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A Regenerative Braking Model to Predict the Energy Efficiency Improvement of Railway Electrification: A Case Study in Sri Lanka

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Abstract: With a prevailing population growth rate of 1.5% per annum in Colombo Metropolitan Region, improvement of public transportation has become a vital necessity while optimizing the expenditure on hydrocarbon fuels. Presently, Sri Lanka railway transportation system occupies Diesel Multiple Units (DMU). If Electrical Multiple Units (EMU)with regenerative braking are to be employed in place of DMUs, energy can be regenerated by converting kinetic energy of moving EMUs. This research study initially focused at developing a generalized regenerative breaking model to investigate the electrical energy requirement to travel from one railway station to another and thereby how much electrical energy that could be generated using regenerative braking. Model is then checked and validated with internationally accepted norms developed for efficiency improvement figures. Subsequently, the model is simulated between Colombo Fort and Veyangoda railway stations and found that 457.86 kWh of electrical energy can be saved in one trip through regenerative breaking.

Keywords: EMU, Energy efficiency, Induction machine, MATLAB Simulink, Regenerative braking

1. Introduction

1.1 Preliminaries

In Sri Lanka, passenger transportation mainly occurs during peak times, such as from 6.00 a.m. to 8.30 a.m. and from 4.00 p.m. to 6.30 p.m. As per the final feasibility study report done on Kelani Valley line in 2019, Colombo Metropolitan Region has recorded a population of 5.8 million and it is expected to be increased at a rate of 1.5% per annum by 2035 [2]. Therefore, more and more traffic can be expected, especially during peak times. Hence it is evident that there is a need for a good passenger transportation system in the near future. Correspondingly, the high interest would be on railway system development for passenger and goods transportation to increase the current share of railway. A proposal for electrification of railways in Sri Lanka had been discussed and feasibility studies had also been carried out under the project named Colombo Suburban Railway Project (CSRP). This was funded by the Asian Development Bank (ADB) and initiated under the Ministry of Transport and Civil Aviation on the 7th of July 2016 with the commencement of Pre-feasibility Study covering the Colombo Suburban Region of Sri Lanka Railway Network [3]. Sri Lankan Railways Network is shown in Appendix A, Figure A1.

Currently Sri Lanka has Diesel Electric Locomotives (class M), Diesel Hydraulic Locomotives (class W), Shunters (class G and class Y), Narrow Gauge Locomotives (class N and class P), Diesel Rail cars (class T) and Diesel multiple Units (class S). The newest of class S is S13A with 1800hp engine [12].

1.2 Multiple Units

A multiple unit train or simply known as multiple units, is a self-propelled train composed of one or more carriages joined together. Multiple units can be controlled by a single driver when they are coupled together. This is shown in Appendix A, Figure A2. A multiple unit has the same power and traction components as a locomotive, but instead of the components being concentrated in one car, they are spread throughout the cars that make up the unit [4]. Diesel Multiple Units are powered using diesel engines where the generator produces electricity to drive traction motors. Electrical Multiple Units are powered by electricity from a third rail or overhead wire. A conventional electric train braking system uses

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dynamic braking. Dynamic braking is the use of an electric traction motor as a generator when slowing down a vehicle such as an electric or diesel-electric locomotive. It is termed rheostatic if the electrical energy produced by the motors operating in generator mode is dissipated as heat by a bank of onboard resistors, referred to as the braking grid. Large cooling fans are therefore necessary to protect the resistors from damage.

1.3 Regenerative Braking

The process of regenerative braking is employed in EMU, whereby the current produced during braking is fed back into the power supply system for use by other traction units, instead of being wasted as heat. It is a normal practice to incorporate both regenerative and rheostatic braking in electrified systems. If the power supply system is not "receptive", i.e., incapable of absorbing the current, the system will default to rheostatic mode to provide the braking effect. For the regeneration to happen, obviously the rotor speed should be higher than the synchronous speed. Accordingly, if the speed and the torque of the induction motor are in opposite directions, the motor consumes mechanical power from the load and produces electric power; here the motor acts as a generator [5].

1.4 Aim of the Research Study

This study aims to assess energy efficiency of EMUs compared to DMUs running on fossil fuels, thereby determining the required electrical energy to travel from one station to another with the amount of electrical energy that can be regenerated by incorporating regenerative braking. Owing to the physical nature of the tracks that could be varying between railway stations, in the model that had been developed in this study, the user is given a chance to enter the constraints that need to be maintained and the other physical parameters such as distance, angle of elevation/declination and speed, etc. The model consists of two Simulink models developed using MATLABSimulink R2016a. First model computes the different parameters required to simulate regenerative power and energy and the second model simulates the regenerative power and energy produced by EMU for a particular run.

2. Literature Review

Several researchers have attempted to compute regenerative energy in EMUs by developing and simulating various types of models. In the research paper by Jia and Liu [6], modelling of AC–DC locomotive has been done. However, the correctness and effectiveness of the model has not been verified by comparing simulation data with the actual statistics. The researchers have simplified the overall structure and analysed the working principle of the electric locomotive based on AC-DC electric locomotives. The model has been established using Power Systems Computer Aided Design/Electromagnetic Transients including DCsoftware.

Energy produced through Regenerative Braking in DC electric rail system is described in [7], where the researcher has done the analysis to store generated energy by installing Energy Storage System (ESS) and to reuse it later when needed. In here, the effect-cause approach is used to model the vehicle. The speed profile and vehicle properties are used as inputs to determine EMU input power. Direct torque control is used in this study and, as per the three different speed profiles fed into the simulated model, almost 76% of the energy used during acceleration can be theoretically regenerated during deceleration.

A mechanical model developed by [8] for an EMU is simulated to observe the evolution of the braking force and power considering two scenarios: flat-track and “downhill-track”. An equivalent induction motor model is used to observe the behaviour during braking, focusing on the necessary conditions for the motor to operate in generation mode.

Therefore, with comparison to other research studies, this research will consider AC-AC system and all possible track path types except curves to quantify the amount of electrical energy that will be required and regenerated.

3. Designing the Proposed Model

3.1 Parameters Related to EMU

The selected EMU has the following characteristics [2]:

Car set configuration	: 5+5
No. of Motor cars	: 6
No. of Trailer cars	: 4
Maximum Passenger count	: 1988
Maximum gradient	: 0.1 degree
Acceleration	:0.83 m/s^2
Deacceleration	: 0.97 m/s^2

Masses of the selected Motor car and Trailer car are as follows [9]:

Mass of Motor car : 52.33 MT

Mass of Trailer car : 36.34 MT

Mass of a passenger : 60 kg

Total Mass of the train when it is fully packed: (52330*6) + (36340*4) + (1988*60) = 578620 kg

3.2 Forces Acting on EMU and Related Parameters

3.2.1 Davis Equation for Drag Force

This is used to calculate rolling and aerodynamic drag resistance.
Established Trailer car coefficients are as follows [9]:

$a_t = 1.347,\ b_t = 0.00385,\ c_t = 0.000165$

$$F_{drag}^{tc} = N_{tc} * M_{tc} * (a_t + b_t * speed_v * 0.28 + c_t * 0.28^2 * speed_v^2) \qquad \ldots(1)$$

Established Motor car coefficients areas follows [9]:

$a_m = 2.35,\ b_m = 0.02922 - 0.00049 * M_{mc} * 10^{-3}$

$$c_m = \frac{0.03722}{M_{mc} * 10^{-3}}$$

$$F_{drag}^{mc} = N_{mc} * M_{mc} * (a_m + b_m * speed_v * 0.28 + c_m * 0.28^2 * speed_v^2) \qquad \ldots(2)$$

$$F_{drag} = F_{drag}^{tc} + F_{drag}^{mc} \qquad \ldots(3)$$

where:

N_{tc} = No. of Trailer cars

N_{mc} = No. of Motor cars

M_{tc} = Mass of a Trailer car in Tonnes

M_{mc} = Mass of a Motor car in Tonnes

$speed_v$ = Attaining Speed in kmh^{-1}

F_{drag}^{tc} = Drag for Trailer car in kg

F_{drag}^{mc} = Drag for Motor car in kg

F_{drag} = Total Drag in kg

3.2.2 Force due to Gravitational Acceleration

This is used to calculate gravitational force which can oppose or aid the movement depending on angle of inclination and declination.

$$F_{gravity} = T_m * g * \sin\theta * 10^{-3} \qquad \ldots(4)$$

where:

θ = Angle of inclination , declination in degrees

g = Gravitational Acceleration in ms^{-2}

T_m = Total mass of the EMU in Tonnes

$F_{gravity}$ = Force due to gravity in kN

3.2.3 Traction Force / Regeneration Force

From Newton's second law of motion,

$$T_{f,r} = ((T_m + F_{drag}) * a \pm F_{gravity} + abs(F_{drag} * g * \sin\theta)) * 10^{-3} / N_m \qquad \ldots(5)$$

where:

a = Acceleration, Deacceleration in ms^{-2}

N_m = No. of Motors

$T_{f,r}$ = Traction Force, Regeneration force in kN

3.2.4 Load Torque / Regeneration Torque

Therefore the Load/ Regeneration torque can be calculated by,

$$\tau_{f,r} = T_{f,r} * R \qquad \ldots(6)$$

where:

R = Wheel Radius in meters

$\tau_{f,r}$ = Load Torque, Regeneration Torque in kNm

3.3 Designed Model

Mainly, there are three models developed in this study. First one is the base model and is used to take the input from the user and governs the other two models. Base model in association with another model known as Force and Torque Simulink model is used to compute forces and torques related to a scenario of accelerating or deaccelerating to attain a certain speed, a scenario of maintaining the attained speed and a scenario of deaccelerating to the final speed. Finally, the third model known as an Asynchronous machine Simulink model is used to simulate the amount of regenerated power and energy.

3.3.1 Input Data from the User

In here, user is given the opportunity to enter the physical data constraints that need to be achieved and maintained during the computation.

Following parameters are taken as the inputs:

- Track name
- Distance of the track part
- Restricted speed limit
- Angle of inclination/declination

3.3.2 Transferring of Parameters to Force and Torque Simulink Model

Once the data is received from the user and stored, next step is to transfer this data to compute the traction force and torque by simulating the Simulink model.

Transferred data has the following characteristics:

- Track number
- Distance of the concerned track part

- Initial speed maintained before entering the concerned track part which is now under consideration
- Final speed that needs to be maintained within the track part
- Inclination or declination of the track part under consideration

3.3.3 Transferring Simulated Parameters to the Workspace

The computed parameters from the traction force and torque Simulink model are then transferred to a workspace and stored in an excel file for further use. The parameters which are taken out from the traction force and torque Simulink model are:

- Track count
- Acceleration/deacceleration achieved
- Distance required to change from initial speed to final speed that needs to be maintained within that track part
- Traction force required to attain the restricted speed
- Torque required to attain the restricted speed
- Distance during which the restricted speed is maintained
- Traction force required to maintain the restricted speed
- Torque required to maintain the restricted speed
- Distance required to brake during the last track part
- Braking force & Braking torque
- Acceleration/deacceleration time
- Constant speed time
- Braking time

3.3.4 Opening and Simulating a Synchronous Machine Simulink Model

The second Simulink model, where the asynchronous machine and the other components are simulated, is used to compute the energy required to travel the full journey and to determine the energy that can be regenerated. For this model, previously determined torques are fed and the said motor is powered up by a three-phase power supply. The Simulink models used for Force and Torque and Asynchronous machine, respectively, are shown in Appendix B.

4. Model Validation

The model can be considered to be valid if the efficiency of regenerative braking lies in the range of internationally accepted efficiency norms. The efficiency figures established in this regard fall between 15%-35% [10,11] and can be calculated using Equations (7) & (8) by considering two aspects, either compared to the amount of energy required to attain the final speed or the amount of mechanical energy that would have been wasted if frictional brakes are applied.

$$\eta_{acceleration} = \frac{\text{Regenerated Electrical Energy}}{\text{Energy required for acceleration}} * 100\% \qquad (7)$$

$$\eta_{deacceleration} = \frac{\text{Regenerated Electrical Energy}}{\text{Energy wasted if frictional brakes are used}} * 100\% (8)$$

Subsequently, the developed model is tested by considering the data described in [3] and simulating the same between four fictitious stations. The observed efficiency figures are found to be 25.52% and 20.38%, respectively, and are within the internationally accepted efficiency norms [10,11].

5. Case Study

Simulation between Colombo Fort and Veyangoda railway stations is carried out after feeding basic data depicted in Table 1to the proposed model. As per the data collected from Diesel Electric Loco Shed-Motive Power sub department, the trains maintain an average speed of 60 kmh^{-1}. The places where the special speed restrictions are applied are extracted from the booklet called "*Notice for Two weeks*" [1]. This is given to the train drivers and station masters to notify whether there are any special speed restrictions to be maintained along the track. Also, the data gathered from Way andWorks office shows that the railway track from Fort to Kandy main line has an inclination of 0.1 degrees up to Rambukkana. It is assumed that the mass of passengers andpassenger count is a constant throughout the journey. The journey is considered to be on a normal day by a normal train (not intercity).

Table 1 – Basic Data Gathered from Railway Department from Colombo Fort - Veyangoda

From Station	To Station	Distance (km)	Speed (kmh^{-1})	Angle (degrees)
Colombo Fort	Maradana	1.895	60	0.1
Maradana	Dematagoda	1.768	25	0.1
Dematagoda	Kelaniya	3.205	20	0.1
Kelaniya	Hunupitiya	1.803	60	0.1
Wanawasala	Hunupitiya	1.35	60	0.1
Hunupitiya	Enderamulla	1.673	60	0.1
Enderamulla	Horape	2.344	60	0.1
Horape	Ragama	1.503	60	0.1
Ragama	Walpola	2.57	60	0.1
Walpola	Batuwatta	0.967	60	0.1

Batuwatta	Bulugahagoda	1.648	60	0.1
Bulugahagoda	Ganemulla	1.791	60	0.1
Ganemulla	Yagoda	1.802	60	0.1
Yagoda	Gampaha	3.214	60	0.1
Gampaha	Daraluwa	2.383	60	0.1
Daraluwa	Bemmulla	1.984	60	0.1
Bemmulla	Magelegoda	2.259	60	0.1
Magelegoda	Heendeniya	1.506	60	0.1
Heendeniya	Veyangoda	1.808	15	0.1

6. Results and Discussion

Tables 2, 3 and 4 can be compiled using Force and Torque Simulink model for each and every track between starting and ending station.

Table 2 - Results of the Scenario of Attaining the Rated Speed

From Station	To Station	Force (kN)	Torque (kNm)	Time taken (s)	Distance taken (m)
Colombo Fort	Maradana	4579.2	915.84	9.19	77.19
Maradana	Dematagoda	3127.2	625.2	3.83	13.4
Dematagoda	Kelaniya	3009.6	601.92	3.06	8.58
Kelaniya	Wanawasala	4579.2	915.84	9.19	77.19
Wanawasala	Hunupitiya	4579.2	915.84	9.19	77.19
Hunupitiya	Enderamulla	4579.2	915.84	9.19	77.19
Enderamulla	Horape	4579.2	915.84	9.19	77.19
Horape	Ragama	4579.2	915.84	9.19	77.19
Ragama	Walpola	4579.2	915.84	9.19	77.19
Walpola	Batuwatta	4579.2	915.84	9.19	77.19
Batuwatta	Bulugahagoda	4579.2	915.84	9.19	77.19
Bulugahagoda	Ganemulla	4579.2	915.84	9.19	77.19
Ganemulla	Yagoda	4579.2	915.84	9.19	77.19
Yagoda	Gampaha	4579.2	915.84	9.19	77.19
Gampaha	Daraluwa	4579.2	915.84	9.19	77.19
Daraluwa	Bemmulla	4579.2	915.84	9.19	77.19
Bemmulla	Magelegoda	4579.2	915.84	9.19	77.19
Magelegoda	Heendeniya	4579.2	915.84	9.19	77.19
Heendeniya	Veyangoda	2916	582.96	2.3	4.82

Table 3 - Results of the Scenario of Maintaining the Rated Speed

From Station	To Station	Force (kN)	Torque (kNm)	Time taken (s)	Distance (m)
Fort	Maradana	4097.04	819.36	99.78	1676.37
Maradana	Dematagoda	2644.32	528.96	247.63	1733.8
Dematagoda	Kelaniya	2527.2	505.44	568.63	3184.3
Kelaniya	Wanawasala	4097.04	819.36	94.30	1584.37
Wanawasala	Hunupitiya	4097.04	819.36	67.34	1131.37
Hunupitiya	Enderamulla	4097.04	819.36	86.57	1454.37
Enderamulla	Horape	4097.04	819.36	126.51	2125.37
Horape	Ragama	4097.04	819.36	76.45	1284.37
Ragama	Walpola	4097.04	819.36	139.96	2351.37
Walpola	Batuwatta	4097.04	819.36	44.55	748.37
Batuwatta	Bulugahagoda	4097.04	819.36	85.08	1429.37
Bulugahagoda	Ganemulla	4097.04	819.36	93.59	1572.37
Ganemulla	Yagoda	4097.04	819.36	94.25	1583.37
Yagoda	Gampaha	4097.04	819.36	178.30	2995.37
Gampaha	Daraluwa	4097.04	819.36	128.83	2164.37
Daraluwa	Bemmulla	4097.04	819.36	105.08	1765.37
Bemmulla	Magelegoda	4097.04	819.36	121.45	2040.37
Magelegoda	Heendeniya	4097.04	819.36	76.63	1287.37
Heendeniya	Veyangoda	2432.64	486.48	428.13	1798.12

Table 4 - Results of the Scenario of Deaccelerating from the Rated Speed

From station	To station	Force (kN)	Torque (kNm)	Time taken (s)	Distance taken (m)
Fort	Maradana	-3006	-601.2	494.1	141.44
Maradana	Dematagoda	-2235.36	-447.12	148.23	21.22
Dematagoda	Kelaniya	-2173.2	-434.64	98.82	12.12
Kelaniya	Wanawasala	-3006	-601.2	494.1	141.44
Wanawasala	Hunupitiya	-3006	-601.2	494.1	141.44
Hunupitiya	Enderamulla	-3006	-601.2	494.1	141.44
Enderamulla	Horape	-3006	-601.2	494.1	141.44
Horape	Ragama	-3006	-601.2	494.1	141.44
Ragama	Walpola	-3006	-601.2	494.1	141.44
Walpola	Batuwatta	-3006	-601.2	494.1	141.44
Batuwatta	Bulugahagoda	-3006	-601.2	494.1	141.44
Bulugahagoda	Ganemulla	-3006	-601.2	494.1	141.44
Ganemulla	Yagoda	-3006	-601.2	494.1	141.44
Yagoda	Gampaha	-3006	-601.2	494.1	141.44
Gampaha	Daraluwa	-3006	-601.2	494.1	141.44
Daraluwa	Bemmulla	-3006	-601.2	494.1	141.44
Bemmulla	Magelegoda	-3006	-601.2	494.1	141.44
Magelegoda	Heendeniya	-3006	-601.2	494.1	141.44
Heendeniya	Veyangoda	-2123.04	-424.56	49.41	5

The results obtained through the simulation of Asynchronous machine Simulink Model for each track between starting and ending station is as shown in Table 5.

Table 5-Computed Regenerated Energy Values

From Station	To Station	Energy required for acceleration(kJ)	Energy that would have been wasted if regenerative braking is not used(kJ)	Regenerated Power(kW)	Regenerated Energy (kJ)
Fort	Maradana	353450.4	425193.6	-1089.4	-102960
Maradana	Dematagoda	41894.2	47425.4	-4.1	-771.84
Dematagoda	Kelaniya	25807.9	26346.9	-8.2	-24.79
Kelaniya	Hunupitiya	353450.4	425193.6	-1089.4	-102960
Wanawasala	Hunupitiya	353450.4	425193.6	--1089.4	-102960
Hunupitiya	Enderamulla	353450.4	425193.6	-1089.4	-102960
Enderamulla	Horape	353450.4	425193.6	-1089.4	-102960
Horape	Ragama	353450.4	425193.6	-1089.4	-102960
Ragama	Walpola	353450.4	425193.6	-1089.4	-102960
Walpola	Batuwatta	353450.4	425193.6	-1089.4	-102960
Batuwatta	Bulugahagoda	353450.4	425193.6	-1089.4	-102960
Bulugahagoda	Ganemulla	353450.4	425193.6	-1089.4	-102960
Ganemulla	Yagoda	353450.4	425193.6	-1089.4	-102960
Yagoda	Gampaha	353450.4	425193.6	-1089.4	-102960
Gampaha	Daraluwa	353450.4	425193.6	-1089.4	-102960
Daraluwa	Bemmulla	353450.4	425193.6	-1089.4	-102960
Bemmulla	Magelegoda	353450.4	425193.6	-1089.4	-102960
Magelegoda	Heendeniya	353450.4	425193.6	-1089.4	-102960
Heendeniya	Veyangoda	14060.9	10724.6	-15.20	-140.21
	Total	**5736969.4**	**6887594.6**		**-1648297**

It should be noted that the regeneration occurs only if the rotor speed is greater than the synchronous speed. This can be fed as a negative torque to the Asynchronous machine model to compute the regenerated power and energy.

Appendices C, D, E and F show the regenerated power and energy plots for a single asynchronous machine obtained at four sets of speed.

Efficiency figures are calculated with respect to the amount of energy required to accelerate the EMU to attain the final speed and also with respect to the amount of energy that would have been wasted if frictional brakes are used. This can be tabulated as shown in Table 6.

Table 6 - Efficiencies with Respect to the Energy Requirement for Acceleration and Energy that would have been Wasted if Frictional Brakes are Used

From Station	To Station	Efficiency with respect to the energy required for acceleration	Efficiency With respect to the energy that would have been wasted if frictional brakes are used.
Fort	Maradana	29.1	24.2
Maradana	Dematagoda	1.84	1.63
Dematagoda	Kelaniya	0.0961	0.0941
Kelaniya	Hunupitiya	29.1	24.2
Wanawasala	Hunupitiya	29.1	24.2
Hunupitiya	Enderamulla	29.1	24.2
Enderamulla	Horape	29.1	24.2
Horape	Ragama	29.1	24.2
Ragama	Walpola	29.1	24.2
Walpola	Batuwatta	29.1	24.2
Batuwatta	Bulugahagoda	29.1	24.2
Bulugahagoda	Ganemulla	29.1	24.2
Ganemulla	Yagoda	29.1	24.2
Yagoda	Gampaha	29.1	24.2
Gampaha	Daraluwa	29.1	24.2
Daraluwa	Bemmulla	29.1	24.2
Bemmulla	Magelegoda	29.1	24.2
Magelegoda	Heendeniya	29.1	24.2
Heendeniya	Veyangoda	0.997	1.31

Therefore, efficiency figures can be calculated using previously mentioned equations (7) and (8) as follows:

Overall Efficiency with respect to the energy required for acceleration

$$= \frac{\text{Regenerated Electrical Energy}}{\text{Energy required for acceleration}} * 100\%$$

= 1648297*100/5736969.4

= 28.73%

Overall Efficiency with respect to the energy waster if frictional braking is used

$$= \frac{\text{Regenerated Electrical Energy}}{\text{Energy wasted if frictional brakes are used}} * 100\%$$

= 1648297*100/6887594.6

= 23.9%

The efficiency figures are within the accepted range.

7. Conclusion and Future Work

This research study assessed the energy efficiency improvement of an EMU with regenerative breaking against a normal EMU and trains running with fossil fuels. To accomplish the same, forces acting on an EMU when moving uphill, flat and downhill tracks were assessed and modelled by developing Force and Torque Simulink model. After assessing the functionality and structure of a general EMU, the Asynchronous Machine model was developed to quantify the amount of electrical energy that can be generated using regenerative braking. Finally, the model was validated comparing with internationally accepted efficiency norms. The outcome of the study revealed that, if an EMU runs from Fort Railway station to Veyangoda station, 28.73% of energy requirement for acceleration can be recovered by incorporating regenerative braking. Also, it is observed that the amount of regenerated energy is 23.9% of the energy that would have been wasted if frictional brakes were used. Total energy saving would be around 457.86 kWh.

The model could be used to compute the total amount of energy that could be approximately saved by regenerative breaking if the Sri Lanka Railway Department can provide the required data and the declared daily train schedules.

Moreover, this model can be improved to automatically set the supply frequency to a low value in order to enhance regeneration.

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Appendix A

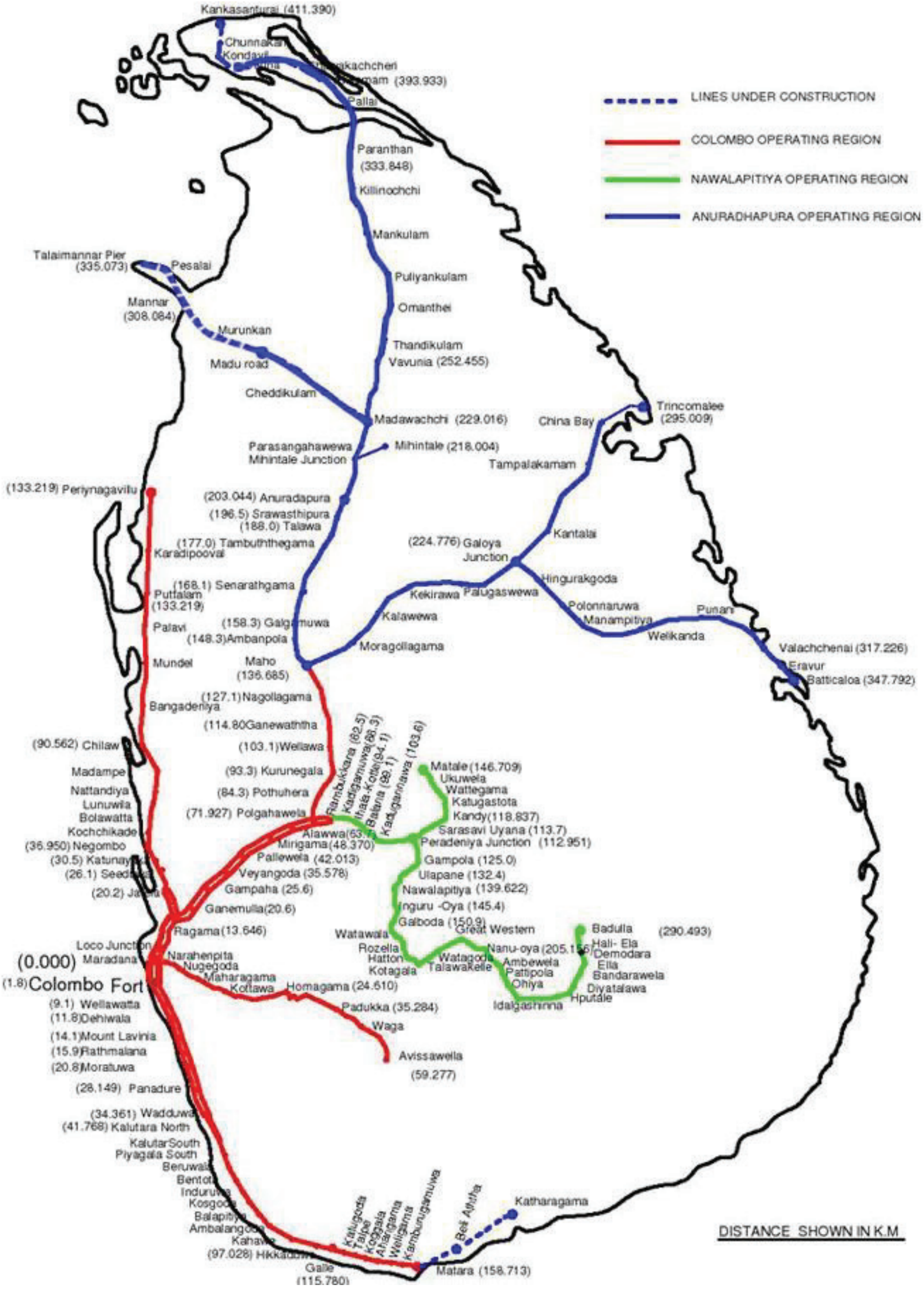

Figure A1: Sri Lankan railway network

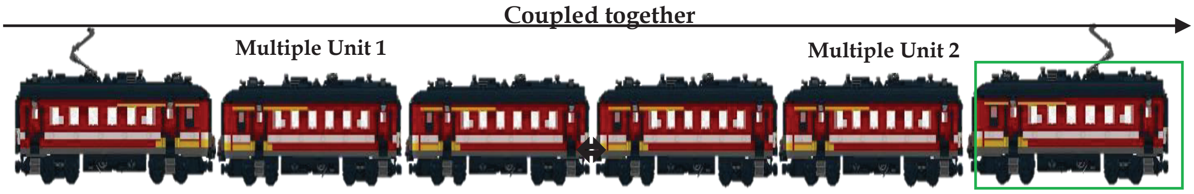

Figure A2: Coupled EMUs driven by a single driver

Appendix B – Simulink Models

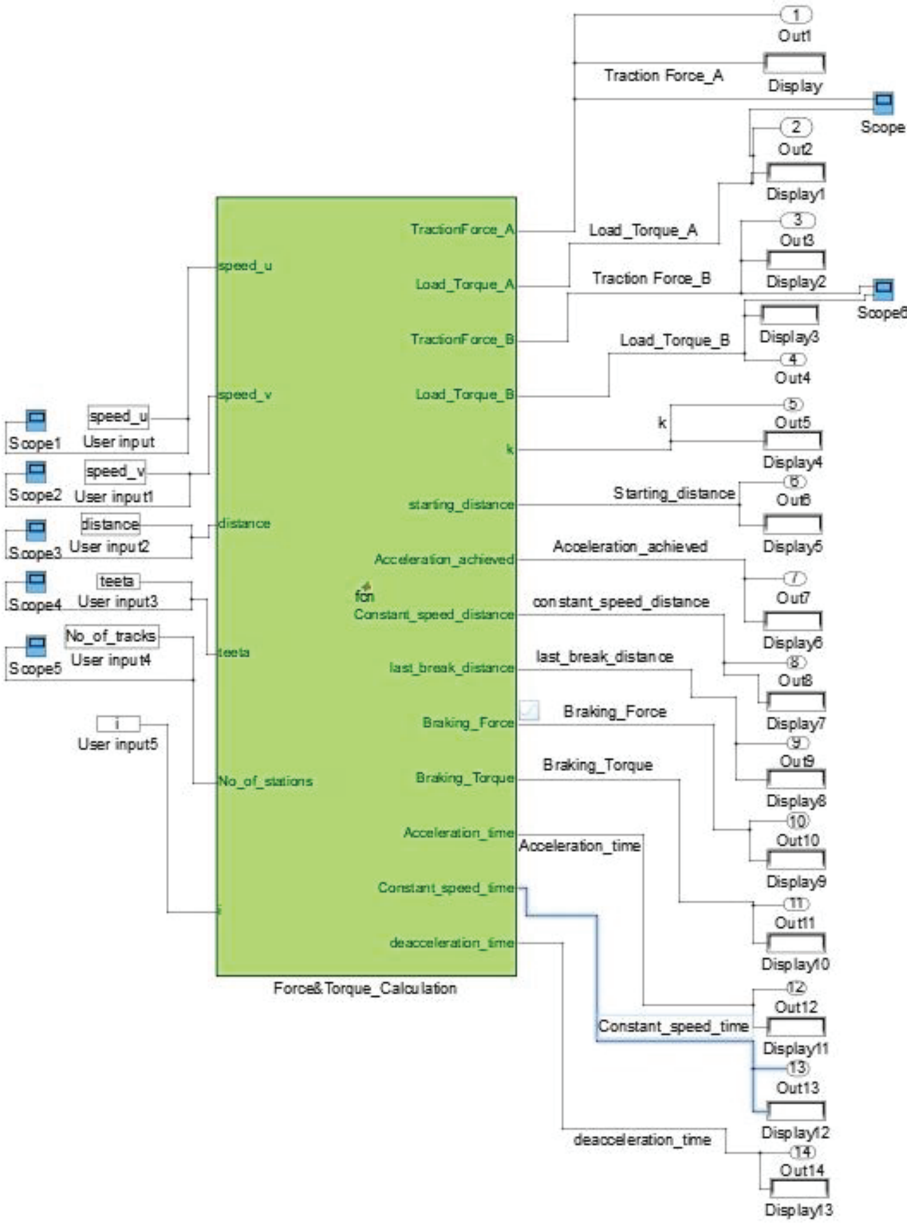

Figure B1 - Force and Torque Simulink model

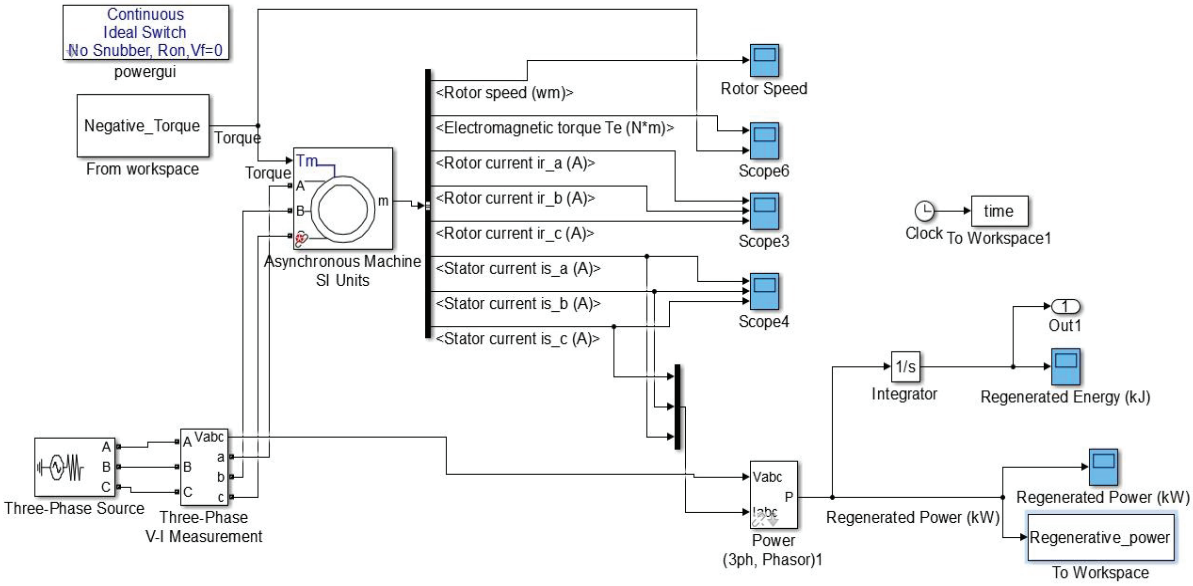

Figure B2 - Asynchronous Machine Simulink Model

Appendix C – For Rated Speed – 60 kmh⁻¹ – per Motor Basis

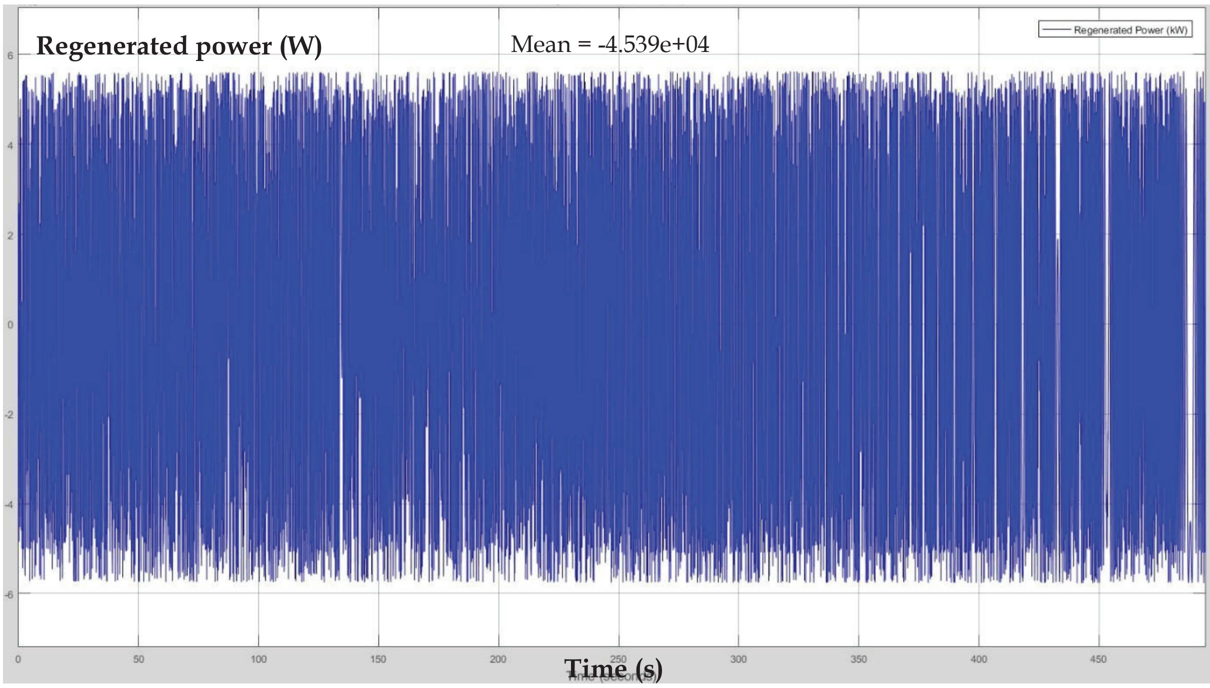

Figure C1 - Regenerated Power for 60 kmh^{-1}

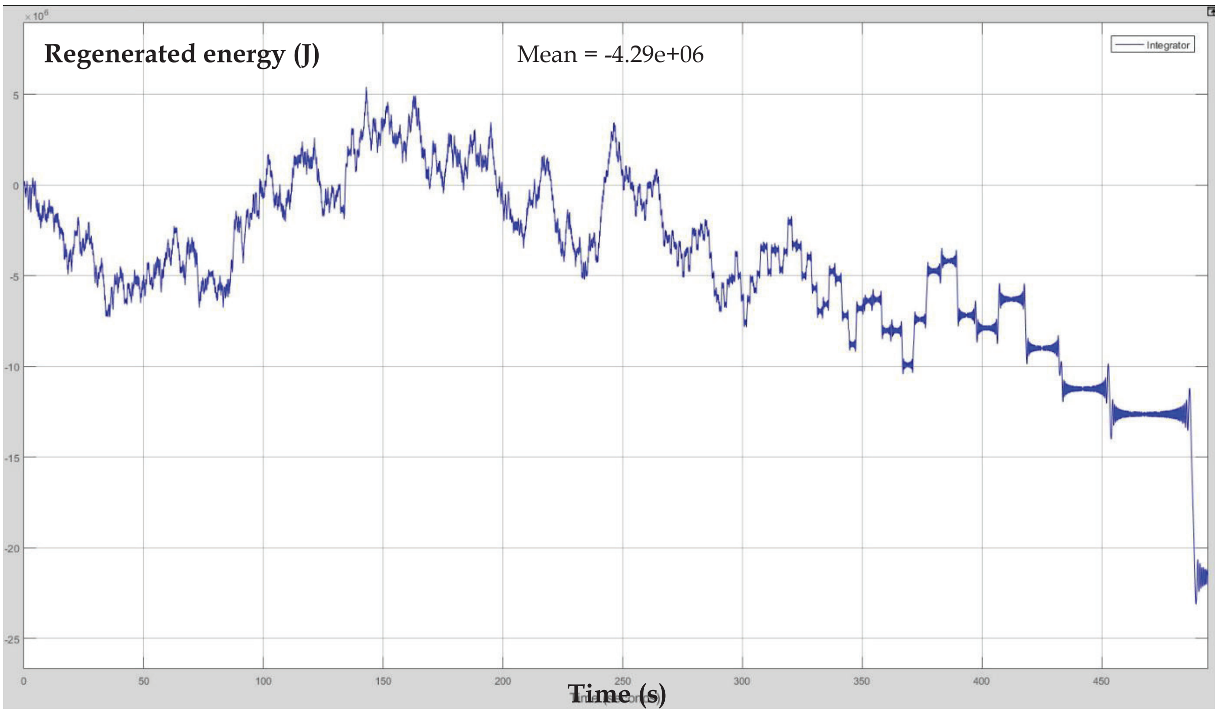

Figure C2 - Regenerated Energy for 60 kmh^{-1}

Appendix D - For Rated Speed – 25 kmh^{-1}– per Motor Basis

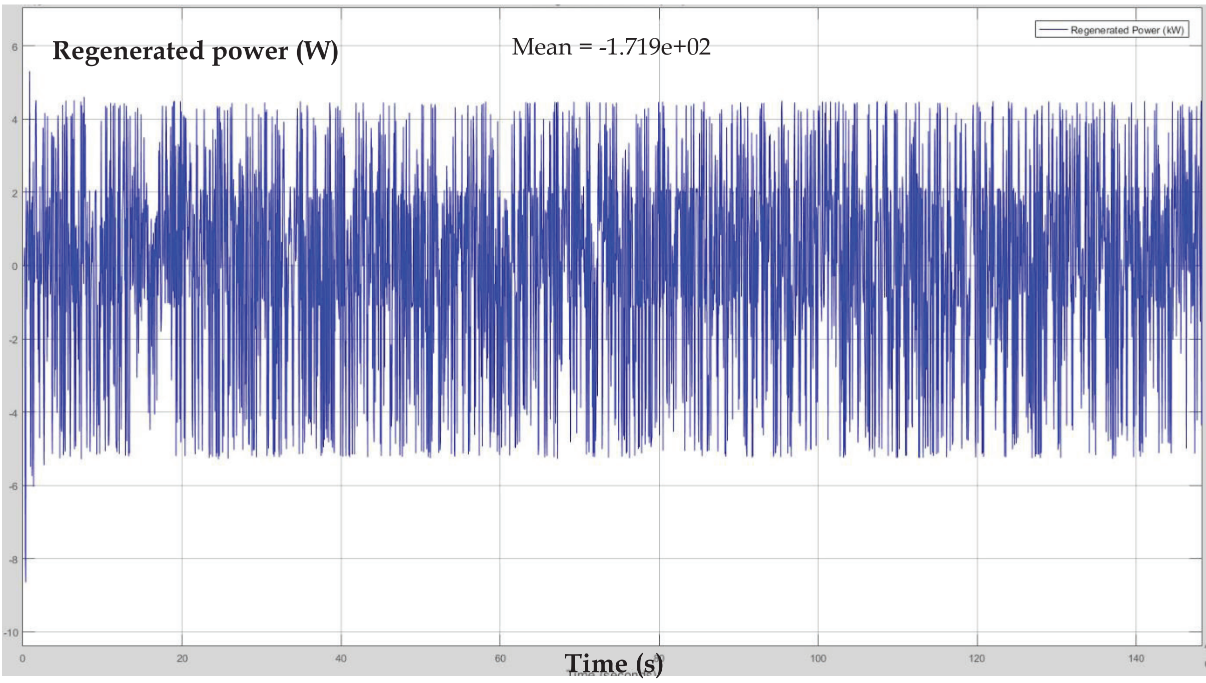

Figure D1 - Regenerated Power for 25 kmh^{-1}

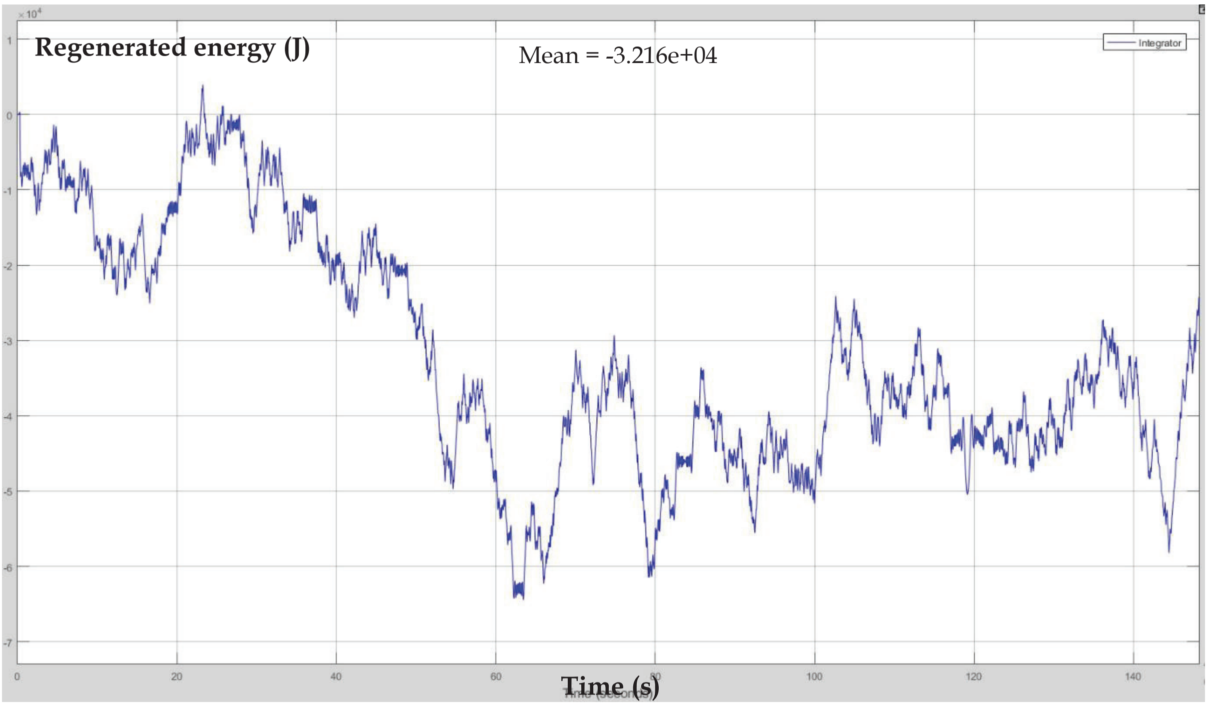

Figure D2 - Regenerated Energy for 25 kmh^{-1}

Appendix E - For Rated Speed – 20 kmh^{-1}– per Motor Basis

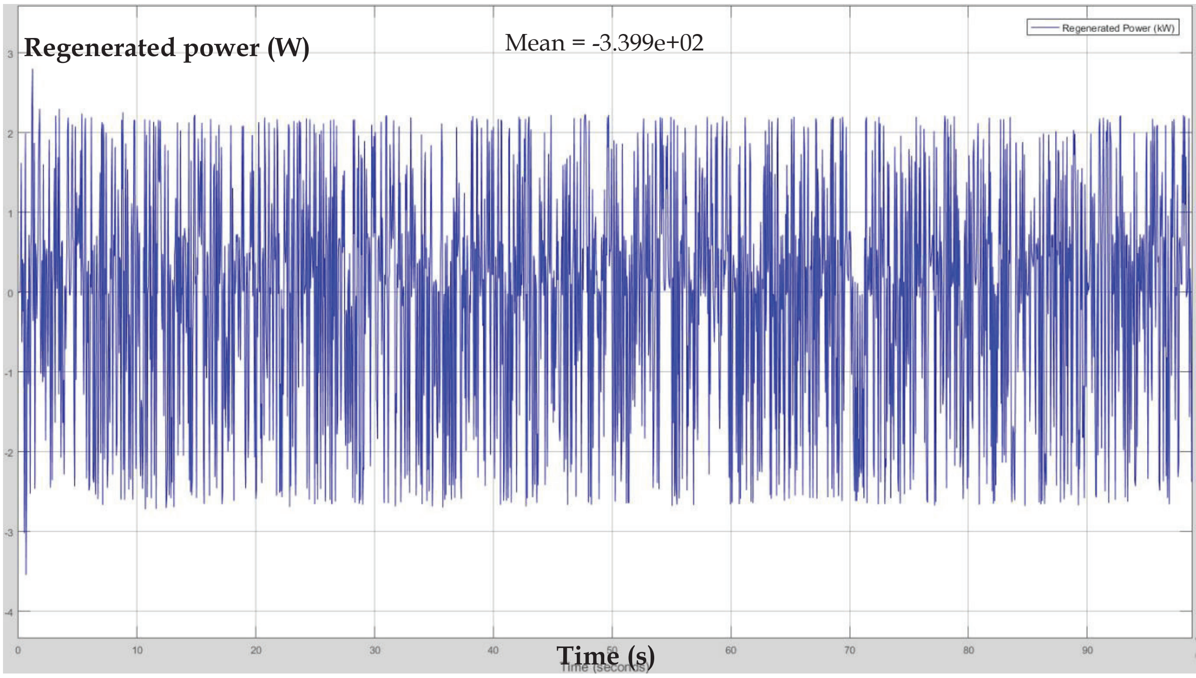

Figure E1 - Regenerated Power for 20 kmh^{-1}

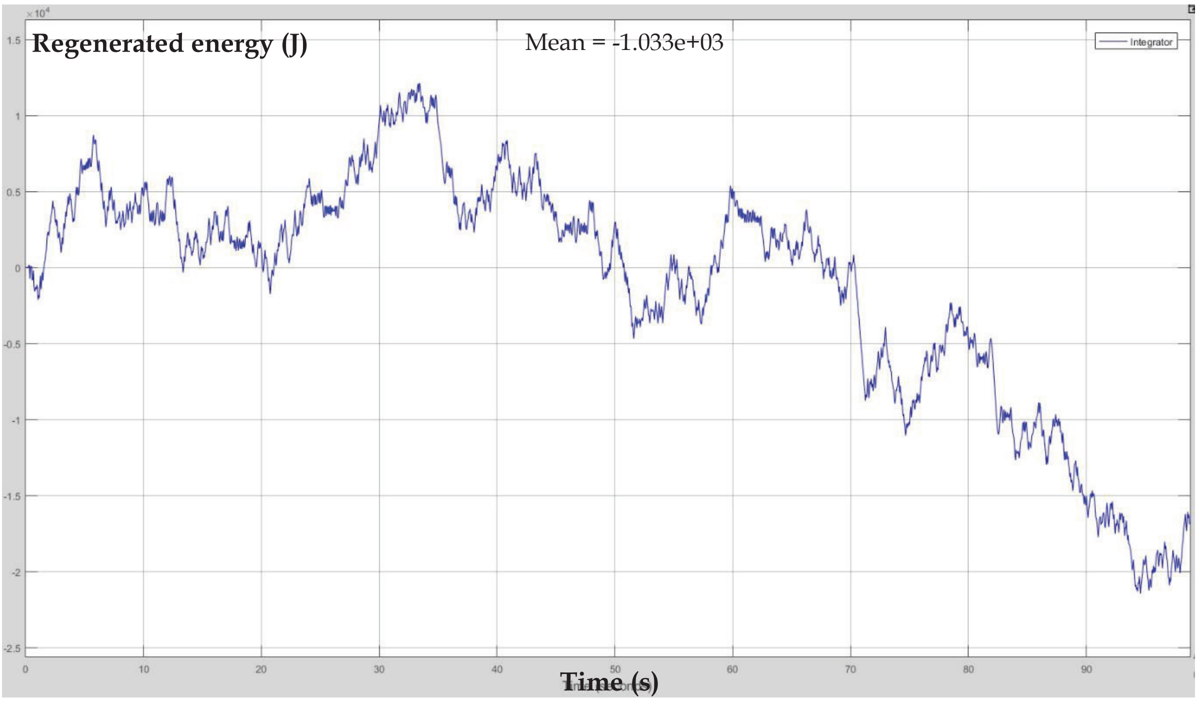

Figure E2 - Regenerated Energy for 20 kmh^{-1}

Appendix F - For rated speed – 15 kmh^{-1}– per motor basis

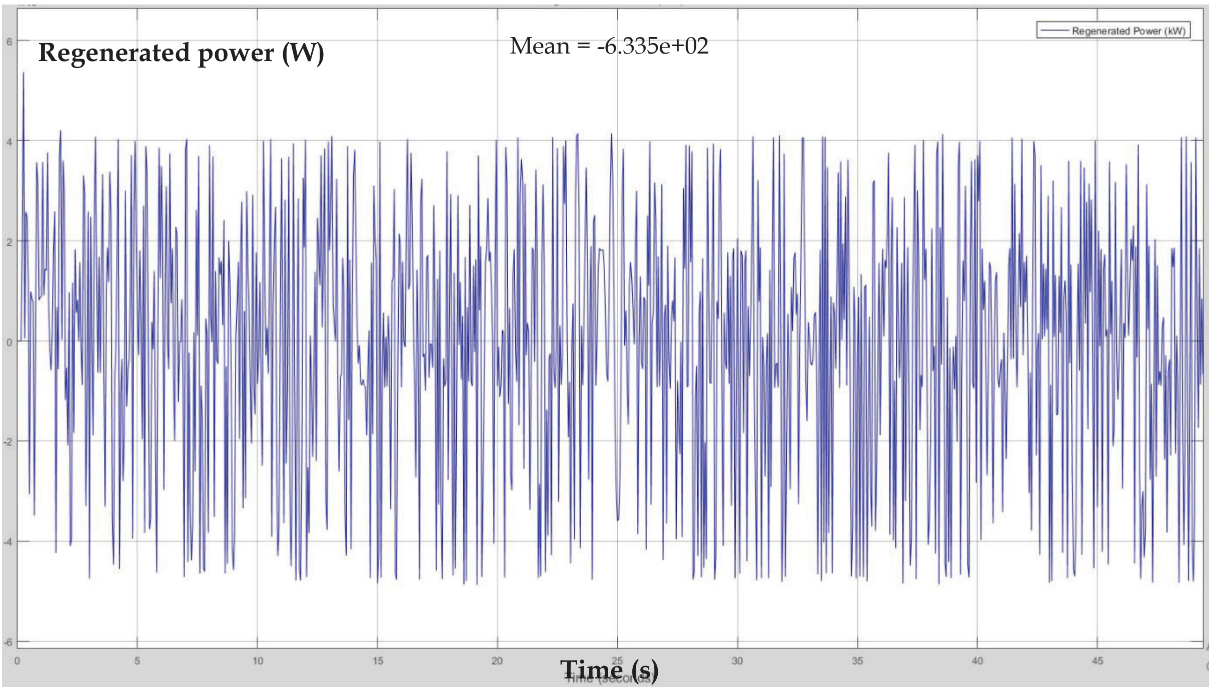

Figure F1 - Regenerated power for 15 kmh^{-1}

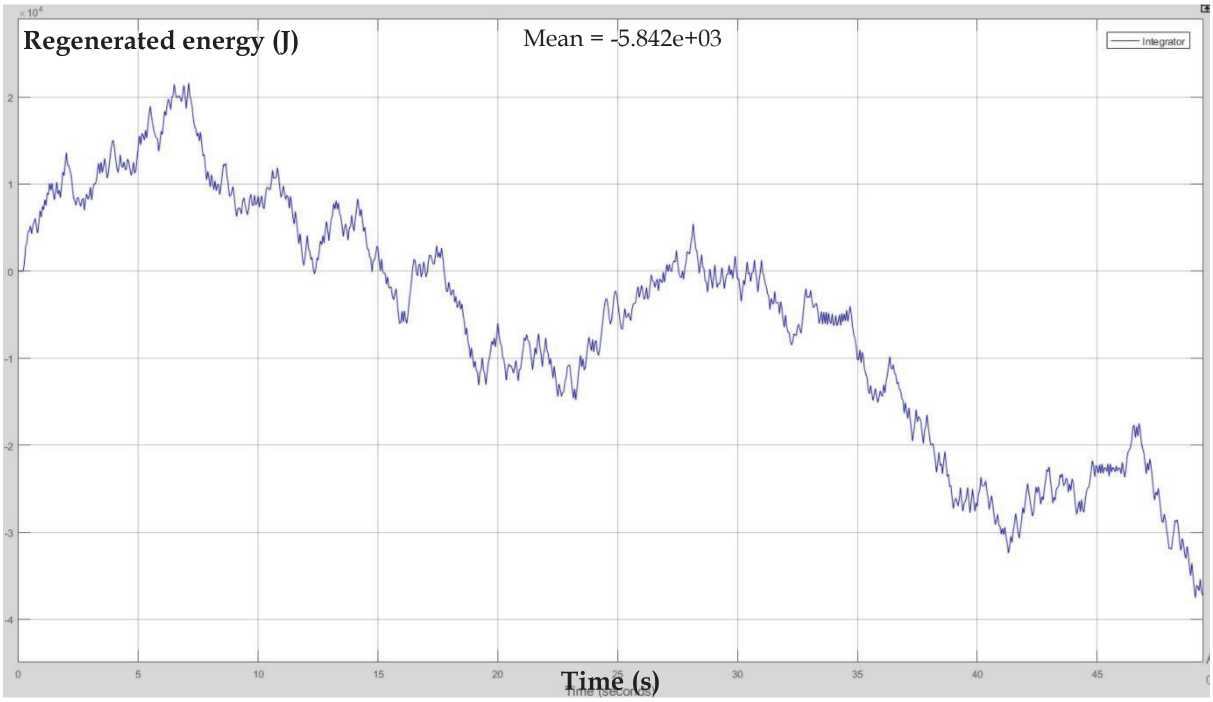

Figure F2 - Regenerated Energy for 15 kmh^{-1}