INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN ECONOMICS & MANAGEMENT SCIENCES

OPEN ACCESS JOURNAL

Vol 12, Issue 2, (2023) E-ISSN: 2226-3624

Technoeconomic Assessment of Electric Vehicles for Optimal Microgrid Energy System Planning

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To Link this Article: http://dx.doi.org/10.6007/IJAREMS/v12-i2/18380 DOI:10.6007/IJAREMS/v12-i2/18380

Published Online: 16 August 2023

Abstract

Microgrids are well-known for their dependability, sturdiness, and capacity to incorporate renewable energy sources. Due to fuel depletion and environmental concerns, the hybrid electric vehicle (HEV) might revolutionise personal and public transportation. Due to the rising number of EVs, the electrical system vulnerable to an increase in generation and load that might generate an imbalance. Malaysia lacks a complete energy analysis of a microgrid in the presence of electric vehicles with demand response strategy in commercial and industrial enterprises. This project aims to develop a simulation model using hybrid optimization of multiple energy resources (HOMER) software to analyze the optimum energy system planning of electric cars in a microgrid and to examine the operational management strategy of electric vehicle with demand response. Given the contribution of inelastic loads to this microgrid, demand side management (DSM) has been implemented to control these loads. The DSM issue has been addressed using demand response (DR) program in HOMER Grid considering enhanced time of use (ETOU) of the grid. Simulations using the HOMER Grid programme are run to determine the optimal energy planning for a microgrid system at UiTM Shah Alam when electric vehicles are presented. The value of simulation when DSM has been implemented will bring smaller value of LCOE, smaller carbon emission and reduction in energy demand and the price-based DSM helps in achieving the objective of this project.

Keywords: Energy Planning, Residential Microgrid, Electric Vehicle (EV), HOMER Software, Demand Side Management (DSM).

Introduction

The automobile sector has grown to be one of the most significant industries in the world, not just economically, but also in terms of research and development. More technology aspects are being implemented on automobiles to increase the safety of both passengers and pedestrians. Furthermore, there are more automobiles on the highways, allowing us to travel quickly and pleasantly. However, this has resulted in a significant increase in air pollution

levels in metropolitan areas. Malaysia's carbon dioxide emissions have been rising year after year, accounting for 0.36 percent of world carbon dioxide (CO2) emissions (Richie et al., 2020). Road transport accounts for three-quarters of all greenhouse gas emissions (Commisison, 2023). The most promising strategy to minimize this share is to replace internal combustion engines (ICE) in regular automobiles with electric vehicles (EV) and implementing technology such as microgrids (Bimenyimana et al., 2021).
EV use has skyrocketed in the last decade. Vehicle-to-grid (V2G) and grid-to-vehicle (G2V) schemes can utilize EVs as temporary energy storage systems (ESS) in numerous applications (AbuElrub et al., 2020; Hemmati & Mehrjerdi, 2020; Himabindu et al., 2021; Wang et al., 2018; Zhenwei et al., 2012). On the other hand, renewable energy resources have the potential to lower the quantity of energy utilized by the electrical grid. However, the widespread use of renewable distributed generator (DG) and electric vehicles (EVs) raises generation and load risks. Microgrid installation has been encouraged globally to address contemporary concerns of energy inequity and environmental difficulties (AbuElrub et al., 2020; Bimenyimana et al., 2021; Himabindu et al., 2021). This emphasizes the need of managing the supply demand situation in microgrid to maximize advantages to the microgrid operator and vehicle owners while without affecting technical aspects of the supply system and automobiles (AbuElrub et al., 2020; Bimenyimana et al., 2021; Gupta et al., 2022; Karfopoulos et al., 2011; Popescu, 2021).

The aims of the paper are listed as below

1. To design a simulation model in the hybrid optimization of multiple energy resources (HOMER) software to investigate the most effective way to plan the energy infrastructure for electric vehicles within a microgrid.
2. To analyse the operational management strategy for electric vehicles that integrates demand response.

The DSM problem has been solved by using an evolutionary-based optimization strategy. Energy planning for a microgrid at UiTM Shah Alam is optimised via simulations utilising the HOMER Grid application in the presence of EV.

Materials and Methods

Methodology

An overview of the project's workflow is shown in Figure 1. The first steps include literature reviews, statistical analysis, and data collection for the simulation. Building a model of HOMER is the next logical step. At that point, the model was assessed to see whether it successfully achieves the project's goal. The performance of all EV presence instances was then thoroughly analysed thereafter. In addition, the total savings of money and time also have been examined.

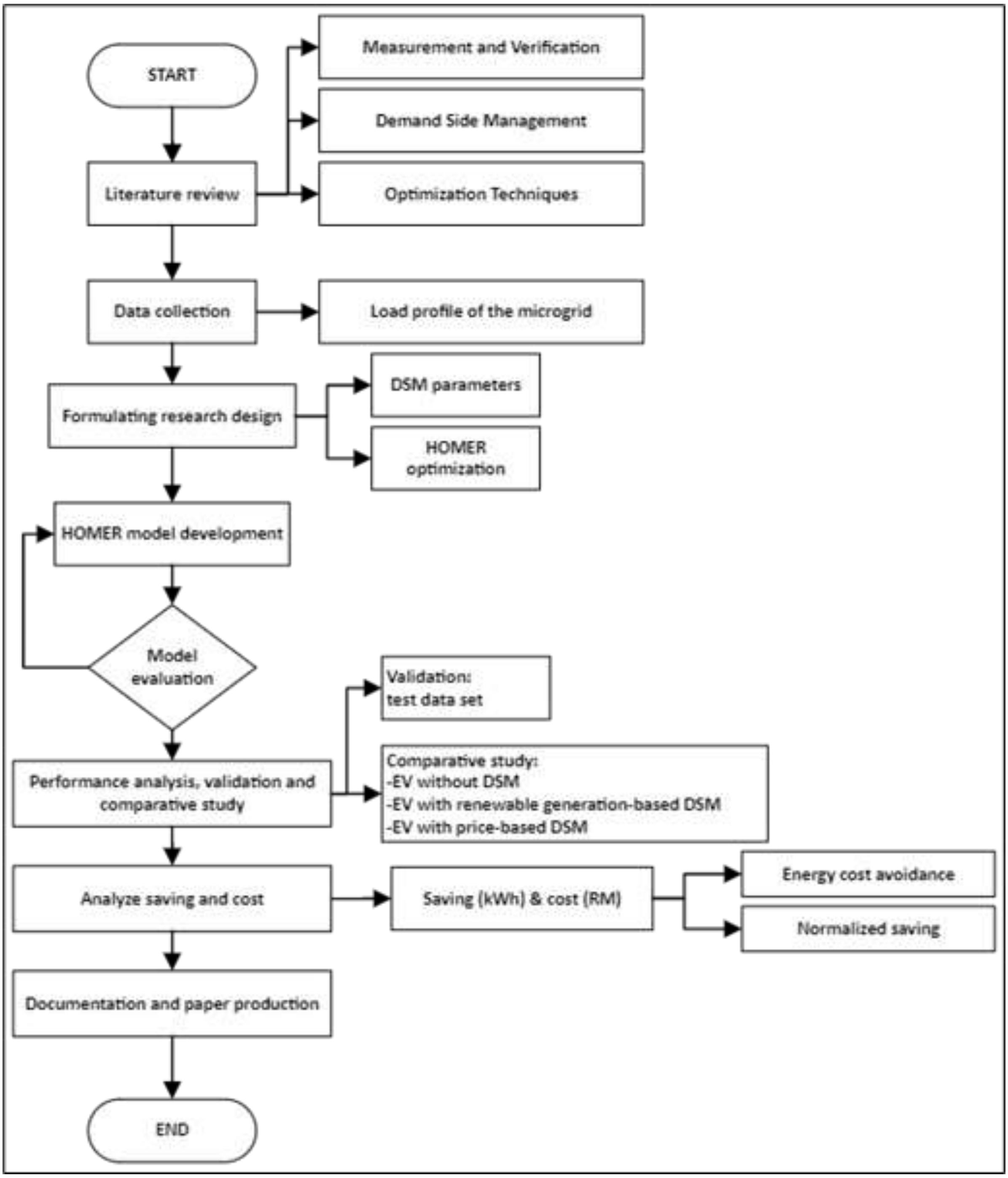

Figure 1: Flowchart of the project

Descriptions of Microgrid System

Smart microgrids have advanced metering infrastructure (AMI) placed on the consumer side, which is capable of transmitting information about a customer's load profile to the power supplier. The data produced by this AMI is used by the provider to schedule the elastic loads for DSM. The following are the presumptions:

i) Each household, business, and electric car charging station in this microgrid has an AMI facility, which provides customers with dynamic pricing information.
ii) The AMI system gives the provider access to the loads.

Descriptions of Standalone Microgrid of Proposed Work

In this work, the microgrid has been taken as a standalone system for UiTM Shah Alam as shown in Figure 2.

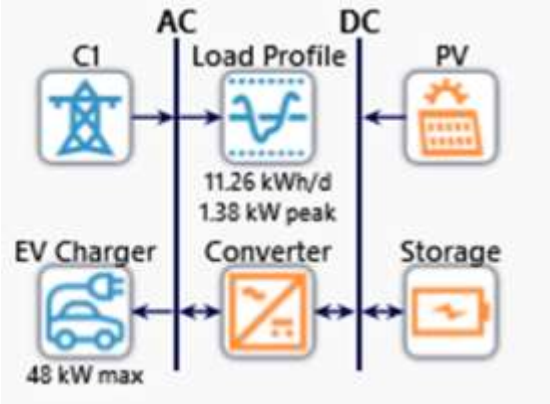

Figure 2: Standalone microgrid of the proposed work

In this microgrid, PV generation is considered a renewable resource. Additionally, a dispatchable diesel generator has been installed as a standby power supply. The battery energy storage is used to store excess renewable energy and provide service to clients when the renewable energy supply is not enough. DC electricity is generated by PV units, but AC power is required to charge batteries. As a result, all electricity must be transformed into AC before it can be used by the consumers. In such case a converter is used to transform AC electricity into direct current (DC).

Optimization of Microgrid System

The HOMER (Hybrid Optimization of Multiple Energy Resources) software was utilized to conduct the study in this paper. The National Renewable Energy Laboratory (NREL) in the United States created HOMER, an open access software application. This software application is used to develop and analyze off-grid and on-grid power systems for remote, stand-alone, and distributed generating applications from a technical and economic standpoint. It enables users to explore a wide range of technological solutions while taking into consideration energy resource availability and other factors (Software, 2014). The GSMA employs HOMER as one of its design tools for renewable energy base stations. It is also a great tool for extensive simulation of demands (hourly, daily, monthly, and annual scenarios), cost-effective optimization, and sensitivity analysis (Bimenyimana et al., 2021).

From utility-scale and distributed generation to stand-alone microgrids, HOMER has created a suite of tools to maximize the ROI of your hybrid power system. Both HOMER Pro and HOMER Grid fall under this category. The modelling capabilities of HOMER Pro for distributed generation are extensive, making it an ideal analogue to the Swiss Army knife. Microgrids and multi-generator island/village utilities are its core emphasis, although it can also mimic unstable grids, grid expansion, and other control systems. Minimizing demand and time of use charges for Behind-The-Meter projects, such as solar plus storage and more complicated systems like wind, backup generators, and combined heat and power, is a growing modelling problem that HOMER Pro cannot address.

DSM Modelling Technique

Optimization Techniques used for DSM

For economic operation, demand side management was used to regulate elastic loads while considering the contributions of inelastic loads connected with the microgrid. The authors of (Pal et al., 2020) used DSM principles to create a smart independent microgrid system. DSM's capability is required to achieve a better balance between load and power generation in the microgrid. As an outcome, the cost of energy (COE) with DSM is significantly lower than without DSM, and price-weighted DSM performs better for microgrid design optimization.

However, the authors cautioned that, in terms of COE, a wind turbine is not suggested for their proposed work due to the high installation costs. Using Monte Carlo simulation, the authors suggested an optimum design in (Parashar et al., 2017). Particle swarm optimization (PSO), one of the DSM methods, is used to define and solve the issue. In (Awais et al., 2015), the authors utilized the DSM strategy by solving the load scheduling problem using genetic algorithm (GA) based on different load shifting techniques. The simulation results suggest that the proposed algorithm can cut expenditures while also lowering the smart grid's peak load demand based on load shifting technique. In (Zhang et al., 2022), authors proposed MGSA-PSO algorithm aims to optimize the load dispatch of the microgrid with EVs. The results shows that this technique can reduce operating costs and improve grid stability.

Mathematical Solutions for DSM

Objective Functions

The objective of the DSM program is to schedule the elastic loads for minimizing the total tariff of the customers in 24 hours. So, the mathematical expression of the objective function (Pal et al., 2020) can be represented as below:

$$min(f) = \sum_{t=1}^{24} Tr^{(t)} * \left(eL^{(t)} + inL^{(t)}\right) \qquad \textbf{(1)}$$

where f is the objective function to be minimized, t is the 1-hour time slot of 24 hours, $Tr^{(t)}$ is the price weight/reverse renewable weight at t^{th} hour. $eL^{(t)}$ and $inL^{(t)}$ are the elastic load and inelastic load respectively at t^{th} hour.

Optimization Cost

The optimization cost focus on levelized cost of energy (COE) and net present cost (NPC). The COE is a convenient metric with which to compare systems. So, the mathematical expression can be expressed below in (2). The total NPC is HOMER's main economic output, the value by which it ranks all system configurations in the optimization results, and the basis from which it calculates the total annualized cost and the levelized cost of energy (LLC, 2017). The mathematical expression is expressed in (3).

$$COE = \frac{C_{ann,tot} - c_{boiler} * H_{served}}{E_{served}} \qquad \textbf{(2)}$$

where $C_{ann,tot}$ is the total annualized cost of the system, c_{boiler} is the boiler marginal cost, H_{served} is the total thermal load served and E_{served} is the total electrical load served.

$$NPC = V_{cost,present} - V_{revenue,present} \qquad \textbf{(3)}$$

where $V_{cost,present}$ is the present value of all the costs the system incurs over its lifetime and $V_{revenue,present}$ is the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue.

Constraints

The total required energy in a day by the elastic loads should be fulfilled. The lower and upper limits should be maintained too to keep the load within peak supply capacity. So, the following constraints i.e., equality constraints (2) and inequality constraints (3) should be satisfied.

$$\sum_{t=1}^{24} eL^{(t)} = total_{eL} \qquad \textbf{(4)}$$

$$eL_{min} < eL^{(t)} < min\left(SC^{(t)} - inL^{(t)}, eL_{max}\right) \qquad \textbf{(5)}$$

where $total\_eL$ is the total energy required by the elastic loads in the microgrid, $SC^{(t)}$ is supply capacity of the microgrid system at t^{th} hour. eL_{min} and eL_{max} are lower and upper limits of the respective elastic loads.

Test Data

Input Data for Microgrid System

Project duration and cost: In HOMER, the overall project length is 25 years. The cost of capital, the cost of replacement, the cost of operation and maintenance (O&M), and the life expectancy of each component have all been included into HOMER to determine the best microgrid design. Table I contains the data that have been gathered so far.

Table 1
Data of power usage during testing

Component Name	Capital Cost (RM)	Replacement Cost (RM)	O&M Cost (RM)	Lifetime (Years)
Solar PV	3,470,000	3,470,000	3,000	25
Battery energy storage	6,500	6,500	0	10
Power converter	300	300	0	15

The load profile and PV/wind profile have to be provided additionally in HOMER as input data.

Load data: All loads, including residential, business, and EV charging station loads, have been categorised as AC loads. Figure 2 shows the monthly average of 24 hours of load for this project. An average of 24 hours of varying loads is shown in Figure 3. These are the initial load profiles before the DSM programme is implemented.

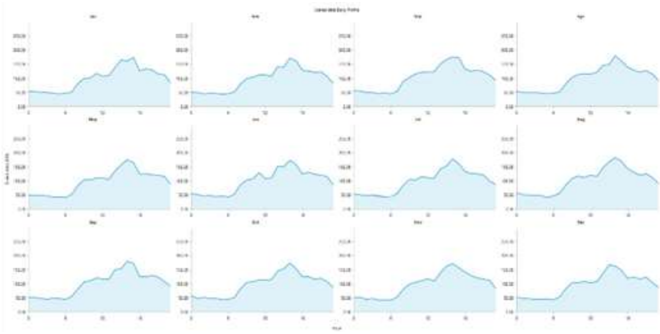

Figure 3: Monthly average of 24 hour profile of the total load

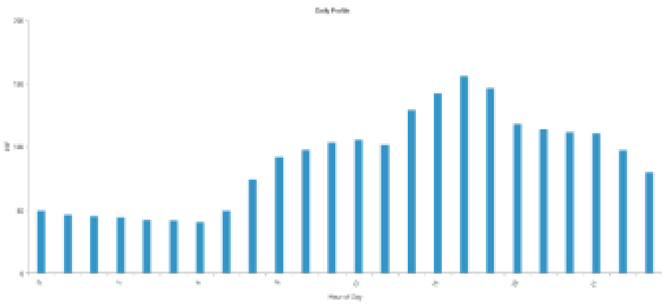

Figure 4: Daily average 24 hour load profile

PV power generation: Solar PV is renewable and non-dispatchable energy resources. The generation from renewable unit varies throughout the year Figure 4 represent the average monthly solar radiation which is considered for this work.

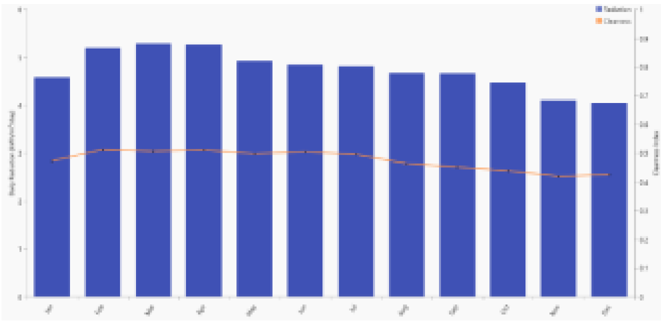

Figure 5: Average monthly solar radiation

Input Data for DSM

Two types of DSM techniques have been used in this work. The outcome results have been compared in the results and discussion section to check the robustness. The DSM techniques and its' input data have been presented below:

i) DSM with renewable coordination: Reverse PV profile in Demand Response Program has been used to schedule the elastic loads. With the present method, the elastic loads will be shifted to those slots when renewable power generation are available and match the load pattern with PV profile. The reverse PV profile that is used has been illustrated in Figure 6.

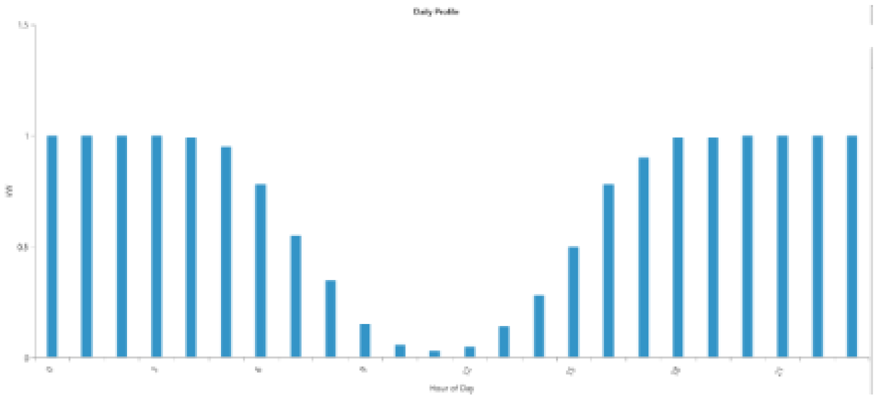

Figure 6: Hourly reverse renewable weight

ii) DSM with Dynamic Price: DSM needs to follow the dynamic price weight given by the utility company if the objective is to cut the peak load demand. Time of Use (TOU) tariff scheme offers different tariff rates at different times of the day (Berhad, 2023). For example, tariff rates during Off-Peak period and Mid-peak period will be lower than Peak period. Table II illustrates the Enhanced Time of Use (ETOU) time zones and Table III illustrates the price-based DSM program.

Table 2
ETOU Time Zones (Berhad, 2023)

	Enhanced Time of Use Time Zones
Time Zone	**Hours**
Mid-Peak	08:00 – 11:00 hours
Peak	11:00 – 12:00 hours
Mid-Peak	12:00 – 14:00 hours
Peak	14:00 – 17:00 hours
Mid-Peak	17:00 – 22:00 hours
Off-Peak	22:00 – 08:00 hours

Table 3
ETOU RATE (Berhad, 2023)

Tariff Category	Demand Charge (RM/kW/Month)		Energy Charge (sen/kWh)		
	Peak	Mid-Peak	Peak	Mid-Peak	Off-Peak
Commercial C1 MV ETOU	34.00	28.80	58.40	35.70	28.10
Commercial C2 MV ETOU	48.40	42.60	63.60	33.90	22.40
Industrial D LV ETOU	42.10	37.20	48.40	32.70	24.90
Industrial E1 MV ETOU	35.50	29.60	56.60	33.30	22.50
Industrial E2 MV ETOU	40.00	36.00	59.20	33.20	21.90
Industrial E3 MV ETOU	38.40	35.00	57.60	32.70	20.20

Results and Discussion
Comparison in terms of optimal design of microgrid has been done for three cases.

Case 1: EV without DSM program
Case 2: EV with renewable generation-based DSM
Case 3: EV with dynamic price-based DSM

Case 1: EV without DSM program
In the first case, the initial load profile which is without DSM has been used as an input load profile in HOMER Grid. Cash flow for various microgrid cost type is shown in Figure 7. From there, the operating cost is the highest in 25 years because the operation of system works efficiently need to be made sure. Because DSM has not been included into the system, Fig. 8 shows that the cumulative economics of the proposed and based systems are quite close. The proposed system in this case is the system that consists of battery, converter, and EV. The consumption of energy in Fig. 9 also proved the needs of DSM in the system. In Figure 10, the annual utility bill is high which proves that the needs of DSM in the system to lower the consumption. The total proposed system is about RM 430k. Annual carbon dioxide emission for this case is 620t/yr. Emissions are based on an assumption of the grid's generation sources.

Figure 7: The cash flow of different cost type of the microgrid (Case 1)

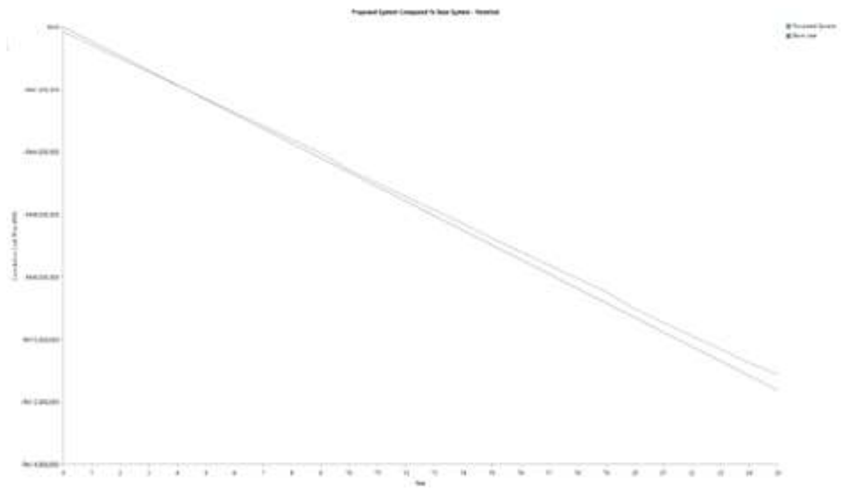

Figure 8: Cumulative economics comparison between proposed and based systems (Case 1)

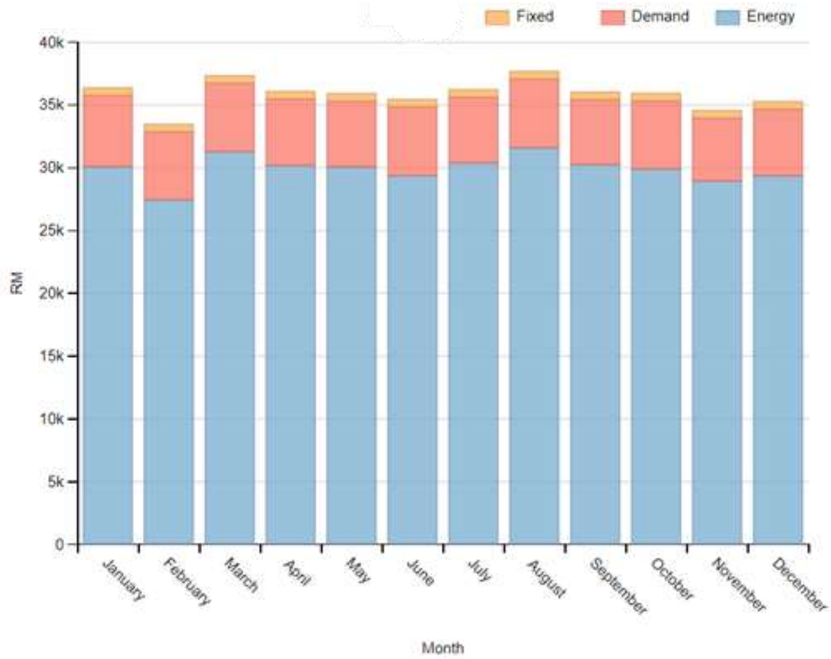

Figure 9: Monthly electricity breakdown (Case 1)

Annual Utility Bill Comparison

	Base Case C1	Current Case C1	Savings
Consumption Charge	RM355,778.63	RM358,036.12	-RM2,257.48
Demand Charge	RM101,965.24	RM65,173.10	RM36,792.13
Demand Response	RM0	RM0	RM0
Fixed Rate	RM7,200.00	RM7,200.00	RM0
Minimum Rate	RM0	RM0	RM0
Taxes	RM0	RM0	RM0
Total	RM464,943.87	RM430,409.22	RM34,534.65

Figure 10: Annual utility bill comparison (Case 1)

Case 2: EV with renewable generation-based DSM

In case 2, the ideal microgrid design was based on the output findings of planned load utilising the renewable generation-based DSM programme. In Fig. 11, we can see that the operating cost is very low compared to in case 1 since DSM implementation in this case focusing in load shifting that does not require advance operation. As can be shown in Figure 12, the suggested systems have better cumulative economics than the based systems because of the utilisation of renewable energy sources and the DSM. Figure 13 displays the monthly electricity production data from the, with a reported surplus of 3.725 percent and 495,810 total energy production units produced in that year. The extra electricity has grown from 0% in comparison to basic scenario (case 1). The peak demand was 296.15 kW since case 1 had no DR occurrences. Referring to Figure 14, the yearly electricity cost has decreased significantly with DSM implementation, supporting the goal of DSM.

The utility savings also increased by a lot reaching to RM 10M since the proposed system in this case only cost about RM35k annually. If the implementation of DR before and after were examined, there is a decrease in peak load because as shown in Figure 15, the peak load before DR events was 88.78 kW and during DR events was 79.1 kW. In this scenario, yearly emissions of carbon dioxide are calculated to be 58.2 tonnes.

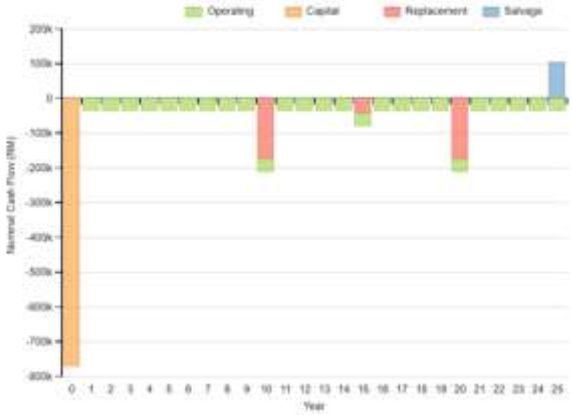

Figure 11: The cash flow of different cost type of the microgrid (Case 2)

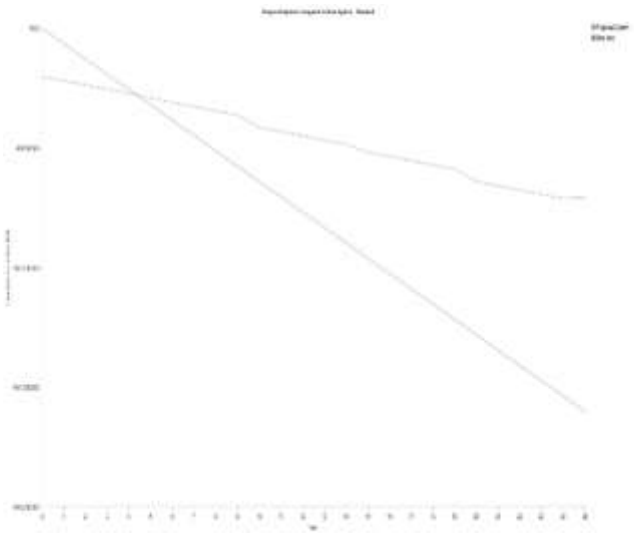

Figure 12: Cumulative economics comparison between proposed and based systems (Case 2)

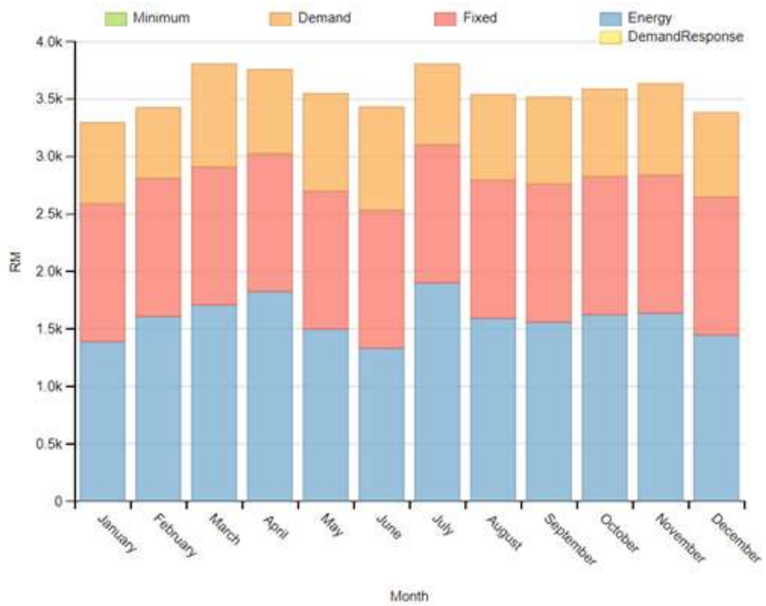

Figure 13: Monthly electricity breakdown (Case 2)

Annual Utility Bill Comparison

	Base Case C1	Current Case C1	Savings
Consumption Charge	RM10,106,970.53	RM19,061.24	RM10,087,909.28
Demand Charge	RM47,233.91	RM9,196.67	RM38,037.24
Demand Response	-RM3,559.06	-RM7,730.84	RM4,171.78
Fixed Rate	RM14,400.00	RM14,400.00	RM0
Minimum Rate	RM0	RM0	RM0
Taxes	RM0	RM0	RM0
Total	RM10,165,045.37	RM34,927.07	RM10,130,118.30

Figure 14: Annual utility bill comparison (Case 2)

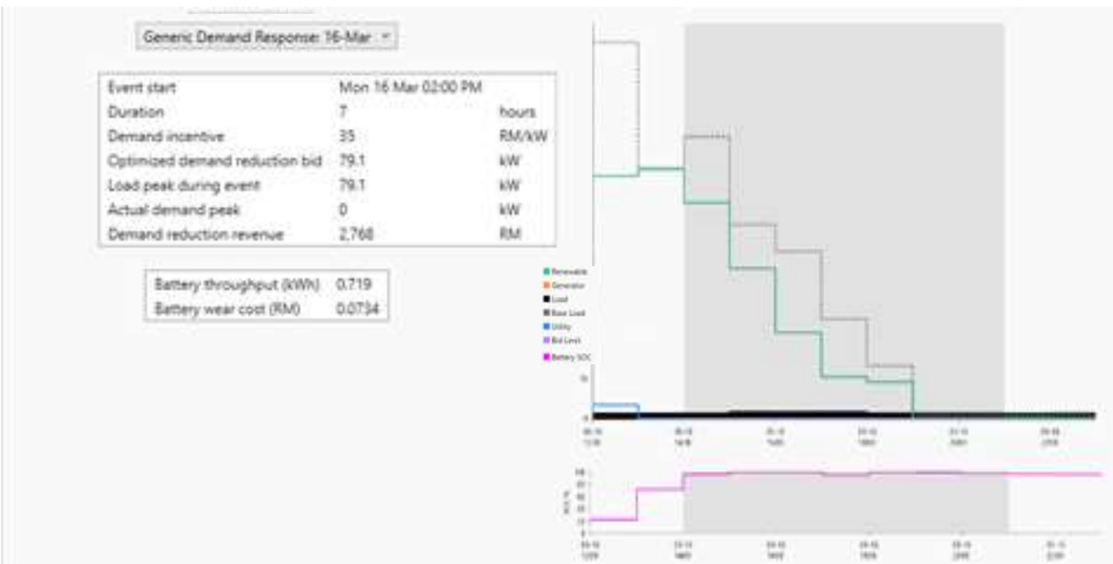

Figure 15: Demand response (DR) events (Case 2)

Case 3: EV with price-based DSM

Case 3 is an ideal microgrid design based on planned load output data from a price-based DSM programme. Nominal cash flow of the system by cost type is shown in Fig. 16 and is consistent with the previous scenarios. As can be observed in Figure 17, when the ETOU rate is included, the suggested systems' cumulative economics are higher. It is possible that monthly power output will exceed demand by 0.82 percent, and as shown in Figure 18, energy production is comparatively greater than in scenario 2.

As a result of ETOU's design, which prioritised price-weighted DSM and tariff above load shifting, this result was predictable. Considering the suggested system has an annual electricity expenditure of RM 82,000, the savings from the base case are substantial, as illustrated in Figure 19. Peak measured load for Case 3 was 236kW, and its DR occurrences are shown in Figure 20. Case 2's DR peak load is lower than Case 3's because of the emphasis on load shifting rather than utility pricing. Since the initial peak demand was 297.29 kW per year, this demonstrated the efficiency of DSM. This scenario results in 236 t/y of CO2 emissions.

Figure 16: The cash flow of different cost type of the microgrid (Case 3)

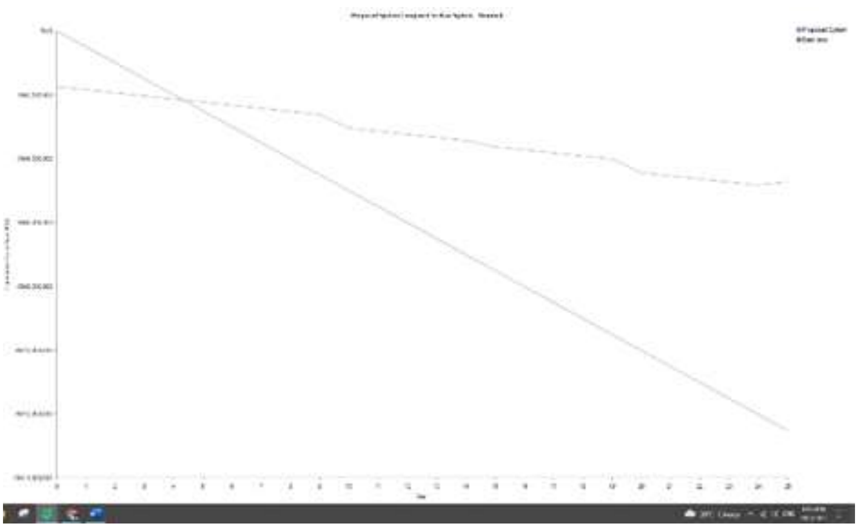

Figure 17: Cumulative economics comparison between proposed and based systems

(Case 3)

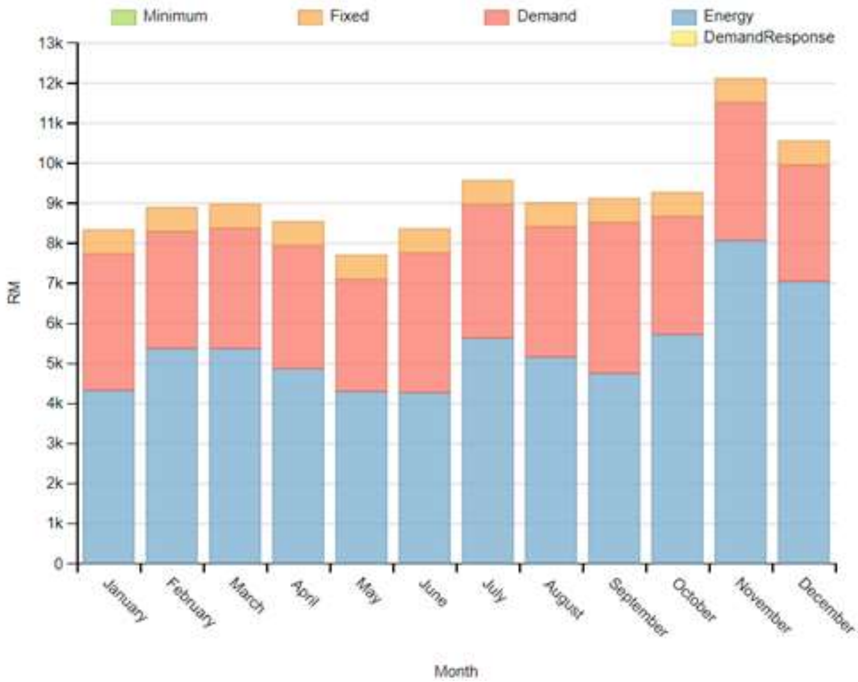

Figure 18: Monthly electricity breakdown (Case 3)

Annual Utility Bill Comparison

	Base Case C1	**Current Case** C1	**Savings**
Consumption Charge	RM580,140.04	RM64,724.90	RM515,415.14
Demand Charge	RM170,278.11	RM38,272.92	RM132,005.19
Demand Response	RM1,872.75	-RM27,706.67	RM29,579.42
Fixed Rate	RM7,200.00	RM7,200.00	RM0
Minimum Rate	RM0	RM0	RM0
Taxes	RM0	RM0	RM0
Total	RM759,490.90	RM82,491.15	RM676,999.74

Figure 19: Annual utility bill comparison (Case 3)

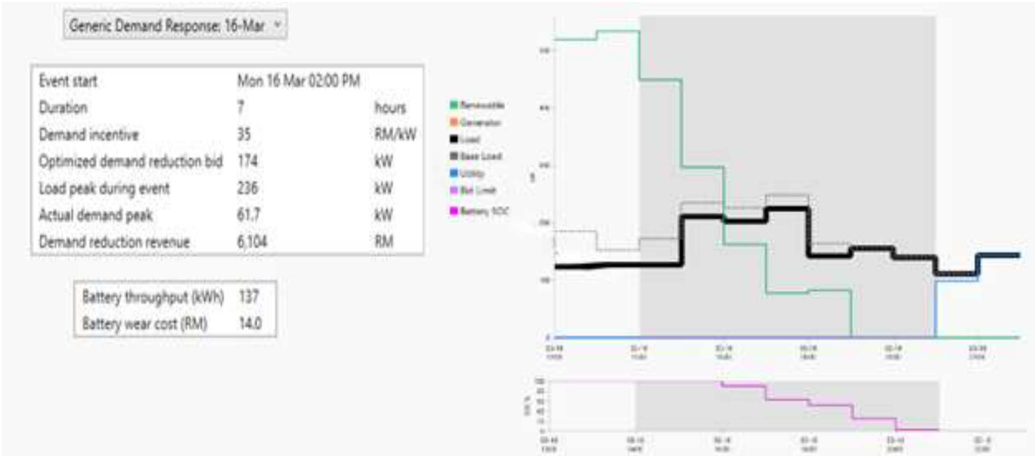

Figure 20: Demand response (DR) events (Case 3)

Comparison between the three cases

For the first case, the initial load profile which is without DSM has been used as an input load profile in HOMER Grid. In case 2 and 3, the output results of scheduled load using DSM program have been taken to design the microgrid optimally. Table IV presents the comparison between three cases for optimal sizes of microgrid's components with the cost of energy (COE).

Table 4

Comparison between three cases for optimal design of the microgrid

Case	*Case 1*	*Case 2*	*Case 3*
Optimization Technique	*Without DSM*	*Renewable generation-based DSM*	*Dynamic price-based DSM*
PV (kW)	*0*	*256*	*779*
Battery (kWh)	*238*	*356*	*330*
Converter (kW)	*113*	*147*	*554*
LCOE (RM/kWh)	*0.462*	*0.240*	*0.184*
NPC (RM)	*5.81 M*	*1.38 M*	*3.25 M*

It can be shown in Table 4 that the LCOE in example 1 is the largest compared to cases 2 and 3. This is due to the fact that the loads aren't scheduled properly. In such a scenario, the load fluctuation is increasing, and the peak is also large. In case 2, the load profile has functioned more effectively. Since the PV coordination guidelines were adhered to in case 2, the size of the PV installation is much larger than it was in case 1. The high value of PV power in case 3 is because it has high peak demand and it forces to install high-capacity generation unit. Case 3 utilises a scheduling method known as dynamic price weight for its load profile. Since Case 3 has the lowest LCOE compared to other cases because the load curve of case 3 is flatter *making it the best design for the microgrid in this study, and the exact findings of the scenario are shown below.*

Table V presents the emission quantity of various pollutants for all cases. Case 1 have the highest carbon emission due to the lack presence of renewable energy. The emission assumption presented is based on the calculation in HOMER software that simulates the pollutant in the surrounding area.

Table 5
Emissions details of the microgrid

Pollutant	*Case 1*	*Case 2*	*Case 3*
Carbon dioxide	*619,942 kg/yr*	*58,175 kg/yr*	*235,889 kg/yr*
Carbon monoxide	*0*	*0*	*0*
Unburned hydrocarbons	*0*	*0*	*0*
Particulate matter	*0*	*0*	*0*
Sulfur dioxide	*2,688 kg/yr*	*252 kg/yr*	*1,023 kg/yr*
Nitrogen dioxide	*1,314 kg/yr*	*123 kg/yr*	*500 kg/yr*

Conclusion

In this study, DSM was used to plan elastic loads, which included electric vehicles. The optimal design of microgrid with presence of EV has been determined with a planned load profile. The microgrid with DSM has a LCOE that is more economically viable than the microgrid without DSM. The performance of the price-based DSM is superior for the most effective design of the microgrid in UiTM Shah Alam. This work can be extended by including other renewable energy resources. The inclusion of these resources, despite the expenses that come with its installation, contributes to a reduction in the emissions of pollutants.

Acknowledgement

The author would like to express gratitude to the UiTM Solar Research Institute (SRI) for their assistance in gathering data. In addition, thank you to my supervisor, Assoc. Prof. Ir. Dr Nofri Yenita Dahlan, for her guidance in completing the study.

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