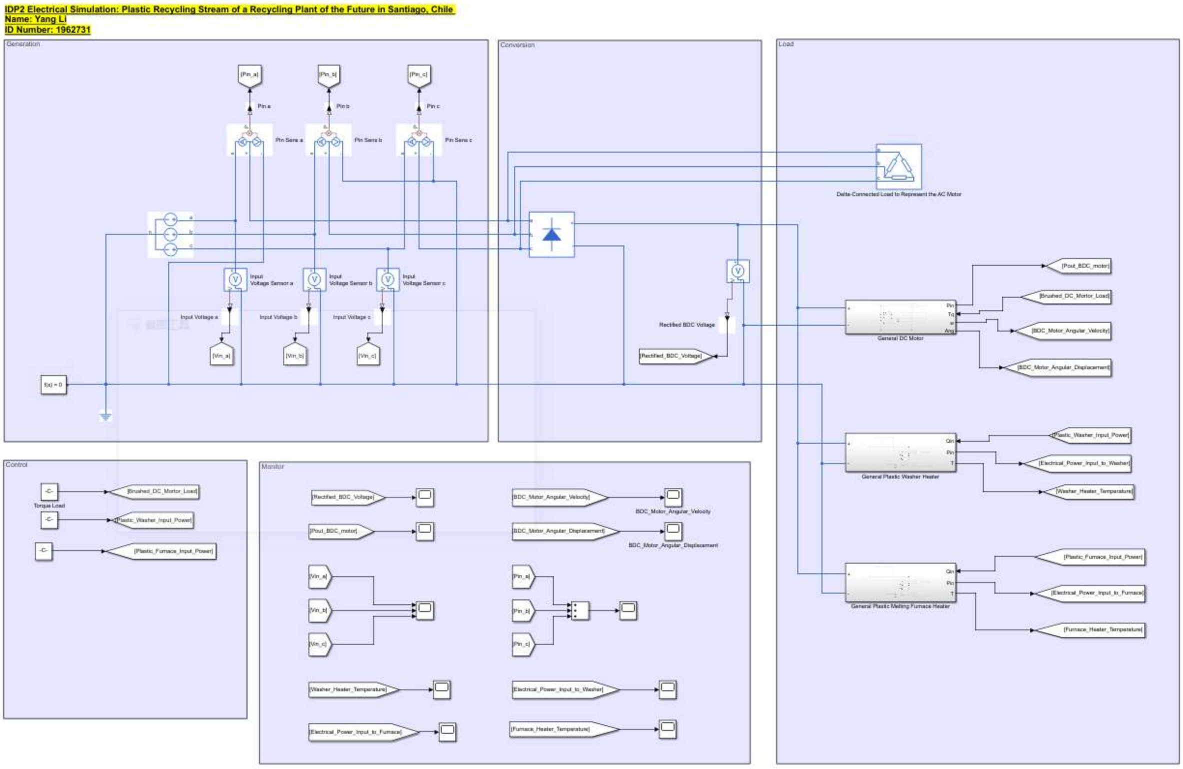

Figure 1. Overall Model

Power Generation

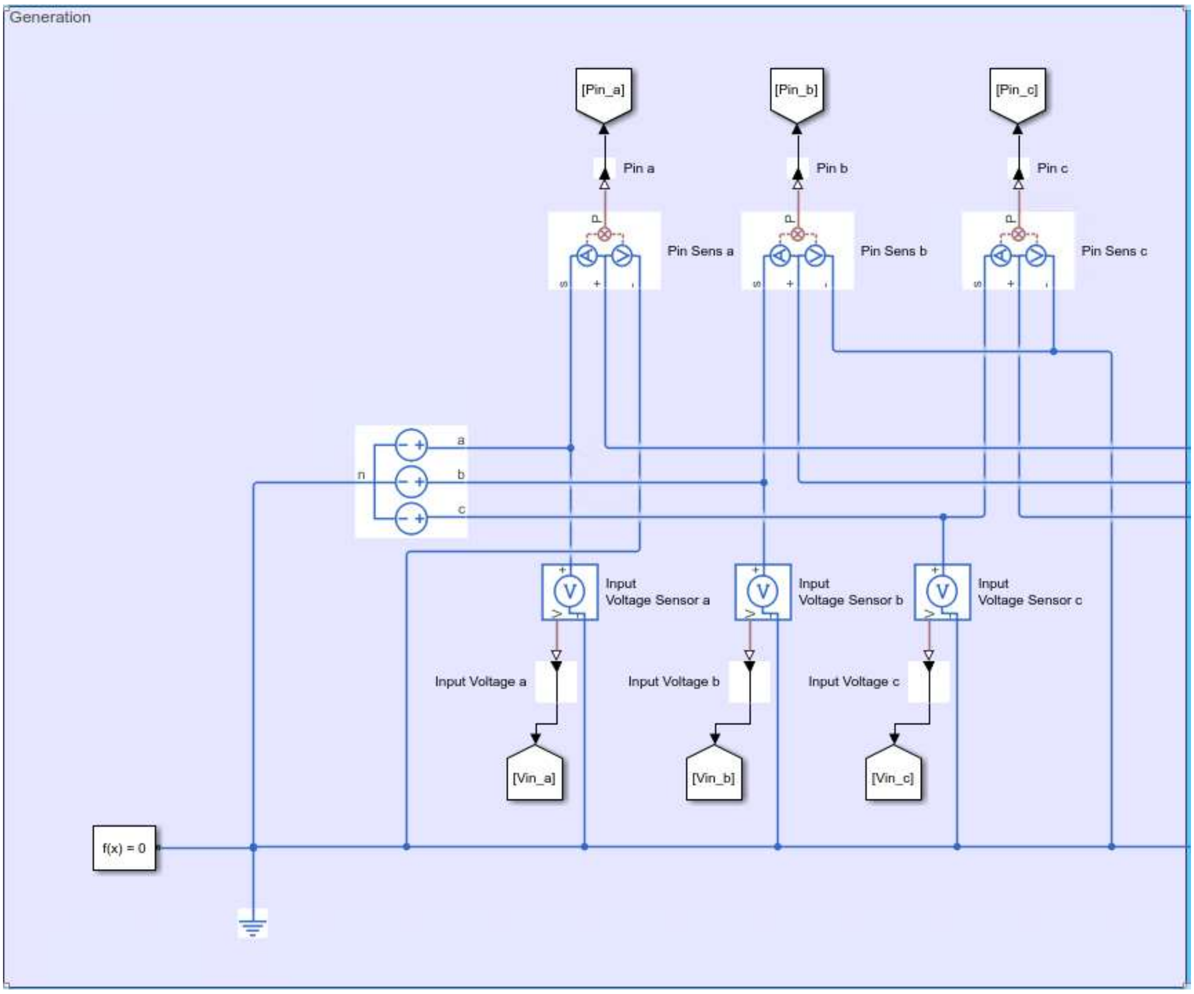

Figure 2. Power Generation

Instead of using the provided DC voltage supply, a three-phase voltage source is used with line-to-line voltage of 380 V and frequency of 50 Hz, which is the standard industrial power supply in Chile [3]. Short-circuit power level is tuned up to 1 T*VA, to cope with the significant power consumption of the stream.

Power Conversion

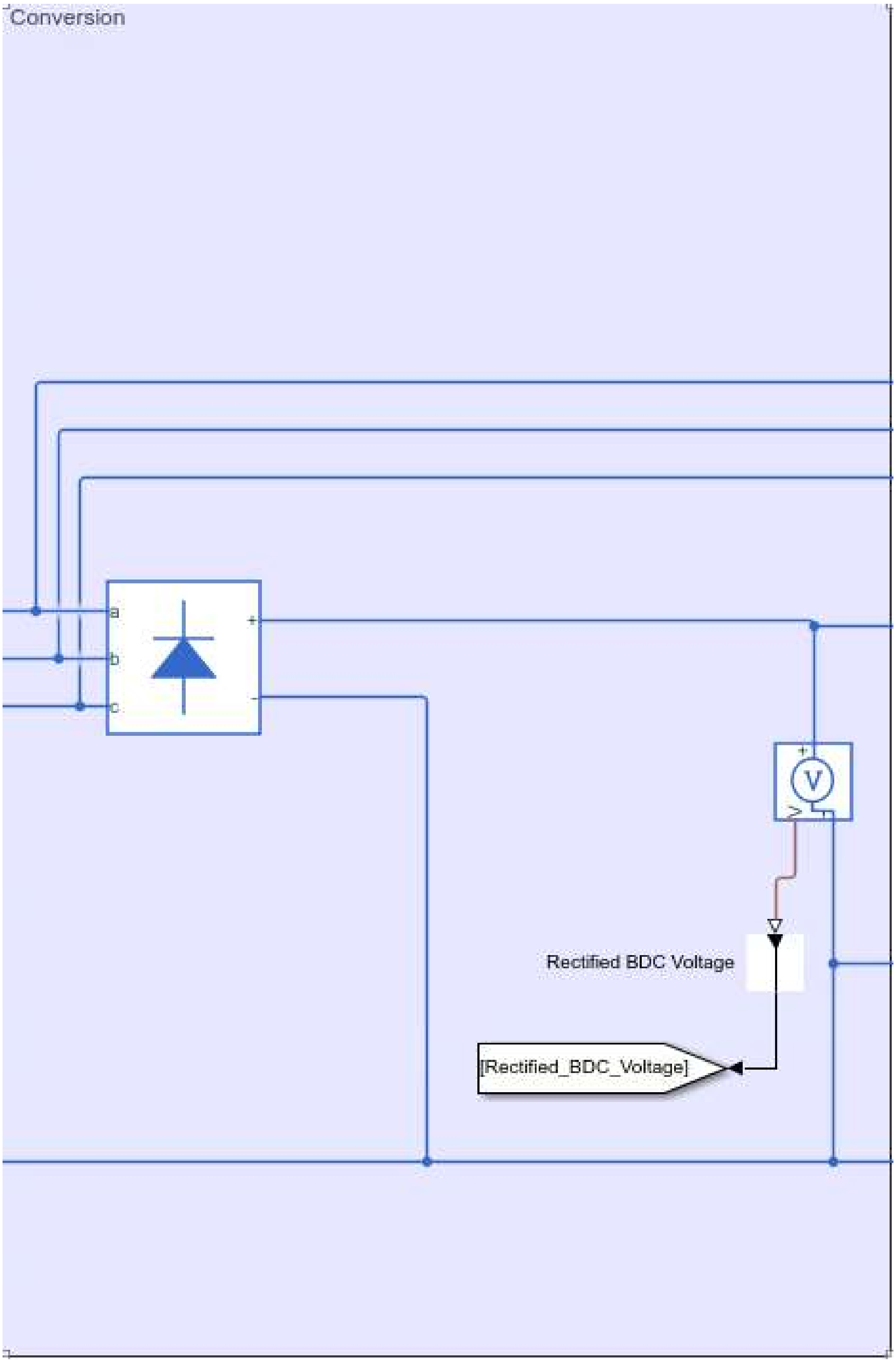

Figure 3. Power Conversion

The Simplified Induction Motor can directly use power from the Voltage Source (Three-Phase), hence it does not need any power conversion. The other three load sections require a DC input, hence a Rectifier (Three-Phase) is implemented.

Load

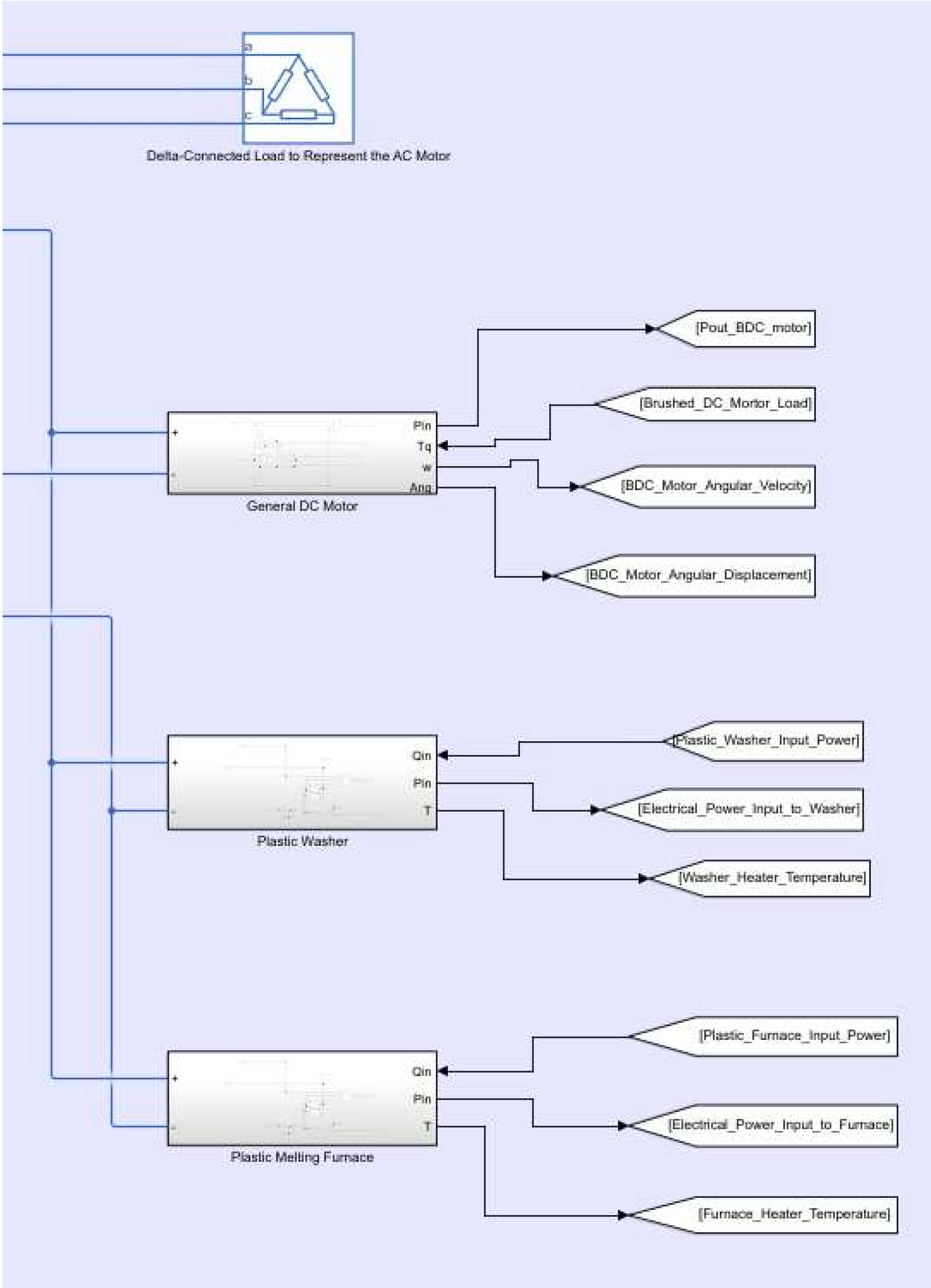

Figure 4. Overall Load

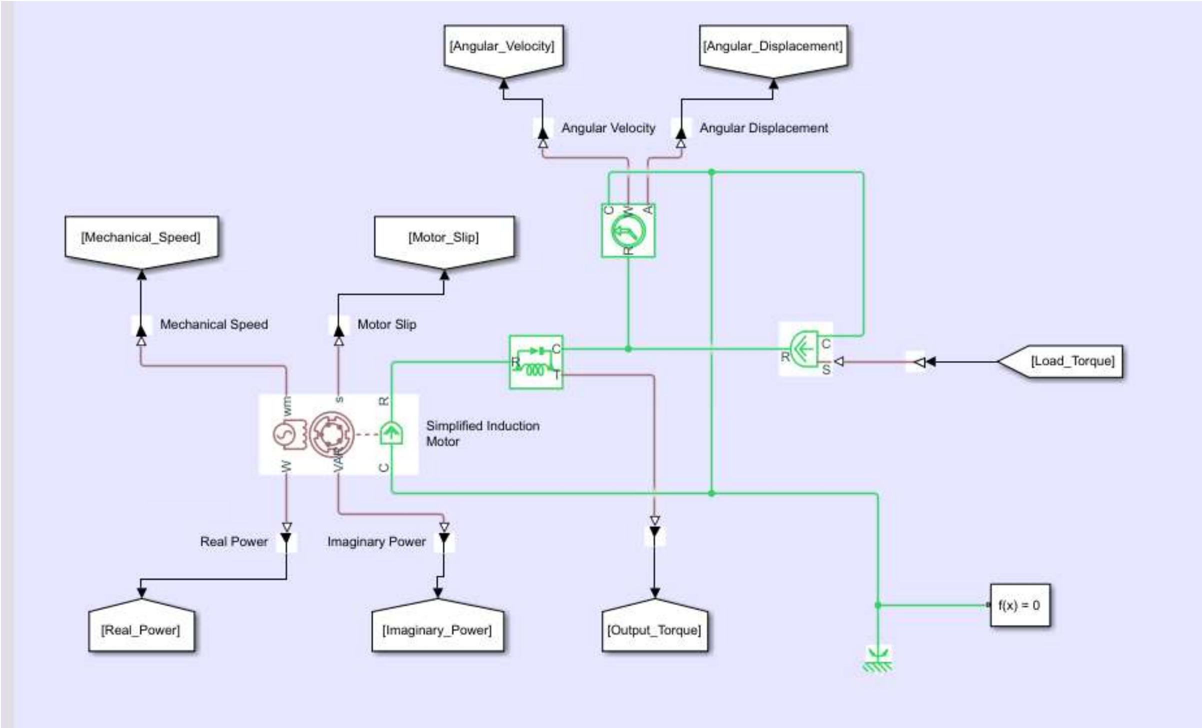

Figure 5. AC Induction Motor

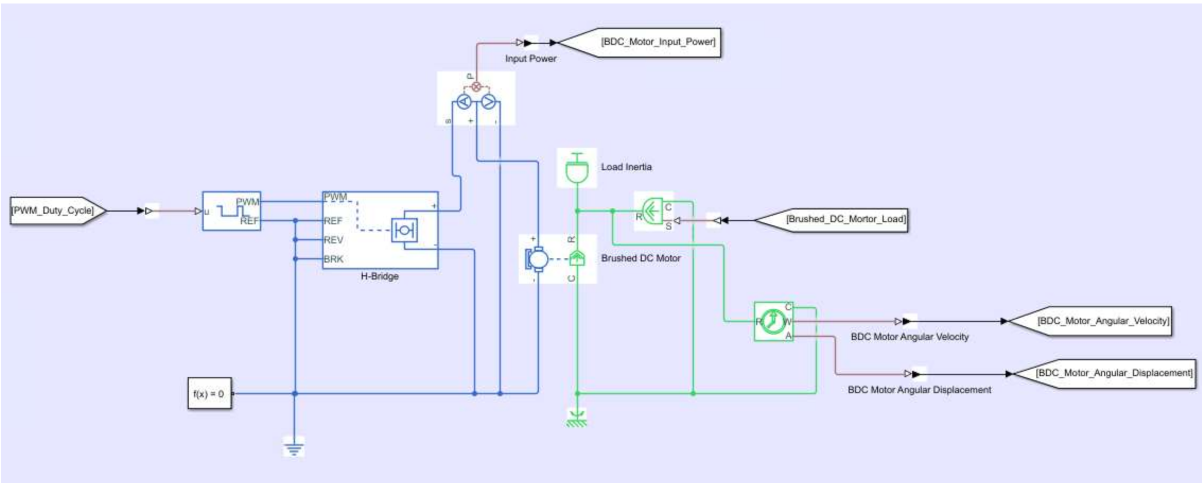

Figure 6. Brushed DC Motor

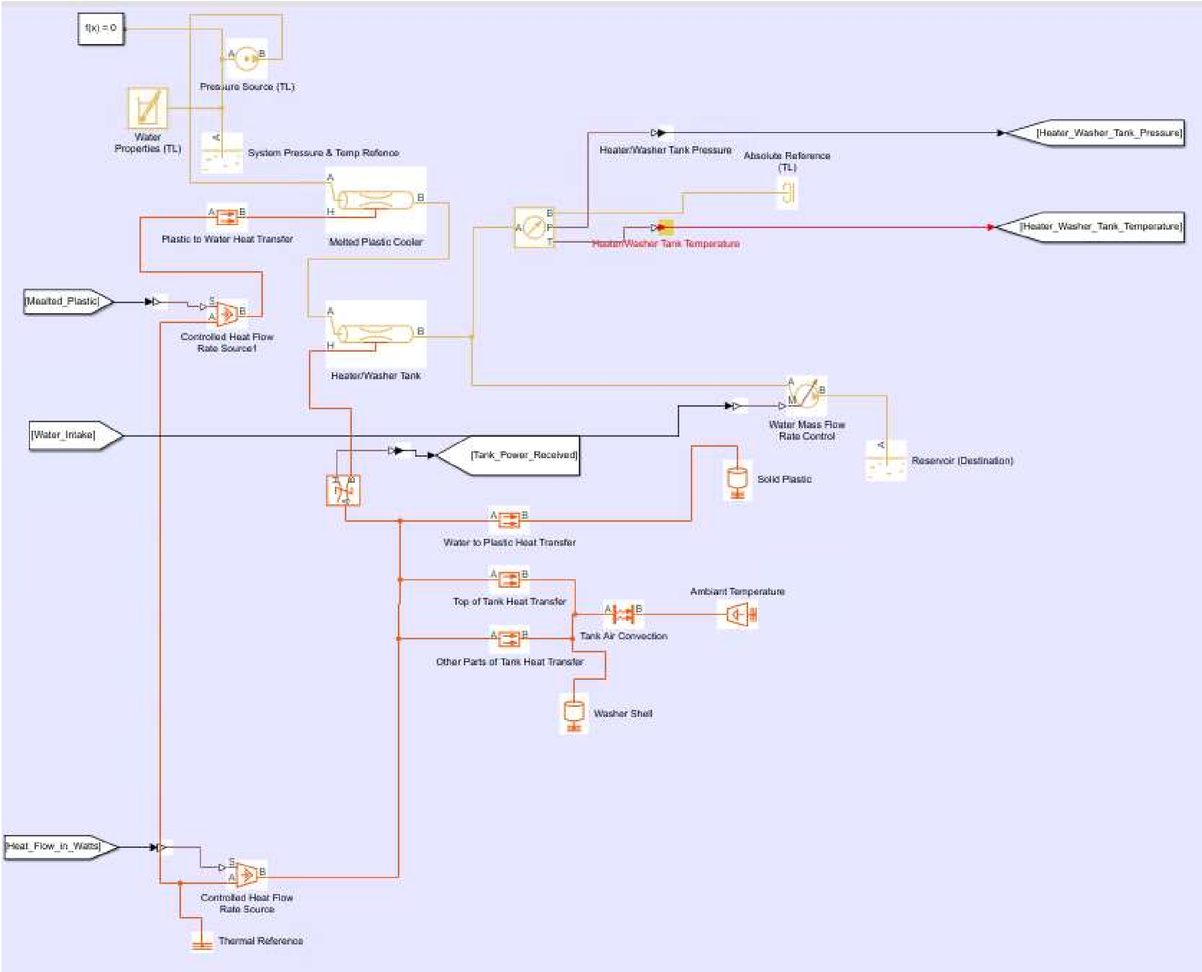

Figure 7. Plastic Washer

The motor models have load torque and inertia being considered, and the washer is all in thermal liquid domain, but with input and output power calculated. Except for the first one, the other three screenshots are of individual load files instead of the subsystems shown in the first one. The generalised subsystems in the first screenshot are only to show that the supplied power can be converted to their input requirements. The representative models inside the subsystem blocks are shown as follows.

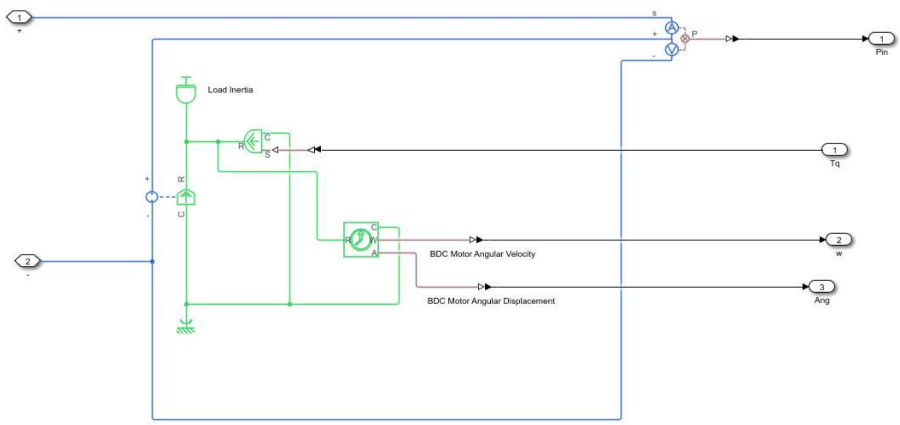

Figure 8. General DC Motor

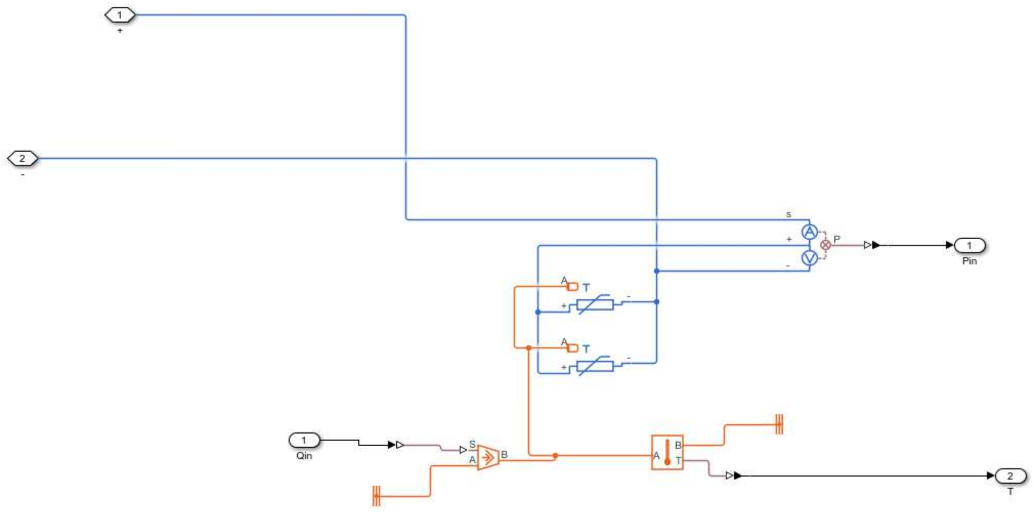

Figure 9. General Plastic Washer Heater / Plastic Melting Furnace Heater

Control

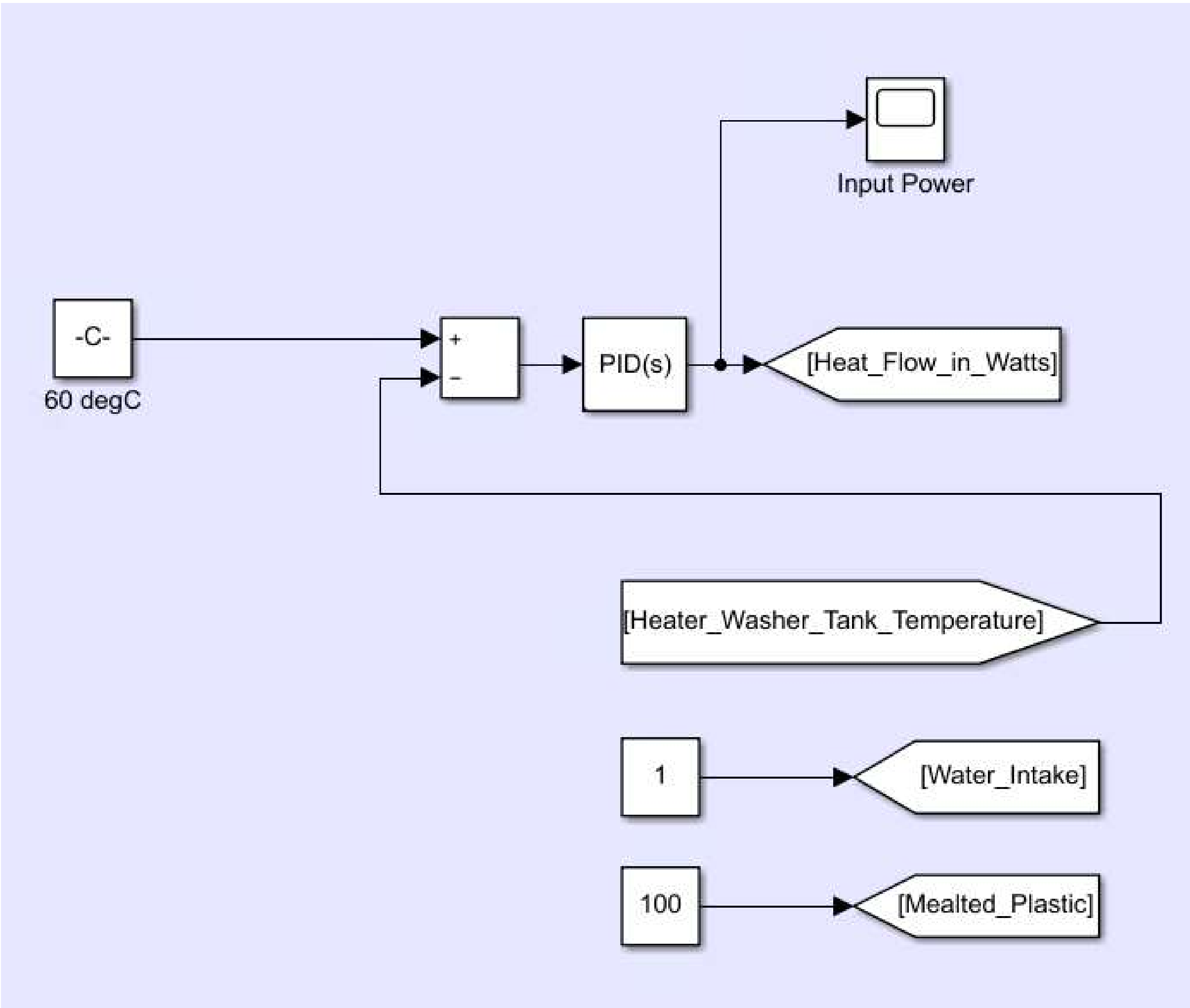

Figure 10. Plastic Washer Temperature Close-loop PID Control

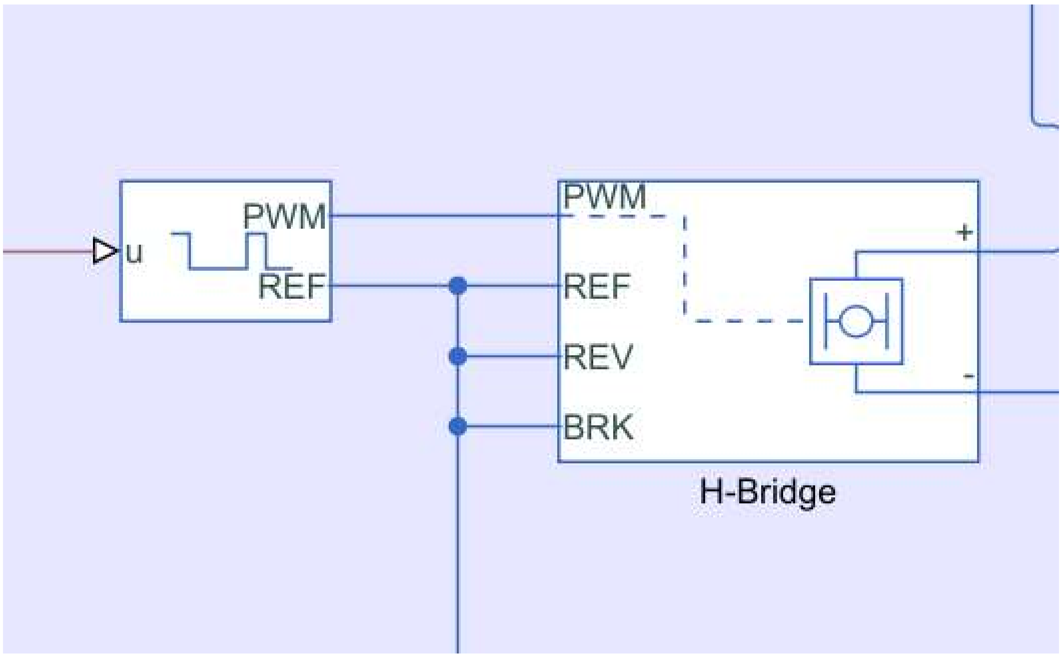

Figure 11. H-Bridge Control of the DC Motor

The most sophisticated control modules are shown in Figure 10 and Figure 11. The one shown in Figure 10 maintains the water in the washer tank at 60 °C with a close-loop PID controller. The motor controllers are open-loop, but they are able to maintain the motor at a relatively stable speed under varying load torque.

Analysis: The Simulation Result

<These should be graphs conveying source/load and efficiency/loss characteristics following those given in the template. In addition to electrical inputs and outputs, those from other domains such as mechanical and thermal can be included as applicable. - 40% of marks >

Inputs and Outputs

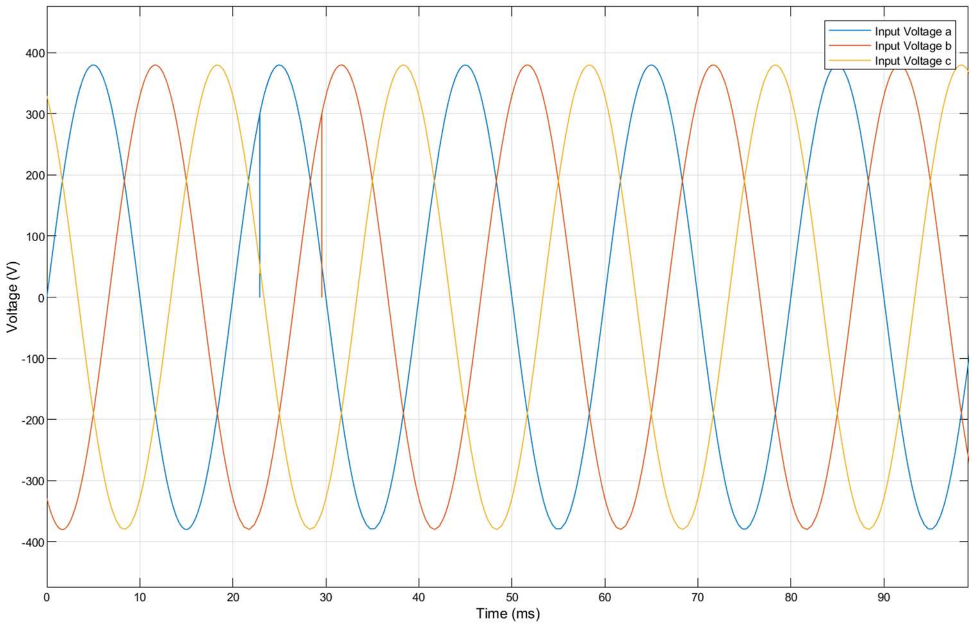

Figure 12. Input Voltage (Three-Phase)

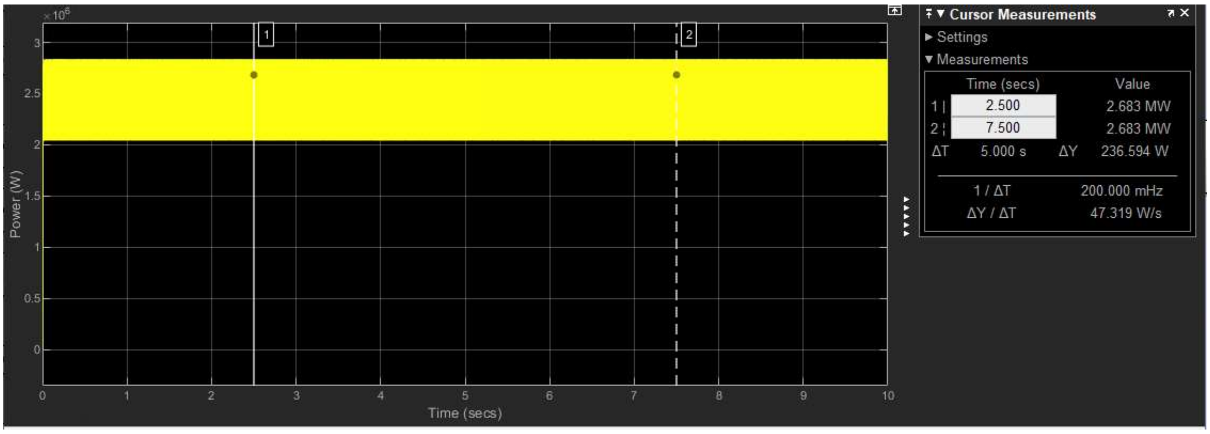

Figure 13. Electrical Power Input to the Heater in the Plastic Washer

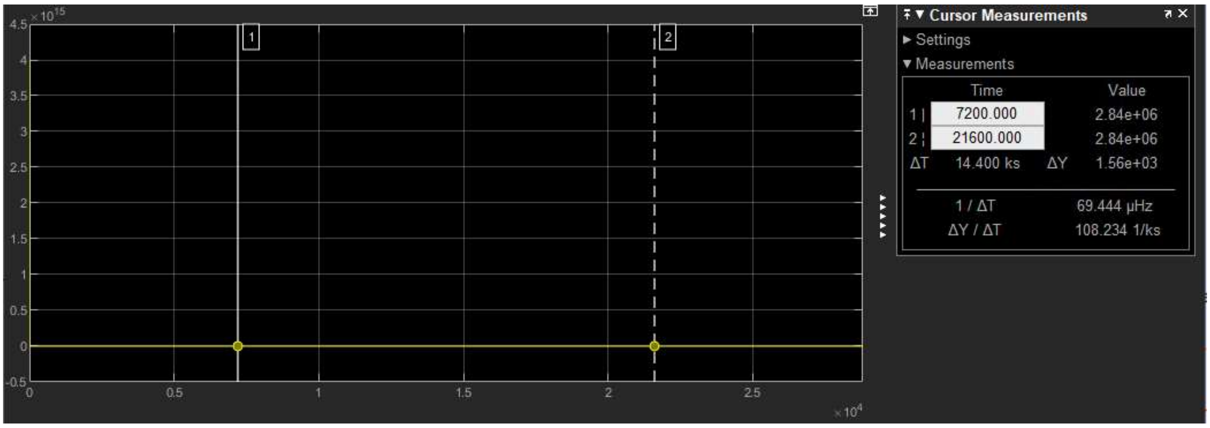

Figure 14. Power Required by the Heater in the Plastic Washer

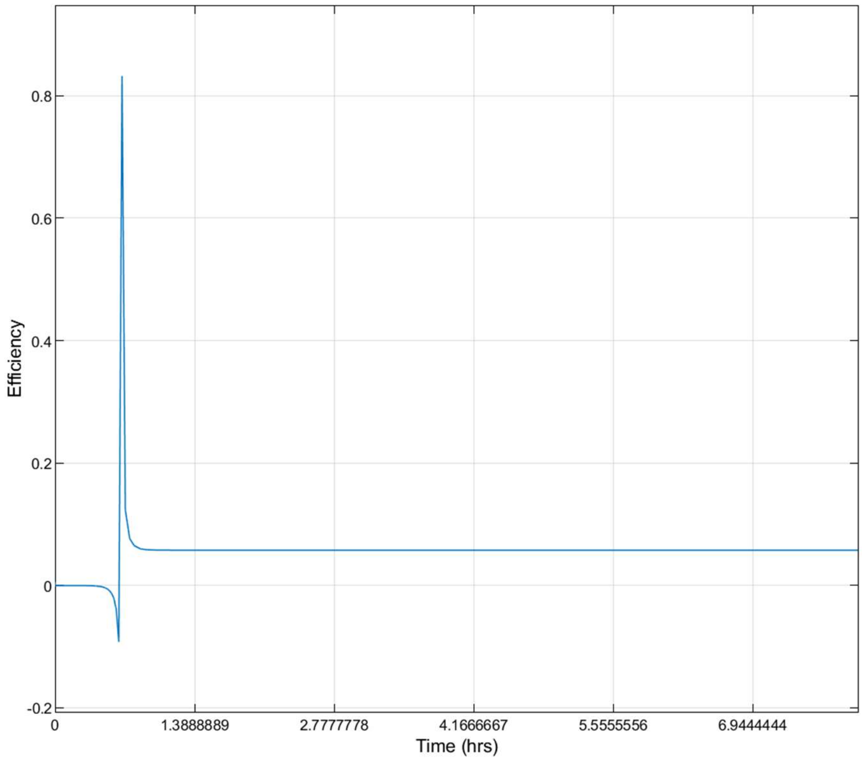

Figure 15. Plastic Washer Overall Efficiency

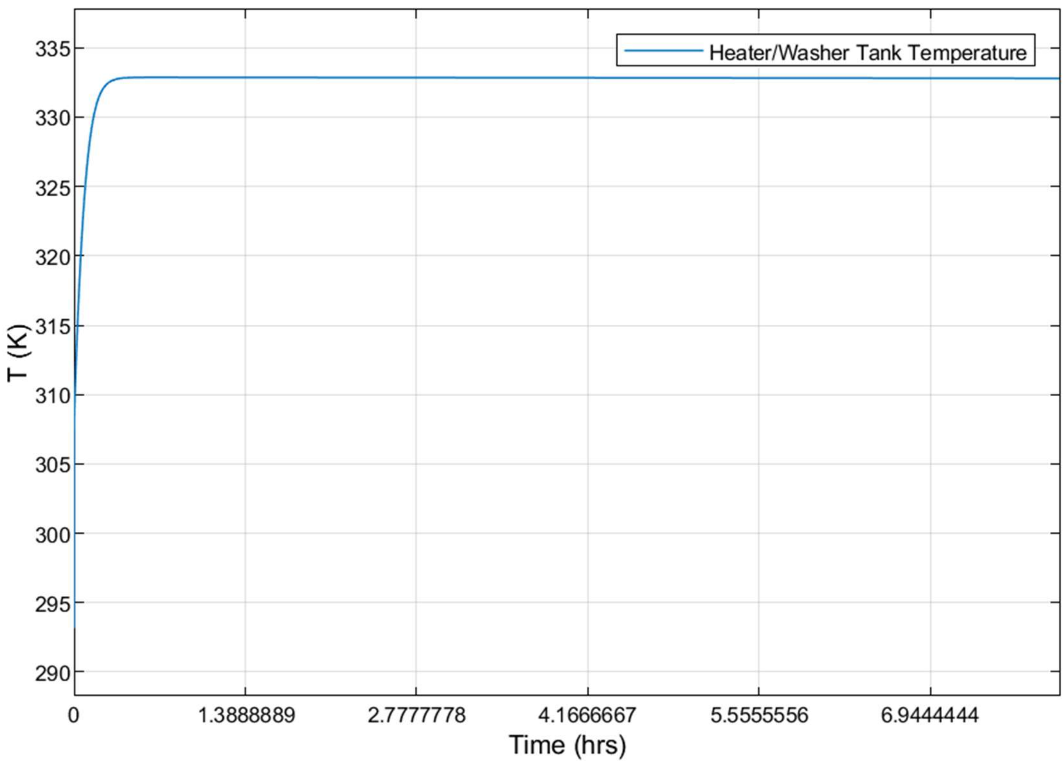

Figure 16. Heater/Washer Tank Temperature

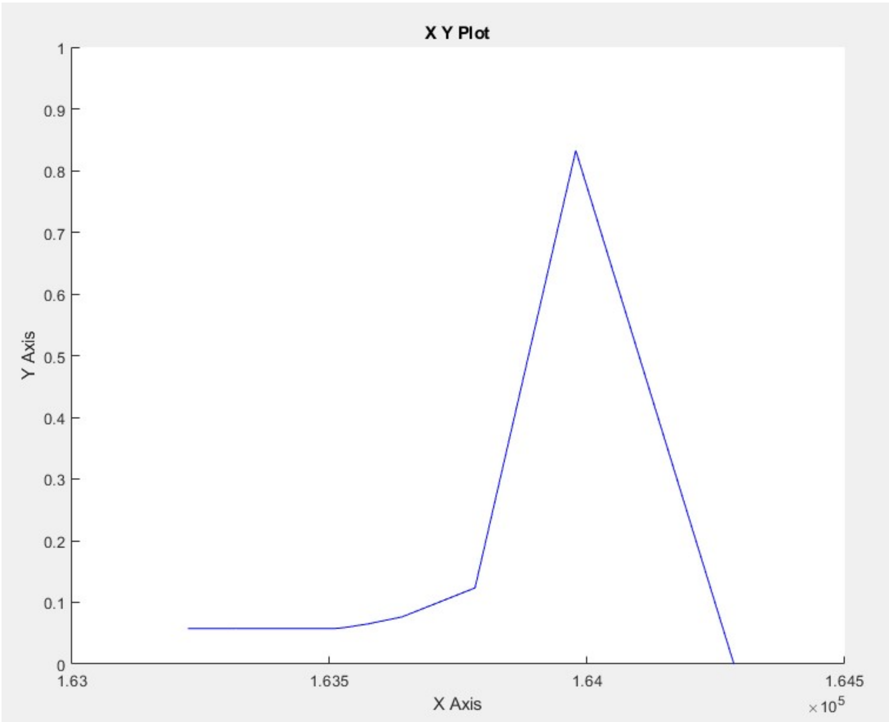

Figure 17. Graph of Efficiency vs Power out of the Plastic Washer

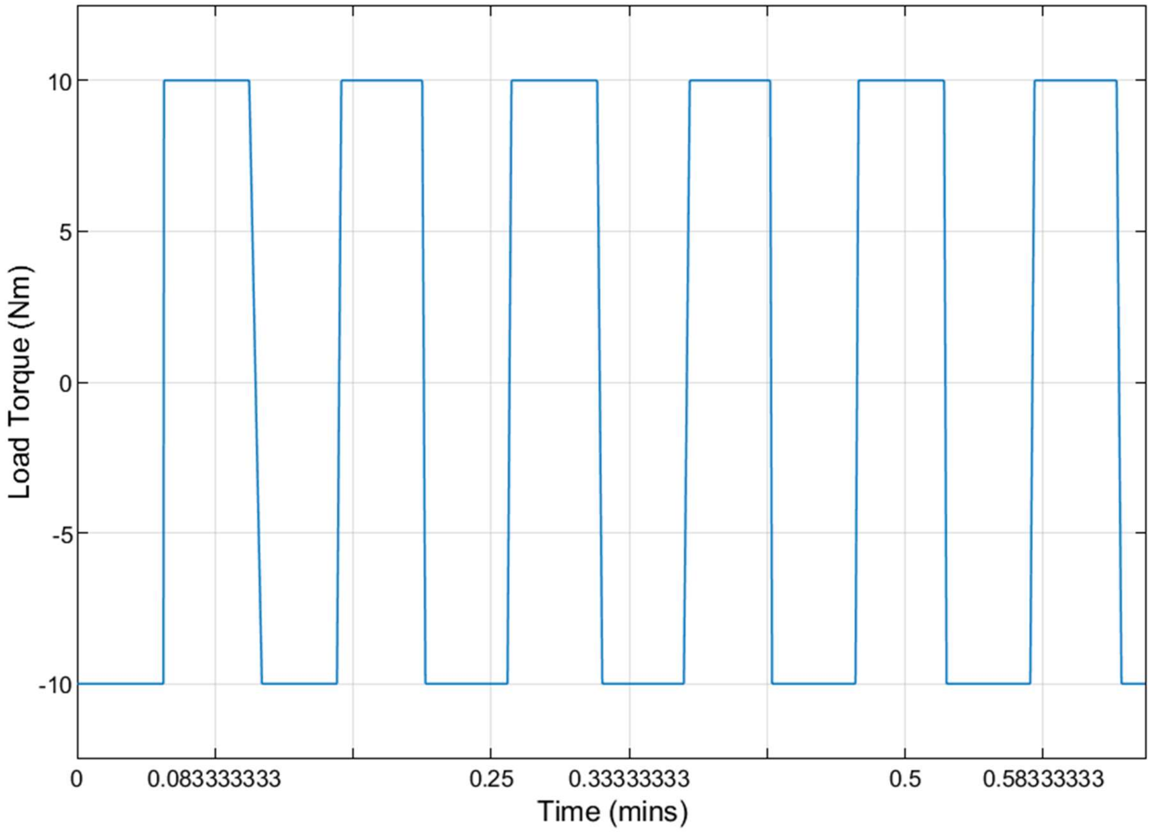

Figure 18. Load Torque for AC Induction Motor

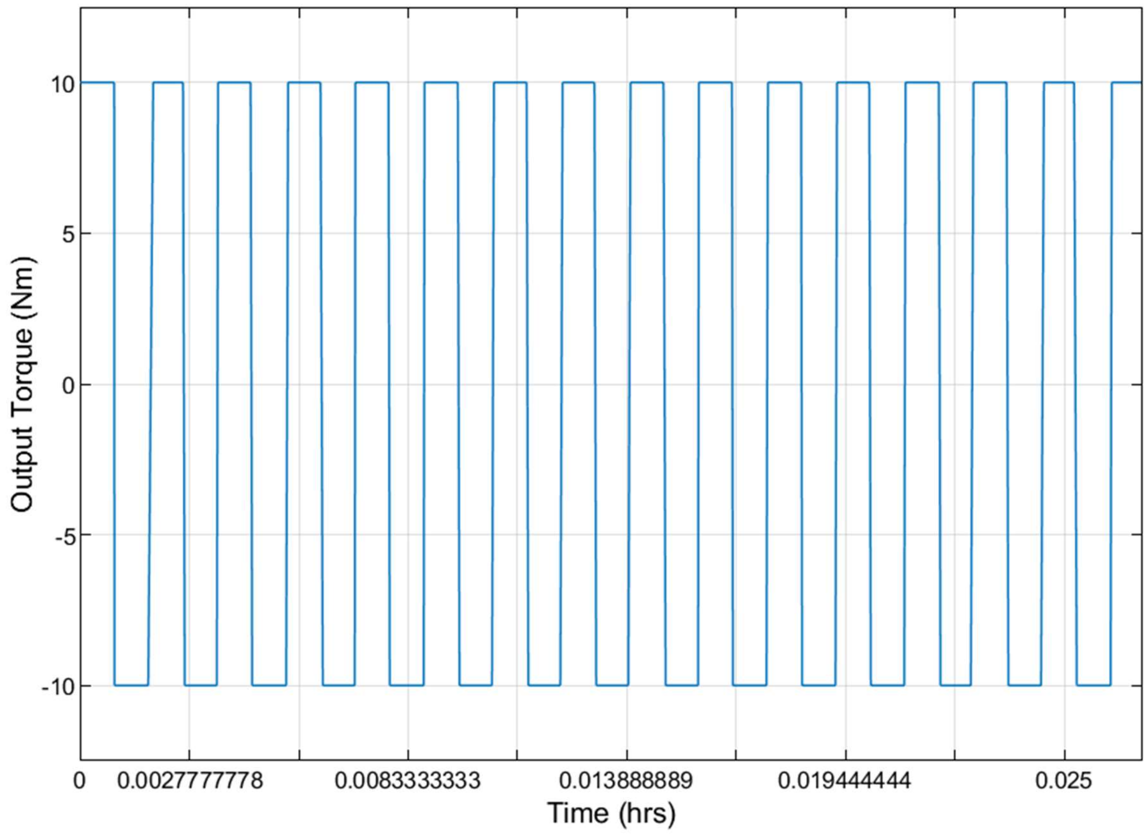

Figure 19. Output Torque of AC Induction Motor

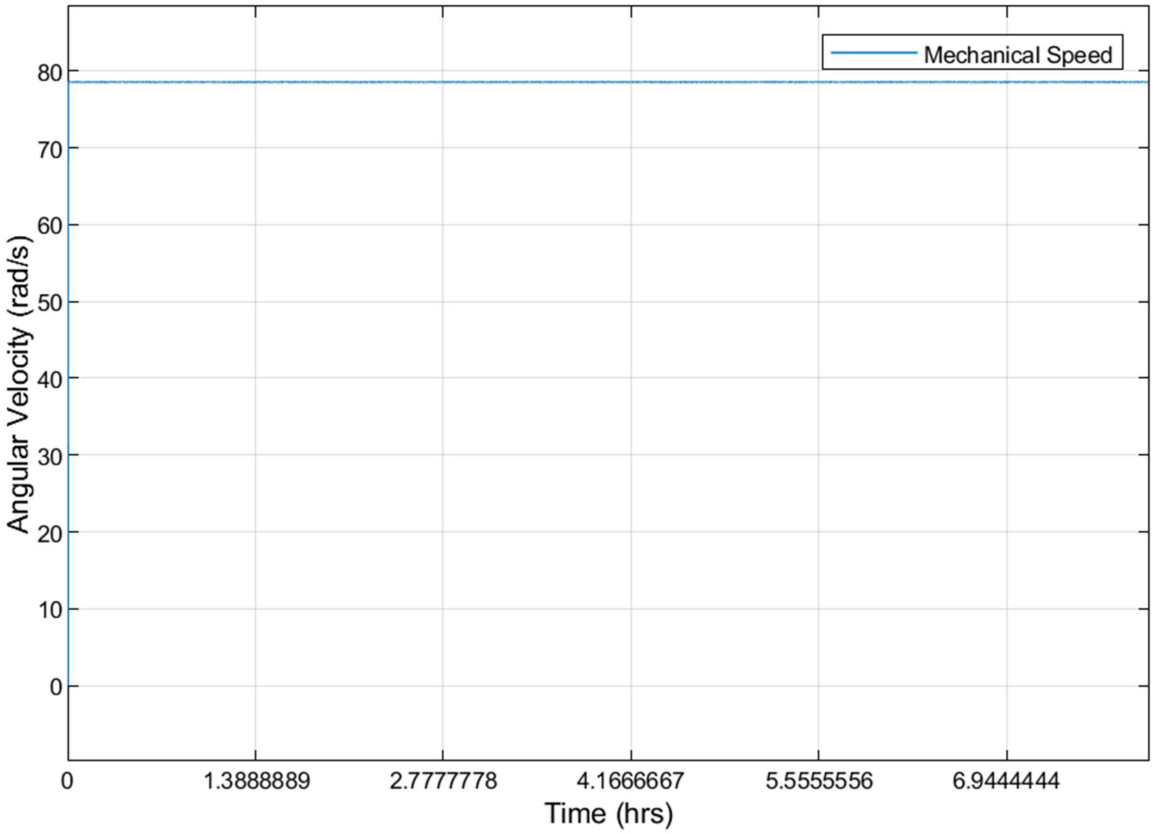

Figure 20. Speed Responds of the AC Motor

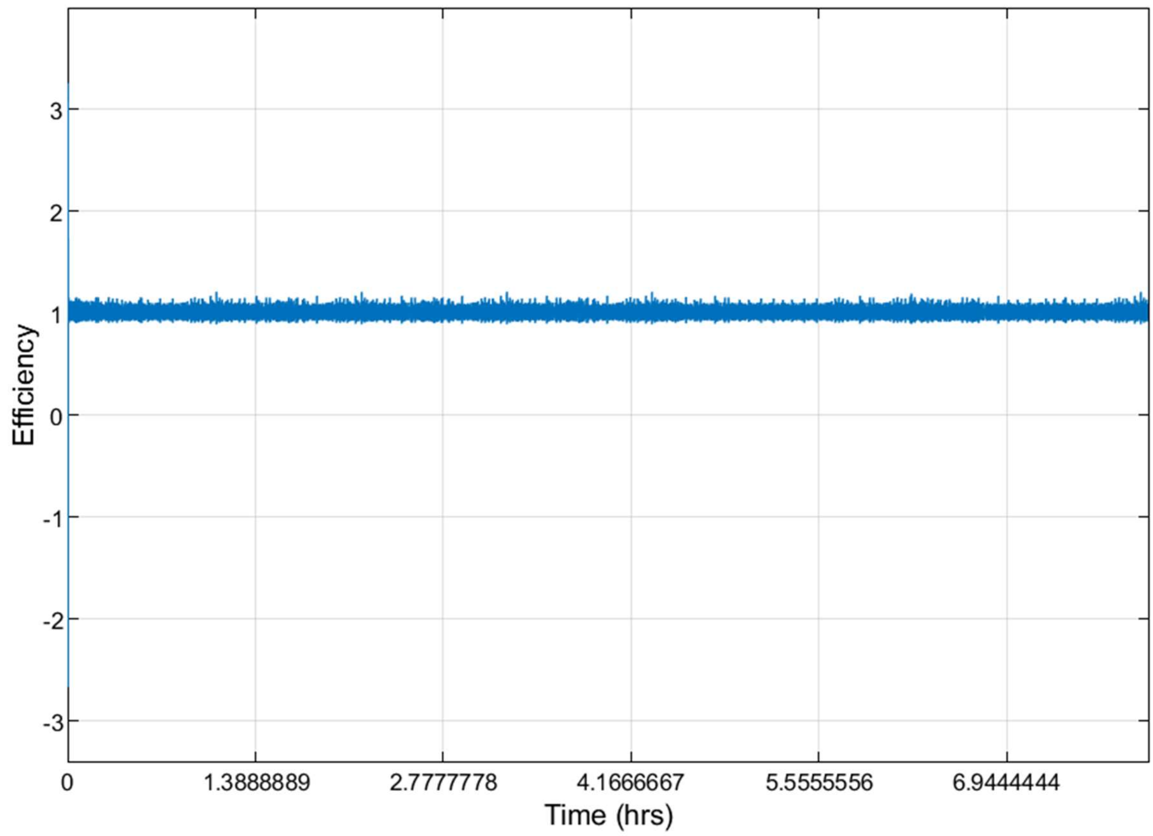

Figure 21. Efficiency of the AC Induction Motor

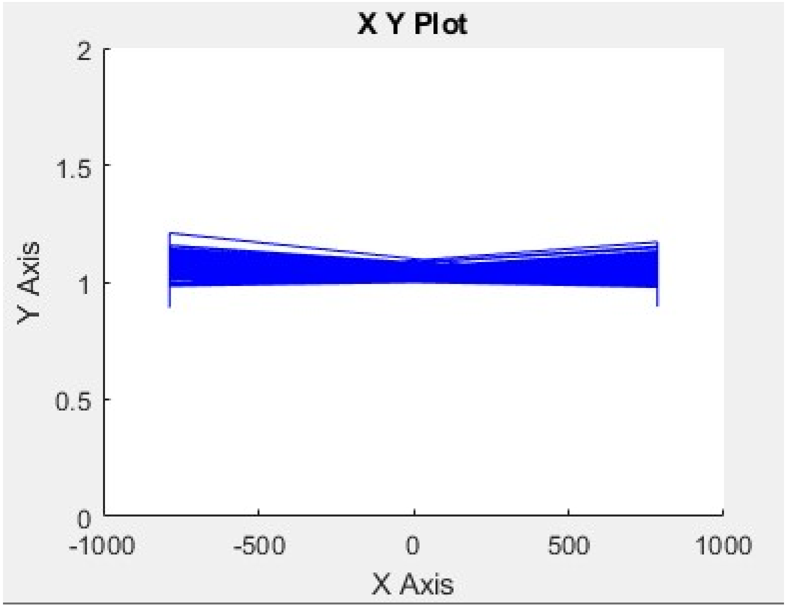

Figure 22. Efficiency vs Power Out Plot of the AC Induction Motor

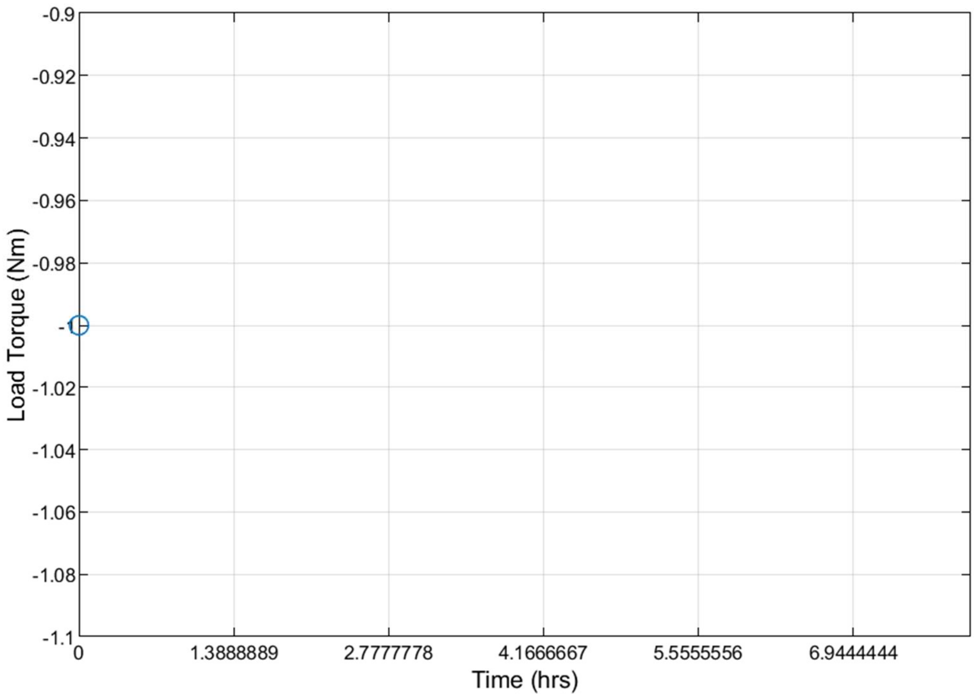

Figure 23. Constant Load Torque for the DC Brushed Motor

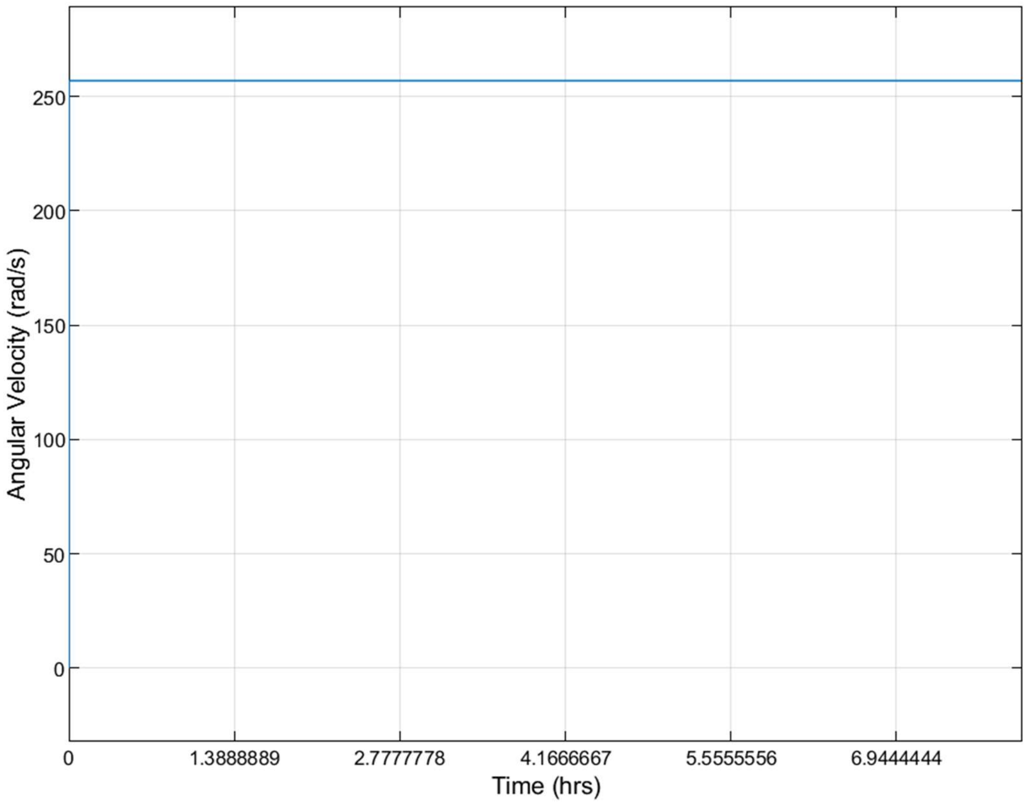

Figure 24. Angular Velocity of the Brushed DC Motor

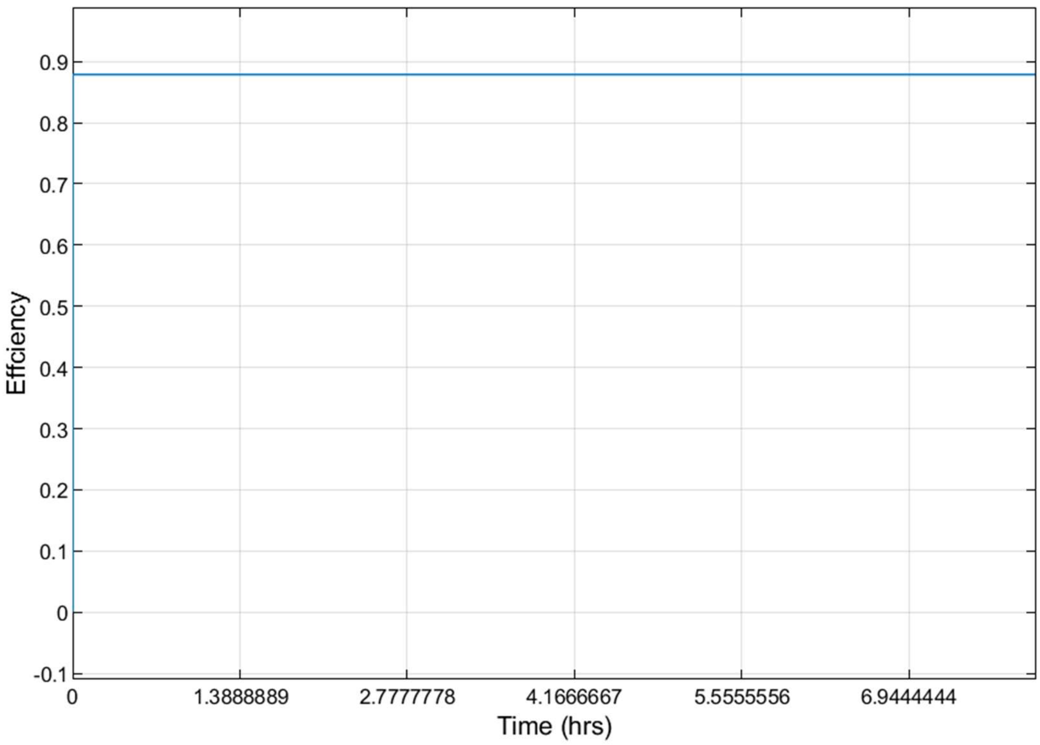

Figure 25. Efficiency of the Brushed DC Motor

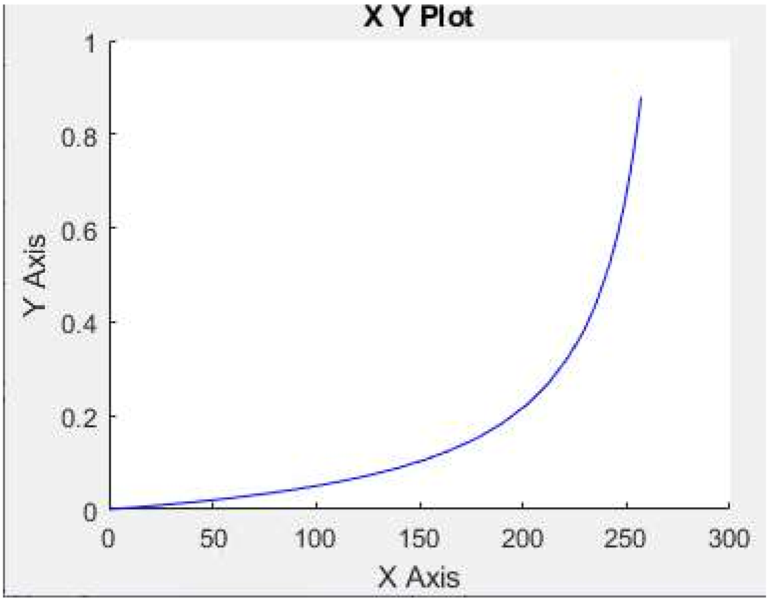

Figure 26. Efficiency vs Power out Curve for Brushed DC Motor

The main power supply stays a 380 V (phase-to-phase), 50 Hz three-phase ideal supply throughout the simulation as in Figure 12. The temperature of the heater/washer tank stays relatively constant at its required final value of 60 °C (Figure 16) and it consumes 2.84 MW at its steady state (Figure 14). The control systems of the AC and DC motor are in-build controllers. The AC motor's capability of maintaining a constant angular velocity (Figure 20) under varying load is better than the DC motor. To generate a neat efficiency curve, a constant load was given to the DC motor.

Energy Efficiency

The most intuitive design feature that improves the efficiency of the stream is the colling water for the furnace is then later used as the water to wash plastics. The efficiency of the washer is mostly affected by the heat transfer between the heater, water, plastic, and the environment. When the power transferred to water and plastic is 0.164 MW, the efficiency of the system reaches its maximum (Figure 17). The model of the AC motor is a simplified one, hence it has an efficiency of around 100% all the time (Figure 22). The maximum efficiency of the DC motor is achieved at its nominal power (Figure 26).

APPENDIX

[1] Maxon DC Motor. RE 65 Ø65 mm, Graphite Brushes, 250 Watt. Available from: https://www.maxongroup.com/medias/sys_master/root/8841119432734/EN-143.pdf [Accessed 17th May 2021].

[2] Siemens. Data sheet for three-phase Squirrel-Cage-Motors SIMOTICS. Available from: https://github.com/Yang-Li86/UoB_MREng_yr_2.git [Accessed 17th May 2021].

[3] worldstandards. Three-phase electric power (industrial applications only). Available from: https://www.worldstandards.eu/electricity/three-phase-electric-power/ [Accessed 17th May 2021].