USE OF ELECTRIC VEHICLES AS A QUICK RESPONSE ENERGY STORAGE: CASE STUDY FOR SRI LANKA

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Declaration

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Abstract

Use of Electric Vehicles as a Quick Response Energy Storage: Case Study for Sri Lanka

With the fossil fuels depleting, the non-conventional energy sources is taking the wheel I the field of electricity generation. Yet, their inconsistencies owing to reliance on intermittent energy sources such as wind and solar necessitate means of catering the dips in generation. V2G systems become instrumental is levelling out the load curve, facilitating charging of plugin vehicles during over generation and discharging at times of lack of generation.
The study was done to analyse the practicability of implementing plugin vehicle based energy storage in Sri Lanka.
A survey was done to identify the plugin electric demographic that included plugin patterns, distance driven, length of ownership and the willingness to remain in EV segment, traction battery degradation and overall attitude towards partaking in a V2G scheme. Main challenge is quantifying the battery degradation with extensive usage as a V2G source. In contrast, using EV batteries as quick response, low duration, low energy power source, it was understood that enormous financial and economic benefits can be yield merely by minimising un-served energy following load shedding caused by frequency violation events. With low count of average daily frequency violations battery discharge becomes minimal, alleviating the adverse effect on the vehicle range with remaining charge and cyclic ageing.
Considering the cost benefit obtained from preventing load shedding versus the costs incurred by EV owners, using EVs as a fast response, low duration energy storage that can cater system emergencies is profitable in utility perspective.

Keywords: V2G, plugin vehicle, EV, range anxiety

To my wife and my parents

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L.S.N.Bambarawane

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List of Abbreviations

Abbreviation	Description
EV	Electric vehicle
PEV	Plugin Electric Vehicle
HPR	Hornsdale Power Reserve
SOC	State of Charge
SOH	State of Health
CEO	Chief Executive Officer
PV	Photo voltaic
V2G	Vehicle to Grid
BEV	Battery Electric Vehicle
IEA	International Energy Authority
PHEV	Plugin Hybrid Electric Vehicle
APC	Available Power Capacity
CPC	Contracted Power Capacity
D.o.D	Depth of Discharge
LKR	Sri Lankan Rupee
USD	United State Dollars
DMT	Department of Motor Traffic

List of Appendices

1.1 Rise of Electric Vehicle Technology

Electric car is taking the world by storm although the earliest versions, the likes of G-Wiz, were highly criticised for impracticality, lack of general creature comforts and zero attention to occupant safety. In the following years, plugin electric vehicle market has grown by heaps and bounds. Electric vehicles are now being built in par with gasoline-engine counterparts in terms of quality and safety. With the aid of cutting edge technology, in 2020 electric vehicles will be faster than the 8000cc, 1500hp Chiron, which is considered as the epitome of engineering, as the former CEO of Tesla Inc is predicting unveiling their latest model Tesla Roadster [1]. One of the major advantages of EVs is the zero emissions. Although they rely on electricity generated somewhere sourced by a variety of coal, nuclear, solar or wind, they are not burdened with internal combustion engines that do not operate at ideal efficiency under varying load. With growing concerns of depleting fossil fuels and the worryingly rising adverse environmental effects the whole world is now at a pivotal point.

EVs do not need engine oil changes, transmission oil replenishment, air filter replacement etc. Cars equipped with conventional combustion engines need to be serviced in regular intervals be it every 3500km or 10,000km depending on the lubrication oil used. They emit no smoke or noise. As awareness of climate change is rising people have become more concerned regarding their carbon foot print. EVs will undoubtedly improve the urban atmosphere, ridding them of the harmful gases and particulate matter released at the exhaust tip of the general population of internal combustion engines. Cities such as Beijing where air pollution is reaching life threatening levels, coupled with their EV-friendly policies, will definitely benefit from rising EV demographic, be it personal or public transportation.

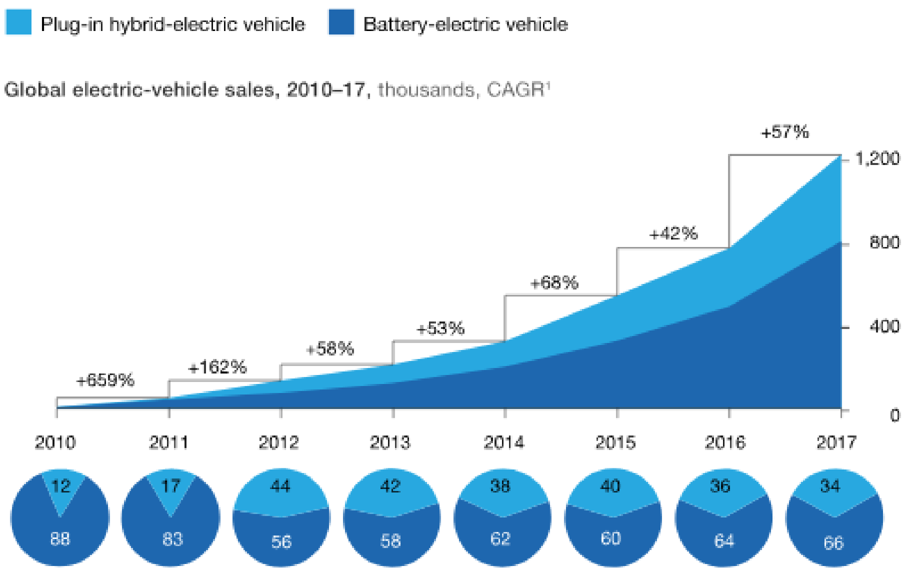
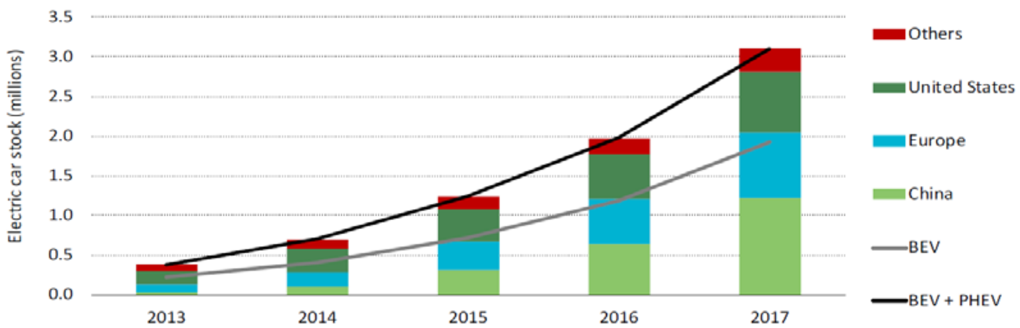


Figure 1: Global EV Sales 2011-2017

The Figure 1 is an excellent indication of popularisation of plugin electric vehicles. Scepticism was common among motorists when they were given the option to migrate from regular fuel fired car to hybrid cars. Similar situation is observed in around 2010 when mass produced electric vehicles began to enter the market. Towards 2017 electric vehicle population rise has become comparable to that of hybrid vehicle sales.



Notes: The electric car stock shown is primarily estimated on the basis of cumulative sales since 2005. Where available, stock numbers from official national statistics have been used (provided that the data can be shown to be consistent with sales evolutions).

Sources: IEA analysis based on country submissions, complemented by ACEA (2018); EAFO (2018a).

Figure 2: EV vs PHEV Sales
Source: Global EV Outlook – IEA

1.2 Intermittency in Power Generation and Potential for Energy Storage

More and more are invested in the fight against climate change. Like the plugin vehicles, non-conventional renewable energy sources have grown in efficiency and effective ever the years. Yet, the more practicable and established NCRE sources such as wind and solar that are still hindered by the intermittence of wind fronts and volatile solar irradiance. A study on offshore wind farm in Denmark had identified that at presence of cloud cover its rated output drops from 100% to 0 within mere 15 minutes. Imagine the repercussions of losing a 100MW plant operating at full load suddenly [2]. Same applies to solar PV systems. Cloud covers, rainy days renders solar cells ineffective. Overall, adding more and more environmentally friendly yet intermittent energy sources to a power grid present the power systems operators with the ultimate predicament. That is adhering to reliability and quality based guidelines amongst the numerous fluctuations. A spinning reserve, preferably fast acting hydro power plants or gas turbines, must be kept in operation at their less than efficient operating points to cater the frequency dips caused by the intermittency of NCREs. A spinning reserve is anyway a mandatory and crucial component of a power system. Yet, in a network that has lion’s share of NCRE requires extra effort on maintaining a storage that can cut in fast enough in situations where NCRE fail to deliver.

Using these sources coupled with a battery bank will solve intermittency issues although at a cost not yet seen as feasible. Popularisation of V2G, a vehicle based energy storage has its roots in efforts to solve intermittency issues of renewable energy sources. The idea first came up in mid-1990 [3]. As the batteries are mobile and already provides the primary objective as transportation, the enormous upfront capital needed to build battery banks is greatly reduced [4]. Batteries can response fast compared to majority of conventional thermal generators (gas turbines have this capability) that cannot rapidly increase or decrease their loads. Moreover a study is United States showed that 95% of vehicle population is parked. If the parked vehicle is assumed as a Nissan Leaf, that is 24kWh of potential energy being left unused. However, the power capacity of a plugin vehicle is limited by its inverter charger. Every country owns a sizeable vehicle fleet. With current trends of rising EV popularity it is near future when the entire fleet is electrified. Thus, a large parked fleet of vehicles will have a high potential to deliver electricity and absorb the dips and drops caused by the intermittent power sources [5].

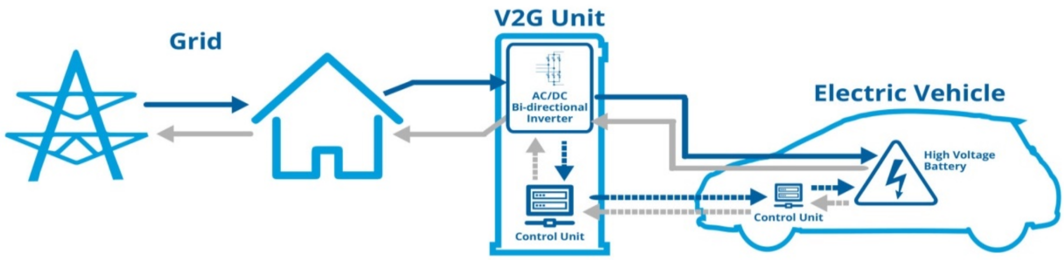


Figure 3: Basic Configuration of V2G

The main advantage is the rising trend in plugin vehicle market. More and more manufacturers are introducing newer models. Countries have taken steps to subsidise taxes on EV manufacturers. China, the leader as of now in EV sales, provided unheard-of concessions on electric vehicles in the few past years [6]. Since recently they have applied more stringent conditions to encourage further research and development, pushing the envelope. Concessions are now limited by lower bounds for vehicle range. This approach prevents mass production of little-engineered vehicles and promotes development of more compact batteries that can store higher amount of charge with better thermal management of cell assemblies [6]. While batteries with higher energy density make the vehicles more energy efficient with lightened weight, their range on a single charge increases.

1.3 Factors that Involve Vehicle to Grid system (V2G)

Vehicle to Grid system is basically moving a step further from conventional unidirectional charging of a plugin vehicle [4]. The charger should be bidirectional, facilitating power flow from the grid to the car when the battery state of charge is low and power flow from the car to the grid when required. Since transportation is the primary objective of a vehicle, partaking in V2G scheme must not deplete the traction battery affecting range adversely. Evidently, the higher a battery is used, the sooner its lifetime will end. Battery ageing occurs as a battery is used and as when it sits unused. Once used regularly in vehicle-to-grid services, the bi directional charger employed must maintain a minimum state of charge (SOC) the user defines in order to prevent the traction battery from running too low. Thus, for every discharge, the charger must evaluate if the SOC is adequate and fill up the battery accordingly. Predicting the grid connectivity of a fleet of vehicles is also difficult. Traffic patterns, personal preferences and many more factors can influence the times which each vehicle stays plugged in and stays on road. Capacity estimation becomes even more difficult as it depends on traffic conditions, battery health (SOH), battery state of charge, battery ageing, and government policy changes that may affect the sale of plugin vehicles etc.

The concept of using electric vehicle as a new source of energy was put forward in latter part of 1996 by Willet Kempton et al. in his paper [3]. They argued that the entire fleet combined has 10 fold the capacity of all electricity generators on US soil. Although the capabilities of electric vehicles as a power source are still being researched on, there is an undeniable potential. If the charge levels of each EV battery can be approximated, a model can be developed to predict the possible power/energy output of the fleet. Of course, to prevent over-discharge and denying the vehicle the ability to serve as a medium of transport, stringent measures must be taken. This will be further discussed extensively in the next chapter.

1.4 Objective

Cost of un-served energy is a significant factor in determining remedial measures to handle frequency events that trigger load shedding. Function of industries especially, in addition to the regular daily life of citizens, be it professional or personal, are greatly affected in the events of load shedding in frequency violation events. This is the reason why cost of a unit of electricity that is un-served is significantly higher than unit cost of electricity under regular billing schemes. In economic perspective, investors of industries seek affordable and reliable power supply. Annual un-served energy is a significant parameter that is representative of the nature of a country's power supply. Several causes, such as generator tripping, transmission lines tripping, forced outages of generators, may lead to un-served energy. Main focus here would be to address the energy that power system fails to cater following generator tripping (in years where blackouts took place, un-served energy has escalated significantly). The V2G network can be programmed to trigger at frequency events below a particular level which must be above the existing load shedding set points. An aggregator, preferably System Control Centre, can communicate with each EV and trigger them as the respective SOC levels permit.

The existing V2G systems deal with around-the-clock charging and discharging cycling of the batteries. As regulatory work, i.e. frequency control etc., is identified to be the most fitting duty for the likes of batteries used in EVs, cycling ageing becomes a critical factor. In this research, a new approach is proposed where an EV battery is used to cater for dips in the power system frequencies which subsequently trigger load shedding schemes. Taking past data in to consideration, the possibility of using EV based battery storage is discussed which can replace an expensive open cycle gas turbine that burns fossil fuels. If the number of frequency violation events per day is low, for example 2 events per day only, the times of discharge and depth of discharge for battery will be insignificant. Thus, in this approach financial influence owing to battery degradation can be ignored. Moreover, EVs are readily available as a mode of transportation, which cuts down the high initial cost of a pumped storage (which may cost as high as 1.5 to 2.5 million USD per MW installed), a peaking gas turbine (which costs around 800USD/kW) with high operating cost or any other alternative for frequency regulator plant.

2.1 V2G

Modelling the V2G capacity, is difficult as connectivity of electric vehicles is highly volatile, the more so as predicting the available capacity on each battery is a greater hardship.

Literature [8] describes two parameters regarding the energy storage capacity of a fleet of electric vehicles.

1. Contracted power capacity

   A measure of total capacity of the fleet – connected and on the move. Primary purpose of an EV is transportation.
2. Available Power Capacity (APC)

A measure of total capacity that is connected to the grid and capable of delivering power. Any secondary use must not be allowed to consume the battery too much. Furthermore, not all cars are connected to the grid at any time. A sizeable amount may be on road, transporting people.

The maximum V2G power is determined by the power of electronic converters of the battery charger aboard the electric vehicle. For example, a Mitsubishi MiEV is a small electric car that comes with a 16kWh battery. However, maximum power than can be drawn is only as good as its charger. Ideally, we must be able to draw 32kW for 30 minutes before the said battery depletes. Since the battery is charged via a 2.5kW, the maximum power the charge unit can handle is 2.5kW, reducing the usable power output. Output power depends on battery state of charge and state of health as well. State of health refers to the charge level of the battery. A flat battery cannot deliver any power and trying to extract further could cause serious damages to it. Besides, drawing power until a battery level goes to low rids the EV of its primary function – transportation [10].

2.2 Deep Cycling vs. Shallow Cycling of Batteries

Research [9], [2] indicates that the more the energy is drawn out of the battery per cycle, the worse the effect on the lifetime of the battery. Using Saft Li-ion batteries [9] have conducted a test by discharging it 100% against 3% discharge. They have found out that when the battery is discharged by only 3%, the Li-ion battery has lasted 1,000,000 cycles in its lifetime. Nevertheless, they identified that when discharged 100%, the lifetime of battery has been reached only at mere 300 cycles. The same test has been carried out on Ni-MH batteries by achieving discharge levels of 3% and 80%. The results have similar results as Li-ion counterparts did. Evidently, if an EV is to be used in V2G services, the depth of discharge (D.o.D.) must be kept as low as possible. Deep cycling approximates V2G battery use for peak power or spinning reserve at longer dispatches, whereas 3% cycling is closer to that of regulation services. Low depth of discharge also implies that there is only minute effect on the expected range of the vehicle.

2.3 Techniques to Model Available Capacity

2.3.1 Based on Distance Travelled

Different researches have approached this problem in unique ways. One is the prediction of available battery levels assessing the distance covered by each vehicle. If a vehicle is spending extensively in traffic jams, plugin SOC will be too low despite possible short range travels. Below is the said approach as a mathematical model [10],

$$P_{vehicle} = \frac{\left(E_s - \frac{d_d + d_{rb}}{\eta_{ev}}\right)\eta_{inv}}{t_{disp}}$$

1. $P_{vehicle}$ - maximum power of V2G in kW
2. E_S - stored energy available as DC kWh to inverter
3. d_d - distance driven since energy storage was full
4. d_{rb} - the distance of the range buffer required by the driver (A Californian study has revealed that drivers only need 20 miles of range [10])
5. η_{veh} - the vehicle driving efficiency km/kWh,
6. η_{inv} - the electrical conversion efficiency of DC to AC inverter
7. t_{disp} - time the vehicle's stored energy is dispatched in hours

The particular paper also discusses [10] the economic value of V2G as revenue minus the cost. Total revenue (r) is defined as,

$$r = p_{el}E_{disp} = p_{el}P_{disp}t_{disp}$$

whereas p_{el} is the market rate of electricity in \$/kWh, P_{disp} is the power dispatched in kW and t_{disp} is the total time the power is dispatched. The cost is calculated from purchased energy, wear and capital cost. Assuming annual basis the general formula for cost is,

$$c = c_{en} E_{disp} + C_{ac}$$

Where c is the total cost per year, c_{en} the cost per energy unit produced, E_{disp} the electricity energy dispatched in the year, and C_{ac} is the annualised capital cost.

2.3.2 Dynamic Scheduling Method

In their research Kumar et al. [11] arrive at an algorithm for real-time V2G capacity estimation using dynamic EV scheduling is proposed. The algorithm estimates the V2G capacity by taking into account the main constraints on meeting the load demand while ensuring the chargeability of the EVs. It uses model based scheduling approach to overcome the disadvantages of existing scheduling methods. The load models used in the paper are forecasted building load demand without EVs [3] and predicted EV charging profiles [12]. Appropriate dynamic priority criteria required specifically for EV scheduling is also proposed. The objective function of the algorithm is to minimize the variance in priority values of the connected EVs. Minimizing the variance in priority values of the EVs will reduce the variations in fairness given to the EVs. It defines a set of parameters as

i	EV number.
j,k,l	Half-hourly intervals.
n	Total number of EVs.
$p_l^{EV,i}$	Predicted charging profile of an EV
P_{cc}	Contracted capacity.
p_j^{PD}	Forecasted building load demand after considering RESs
$p_l^{uEV,i}$	Load demand of an EV
p_j^{uEV}	Unscheduled total load demand of all EVs
m_i	Departure interval of an EV
k_i	Total number of intervals required for charging an EV
$p^{average}$	Average power used for achieving a smooth valley filling
p_j^{TD}	Total building load demand after considering RESs and EVs.
ρ_i	Priority value of an EV.

$\alpha_i, \beta_i, \delta_i, \chi_i$	Priority parameters based on battery SOC, slack time available for charging, number of intervals used for charging and V2G power supplied respectively.
SOC_i	EV battery SOC in percentage.
$p_i^{v2g\max}$	Maximum V2G power of an EV.
$p_i^{v2gcont}$	Continuous V2G power of an EV.
$E_i^{v2gav'lable}$	V2G energy available of an EV.
$SOC_i^{current}$	Current SOC of an EV.
SOC_i^{final}	Desired final SOC of an EV.
$SOC_i^{\min}$	Minimum required SOC for charging an EV to SOC_i^{final} before departure time.
$E_i^{v2g\max}$	Maximum V2G energy available of an EV.
P_i^{v2g}	V2G power available of an EV.

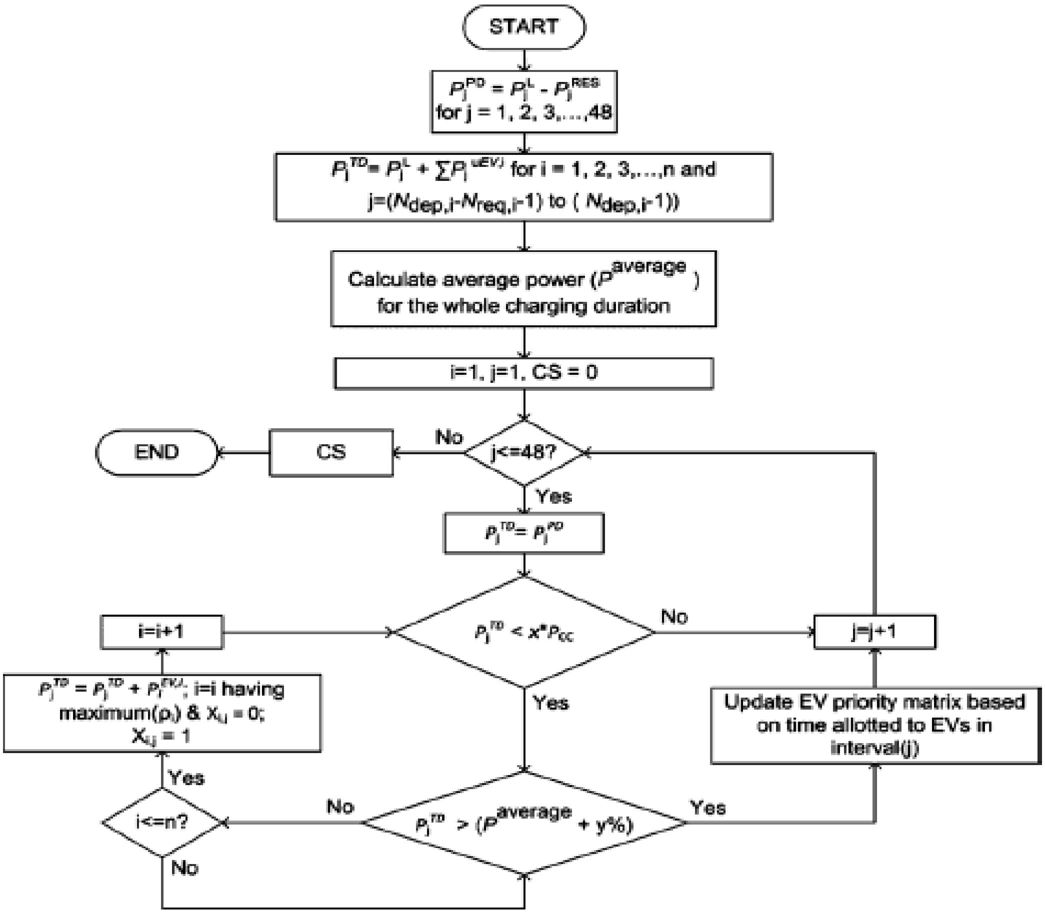


Figure 4: Flowchart for EV scheduling algorithm

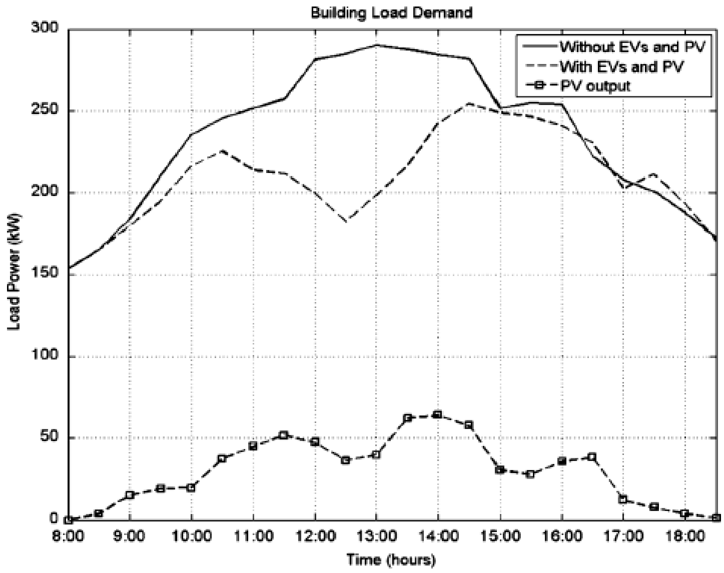


Figure 5: Demand Curve with and without V2G

Using this method the using a car pool of 15 vehicles they have simulated the effect of V2G in reducing the overall dependency on the national grid of the country.

However, this method has not considered the battery degradation which is a weak point. It was found that the parameters such as contracted capacity, load demand, battery capacity, and arrival and departure times have a unique impact on the V2G capacity of the EVs. The proposed V2G estimation method was also compared with the fixed minimum SOC limited estimation method and plug-in probability based estimation methods which do not employ scheduling of EVs. It was observed that the proposed method improved the accuracy of V2G estimation and was not affected by the time remaining before departure. Thus, the algorithm developed is commendable in terms of practicality as it does not hinder EV range.

2.4 Duty of Aggregator

Kempton et. al. [10] introduced in the literature the concept of an actor that aggregates EV. The model assumes that each EV owner cannot bid in the electricity market nor have transactions with electrical utilities due to a lower power capacity (kW rather than MW). The solution is an aggregator that serves as a middleman between EV owner and electrical utilities or electricity market. The aggregator either controls dispersed vehicles or operate with on-site vehicles (e.g. corporation's fleet). The authors identified several types of corporations that can be aggregators, for instance: local distributions companies; Energy Service Companies (ESCO); vehicle manufacturers; cell phone operators; electricity retailer.

The aggregator is effectively a distribution system operator that earns his profit by selling energy to EV. Aggregator is responsible for meeting participants requirements based on their contracts to supply V2G power. Depending on the function of V2G, be it spinning reserve job or regulation services, aggregator must essentially monitor, control and manage the EVs and discharging while coordinating with the main system control operator. If the EVs are distributed wide, intelligent communication network should be in place between the EVs and aggregator. They suggest EV parking lots to simplify communication claiming the approach is costly to implement. However, in the method proposed in this thesis it is impractical and inconvenient for EV owners to gather their vehicles to a single location.

2.5 Quick Response Capacity of V2G

All over in the literature the highlight of functions of V2G has always been its ability to respond extremely quickly. The best example is the Hornsdale Power Reserve which prevented load shedding schemes from taking over when a coal power station at 560MW tripped. The 100MW/129MWh battery responded within a few milliseconds and restored system frequency making time for other large generators to increase their load set points. Studies [22] have been carried out regarding the quick response times against the external load changes.

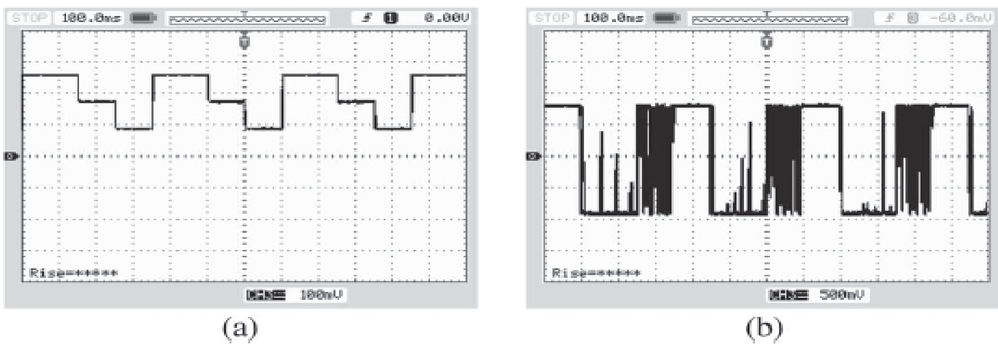


Figure 6: Output current of a load is denoted by (a) and corresponding charger current is denoted by (b)

This graph is indicative of the rapid response characteristics of EV battery. A horizontal division corresponds to 100ms. Evidently, as the load current changes, the

EV battery has responded almost immediately without a noticeable ramp. Considering the 100ms division, the response time should be a few milliseconds.

V2G functionality as a frequency regulator has also been analysed. The researchers have plotted [Figure 7] the frequency fluctuations with and without V2G services.

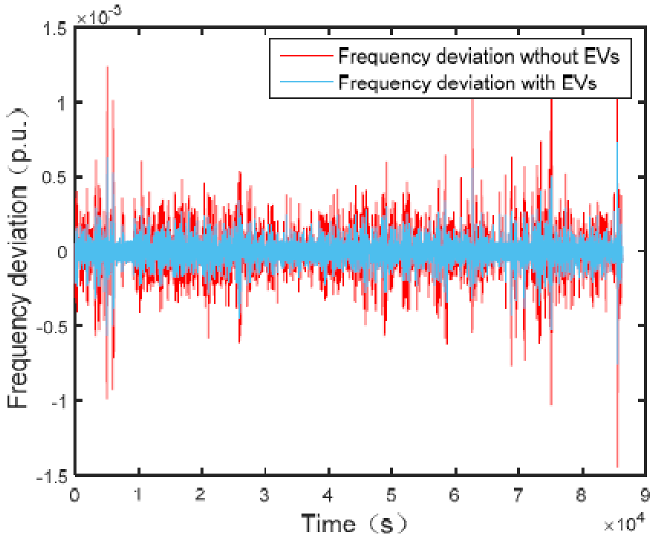


Figure 7 : Frequency Regulation with and without V2G

As evidently illustrated in Figure 7, the range of frequency violations has significantly reduced in the presence of V2G scheme. Thus, V2G schemes can respond quickly enough to cushion the variations in the frequency by changing between charging and discharging modes. Therefore, in this case study, V2G can ably facilitate the intended purpose of functioning as a fast response energy storage that can prevent load shedding.

CHAPTER 03 GROWTH OF EV DEMOGRAPHIC IN SRI LANKA

3.1 EV Sales in Sri Lanka

The statics related to electric vehicle sales in the country was obtained from the Department of Motor Traffic after making an official request [See Appendix – J]. Information obtained included all electric vehicles cars, vans, lorries, bikes, and so on. The objective was to analyse the growth in demand for electric vehicles under the externalities. Obviously, wide adoption of a newer technology is not commonplace, especially in a country where vehicles are taxed excessively. Vehicles owners are less than enthusiastic about owning automobiles that carry state of the art technology that will cost a fortune to mend if premature failure occurred. For example, Sri Lankan motorists feared the automatic gearboxes when they came fitted as standard to models that previously had won the trust of majority. The early scepticism meant that well-known professionals in automobile industry were inundated with questions on maintenance, longevity and the rest. Introduction of electric vehicles to Sri Lankan market did not set itself much apart a scenario such as this.

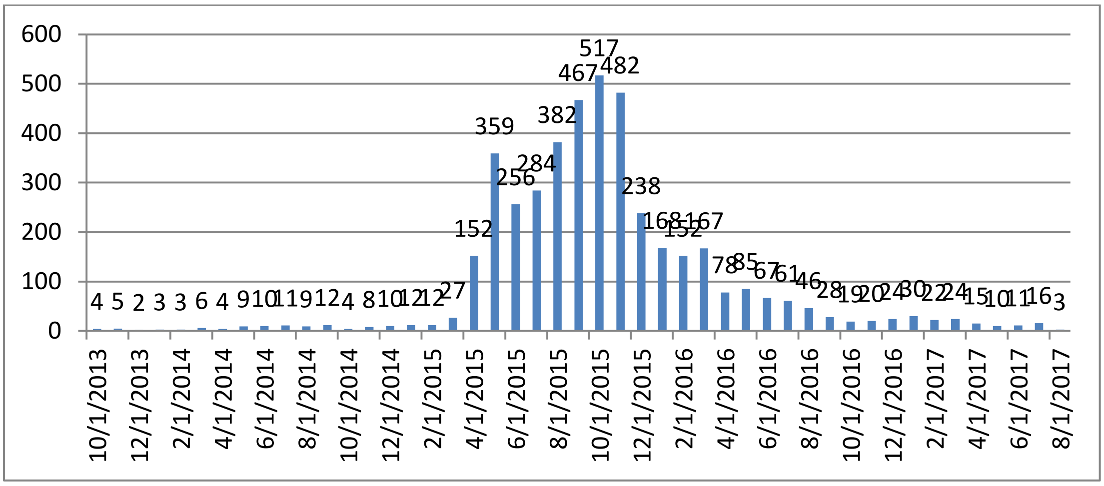


Figure 8: EV sales in Sri Lanka from 2013

The first electric Nissan Leaf was recorded in October, 2013 [12]. However, earliest records of electric vehicle registration are from 2005. A handful number of REVAi, a micro electric car, have been registered throughout 2005. Built in India by Reva Electric Car Company, REVAi failed to qualify as a highway worthy automobile and was recognised as a neighbourhood electric vehicle (US) or a quad cycle (United Kingdom). REVAi sales did not flourish primarily owing to its limited theoretical range of 80km on a single charge and the impractical, rather unsafe chassis and body. Usage of the electric equipment and the air conditioner had significant impact on the range of the car while it only could carry a total weight of a mere 270kg, people and luggage combined.

However, growth in sales of Nissan Leaf rose as it was indistinguishable from yet another automobile. Although, Tesla Roadster was already available in the world market by 2008, two years before Leaf was mass produced, its pricing was not an attractive option to local market. At first no evident popularisation of EVs is observed in Sri Lankan context. In February, 2015 consequent to Government's decision to reduce taxes imposed as low as 5% the EV registration escalated by leaps and bounds. The source of persuasion for mass adoption of rather new, unproven technology is not very clear either. The car was first promoted with a claimed range of 150km on a single charge and that full charge costs only 18kWh of energy. Of course, in a normal household this will add up on top of the regular bill. Thus, several charges per month will contribute to the overall running cost more significantly than salesman claims. On average a Lead does ~6km/kWh while a hybrid car that does ~17km/l, an equivalent 2km/kWh. Weighing in the maintenance cost, electric become not only a significantly energy efficient but also a cost effective means of transport. Moreover, introduction of tax concessions made them vastly affordable in comparison to equally equipped conventional automobiles. When the initial growth rates from the years 2014 and early 2015 are analysed, interest of EV buyers seems to have not been influenced by the concerns over traction battery degradation or premature failure of same. Even now, significant part of an EV's value lies in its battery. According to Nissan, replacing a battery of a Leaf from the years 2011-2015 will cost 5,499USD while a 40kWh battery from the 2018 model will cost 7,800USD. Alternatively, resorting to a refurbished battery cost nearly half as much, at 2,850USD [15].

Several countries have set themselves on the map by being rather aggressive adopters of EV transportation. China, especially, has been offering outrageous concessions to automakers and EV buyers alike in order to promote electric vehicles sales in general, not cars or bikes alone. Earliest efforts to promote electric vehicles in China were initiated in 60's and they faded away in the 80's. Burdened by social pressure to improve urban pollution and reduce oil dependency, Chinese government made a policy decision to have five million plugin vehicles, battery-electric and plugin hybrid, and to manufacture one million of the same by year 2020. Moreover China ventured in to making electric busses. As of 2015, nearly all the plugin electric buses in the world were deployed in China. The stock of buses grew six fold in the years 2014 and 2015. Compared to Sri Lankan context this is progression from merely setting lower tax rates to promote EV sales. If the local Government is venturing in to reducing its dependency on fossil fuels stringent policies concerning EVs must be put in place and shall not vary as State changes. With the massive growth, China is now cutting down subsidies such that the average purchasing incentive of electric cars may be less than one third of the 2018 level. In order to qualify for incentives, it is rumoured that current range of 150km has been increased at least to 200km (125 miles) at a single charge. The government has reduced subsidies to emphasize the need for technical improvements to ensure the long-term success of the industry.

Figure 9: Overall vehicle sales in Sri Lanka
Source: https://tradingeconomics.com/sri-lanka/car-registrations

As depicted in the Figure 7, overall vehicle registrations have increased from mid-2012 towards mid-2015 afterwards where there is a dramatic decline. The peak sale figure near 2016 is owing to the taxes on mini city cars being slashed.

Until 2012, electric vehicles have not been explicitly referred to in the budget proposals. In the gazetted budget in March, 2013 the duty imposed on EVs was defined as 12%. This had virtually no impact on the selling statistics of the vehicles. However, in early 2015, the duty imposed on EVs was dropped significantly to 5% [14]. At the time Leaf was becoming popular owing to its functions, practicality and affordability around the globe. Motivated by the Government’s gesture and its environmental policies car importers capitalised on the opportunity [18]. This dropped the market value of the Leaf to below 3 million LKR. Some European electric variants entered the market, but because of the pricing only a limited crowd opted for them [16] [17].

8704.90	Other :	
8704.90.30	Other electric, not more than five years old	12%
8704.90.40	Other electric, more than five years old	12% or Rs. 109,000/= per unit

Figure 10: Budget 2013 - Gazette No.1751/28 - 2012.03.30

8703.90	Other :	
8703.90.30	Other electric, not more than two years old	05%
8703.90.40	Other electric, more than two years old	05%

Figure 11: 2015 Interim Budget Proposals - Excise (Special Provisions) Duty

8703.90.30	---	Other electric, not more than three years old		15%	u
8703.90.40	---	Other electric, more than three years old		25%	u

Figure 12: Customs Imports Duty Changes Effective from 2015/02/27

87039022	Driven by electric motors powered by on board accumulators/ batteries charged by external electric source(e.g. National grid)	50%
87039023	Driven by electric motors powered by on board accumulators/ batteries charged by external electric source(e.g. National grid) and also supported by on board electric generator(through internal combustion engine)	50%

Figure 13 : Excise (Special Provisions) Act, No. 13 of 1989 (Order under section 3) 21.11.2015

8703.80.41	Capacity of motors not exceeding 50kW	Rs. 20,000 per kW
8703.80.42	Capacity of motors exceeding 50kW, but not exceeding 100kW	Rs. 30,000 per kW
8703.80.43	Capacity of motors exceeding 100kW, but not exceeding 200kW	Rs. 45,000 per kW
8703.80.44	Capacity of motors exceeding 200kW	Rs. 60,000 per kW

Figure 14: Extract from 2018 excise budget

The frequent fluctuations [refer Figure 8 to 12] had left importers in great debt as the vehicles already in their stocks often lose value simply because the Government offers tax concessions abruptly which cuts down the prices of new imports [18]. Furthermore, vehicles in the second-hand market depreciate and appreciate in response to drops and hikes in vehicle import duty. The Government justifies the decision to increase the import duty by referring to the financially-privileged who have exploited the low taxes to import exuberant luxury battery electric variants. As per the information obtained from the Department of Motor Traffic, the drop in sales in late 2015 never recovered. With 5% import duty scheme tax charge on a Leaf and a Tesla Model S was 187,000LKR and 700,000LKR respectively. In accordance with duty scheme established in 2018, an unregistered Nissan Leaf with 80-kW motor will be subjected to a duty of 2.4 million LKR. Effectively, an EV buyer now has to pay an equivalent value of another car merely as tax.

Analysing the overall car purchases in the past few years, Table 1 states the component of electric vehicle sales. The tax hike in 2015 has affected the car sales in general. Still, EVs have taken a year or so to lower its share in full market. Afterwards it has gradually declined to a state indistinguishable from the pre-5%-tax era.

Table 1: EV sales percentage out of total vehicle sales. See [13]

Year	New Car	EV	Percentage
2013	28380	11	0.03%
2014	38780	89	0.02%
2015	105628	3188	3.02%
2016	45172	915	2.02%

As of 2018/08, the entire population of EVs in the country was at 4334.. In comparison, 2015 has been a record-breaking year where EV sales outnumber the combined figure of years 2016, 2017 and 2018.

3.2 Analysis of EV Composition

DMT-sourced information revealed the composition of the country's electric vehicle demographic. As is evident from sight of public road Nissan Leaf dominates local EV backdrop with an enormous share. This information is vital as the energy/power capacity of the domestic EV demographic can only be logically approximated by assessing the different models that carry battery packs and charger inverters of various capacities. Even if expensive EV variants such as Tesla Model S carry large battery packs they have minuscule effect with the low share out of the population. Following is the summary of the information gathered from DMT as at 2017/08.

Table 2: Survey results on EV population composition

EV Model	Number	Percentage
Nissan Leaf	4208	96.05%
Nissan e-NV200	15	0.34%
Mitsubishi i-MiEV	48	1.10%
Mitsubishi Minicab-MiEV	63	1.44%
Tesla Model S	23	0.52%
BMW i3	9	0.21%
Mahinda e2o	5	0.11%

Reva Classe (G-Wiz)	10	0.23%
Total	4381	

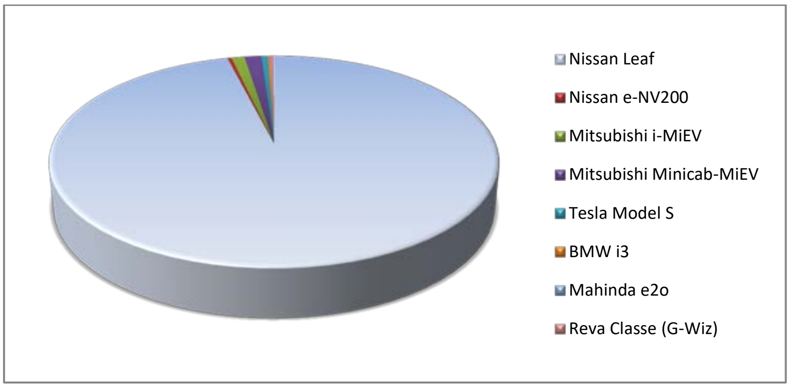


Figure 15: Electric Vehicle Composition

The E-NV200 and Mitsubishi MINICAB-MiEV are regular sized and mini vans respectively. MINICAB has two models, a people carrier and mini single cab, both offering identical powertrains despite different body shells. With over 96% of EVs in Sri Lanka being Leafs, further in the study, it will be assumed that all vehicles are Nissan Leaf for convenience in modelling. Further, with demotivating import duty structure, European and American variants will not be at all affordable to the general public.

3.2.1 EV Sales Growth Scenarios

The objective of the research is to identify the feasibility of creating EV based energy storage in Sri Lanka that can prevent load shedding. Yet, with volatile decisions of policy makers the natural growth rate of EV has been hindered, halting the rise of EV population prematurely. Observation of early trend reveals an upward trend. Thus two scenarios were built to predict the likely growth if import duties remained favourable to EV sales from the point that sales began to decline. For both scenarios the actual data and the resultant data derived from the model were compared with the aid of F number – a built in function of MS Excel. As the tax induced drop is artificial, both scenarios omit the value set afterwards.

3.2.1.1 Scenario 1

In this scenario it is assumed that local EV sales resemble the global EV population which is exponentially rising. This scenario assumes a rapid incline in the early stages and then steadies itself at a growth rate of 5%-6% overall.

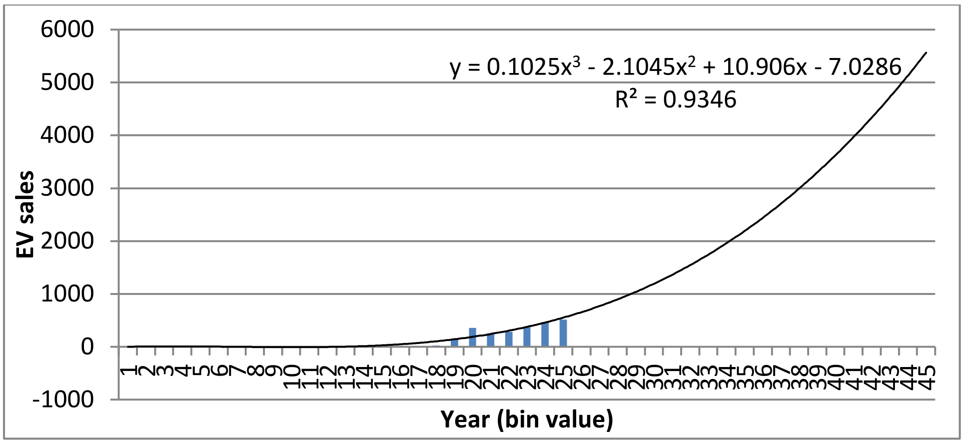


Figure 16: EV sales growth projection - scenario 1

Here, the rate is not compared to the total car sales and is considered independent. The years are represented by bin values – '0' as 2013/10 and rise of bin value by 1 is considered as increment of one month [See Appendix – B]. When sales are projected up to 2018/10, the total number of vehicles is 223,558. Since the F number this yields is 0.9346, it can be considered as a good approximation. Although seems farfetched in a way, high sale rate coupled with adequate spare parts inflow, may become self-sustainable. Past experiences tell us that more popular an automobile brand becomes cheaper and more commonplace its spare parts get.

3.2.1.2 Scenario 2

In this scenario, it is assumed that share of EV out of population remains at 2-3% and stabilises at around 1500 units per month. With rate of advent of technology, practicable range of a car may still seem inadequate to significant amount of users who travel extensively on a daily basis. Therefore, an upper-bound was set for the sales of vehicles.

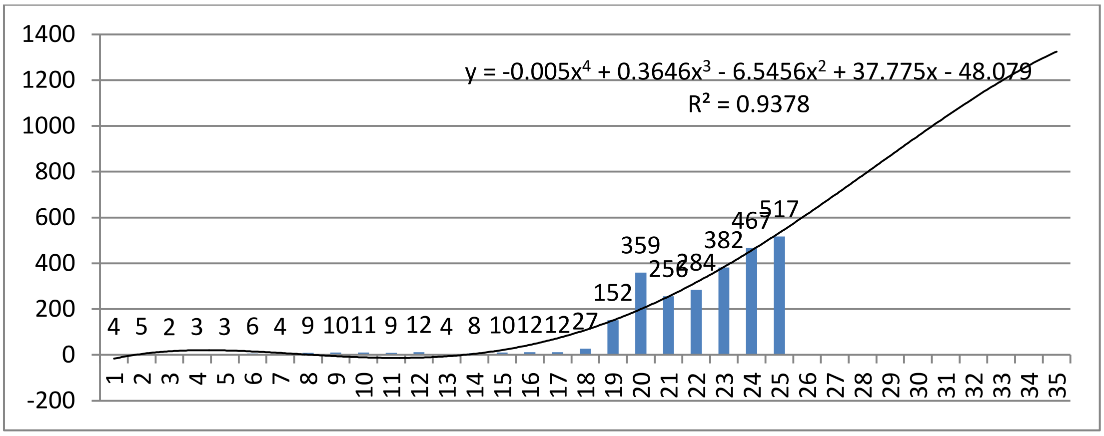


Figure 17: EV sales growth projection - scenario 2

In this scenario [See Appendix – B] the projected amount of cars in the market is lower than in the first. However, the F number received is 0.9378 which is a slightly better approximation. These figures would have been more representative of the actual sales rise if there was more data available over a wider span of years. Yet, owing to duty fluctuations both scenarios were constructed on figures gathered over 24 months only. Assuming sales follows this scenario the total amount of EVs in Sri Lanka would be 52514. Scenario 1 yields around four fold the cars scenario 2 does. At initial stage the escalation of EV population is large, even though it stabilises around a rate of 6%.

Globally EV sales showed a rise of 54% in 2017 over figures of 2016. Market in China expanded in EVs as much as by 27% in the recent years. They intend to have 2 million EVs by the year 2020 and an astonishing 7 million in 2025. Norway is hoping to rid their roads of conventional gasoline vehicles in as near as 2020. In October of 2018, 45% of new car purchases have been EVs. In a global backdrop such as this, if sensible import duties were imposed promoting EVs, rapid expansion of EV market would be no stranger to Sri Lanka as well.

3.2.1.3 Scenario 3

The escalation of taxes in late 2015 was a massive blow to sales of electric cars. The sales began to plummet and never recovered in the face of ever increasing taxes in the years later on. The moving average of monthly sales dropped to around 15 cars per month towards the end date of data obtained from the DMT. If this rate sustained till October-2018 there would be 4540 electric vehicles. If the average sales reach 20 cars per month, total population would be 4614 EVs. For the population to reach, say 35,000 cars, it will take over 125 years. Therefore if the policy makers hope to popularise zero emission transportation, excessive taxes imposed on EVs need to be reduced immediately. As the specification in terms of range, reliability and features of newer electric cars improve; it is natural for the cost to escalate. If we were to reach 35,000 EVs by the year 2030, we would 200 new EV registrations ever month till 2030.

CHAPTER 04 MODELLING LOCAL EV DEMOGRAPHIC

4.1 Conducting an Online Survey

In previous chapter, the total number of electric vehicles available in the country was discussed. However, to assess the grid connectivity times and the available capacity of the cars connected at any given time, information on EV population alone is inadequate. No information is readily available in literature which describe the daily duration a car remains plugged in nor the state of charge (SOC) the car's battery has at the time of plugging-in and unplugging.

The survey [See Appendix – C] was constructed using free online platform – Google Forms [Available at: **https://goo.gl/TWiDL1**]. The questions focused on gathering information on,

1. The model of the car/battery capacity
2. Expected mileage on a weekday and a weekend
3. Availability of net-metering at home
4. Usual plugin and unplug times
5. Average SOC when the car is plugged-in and unplugged
6. Interest in partaking in V2G services and reasons if otherwise
7. Intention to buy another EV after selling the current vehicle

Gaining access to a group of EV owners of course was difficult. Since it was impractical to meet owners individually, the questionnaire was published on the Facebook page of a local group of electric vehicle owners [https://www.facebook.com/groups/evclub.lk/]. The membership is over 7000 now. However, judging by number of replies to the survey, majority of its members must be enthusiasts rather than owners. The survey, with approval of admins, was repeatedly posted on the page to retrieve maximum possible replies as a larger sample will yield more accurate results. However, 35 replies were received over a course of around four months.

Initially the survey extensively raised questions in order to build rich set of data. However, feedback was received from early responders complaining that the quiz was too complicated and lengthy. Thus, questions were combined and made less complex such that only vital information was requested. Consequently, survey results were analysed and a model was built to predict the number of cars that are connected to the Grid at any given time of day.

4.2 Survey Findings

4.2.1 The Demography

Survey results indicate that selected segment of the EV owners relates to the general population to some extent. Amongst the entire EV demographic, Leaf has a share of over 96%. 83% of the owners subjected to the survey own Nissan Leafs. Moreover, four responders claimed ownership of a Chinese mini car called Shifeng D101. This model had not been recorded DMT-sourced data. Perhaps, D101 is a new import that excluded until the last date of the records received from DMT. Out of 35 responses, 4 were D101. In addition, there was one instance each from Outlander PHEV and BMW i3.

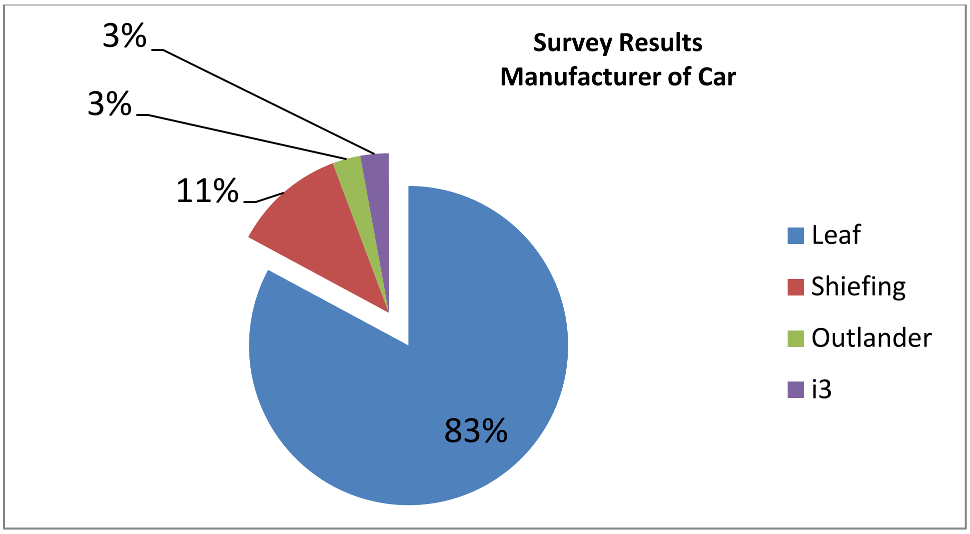


Figure 18: Survey results - EV composition

4.2.2 Distance Travelled

Range anxiety is a serious issue that concerns whoever drives an EV. Charging stations are still not commonplace, which forces the drivers to plan their trips ahead assessing the current SOC and the charging stations available in his/her route.

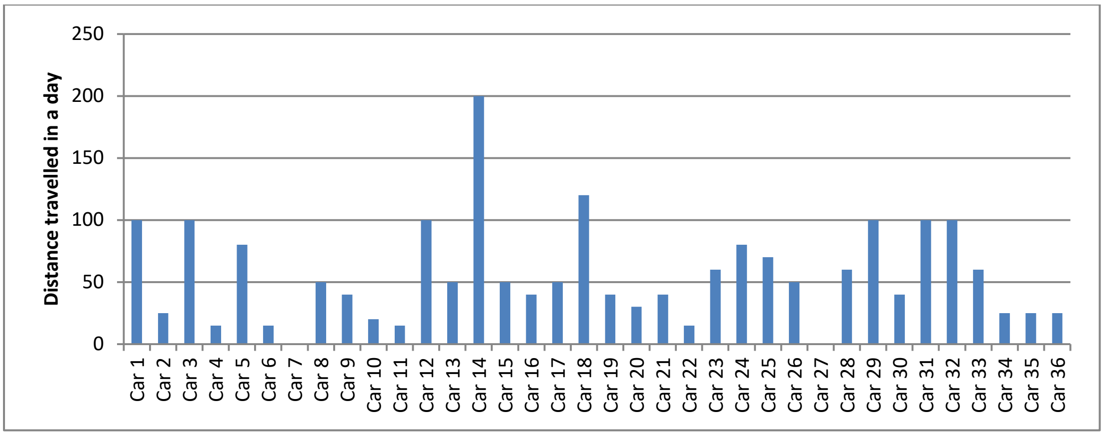


Figure 19: Survey results - distance travelled in a day

Except for a few exceptional cases most drivers use the car for short trips. Most would not even need to charge their cars daily as an average Nissan Leaf can travel around 130km on a single charge with A/C. The owner who travels over 200km must be charging his car twice a day or once a day if he is careful with economic driving. Still, even for a regular gasoline powered car or a hybrid this is high mileage. However, if the battery of the vehicle is well looked-after, in terms of maintenance cost, his expenses must be a lot lower than a regular car. Electric cars are famous for their very low maintenance costs. The only downside is the battery degradation. Yet, Nissan is offering a warranty of 100,00km/8 year warranty which is not directly transferred to local buyers via car importers.

4.2.3 Plugin and Unplug Times

Except for 1 owner, all owners leave their cars plugged in to the charger from around 1800hrs to 0700hrs next day. A minority claimed that they plugin the cars at work, but not all companies endorse daytime charging of EVs as it adds to their electricity costs. The findings of plugin and unplug times are as follows.

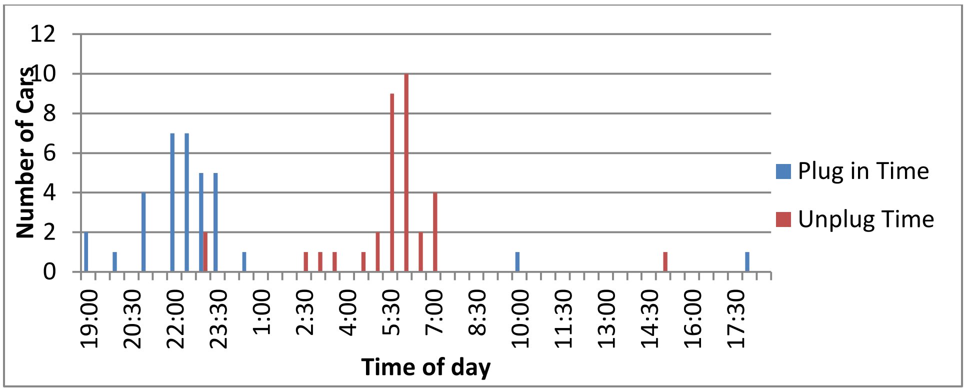


Figure 20: Survey results - car plugin/out times

Now that car connectivity information is gathered, cumulative count of cars connected to the grid is plotted against time. This is done by incrementing the car count by one when a car is connected and decrementing by one when a car is unplugged. Then a model that approximates the number of cars connected to grid at a time.

4.2.3 Motivation to Partake in the Scheme

The survey included questions that measure the interest of EV owners to partake in a scheme where they leave their traction batteries at the disposal of power grid operator. As is common with any case of early adoption of new technology, it is natural for people to refuse in fear of the adverse effect the scheme may have on the battery. Out of the 35 cars surveyed, 4 owners declined to participate in V2G scheme. However, their reasons were not limited to fear of battery degradation. The reasons are as follows,

1. Battery degradation
2. Have their own off grid systems, not interested in the grid
3. Travel needs/range anxiety

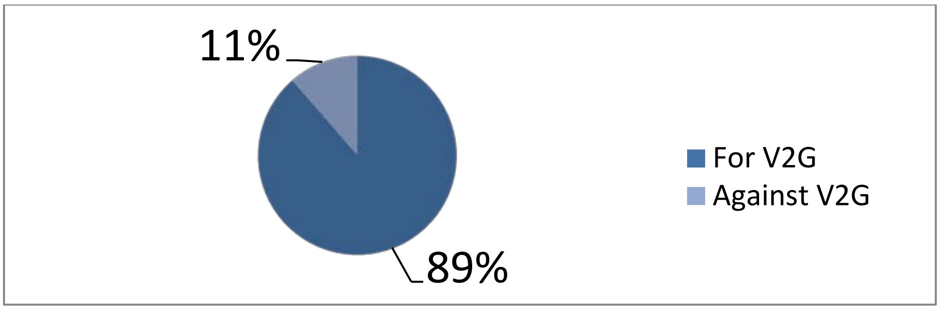


Figure 21: Interest in V2G

Since the proposed system deals with only a few discharges per day, first of the three can be ignored. As discussed in their EV forum, some members employ used EV batteries to configure their personal off-grid systems. This is somewhat similar to the concept – V2H (vehicle-to-home) where V2G energy is localised in a domestic level. The last factor, range anxiety, is a common problem amongst electric vehicle owners irrespective of their partaking in V2G or avoiding it. In such scheme where regulation service is expected from EVs around the clock, range anxiety will play a significant role.

Later in this dissertation, it will be pointed out that the first and third reason will be neutralised by the very nature of likely discharge patterns of the proposed energy storage method. Therefore, the energy curves deduced in the latter stages will not be adjusted to accommodate the willingness of partaking based on the assumption that said reasons will become invalid.

4.3 Modelling Car Connectivity

Next step is to build a relationship between the time of day and the number of cars connected. Several mathematical distributions were used for the task and Weibull distribution yielded the best approximation of the situation. Weibull distribution takes the form below.

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}$$

Here α and β are shape and scale parameters. To improve results, a correction factor 'γ' was introduced in front of the equation. 'x' is the bin value which represents the time of day within 24 hours. Bin value 1 is taken as 1900hrs today and bin value 48 is taken as 1730hrs the following day. An increment of bin value is represented by 30 minutes, making the sampling duration half an hour. Percentage cumulative column is derived from dividing cumulative car count from total population. Values obtained from the Weibull density function was then multiplied by total number of cars to get the expected number of cars connected at a given time. An error (e) was defined as the difference between actual number of cars connected (obtained from survey results) against expected number of cars connected (derived with Weibull distribution). Then root mean error (RMSE) was calculated. The shape parameter (α)

and scale parameter (β) optimised such that RMSE is minimised. Figure 19 shows comparison of actual versus the expected number of cars connected.

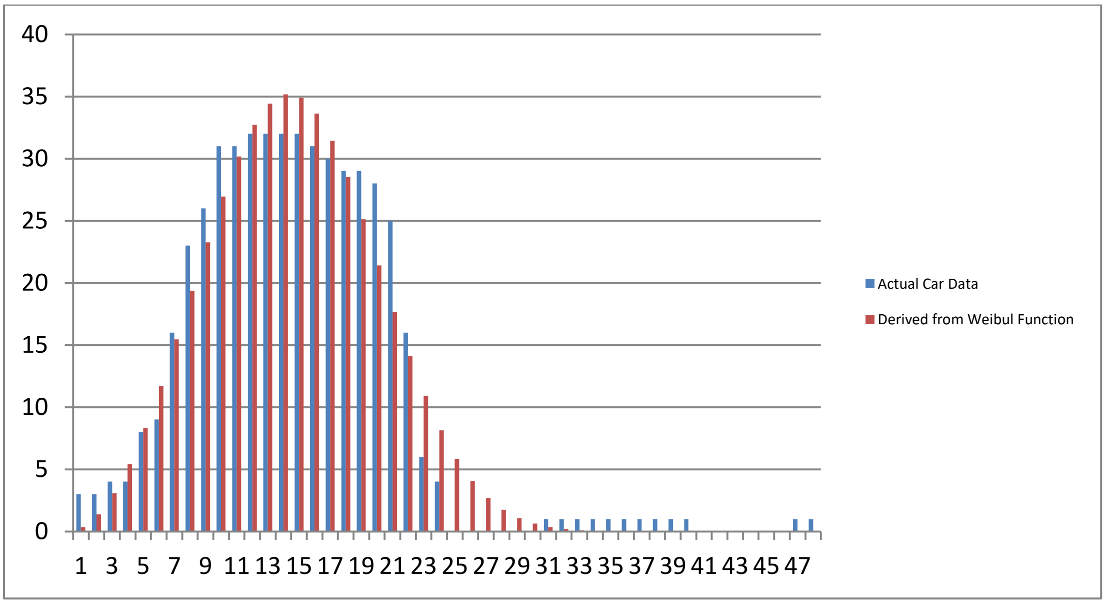


Figure 22: EV grid connectivity model

The optimised parameters of the distribution are as follows.

α	2.9861
β	16.31
γ	14.012

4.4 Modelling Energy Stored in EVs

The vehicles may have different levels of state of charge (SOC) when they are plugged in. moreover, the plugin and unplug times depends on the lifestyle of the owners while state of charge of the battery is reliant on traffic conditions, distance travelled, SOC when the car was unplugged before travelling and the capacity of the battery. Thus, to derive a model on the energy stored on an EV battery the SOC needs to be incorporated in to the model as well.

Assume 'n' number of cars are in the population and let car No.1 be denoted by C_1. Let us say that C_1 is plugged in for charging at time t_1 and is unplugged at time t_2. The period between t_1 and t_2 is unique to the car as it depends on the lifestyle of the owner. However, C_1 may have battery level at SOC_1 on one day and SOC_2 on another as it depends on externalities that exclude the owner. Following is the graphical representation of the very argument.

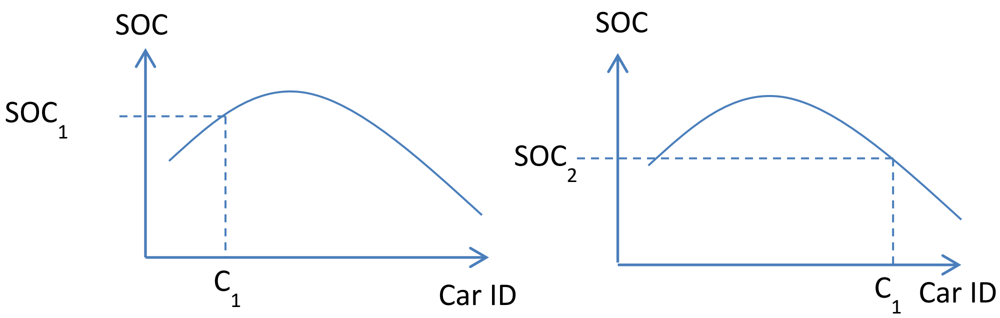


Figure 23: Randomisation of EV SOC

This randomness of SOC must be included in whatever the distribution built to quantify the energy stored in the EV population at any given time, more accurately. Consequently, 20 scenarios were developed where plugin SOCs of 35 cars were assigned to each other. For instance, let us assume that on day 1, C_1 is plugged in with battery at SOC_1. On day 1, C_1 will be plugged in with battery level at SOC_2. Similarly, up to C_{35} initial SOC is assigned randomly. This randomisation changes the time each car takes to achieve full charge and provides a more reasonable approach to approximate the charge level of the fleet, hence the energy stored.

Certain assumptions were made regarding model of EV, capacity of on-board charger and the hourly rise of SOC to quantify the instantaneous SOC of the EV population.

1. Since 97% of the local population and 83% of surveyed population was Nissan Leafs, it was assumed that every electric vehicle is a Leaf.
2. Moreover it was assumed that all cars are equipped with 3.3kW on board charger unit as they coupled with Level 1 home chargers. Nissan discourages frequent DC fast charging (*ChadeMo*) as it contributes to accelerated battery degradation. (Leaf is criticised for having a low performance draught cooling while Tesla, Chevrolet Bolt employ liquid cooling)
3. All cars come equipped with 24kWh battery (entire survey sample had 24kWh Leafs. DMT statistics did not indicate battery capacity of majority of registered vehicles). This gives a full charge time of approximately 7 hours.

Developing all 35 scenarios indicated that the cumulative SOC curve of each instance resembles all others. Therefore, average of all scenarios was taken as the final cumulative SOC distribution throughout 24 hours. Figure 21 to 23 are distributions obtained for scenario 1, 10 and 16 (S1, S10 and S16) [See Appendix – I].

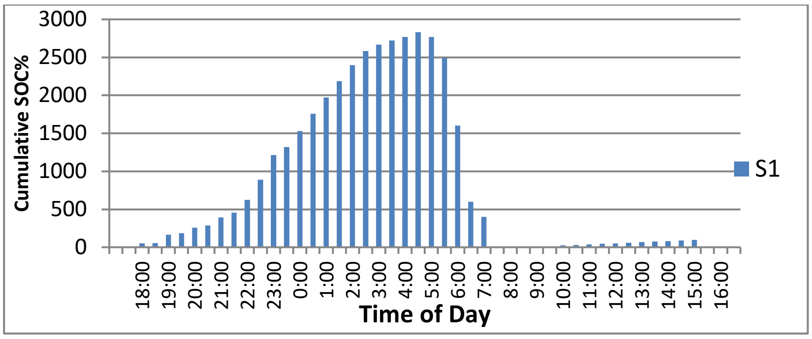


Figure 24: Cumulative SOC - scenario 1

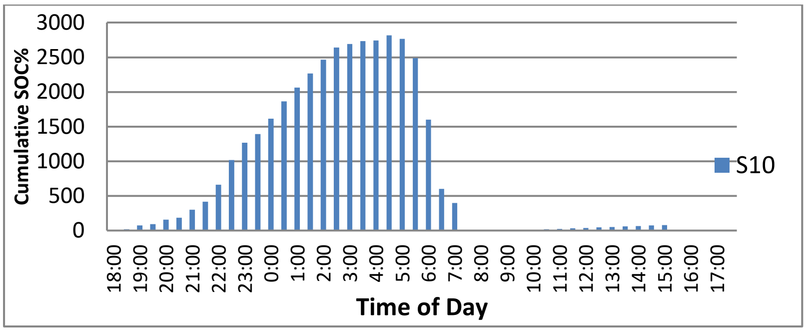


Figure 25: Cumulative SOC - scenario 10

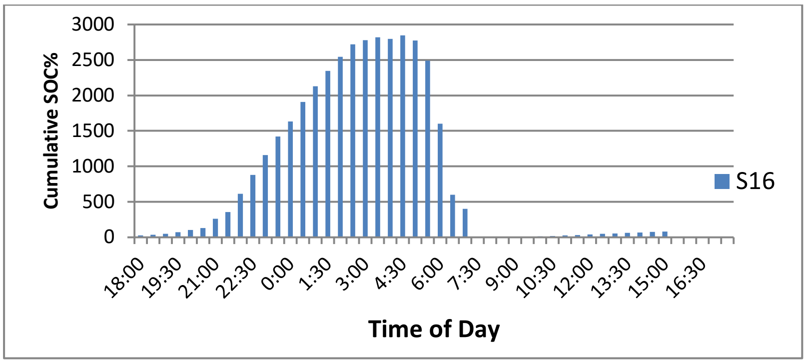


Figure 26: Cumulative SOC - scenario 16

Once all scenarios are combined, the average distribution takes form as in Figure 24.

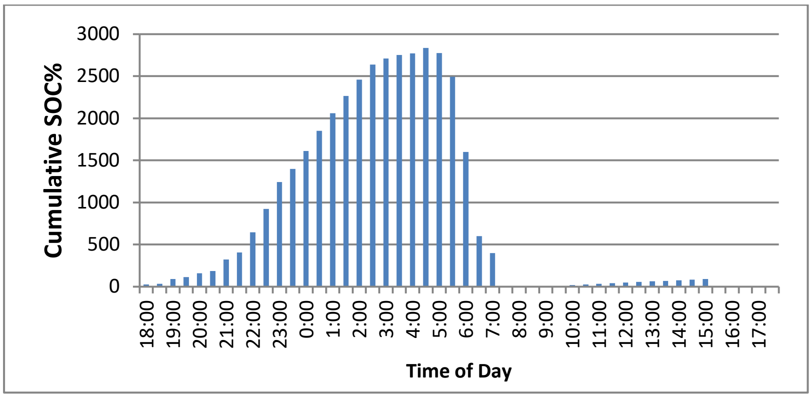


Figure 27: Effective combined result for SOC around the clock

Now that SOC has been modelled for the day, available power must be derived. By dividing the curve by 100, we get the effective number of cars at full charge (100% SOC being a fully charged car). We are aware that a fully charged car can ably deliver power at rated capacity of its charger (3.3kW). In assessing the possibility of employing EV demographic as fast response energy storage that can prevent load shedding, power capacity takes precedence over energy capacity since V2G services is not required for extensively long periods under dynamic conditions. Having calculated effective number of fully charged cars connected, effective power output is obtained by multiplying it by 3.3kW (effective power output = effective fully charged cars × 3.3kW). Afterwards, effective power output is divided by total number of cars to get per unit power available. The peak of this curve is the representation of effective maximum power output available by taking in to account the fact that a population of cars may not be at full charge.

This gives the distribution shown in Figure 25.

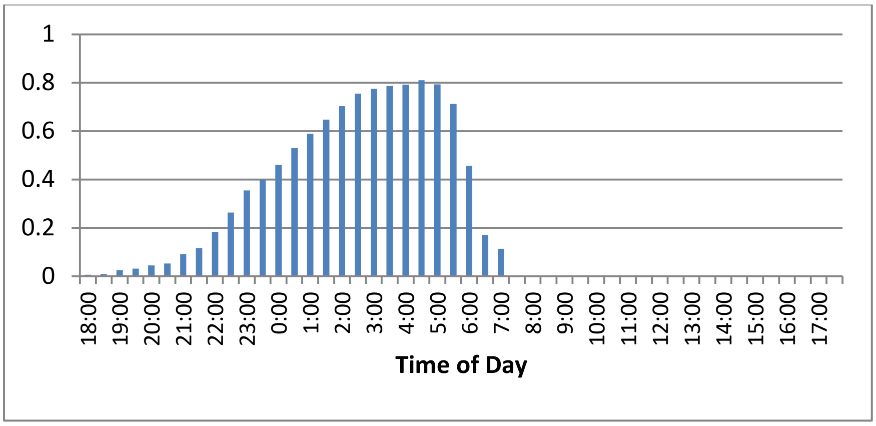


Figure 28: Effective p.u. power output per EV

Now a model must be constructed to represent this behaviour of effective per unit power. Several options such as Weibull, Beta, logarithmic and skewed normal distribution were considered. Best approximation of the observations was obtained using skewed normal distribution. Skewed normal distribution takes the following form in its generic format,

$$f(x) = \pi \frac{2}{\omega} \phi\left(\frac{x-\zeta}{\omega} \right) \varphi\left(\alpha \left(\frac{x-\zeta}{\omega} \right) \right)$$

where φ and ϕ are normal distribution while ζ,ω,α and π are location, scale, shape and correction parameters respectively.

An error (e_{pupwr}) was defined as difference between the observed p.u. power and derivation of the model. The parameters of the distribution model were optimised such that RMSE is minimised. Figure 26 illustrates the comparison between actual and projected curve.

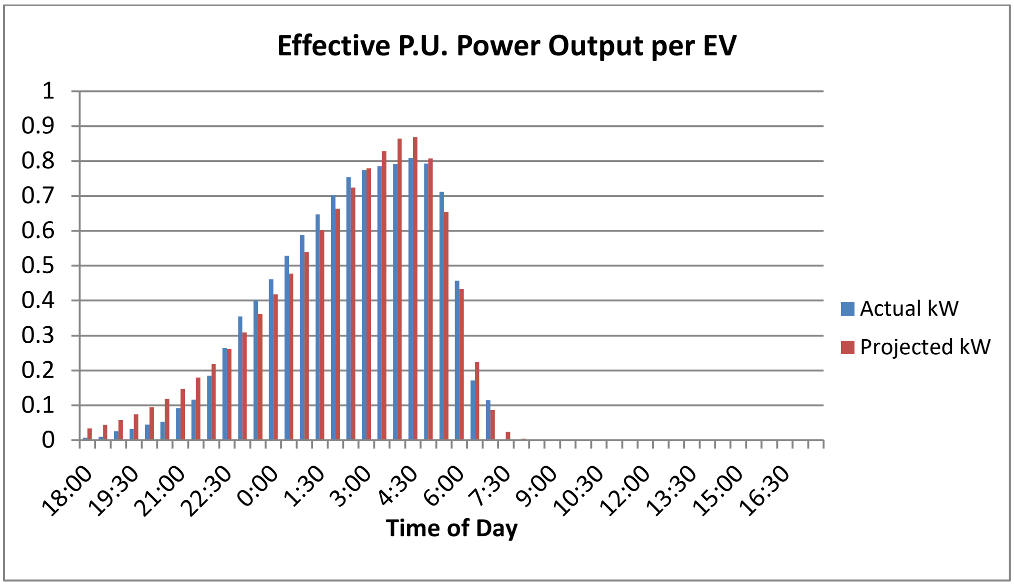


Figure 29: Actual vs projected effective p.u. power curve

The optimised parameters of the distribution are as follows.

ω	9.2082
ζ	24.817
α	-5.5864
π	10.9829

The resultant approximated model of per unit power is as follows.

$$f(x) = 2.3855\phi\left(\frac{x-24.817}{9.2082}\right)\varphi\left(-5.586\left(\frac{x-24.817}{9.2082}\right)\right)$$

From the derivation, it is observed that peak power occurs at 0.868 p.u. Thus the effective maximum power output that can be drawn from a grid connected vehicle is 2.8644kW.

5.1 Evaluation of Un-served Energy and Load Shedding

5.1.1 Background

Research work that have been carried out concerning V2G systems discuss the possibility of using V2G for grid regulation services owing to its limitations such as battery degradation. Still, modelling battery degradation is excessively complicated and different researchers have approached the problem in many a way. Still, a sufficiently vast survey sample had not been subjected to scrutiny as fast as degradation is considered. Thus, the intention of this research is to devise a method that has significant economic result that need not be at the expense of adverse effect on the EV battery.

Tesla Inc. recently installed 100MW/129MWh lithium ion battery storage in Australian national grid, called Hornsdale Power Reserve. 30MW/90MWh portion of the battery is controlled by *Neoen* while the remainder is at the disposal of System Operator for regulation services. On 14th of December 2017, Loy Yang A3, a 560MW coal fired steam plant which was situated over 560 miles away from the battery tripped while operating at full load. Frequency dropped from 50.0Hz to 49.8Hz and within a few milliseconds, HPR responded restoring frequency back to 50.0Hz. Loy Yang A3 tripped at 1:59:19 local time and HPR injected 7.3MW in to the grid effectively assisting in stabilising the grid before Gladston Power Station was able to respond at 1:59:27. Figure 27 illustrates the tripping of LYA3 coal power plant and how HPR responded in a fraction of a second.

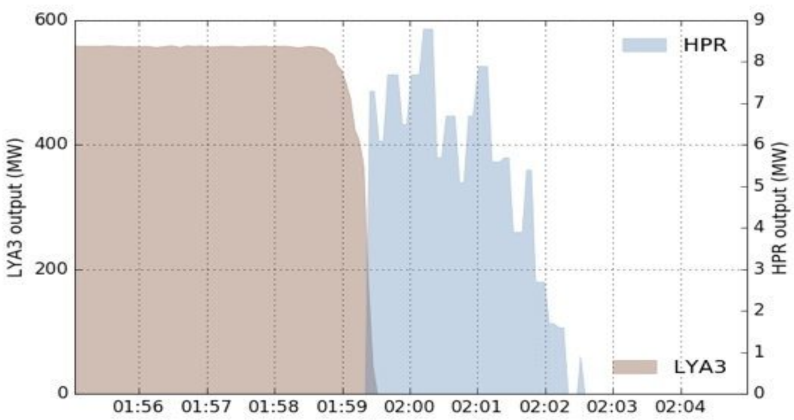


Figure 30: Frequency response of HPR
Source: https://electrek.co/2017/12/19/tesla-battery-save-australia-grid-from-coal-plant-crash/

Taking inspiration HPR, this research proposes implementing a battery storage that can cater low frequency events in the system where load shedding occurs. Considering the cost of un-served energy, even after paying dividends for EV owners who partake in V2G services, this scheme will be lucrative.

To quantify the feasibility of V2G type quick response energy storage that can prevent load shedding during frequency violation events, information that specifies the economic impact of un-served energy must be analysed. Moreover a reasonable frequency band must be defined where V2G service is triggered to limit the strain on the batteries. In case the EV batteries were discharged too frequently, cyclic ageing will be accelerated even though depth of discharge is low. The objective is to keep cycling and depth of discharge at optimum levels where battery degradation can be dismissible [21].

5.1.2 Cost of Un-served Energy

The amount of energy not supplied by the generating system during the period of observation, owing to capacity deficiency is known as un-served energy.

What is cost of un-served energy? Simply put it can be interpreted as economic value of the price consumers would pay to avoid a service disruption. Alternatively, the cost of un-served energy is defined as the value placed on a unit of energy equal to the sum of all losses, arising due to an unplanned outage for a short duration. Needless to say that manufacturing sector, production lines especially, can be greatly disrupted by an unreliable power supply. Machinery stopping midway could cause significant wastage of raw materials that cannot be reused.

Studies on the costs of un-served energy have been carried out in Sri Lanka out in 1990, 1997, 2002 and the latest in 2016. In their research, P.D.C.Wijayatunga and W.L.S.Fernando (1997) have approximated that cost of un-served energy at 142.72LKR.kWh. In 2016, upon recalculation, this figure has been approximated to 195.65LKR/kWh. [20].

Information was gathered regarding un-served energy caused for the years 2016 and 2017 [20]. Un-served energy may be a result of generator tripping, transmission lines tripping, transformer tripping, power cuts due to lack of generation (L.O.G.), and total failures. As this study focuses on a storage that caters power shortages caused by generator tripping, un-served energy resulted in by generator tripping only.

Table 3: Un-served energy of 2016, 2017

	P.Cut		G	T_x	T_f	TOT.F	Un-served, without P.Cut	Grand Total
	L.O.G	Scheduled						
2016	27,132.1	3,098.1	323.3	2,214.8	321.7	11,197.8	14,057.6	44,287.8
2017	6,564.1	0.0	369.9	811.3	529.1	0.0	1,710.3	8,274.4

G, T_x, T_f, and TOTF refer to un-served energy due to generator tripping, transmission line tripping, transformer tripping and total system failures. Un-served energy caused by transmission line failures and transformer failures do not occur because of load shedding. When a significant load is removed from the system, spinning reserves act and reduce their loads quickly (fast acting generators are used as spinning reserves i.e. hydro stations, gas turbines, combines cycle stations in simple cycle mode etc.). Load disconnection from transmission network has no relation to the generator side. For example, a lightning strike and a flashing over of an insulator string are a few reasons for line tripping that are externalities that could occur when all generators are ably catering load at some moment.

Taking the cost of un-served energy as 196.65LKR/kWh we can thus calculate the cost of generator-tripping-induced load shedding.

Table 4: Costs of un-served energy

Year	Loss of Energy Due to Generator Trip	Un-served Energy cost (LKR/kWh)	Total Cost (LKR)
2016	323.3	195.65	63,253,645.00
2017	369.9	195.65	72,370,935.00

5.2 Prevention of Load Shedding

Load shedding occurs owing to many reasons such as generator tripping, transmission lines tripping, transformers failures or total system blackouts. Implementation of an EV based battery bank that triggers on detection of frequency levels dropping beyond a certain threshold is the objective of this research as it cannot affect the loads lost because of transmission lines failures. We must first study the energy lost due to generator tripping. The principle is to inject active power in to the system so that first stage of under-frequency load shedding can be prevented. Let us first look at levels where different schemes of under frequency tripping schemes are implemented.

Five frequency only stages and one that combines both frequency and rate of change of frequency are implemented in 33kV system. There are no under-frequency protection schemes in high voltage network.

1. 48.75Hz for 0.1s,48.5Hz for 0.5s,48.25Hz for 0.5s,47.5Hz instantaneous
2. 49Hz or lower with 0.85hz/1s for 0.1s

Under normal conditions, a loss of 8MW is felt as a 0.1Hz in the National Grid. Therefore, the research proposes the capacity that can withstand the first stage of under frequency based load shedding. That is, upon detection of 1.25Hz drop, the battery bank will dispatch an equivalent of (8MW/0.1Hz×1.25Hz=) 100MW. As a battery pack can respond within a few milliseconds, the load shedding triggered by rate of change of frequency, despite its occurrence at a high frequency point, will still be covered by the scheme.

5.3 Survey of Frequency Violation Events

As mentioned previously, the scheme proposed must respond to 1.25Hz drops in frequency. Frequency of such events must be assessed as too many events will excessively strain the battery bank bringing effects of battery degradation in to play. Data on frequency violations for the year 2017 are as follows [23].

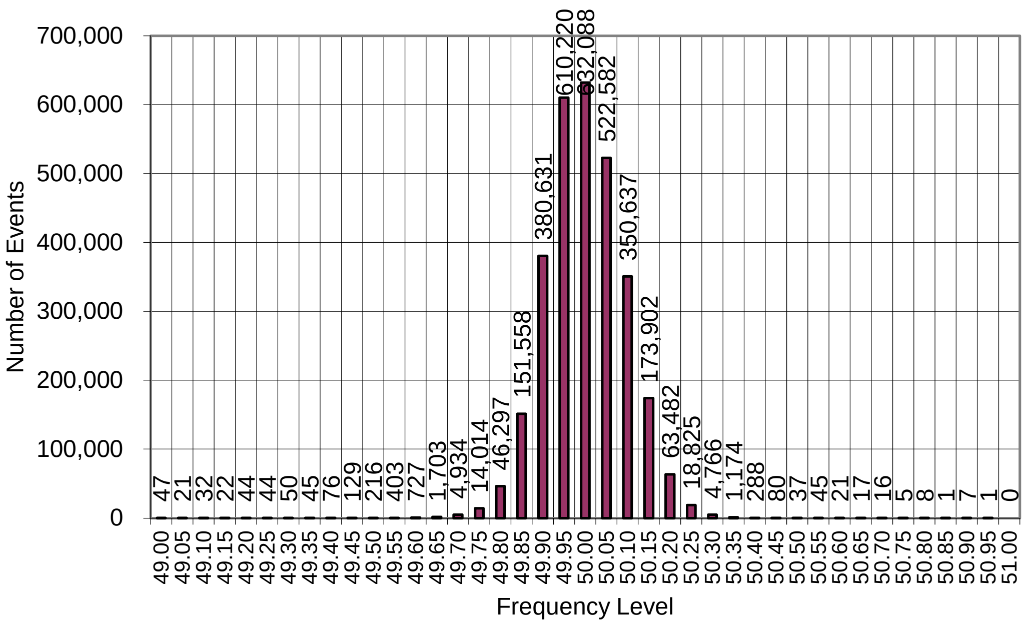


Figure 31: Frequency events of 2017

Scrutinising the frequency violation curve tells System Control Centre is actually performing an admirable duty by strictly adhering to the regulation set for system frequency (50Hz±1% → 49.5Hz to 50.0Hz). Refer the summary in Table 5.

Table 5: Frequency violation event count

Violation Level (Hz)	Event Count
<49.5	510
≤49.5	726
≤49.55	1129

It is noticed that there are no records for events below 49.0Hz. As per the curve, even if the V2G battery storage was triggered at 49.5Hz level, total annual discharge events for the battery will be 726. Once averaged, discharge events will be 1.989 times per day. Thus we can safely conclude that even if the EV population is triggered at 49.5Hz or below there will not be more than 2 events per day.

5.4 Effect of Discharge on EV Battery

Assuming that a single low frequency event lasts for 10 minutes let us investigate the amount of energy drawn by a single electric vehicle providing V2G services. It is assumed that one vehicle is delivering power at maximum continuous rating of its bidirectional inverter charger. Although a 10 minutes frequency event is nearly impossible the energy drawn from a car within that duration is given by,

$$3.3kW \times \frac{10}{60} hrs \times 2 = 1.10kWh$$

Assuming that on average a Nissan Leaf does 6km/kWh, it can be calculated that the effect of couple of discharges is reflected in the drop in range as,

$$\text{Drop in range} = 1.10kWh \times 6km / kWh = 6.6km$$

From the online survey it was found that an average EV travels around 60km per day. There were of course a few exceptional cases where drivers neared the practicable range on a single charge. If the average vehicle daily travels around 60km a loss of 6km in terms of range is not significantly affecting the owner’s travel needs. Moreover, considering the 24kWh battery pack, 1.10kWh loss is equivalent to a depth of discharge of a mere 4.58%. Figure 29 is a simplified graphical illustration of the incident.

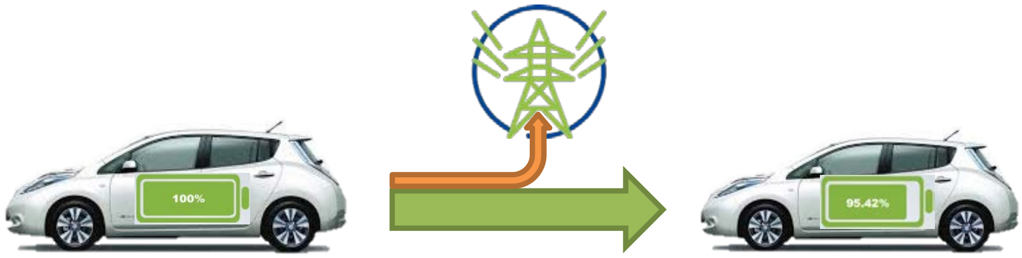


Figure 32: Sample sketch on depth of discharge per day

Researches [09] indicate that depth of discharge (D.O.D) has a significant repurcussions upon the longevity of the traction battery of an electric vehicle. In this proposition, it is observed that D.o.D is less than 4.58% and that the equivalent range lost is only slightly over 6km.

5.5 Paying Dividends for EV Owners

In the previous chapter it was found out that the effective maximum charger output of an EV partaking in EV is 2.8644kW. In this chapter it was argued that the capacity suitable for the fleet of vehicles is 100MW. Thus, the amount of cars required for the fleet is (100MW/2.8644kW=) 34912 No's. Moreover, it is noteworthy thata under two EV sales growth scenarios developed in Chapter 01 yields an EV population in excess of 35,000 vehicles (Scenario 1 – over 200,000 & Scenario – over 50,000)

Compensation paid to EV owners need not be based on kWh as energy value is not significant in regulation work. Therefore a fixed payment for the years is proposed. However, considering the prevented un-served energy and keeping a sufficient margin on returns following payments are suggested per car per annum.

Table 6: Savings from load sheds

Year	Total Loss (LKR)	EV Population	Cost for Payment(LKR)	Savings
2016	63,253,645.00	34912	52,368,000.00	10,885,645.00
2017	72,370,935.00	34912	52,368,000.00	20,002,935.00

By paying 1,500LKR/annum for a car that partakes in implementation of the scheme significant savings can be yielded. The EVs who intend to participate in the scheme can be selected every year on first-come-first-serve basis as allowing entire population to take part may reduce the margin for savings if not completely abolishes it.

In this research it is argued that significant savings can be obtained by proposing a quick response electric vehicle based energy storage. The EVs can be plugged in at their homes and can be controlled by a central aggregator that can communicate with the fleet of vehicles wirelessly. Thus, as in previous researches carried out, the fleet of vehicles need not be parked in a central location where the aggregator is stationed.

Firstly, the Sri Lankan EV population growth was surveyed using the information obtained from Department of Motor Traffic. It was noticed that local motorists have been motivated to experiment with the new, yet unproven technology rather well judging by the rapid growth of sales at the provision of Government concessions on import duty imposed on EVs. However owing to volatile policies of Government, EV sales deteriorated massively. Thus two scenarios were built to predict the growth of EV sales. As significant amount of electric vehicles were needed for putting together sizeable battery storage, growth had to be predicted as existing sales rates, which were discouraged by the heavy import duties, were not at all adequate.

1. Scenario 1 - Growth in line with Global Trends → 5-6% overall growth
2. Scenario 2 - Taxes Remain Unchanged → 3-4% share of total.
3. Scenario 3 – current rate of approximately 20 registrations month remained

After modelling the growth rated of EV population more data was required to access the grid connectivity of the EVs. An online survey constituting a variety of questions that covered a large area was constructed as no information was readily available. This survey covered areas such as type of vehicles, the battery technology, the distance a vehicle travelled in a day, plugin and unplug times and SOC levels at respective plugin and unplug times. The questionnaire was posted on the Facebook page of EV Club Sri Lanka. One of the main problems was the low response rate. Over a course of a few months the survey was repeatedly posted on the FB page upon approval of the administrators. However, only a limited number of replies were received.

The number of EVs connected to a given time of day and the EV energy available were modelled separately using Weibull and skewed normal distributions respectively. They took the following forms, The number of cars connected at a given time,

$$f(x) = 2.5654\left(\frac{x}{16.31}\right)^{1.9861} e^{-\left(\frac{x}{16.31}\right)^{2.9861}}$$

The amount of energy available in the grid connected EV population

$$f(x) = 2.3855\phi\left(\frac{x-24.817}{9.2082}\right)\varphi\left(-5.586\left(\frac{x-24.817}{9.2082}\right)\right)$$

In both models x represents the bin value for time of day, measure half-hourly. Using the models it was found out that maximum effective output a car can deliver is 2.8664kW.

Afterwards system disturbances were studied as the objective of the research is to implement a group of cars that can cater power demand during under frequency events of National Grid. Based on trigger point of 48.75Hz and that 8MW drop causes a 0.1Hz drop in frequency it was theorised that total capacity of the fleet is 100MW. Employing the fact that effective maximum output of a vehicle in the fleet is 2.8644kW it was identified that a total population of 34,912 No's is required for implementation of 100MW. Subsequently, the cost of un-served energy was calculated accounting for the losses incurred by generator tripping. Deducing that fast response energy storage can counter load shedding the savings of calculated provided that an incentive is offered to EVs who opt to participate in the scheme. Under Scenario 1 and 2, would have adequate population for delivering the 100MW maximum power. However, under Scenario 3, it would take roughly 125 years more to reach the target vehicle pool of 34,912 cars. Thus target will be only achieved in the year 2145. We can achieve the target population by 2030 at least, if 200 new EV registrations take place every month till the year 2030. This can only be accomplished if the authorities step in and cut down the taxes on EVs and increase the incentives given to zero emission car owners as most of other countries do at the moment.

Still, the incentive is not attractive to invite more and more EVs to contribute to the scheme. However, in future perhaps the government can intervene and offer subsidies for owners who offer their vehicles to V2G services considering the immense returns gained by minimising un-served energy.

Moreover, regulatory bodies can intervene and develop a methodology to expand this method and implement more extensive regulatory services with the aid of electric vehicles. This method will involve continuous battery activity which may contribute to accelerated-cyclic-ageing. Thus incentives must be provided taking that in to account. They need to intervene in establishing a charging network that facilitates bidirectional power flow instead of the currently installed unidirectional units that only facilitates charging.

References

[1] Mohamed Khalil. (2017, Nov. 17). *A Tesla that will outpace the Bugatti Veyron is set to be released in 2020* [Online], Available: https://www.esquireme.com/content/24798-a-tesla-that-will-outpace-the-bugatti-veyron-to-be-released-in-2020

[2] Jayakrishnan Radhakrishna Pillai, and Birgitte Bak-Jensen, "Integration of Vehicle-to-Grid in the Western Danish Power System", in *IEEE Transactions on Sustainable Energy*, vol. 2, no. 1, 2011, pp. 12-19.

[3] Willet Kempton and Steven E. Letendre, "Electric Vehicles as a New Power Source for Electric Utilities", in Transportation Research Part D: Transport and Environment, vol. 2, issue 3, 1997, pp.157-175

[4] J. Mossoba, M. Ilic, and L. Casey, "PV Plant Intermittency Mitigation Using Constant DC Voltage PV and EV Battery Storage", in *IEEE Conference on Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES)*, Waltham, 2010, pp.297-301.

[5] Cody A. Hill, Matthew Clayton Such, Dongmei Chen, Juan Gonzalez and W.Mack, "Battery Energy Storage for Enabling Integration of Distributed Solar Power Generation", in *IEEE Transactions on Smart Grid*, vol. 3, no. 2, 2012, pp. 850-857

[6] Steve Hanley. (2017, Jun. 16). *China: 12% Electric Cars By 2020 … Or Else* [Online]. Available: https://cleantechnica.com/2017/06/16/china-12-electric-cars-2020-else/

[7] Sayed Saeed Hosseini, Ali Badri, and Masood Parvania, "The Plug-in Electric Vehicles for Power System Applications: The Vehicle to Grid (V2G) Concept", in *IEEE International Energy Conference and Exhibition,* Florence, 2012, pp.1101-1106.

[8] Sekyung Han, and Kaoru Sezakai, "Estimation of Achievable Power Capacity from Plug-in Electric Vehicles from V2G Frequency Regulation: Case Studies for Market Participation", in *IEEE Transactions on Smart Grid*, vol. 2, no. 4, 2011, pp. 632-641

[9] N. Raman, G. Chagnon, K. Nechev, A. Romero, T. Sack, M. Saft, "Saft high power Li-Ion automotive battery technology", in *proc. of 20th International Electric Vehicle Symposium and Exposition*, Long Beach, CA, 2003, pp. 12

[10] Wilett Kempton, and Jasna Tomic, “Vehicle-to-grid power fundamentals: calculating capacity and net revenue,” in *Journal for Power Sources 144*, 2005, pp.268-279.

[11] K.N.Kumar, B.Sivaneasan, P.H.Cheah, P.L.So, and D.Z.W.Wang, “V2G Capacity Estimation with Dynamic EV Scheduling” in *IEEE Transactions on Smart Grid*, vol.5, no.2, 2011, pp.1051-1060.

[12] “New EV and PHEV Registration Data 2005-2017”, Department of Motor Traffic

[13] Motortraffic.gov.lk, *Monthly New Registration of Motor Vehicles-2015*[Online].
Available: http://www.motortraffic.gov.lk/web/images/stories/document/new%20regist%20of%20vehicles%202015.pdf

[14] Tanya Goonewardene (2015, Jul. 17), *Is Sri Lanka ready for electric mobility?* [Online]. Available: http://www.ft.lk/article/433871/Is-Sri-Lanka-ready-for-electric-mobility?

[15] Mark Kane. (2018, Mar. 26). *Nissan Introduces $2,850 Refabricated Batteries for Older LEAF* [Online]. Available: https://insideevs.com/nissan-introduces-refabricated-batteries-for-older-leaf-in-japan-from-new-4r-plant/

[16] Customs.gov.lk, *Excise (Special Provisions) Duty Changes Effective from 2015/12/09* [Online].
Available: http://www.customs.gov.lk/public/files/tariff/xid151209.pdf

[17] Carmudi.lk (2016, Sep. 03), *State of the Sri Lanka’s Vehicle Market: September 2016*[Online]. Available: https://www.carmudi.lk/journal/state-of-the-sri-lankas-vehicle-market-september-2016/

[18] Economynext.com. (2015, Jan. 19). *Sri Lanka electric car ownership goes up* [Online].Available: http://www.economynext.com/Sri_Lanka_electric_car_ownership_goes_up-3-1557-8.html

[19] Namini Wijedasa. (2017, Jan.08). *Tax hikes short-circuit electric car sales, drive investor into debt* [Online]. Available:

http://www.sundaytimes.lk/170108/news/tax-hikes-short-circuit-electric-car-sales-drive-investor-into-debt-223218.html

[20] D. Punsara Colambage and H. Y. Ranjit Perera, “Assessment of cost of unserved energy for Sri Lankan industrial sector”, in *proc. Of 2018 IEEE International Conference on Industrial Electronics for Sustainable Energy Systems (IESES)*, Hamilton, NZ, 2018

[21] Dai Wang, Samveg Saxena, Jonathan Coignard, Elpiniki Apostolaki Iosifidou, and Xiaohong Guan, “Quantifying Electric Vehicle Battery Degradation from Driving vs. V2G Services”, in *proc.Of 2016 IEEE Power and Energy Society General Meeting (PESGM)*, Boston, USA, 2016.

[22] Shuang Gao, K. T. Chau, Chunhua Liu, Diyun Wu, and C. C. Chan, “Integrated Energy Management of Plug-in Electric Vehicles in Power Grid with Renewables”, *IEEE Transactions on Vehicular Technology,* vol. 63, no. 7, 2014, pp.3019-3026.

[23] System Control Centre, “Monthly Operations Report”, Ceylon Electricity Board, 2017

Appendix – A EV grid connectivity model (no's of cars at a given time)

Bin	Time	Plug in	Unplug	Cumul	Cumul %	Weibull	Cars
1	19:00	2	0	3	0.085714	0.010022	0.350762
2	19:30	0	0	3	0.085714	0.039638	1.387332
3	20:00	1	0	4	0.114286	0.08829	3.090155
4	20:30	0	0	4	0.114286	0.154986	5.424516
5	21:00	4	0	8	0.228571	0.238004	8.330126
6	21:30	1	0	9	0.257143	0.334692	11.71421
7	22:00	7	0	16	0.457143	0.441363	15.4477
8	22:30	7	0	23	0.657143	0.553295	19.36532
9	23:00	5	2	26	0.742857	0.664871	23.27048
10	23:30	5	0	31	0.885714	0.769867	26.94533
11	0:00	0	0	31	0.885714	0.861882	30.16588
12	0:30	1	0	32	0.914286	0.934881	32.72083
13	1:00	0	0	32	0.914286	0.983784	34.43243
14	1:30	0	0	32	0.914286	1.005037	35.17631
15	2:00	0	0	32	0.914286	0.997066	34.89732
16	2:30	0	1	31	0.885714	0.960525	33.61838
17	3:00	0	1	30	0.857143	0.89829	31.44015
18	3:30	0	1	29	0.828571	0.815171	28.53097
19	4:00	0	0	29	0.828571	0.71737	25.10794
20	4:30	0	1	28	0.8	0.611772	21.41202
21	5:00	0	3	25	0.714286	0.50517	17.68095
22	5:30	0	9	16	0.457143	0.403557	14.12448
23	6:00	0	10	6	0.171429	0.311588	10.90559
24	6:30	0	2	4	0.114286	0.232293	8.130269
25	7:00	0	4	0	0	0.167041	5.846426
26	7:30	0	0	0	0	0.115737	4.050805
27	8:00	0	0	0	0	0.077181	2.701344
28	8:30	0	0	0	0	0.049482	1.731879
29	9:00	0	0	0	0	0.030464	1.066243
30	9:30	0	0	0	0	0.01799	0.629637
31	10:00	1	0	1	0.028571	0.010177	0.356209
32	10:30	0	0	1	0.028571	0.00551	0.192833
33	11:00	0	0	1	0.028571	0.002851	0.099769
34	11:30	0	0	1	0.028571	0.001408	0.049274
35	12:00	0	0	1	0.028571	0.000663	0.023201
36	12:30	0	0	1	0.028571	0.000297	0.010403
37	13:00	0	0	1	0.028571	0.000127	0.004436
38	13:30	0	0	1	0.028571	5.13E-05	0.001797
39	14:00	0	0	1	0.028571	1.97E-05	0.00069
40	14:30	0	0	1	0.028571	7.18E-06	0.000251
41	15:00	0	1	0	0	2.47E-06	8.66E-05
42	15:30	0	0	0	0	8.05E-07	2.82E-05
43	16:00	0	0	0	0	2.47E-07	8.66E-06

44	16:30	0	0	0	0	7.17E-08	2.51E-06
45	17:00	0	0	0	0	1.95E-08	6.84E-07
46	17:30	0	0	0	0	5.01E-09	1.75E-07
47	18:00	1	0	1	0.028571	1.21E-09	4.22E-08
48	18:30	0	0	1	0.028571	2.72E-10	9.53E-09
		35	35		0		490.4348

Appendix – B EV Sales Projections Under Two Scenarios

Bin	Month	Actual Sales	Scenario 1	Scenario 2
1	10/1/2013	4	2	-16
2	11/1/2013	5	7	4
3	12/1/2013	2	10	16
4	1/1/2014	3	9	20
5	2/1/2014	3	8	20
6	3/1/2014	6	5	15
7	4/1/2014	4	1	9
8	5/1/2014	9	-2	1
9	6/1/2014	10	-5	-5
10	7/1/2014	11	-6	-10
11	8/1/2014	9	-5	-12
12	9/1/2014	12	-2	-11
13	10/1/2014	4	4	-5
14	11/1/2014	8	14	6
15	12/1/2014	10	29	23
16	1/1/2015	12	49	46
17	2/1/2015	12	74	76
18	3/1/2015	27	105	113
19	4/1/2015	152	144	156
20	5/1/2015	359	189	206
21	6/1/2015	256	243	263
22	7/1/2015	284	306	326
23	8/1/2015	382	378	395
24	9/1/2015	467	459	470
25	10/1/2015	517	552	549
26	11/1/2015	482	655	633
27	12/1/2015	238	771	719
28	1/1/2016	168	898	808
29	2/1/2016	152	1039	898
30	3/1/2016	167	1194	988
31	4/1/2016	78	1362	1077
32	5/1/2016	85	1546	1162
33	6/1/2016	67	1745	1243
34	7/1/2016	61	1960	1318
35	8/1/2016	46	2191	1385
36	9/1/2016	28	2440	1441
37	10/1/2016	19	2707	1486
38	11/1/2016	20	2993	1516
39	12/1/2016	24	3298	1530
40	1/1/2017	30	3622	1530
41	2/1/2017	22	3967	1530
42	3/1/2017	24	4333	1530
43	4/1/2017	15	4720	1530

44	5/1/2017	10	5130	1530
45	6/1/2017	11	5562	1530
46	7/1/2017	16	6018	1530
47	8/1/2017	3	6499	1530
48	9/1/2017		7003	1530
49	10/1/2017		7533	1530
50	11/1/2017		8090	1530
51	12/1/2017		8672	1530
52	1/1/2018		9282	1530
53	2/1/2018		9919	1530
54	3/1/2018		10585	1530
55	4/1/2018		11280	1530
56	5/1/2018		12005	1530
57	6/1/2018		12759	1530
58	7/1/2018		13545	1530
59	8/1/2018		14362	1530
60	9/1/2018		15211	1530
61	10/1/2018		16093	1530

Appendix – C Online Survey

Evaluating EV/PHEV Population and Grid Connectivity

Hello, I'm a Masters student at University of Moratuwa. For my research, I'm evaluating the feasibility of implementing V2G scheme in Sri Lankan power system. Kindly fill the following questionnaire so I can identify the amount of energy stored in a car when it is connected to the grid for charging. Thank you.

*Required

What is the model of your EV/PHEV? *

O Nissan Leaf

O Nissan e-NV200

O Mitsubishi Outlander PHEV

O Mitsubishi i-MiEV O

Toyota Prius PHEV O

Tesla Model S

O Tesla Model X

O Volkswagen e-Golf

O BMW i3

O Mercedes Benz B Class Electric Drive

O Shifeng 0101

O Mahindra e2o

O Mahindra E Verito

O Mahindra REVA Classe

O Smart electric drive

O Other:

Battery capacity? (kWh) (pl. do not enter "kWh" in answer you give) *

Your answer

What is the remaining usable battery capacity? (percentage/battery bars) *

Your answer

Approximately,how many kilometers do you drive on a weekday? *

Your answer

Approximately,how many kilometers do you drive on a weekend? *

Your answer
Do you have net metering at home? *

0 Yes

Q No

At what time do you usually plug in the car to charge? *

Your answer

At what time do you usually unplug the car?

Your answer

When you plug in what is the usual battery level? And what is the level of charge you expect at the unplug time? *

Your answer

How often do you plug in the car at work during daytime per month? *

0 All the time

0 Once in a while

0 Never

If provided with adequate compensation, would you be interested in using your car to deliver the energy stored in the battery back to national grid {if you can have a desired battery level when you unplug)? *

O Yes

Q No

If not, why?

Your answer

How long are you hoping to keep the vehicle before selling? Would you buy another in future? *

Your answer

What is your NIC? (Required to identify unique answers and to avoid repetition) *

Your answer

Any further comments?

Your answer

SUBMIT

Never submit passwords through Google Forms.

Appendix – D EV No.1 SOC change under 20 scenarios

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
18:00																				
18:30																				
19:00																				
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21:00																				
21:30																				
22:00																				
22:30	40	25	20	25	20	25	0	10	25	20	10	20	20	20	5	20	30	10	20	10
23:00	47.14	32.14	27.14	32.14	27.14	32.14	7.14	17.14	32.14	27.14	17.14	27.14	27.14	27.14	12.14	27.14	37.14	17.14	27.14	17.14
23:30	54.28	39.28	34.28	39.28	34.28	39.28	14.28	24.28	39.28	34.28	24.28	34.28	34.28	34.28	19.28	34.28	44.28	24.28	34.28	24.28
0:00	61.42	46.42	41.42	46.42	41.42	46.42	21.42	31.42	46.42	41.42	31.42	41.42	41.42	41.42	26.42	41.42	51.42	31.42	41.42	31.42
0:30	68.56	53.56	48.56	53.56	48.56	53.56	28.56	38.56	53.56	48.56	38.56	48.56	48.56	48.56	33.56	48.56	58.56	38.56	48.56	38.56
1:00	75.7	60.7	55.7	60.7	55.7	60.7	35.7	45.7	60.7	55.7	45.7	55.7	55.7	55.7	40.7	55.7	65.7	45.7	55.7	45.7
1:30	82.84	67.84	62.84	67.84	62.84	67.84	42.84	52.84	67.84	62.84	52.84	62.84	62.84	62.84	47.84	62.84	72.84	52.84	62.84	52.84
2:00	89.98	74.98	69.98	74.98	69.98	74.98	49.98	59.98	74.98	69.98	59.98	69.98	69.98	69.98	54.98	69.98	79.98	59.98	69.98	59.98
2:30	97.12	82.12	77.12	82.12	77.12	82.12	57.12	67.12	82.12	77.12	67.12	77.12	77.12	77.12	62.12	77.12	87.12	67.12	77.12	67.12
3:00	100	89.26	84.26	89.26	84.26	89.26	64.26	74.26	89.26	84.26	74.26	84.26	84.26	84.26	69.26	84.26	94.26	74.26	84.26	74.26
3:30	100	96.4	91.4	96.4	91.4	96.4	71.4	81.4	96.4	91.4	81.4	91.4	91.4	91.4	76.4	91.4	100	81.4	91.4	81.4
4:00	100	100	98.54	100	98.54	100	78.54	88.54	100	98.54	88.54	98.54	98.54	98.54	83.54	98.54	100	88.54	98.54	88.54
4:30	100	100	100	100	100	100	85.68	95.68	100	100	95.68	100	100	100	90.68	100	100	95.68	100	95.68
5:00	100	100	100	100	100	100	92.82	100	100	100	100	100	100	100	97.82	100	100	100	100	100
5:30	100	100	100	100	100	100	99.96	100	100	100	100	100	100	100	100	100	100	100	100	100
6:00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
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Appendix – E EV No.2 SOC change under 20 scenarios

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22:00	10	50	30	20	5	40	25	25	20	5	40	70	25	20	60	30	60	20	40	10
22:30	17.14	57.14	37.14	27.14	12.14	47.14	32.14	32.14	27.14	12.14	47.14	77.14	32.14	27.14	67.14	37.14	67.14	27.14	47.14	17.14
23:00	24.28	64.28	44.28	34.28	19.28	54.28	39.28	39.28	34.28	19.28	54.28	84.28	39.28	34.28	74.28	44.28	74.28	34.28	54.28	24.28
23:30	31.42	71.42	51.42	41.42	26.42	61.42	46.42	46.42	41.42	26.42	61.42	91.42	46.42	41.42	81.42	51.42	81.42	41.42	61.42	31.42
0:00	38.56	78.56	58.56	48.56	33.56	68.56	53.56	53.56	48.56	33.56	68.56	98.56	53.56	48.56	88.56	58.56	88.56	48.56	68.56	38.56
0:30	45.7	85.7	65.7	55.7	40.7	75.7	60.7	60.7	55.7	40.7	75.7	100	60.7	55.7	95.7	65.7	95.7	55.7	75.7	45.7
1:00	52.84	92.84	72.84	62.84	47.84	82.84	67.84	67.84	62.84	47.84	82.84	100	67.84	62.84	100	72.84	100	62.84	82.84	52.84
1:30	59.98	99.98	79.98	69.98	54.98	89.98	74.98	74.98	69.98	54.98	89.98	100	74.98	69.98	100	79.98	100	69.98	89.98	59.98
2:00	67.12	100	87.12	77.12	62.12	97.12	82.12	82.12	77.12	62.12	97.12	100	82.12	77.12	100	87.12	100	77.12	97.12	67.12
2:30	74.26	100	94.26	84.26	69.26	100	89.26	89.26	84.26	69.26	100	100	89.26	84.26	100	94.26	100	84.26	100	74.26
3:00	81.4	100	100	91.4	76.4	100	96.4	96.4	91.4	76.4	100	100	96.4	91.4	100	100	100	91.4	100	81.4
3:30	88.54	100	100	98.54	83.54	100	100	100	98.54	83.54	100	100	100	98.54	100	100	100	98.54	100	88.54
4:00	95.68	100	100	100	90.68	100	100	100	100	90.68	100	100	100	100	100	100	100	100	100	95.68
4:30	100	100	100	100	97.82	100	100	100	100	97.82	100	100	100	100	100	100	100	100	100	100
5:00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
5:30	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
6:00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
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Appendix – F EV No.3 SOC change under 20 scenarios

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22:30	20	25	5	70	10	40	60	25	25	25	20	0	60	20	10	20	25	30	20	25
23:00	27.14	32.14	12.14	77.14	17.14	47.14	67.14	32.14	32.14	32.14	27.14	7.14	67.14	27.14	17.14	27.14	32.14	37.14	27.14	32.14
23:30	34.28	39.28	19.28	84.28	24.28	54.28	74.28	39.28	39.28	39.28	34.28	14.28	74.28	34.28	24.28	34.28	39.28	44.28	34.28	39.28
0:00	41.42	46.42	26.42	91.42	31.42	61.42	81.42	46.42	46.42	46.42	41.42	21.42	81.42	41.42	31.42	41.42	46.42	51.42	41.42	46.42
0:30	48.56	53.56	33.56	98.56	38.56	68.56	88.56	53.56	53.56	53.56	48.56	28.56	88.56	48.56	38.56	48.56	53.56	58.56	48.56	53.56
1:00	55.7	60.7	40.7	100	45.7	75.7	95.7	60.7	60.7	60.7	55.7	35.7	95.7	55.7	45.7	55.7	60.7	65.7	55.7	60.7
1:30	62.84	67.84	47.84	100	52.84	82.84	100	67.84	67.84	67.84	62.84	42.84	100	62.84	52.84	62.84	67.84	72.84	62.84	67.84
2:00	69.98	74.98	54.98	100	59.98	89.98	100	74.98	74.98	74.98	69.98	49.98	100	69.98	59.98	69.98	74.98	79.98	69.98	74.98
2:30	77.12	82.12	62.12	100	67.12	97.12	100	82.12	82.12	82.12	77.12	57.12	100	77.12	67.12	77.12	82.12	87.12	77.12	82.12
3:00	84.26	89.26	69.26	100	74.26	100	100	89.26	89.26	89.26	84.26	64.26	100	84.26	74.26	84.26	89.26	94.26	84.26	89.26
3:30	91.4	96.4	76.4	100	81.4	100	100	96.4	96.4	96.4	91.4	71.4	100	91.4	81.4	91.4	96.4	100	91.4	96.4
4:00	98.54	100	83.54	100	88.54	100	100	100	100	100	98.54	78.54	100	98.54	88.54	98.54	100	100	98.54	100
4:30	100	100	90.68	100	95.68	100	100	100	100	100	100	85.68	100	100	95.68	100	100	100	100	100
5:00	100	100	97.82	100	100	100	100	100	100	100	100	92.82	100	100	100	100	100	100	100	100
5:30	100	100	100	100	100	100	100	100	100	100	100	99.96	100	100	100	100	100	100	100	100
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Appendix – G EV No.4 SOC change under 20 scenarios

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22:00	20	20	25	25	20	30	10	25	20	25	0	10	10	20	20	25	30	20	10	60
22:30	27.14	27.14	32.14	32.14	27.14	37.14	17.14	32.14	27.14	32.14	7.14	17.14	17.14	27.14	27.14	32.14	37.14	27.14	17.14	67.14
23:00	34.28	34.28	39.28	39.28	34.28	44.28	24.28	39.28	34.28	39.28	14.28	24.28	24.28	34.28	34.28	39.28	44.28	34.28	24.28	74.28
23:30	41.42	41.42	46.42	46.42	41.42	51.42	31.42	46.42	41.42	46.42	21.42	31.42	31.42	41.42	41.42	46.42	51.42	41.42	31.42	81.42
0:00	48.56	48.56	53.56	53.56	48.56	58.56	38.56	53.56	48.56	53.56	28.56	38.56	38.56	48.56	48.56	53.56	58.56	48.56	38.56	88.56
0:30	55.7	55.7	60.7	60.7	55.7	65.7	45.7	60.7	55.7	60.7	35.7	45.7	45.7	55.7	55.7	60.7	65.7	55.7	45.7	95.7
1:00	62.84	62.84	67.84	67.84	62.84	72.84	52.84	67.84	62.84	67.84	42.84	52.84	52.84	62.84	62.84	67.84	72.84	62.84	52.84	100
1:30	69.98	69.98	74.98	74.98	69.98	79.98	59.98	74.98	69.98	74.98	49.98	59.98	59.98	69.98	69.98	74.98	79.98	69.98	59.98	100
2:00	77.12	77.12	82.12	82.12	77.12	87.12	67.12	82.12	77.12	82.12	57.12	67.12	67.12	77.12	77.12	82.12	87.12	77.12	67.12	100
2:30	84.26	84.26	89.26	89.26	84.26	94.26	74.26	89.26	84.26	89.26	64.26	74.26	74.26	84.26	84.26	89.26	94.26	84.26	74.26	100
3:00	91.4	91.4	96.4	96.4	91.4	100	81.4	96.4	91.4	96.4	71.4	81.4	81.4	91.4	91.4	96.4	100	91.4	81.4	100
3:30	98.54	98.54	100	100	98.54	100	88.54	100	98.54	100	78.54	88.54	88.54	98.54	98.54	100	100	98.54	88.54	100
4:00	100	100	100	100	100	100	95.68	100	100	100	85.68	95.68	95.68	100	100	100	100	100	95.68	100
4:30	100	100	100	100	100	100	100	100	100	100	92.82	100	100	100	100	100	100	100	100	100
5:00	100	100	100	100	100	100	100	100	100	100	99.96	100	100	100	100	100	100	100	100	100
5:30	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
6:00	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
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Appendix – H SOC of 35 No’s of EVs randomised and reassigned to each other to investigate 20 scenarios

				Iter 1	Iter 2	Iter 3	Iter 4	Iter 5	Iter 6	Iter 7	Iter 8	Iter 9	Iter 10	Iter 11	Iter 12	Iter 13	Iter 14	Iter 15	Iter 16	Iter 17	Iter 18	Iter 19	Iter 20
Car1	1	22:30	0.9375	40	25	20	25	20	25	0	10	25	20	10	20	20	20	5	20	30	10	20	10
Car2	2	22:00	0.916667	10	50	30	20	5	40	25	25	20	5	40	70	25	20	60	30	60	20	40	10
Car3	3	22:30	0.9375	20	25	5	70	10	40	60	25	25	25	20	0	60	20	10	20	25	30	20	25
Car4	4	22:00	0.916667	20	20	25	25	20	30	10	25	20	25	0	10	10	20	20	25	30	20	10	60
Car5	5	22:00	0.916667	10	0	25	10	25	20	10	40	20	0	40	20	25	10	50	20	20	30	30	25
Car6	6	22:30	0.9375	25	10	20	10	20	0	40	0	10	50	10	20	25	25	20	25	5	60	40	20
Car7	7	19:00	0.791667	70	20	50	50	60	50	20	10	25	30	10	60	20	0	20	10	0	10	10	20
Car8	8	22:30	0.9375	10	0	40	30	10	10	20	40	10	50	20	10	50	25	0	20	25	5	5	20
Car9	9	19:00	0.791667	30	10	25	10	40	25	30	20	30	20	50	20	20	10	10	0	20	20	60	10
Car10	10	23:00	0.958333	40	40	25	40	25	30	70	40	25	10	10	20	10	50	70	5	30	40	25	20
Car11	11	23:30	0.979167	10	50	40	60	20	20	25	10	10	30	5	25	40	60	25	70	20	20	50	30
Car12	12	21:00	0.875	30	10	25	20	25	40	5	25	50	20	25	0	30	20	10	40	20	50	70	40
Car13	13	10:00	0.416667	25	25	10	25	25	20	20	25	0	10	20	25	30	70	20	10	0	20	10	10
Car14	14	0:30	0.020833	20	20	50	40	40	5	25	20	20	40	40	30	20	20	30	60	20	40	20	25
Car15	15	23:00	0.958333	30	25	20	20	25	50	20	10	40	0	60	10	0	30	25	0	10	20	30	40
Car16	16	23:30	0.979167	10	30	20	0	50	20	20	5	70	40	40	5	10	20	40	30	50	25	10	20
Car17	17	23:30	0.979167	50	70	20	40	30	10	40	50	50	20	0	50	50	50	10	40	10	10	25	20
Car18	18	21:30	0.895833	10	20	30	20	40	10	0	40	40	60	70	30	40	10	50	40	25	40	0	20
Car19	19	22:00	0.916667	20	40	20	50	20	50	50	20	25	25	10	10	10	10	0	50	40	0	0	30
Car20	20	21:00	0.875	25	10	10	25	40	25	20	60	50	25	10	50	0	20	10	25	10	50	30	25
Car21	21	22:30	0.9375	25	50	70	25	10	20	25	25	20	10	20	30	5	40	20	20	20	50	50	10
Car22	22	22:30	0.9375	20	30	10	20	0	20	10	10	10	40	20	20	70	25	40	40	20	25	10	40
Car23	23	23:30	0.979167	20	10	10	40	10	60	20	70	60	20	50	50	40	40	25	10	20	30	20	40
Car24	24	23:30	0.979167	40	20	60	10	50	25	30	30	5	10	25	20	10	50	40	50	10	40	20	50
Car25	25	21:00	0.875	0	5	10	20	70	10	10	20	20	20	50	20	25	25	50	25	50	25	20	30
Car26	26	20:00	0.833333	50	10	40	20	25	10	50	0	10	40	25	25	10	10	10	10	50	25	10	50
Car27	27	18:00	0.75	50	40	0	5	10	40	40	20	20	10	20	25	50	25	40	25	40	20	25	20
Car28	28	21:00	0.875	25	20	10	25	30	20	10	50	30	20	20	10	20	40	25	10	70	70	25	10
Car29	29	23:00	0.958333	5	20	50	20	10	20	20	20	0	25	30	10	30	40	20	30	40	10	20	50
Car30	30	22:00	0.916667	0	40	0	30	20	30	25	20	40	30	20	25	20	0	25	25	25	25	25	0
Car31	31	22:00	0.916667	40	30	40	50	30	0	25	30	25	70	30	40	25	30	25	20	10	25	50	0
Car32	32	23:00	0.958333	60	25	20	0	20	25	50	30	40	10	25	40	25	5	30	20	10	20	25	25
Car33	33	22:30	0.9375	25	25	20	10	20	70	40	50	10	50	30	25	20	10	30	10	40	10	40	5
Car34	34	22:00	0.916667	20	60	25	10	50	25	10	20	30	25	25	40	20	30	20	20	25	0	40	70
Car35	35	23:00	0.958333	20	20	30	30	0	10	30	10	20	20	25	40	40	25	20	50	25	10	20	25

Appendix – I Effective combined result for SOC around the clock

		1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	Average	Effect. Car	Energy kWh	kW	Realistic	Prob kW	Normal Skew
1	18:00	50	40	0	5	10	40	40	20	20	10	20	25	50	25	40	25	40	20	25	20	26.25	0.2625	6.3	0.86625	0.86625	0.0075	0.033553223
2	18:30	57.14	47.14	7.14	12.14	17.14	47.14	47.14	27.14	27.14	17.14	27.14	32.14	57.14	32.14	47.14	32.14	47.14	27.14	32.14	27.14	33.39	0.3339	8.0136	1.10187	1.10187	0.00954	0.044173799
3	19:00	164.28	84.28	89.28	79.28	124.28	129.28	104.28	64.28	89.28	74.28	94.28	119.28	104.28	49.28	84.28	49.28	74.28	64.28	109.28	64.28	90.78	0.9078	21.7872	2.99574	2.99574	0.025937	0.057474246
4	19:30	185.7	105.7	110.7	100.7	145.7	150.7	125.7	85.7	110.7	95.7	115.7	140.7	125.7	70.7	105.7	70.7	95.7	85.7	130.7	85.7	112.2	1.122	26.928	3.7026	3.7026	0.032057	0.073902619
5	20:00	257.12	137.12	172.12	142.12	192.12	182.12	197.12	107.12	142.12	157.12	162.12	187.12	157.12	102.12	137.12	102.12	167.12	132.12	162.12	157.12	157.62	1.5762	37.8288	5.20146	5.20146	0.045034	0.093912715
6	20:30	285.68	165.68	200.68	170.68	220.68	210.68	225.68	135.68	170.68	185.68	190.68	215.68	185.68	130.68	165.68	130.68	195.68	160.68	190.68	185.68	186.18	1.8618	44.6832	6.14394	6.14394	0.053194	0.117941592
7	21:00	394.24	239.24	284.24	289.24	414.24	334.24	299.24	319.24	349.24	299.24	324.24	324.24	289.24	264.24	289.24	259.24	374.24	384.24	364.24	319.24	320.74	3.2074	76.9776	10.58442	10.58442	0.09164	0.146381973
8	21:30	455.66	316.36	371.36	366.36	511.36	401.36	356.36	416.36	446.36	416.36	451.36	411.36	386.36	331.36	396.36	356.36	456.36	481.36	421.36	396.36	407.325	4.07325	97.758	13.44173	13.44173	0.116379	0.179550338
9	22:00	625.66	620.62	600.62	625.62	742.78	660.62	575.62	660.62	690.62	660.62	680.62	687.78	578.5	515.62	660.62	610.62	730.62	665.62	677.78	655.62	646.34	6.4634	155.1216	21.32922	21.32922	0.184669	0.21765211
10	22:30	890.62	895.6	899.86	929.86	939.88	955.6	880.6	934.86	914.86	1019.86	924.86	919.88	935.6	794.86	895.6	879.86	1005.6	969.86	969.88	899.86	922.873	9.22873	221.4895	30.45481	30.45481	0.263678	0.260745941
11	23:00	1215.56	1192.68	1211.96	1236.96	1186.96	1300.56	1247.68	1279.08	1264.08	1269.08	1281.96	1246.96	1237.68	1149.08	1242.68	1159.08	1297.68	1264.08	1266.96	1264.08	1240.742	12.40742	297.7781	40.94449	40.94449	0.354498	0.308709683
12	23:30	1318.36	1418.36	1361.9	1376.9	1351.94	1408.36	1378.36	1456.9	1456.9	1391.9	1402.64	1368.36	1403.36	1408.36	1413.36	1418.36	1417.66	1411.2	1428.4	1406.9	1399.924	13.99924	335.9818	46.19749	46.19749	0.399978	0.361211001
13	0:00	1531.16	1632.56	1583.24	1598.24	1559	1622.56	1591.16	1669.72	1671.16	1613.24	1605.46	1582.56	1617.56	1622.56	1627.56	1632.56	1624.72	1619.72	1628.32	1622.56	1612.781	16.12781	387.0674	53.22177	53.22177	0.460795	0.417685796
14	0:30	1758.22	1866.76	1851.04	1859.58	1803.24	1838.22	1823.22	1896.78	1898.22	1863.22	1845.38	1821.06	1851.76	1856.76	1871.76	1906.76	1851.78	1866.78	1848.24	1856.06	1851.742	18.51742	444.4181	61.10749	61.10749	0.529069	0.477327511
15	1:00	1972.42	2085.26	2066.68	2077.4	2010.3	2046.72	2037.42	2098.18	2098.18	2064.6	2045.32	2022.46	2061.72	2078.1	2083.14	2128.1	2050.34	2061.06	2055.3	2067.42	2060.506	20.60506	494.5214	67.9967	67.9967	0.588716	0.539089962
16	1:30	2186.62	2296.64	2273.78	2288.78	2213.1	2249.52	2243.08	2292.4	2298.1	2264.52	2245.24	2222.38	2265.94	2292.36	2274.56	2345.18	2243.12	2251	2262.36	2267.4	2263.804	22.63804	543.313	74.70553	74.70553	0.646801	0.601705566
17	2:00	2396.58	2490.88	2480.84	2481.6	2400.24	2439.48	2435.88	2480.92	2483.82	2464.44	2442.32	2422.3	2460.2	2499.42	2453.08	2542.3	2435.9	2432.38	2460.9	2458.78	2458.113	24.58113	589.9471	81.11773	81.11773	0.702318	0.663719248
18	2:30	2585.16	2668.02	2675.86	2664.46	2575.2	2617.32	2628.66	2651.64	2650.92	2639.46	2623.04	2612.3	2635.18	2700.1	2628.04	2720.9	2624.42	2600.22	2634.5	2640.88	2638.814	26.38814	633.3154	87.08086	87.08086	0.753947	0.723529156
19	3:00	2668	2732.3	2750.18	2723.06	2653.76	2668.82	2700.12	2713.12	2711.66	2691.72	2698.8	2696.6	2719.46	2785.94	2723.74	2779.48	2695.18	2691.64	2711.72	2706.6	2711.095	27.11095	650.6628	89.46614	89.46614	0.774599	0.779345558
20	3:30	2724.44	2765.28	2781.04	2757.46	2711.66	2706.72	2751.68	2733.92	2743.88	2731.76	2742.44	2730.28	2773.88	2805.98	2775.3	2818.16	2738.18	2728.84	2729.58	2754.6	2750.254	27.50254	660.061	90.75838	90.75838	0.785787	0.828515974
21	4:00	2770.34	2788.28	2782.5	2759.7	2738.84	2752.54	2787.46	2747.6	2756.88	2741.08	2755.36	2755.32	2790.44	2824.04	2788.28	2799.02	2761.14	2739.68	2772.44	2783.18	2769.706	27.69706	664.7294	91.4003	91.4003	0.791345	0.86432954
22	4:30	2831.92	2851.2	2847.6	2819.78	2820.42	2821.86	2864.74	2810.46	2817.6	2816.14	2816.92	2821.18	2829.88	2863.44	2846.92	2844.84	2820.5	2818.22	2851.14	2853.34	2833.405	28.33405	680.0172	93.50237	93.50237	0.809544	0.868458813
23	5:00	2767.72	2787	2790.54	2752.76	2775.58	2774.08	2791.36	2756.26	2757.76	2764.08	2757.72	2766.26	2758.44	2789.18	2779.18	2772.04	2764.8	2776.22	2784.9	2794.82	2773.035	27.73035	665.5284	91.51016	91.51016	0.792296	0.807202338
24	5:30	2493.5	2499.96	2500	2474.18	2492.82	2495.64	2499.96	2490.64	2483.5	2488.5	2485.68	2490.64	2484.18	2497.82	2495.64	2490.64	2491.36	2495.68	2495.68	2500	2492.301	24.92301	598.1522	82.24593	82.24593	0.712086	0.65405814
25	6:00	1600	1600	1600	1599.96	1600	1600	1600	1600	1599.96	1599.96	1592.82	1600	1599.96	1600	1600	1599.96	1600	1600	1600	1600	1599.631	15.99631	383.9114	52.78782	52.78782	0.457037	0.433743661
26	6:30	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	6	144	19.8	19.8	0.171429	0.223238396
27	7:00	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	4	96	13.2	13.2	0.114286	0.085788685
28	7:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.023978636
29	8:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004790633
30	8:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.000676225
31	9:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.69096E-05
32	9:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.61523E-06
33	10:00	25	25	10	25	25	20	20	25	0	10	20	25	30	70	20	10	0	20	10	10	20	0.2	4.8	0.66	0	0	2.21053E-07
34	10:30	32.14	32.14	17.14	32.14	32.14	27.14	27.14	32.14	7.14	17.14	27.14	32.14	37.14	77.14	27.14	17.14	7.14	27.14	17.14	17.14	27.14	0.2714	6.5136	0.89562	0	0	7.33071E-09
35	11:00	39.28	39.28	24.28	39.28	39.28	34.28	34.28	39.28	14.28	24.28	34.28	39.28	44.28	84.28	34.28	24.28	14.28	34.28	24.28	24.28	34.28	0.3428	8.2272	1.13124	0	0	1.67958E-10
36	11:30	46.42	46.42	31.42	46.42	46.42	41.42	41.42	46.42	21.42	31.42	41.42	46.42	51.42	91.42	41.42	31.42	21.42	41.42	31.42	31.42	41.42	0.4142	9.9408	1.36686	0	0	2.65427E-12
37	12:00	53.56	53.56	38.56	53.56	53.56	48.56	48.56	53.56	28.56	38.56	48.56	53.56	58.56	98.56	48.56	38.56	28.56	48.56	38.56	38.56	48.56	0.4856	11.6544	1.60248	0	0	2.88947E-14
38	12:30	60.7	60.7	45.7	60.7	60.7	55.7	55.7	60.7	35.7	45.7	55.7	60.7	65.7	100	55.7	45.7	35.7	55.7	45.7	45.7	55.415	0.55415	13.2996	1.828695	0	0	2.16459E-16
39	13:00	67.84	67.84	52.84	67.84	67.84	62.84	62.84	67.84	42.84	52.84	62.84	67.84	72.84	100	62.84	52.84	42.84	62.84	52.84	52.84	62.198	0.62198	14.92752	2.052534	0	0	1.11496E-18
40	13:30	74.98	74.98	59.98	74.98	74.98	69.98	69.98	74.98	49.98	59.98	69.98	74.98	79.98	100	69.98	59.98	49.98	69.98	59.98	59.98	68.981	0.68981	16.55544	2.276373	0	0	3.94622E-21
41	14:00	82.12	82.12	67.12	82.12	82.12	77.12	77.12	82.12	57.12	67.12	77.12	82.12	87.12	100	77.12	67.12	57.12	77.12	67.12	67.12	75.764	0.75764	18.18336	2.500212	0	0	9.59181E-24
42	14:30	89.26	89.26	74.26	89.26	89.26	84.26	84.26	89.26	64.26	74.26	84.26	89.26	94.26	100	84.26	74.26	64.26	84.26	74.26	74.26	82.547	0.82547	19.81128	2.724051	0	0	1.60036E-26
43	15:00	96.4	96.4	81.4	96.4	96.4	91.4	91.4	96.4	71.4	81.4	91.4	96.4	100	100	91.4	81.4	71.4	91.4	81.4	81.4	89.26	0.8926	21.4224	2.94558	0	0	1.83215E-29
44	15:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.43877E-32
45	16:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.74794E-36
46	16:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.86048E-39
47	17:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.23867E-43
48	17:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.25535E-46

Appendix – J **Request letter to Department of Motor Traffic to obtain EV registration details (Scanned copy)**

විදුලි ඉංජිනේරු විද්‍යා අංශය
DEPARMENT OF ELECTRICAL ENGINEERING
මොරටුව විශ්වවිද්‍යාලය, මොරටුව
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Dr. Asanka S. Rodrigo, Senior Lecturer in Electrical Engineering email: *asanka@elect.mrt.ac.lk*

Your Ref: Our Ref: 20th July, 2017

Administrative Officer,
Department of Motor Traffic,
No. 341, Alvitigala Mawatha,
Colombo 05

Requesting Information Regarding Registration of Electric and Plug-in Hybrid Vehicles

The bearer of this letter, Mr.L.S.N.Bambarawane (871480230V) is currently carrying out a research on "Implementation of a Plugin Electric Vehicle Based Energy Storage" under my supervision, for his Master of Science degree at University of Moratuwa.

He needs monthly records of new registration of electric vehicles and plugin hybrid vehicles from January, 2005. Moreover, total number of cars of each manufacturer belonging to the categories of electric vehicles and plugin hybrid vehicles is also required. Kindly make arrangements to release the information he requires.

I confirm that this information is used for academic purpose only.

Your cooperation in this regard is highly appreciated.

Yours faithfully,

Department of Electrical Engineering
University of Moratuwa,
Sri Lanka

Dr. Asanka S. Rodrigo,
Senior Lecturer,
Department of Electrical Engineering
University of Moratuwa, Sri Lanka