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A review on maximum demand shaving

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Review

Grid-Tied Photovoltaic and Battery Storage Systems with Malaysian Electricity Tariff—A Review on Maximum Demand Shaving

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Abstract: Under the current energy sector framework of electricity tariff in Malaysia, commercial and industrial customers are required to pay the maximum demand (MD) charge apart from the net consumption charges every month. The maximum demand charge will contribute up to 20% of the electricity bill, and will hence result in commercial and industrial customers focussing on alternative energy supply to minimize the billing cost. This paper aims to review the technical assessment methods of a grid-connected solar photovoltaic (PV)—battery storage system—with respect to maximum demand shaving. An effective battery storage system can provide the extra energy needed during the peak energy consumption periods, as well as when renewable energy (RE) sources go offline. Based on the reviews, maximum demand shaving with good Return-of-Investment (ROI) can be achieved by considering the actual load profile, technical, and economic aspects of the solar PV-battery system and the Malaysian electricity tariff for commercial and industrial customers.

Keywords: electricity tariff; maximum demand (MD); peak shaving; photovoltaic; battery storage system; net metering

1. Introduction

The rapid depleting conventional energy sources and today's continuously increasing energy demand have led to the intensive research for new, more efficient, and green power plants, with advanced technology. In recent times, new energy and clean fuel technologies are being intensively pursued and explored due to the increasing environmental concern worldwide [1,2]. The increased penetration rate of solar photovoltaic (PV) generation systems in the utility grid reduces greenhouse emission, increases energy independence, and improves the reliability of the infrastructure. Solar PV systems can also offer an alternative solution to the reduction of maximum demand (MD) because of the capability to supply power during peak hours. Unfortunately, environmental factors, such as irradiation and changes in the temperature, affect the output power of a solar PV. The sporadic characteristics of a solar PV generation system reduce the power quality of the utility grid [3–10]. The use of batteries in combination with PV systems in commercial buildings and industries are expected to become a widely applied energy storage solution to cater for peak shaving and peak shifting.

In recent years, energy storage became a promising technology in reducing the peak demand. Large-scale energy storage technologies, such as thermal storage, pumped hydro storage, fuel cell storage, batteries, and supercapacitor has financial and technical limitations to be resolved [11–14]. Battery energy storage system (BESS) is receiving more attention with an increasing amount of electricity that is produced by renewable energy sources like wind and solar PV [15–19]. Therefore, it is vital to analyze the profitability and potential of investment in BESSs. The idea behind energy arbitrage is to take advantage of daily energy price differences in order to buy cheap energy that is available and store in the battery during periods of low demand. The stored battery capacity can be used during peak load when the prices are high [20].

Smart-grid technologies, such as smart meters, have allowed for dynamic pricing. Time-of-Use (TOU) pricing is an example of dynamic pricing that has been progressively adopted, whereby electricity charges are fixed for a particular time period on an advance or forward basis. Such systems usually offer two or three price levels (e.g., "off-peak", "mid-peak", and "on-peak"), which is determined by the time of day. By storing energy during low off-peak price periods, consumers and businesses may continue to operate at the optimum levels even during peak times and avoid paying the high TOU rates by utilizing the stored energy [21]. In addition to TOU-based charge, electricity bill may include demand charges. It is defined as a charge that is determined by using the maximum demand (or peak demand) that is occurring during a certain billing period [22]. The demand charge is billed at a fixed rate, which is calculated on a per kW basis. This charge is applied to commercial and industrial customers and other large energy users for sharing the infrastructure and maintenance costs that are incurred by the electricity provider to provide the peak power when needed [23].

Self-consumption refers to the percentage of solar PV electricity that is used up locally vs. the total electricity generated by the solar PV. A self-consumption PV maximizes the use of solar array-produced electricity on-site and minimizes the electricity used from the utility grid. Self-consumption is economically feasible, although its profitability relies on the regulatory policies that are set by various countries [24]. Different forms of incentives exist for renewable energy, for instance, feed-in tariff (FiT), net metering (NEM), quota and trading systems, portfolio standards, tax credits, as well as pricing laws.

Malaysia has taken few steps to expand the clean energy deployment by adoption of renewable energy tariff mechanisms under the country's 2011 Renewable Energy Act. NEM scheme is appropriate to match the current FiT and accepted worldwide, besides further contribute in accomplishing the national RE target, and decrease reliance on imported fossil fuels. However, low incentives will lower the profit under the current TOU pricing scheme of Malaysian electricity tariff [25]. This has led to studies on optimization of solar PV with battery energy storage system in order to maximize the benefits that are related to the electricity price variances under time-of-use of real-time pricing.

2. Energy Sector: Malaysia

2.1. Electricity Tariff Schemes

The average electricity tariff in Malaysia increased by 15% in January 2014, from the average rate of MYR 0.3354/kWh (USD 0.0906/kWh) to MYR 0.3853/kWh (USD 0.104/kWh) [26]. The increase in electricity rates is to stabilize the country's economy by dipping fuel subsidies for the power sector. Besides, the increase in electricity price is inevitable as the price of fossil fuel continues to upsurge. In regards to new generating plants, Figure 1 shows the increasing trend of total installed generation capacity and maximum demand in Malaysia. Commercial and industrial sectors are the major contributors of total energy consumption, followed by residential, transportation, and etc. The continuous increase in the maximum demand necessitates further new power plants and grid reinforcement to cater for energy demand in Malaysia [26]. Tenaga Nasional Berhad (Kuala Lumpur, Malaysia) (TNB), the sole provider and distributor of electricity in Peninsular Malaysia predict that the peak demand will reach up to 20,669 kW by 2020. TNB has stated that the demand for electricity is being driven by economic growth, which is anticipated to raise at an annual rate of 3% up to 2030.

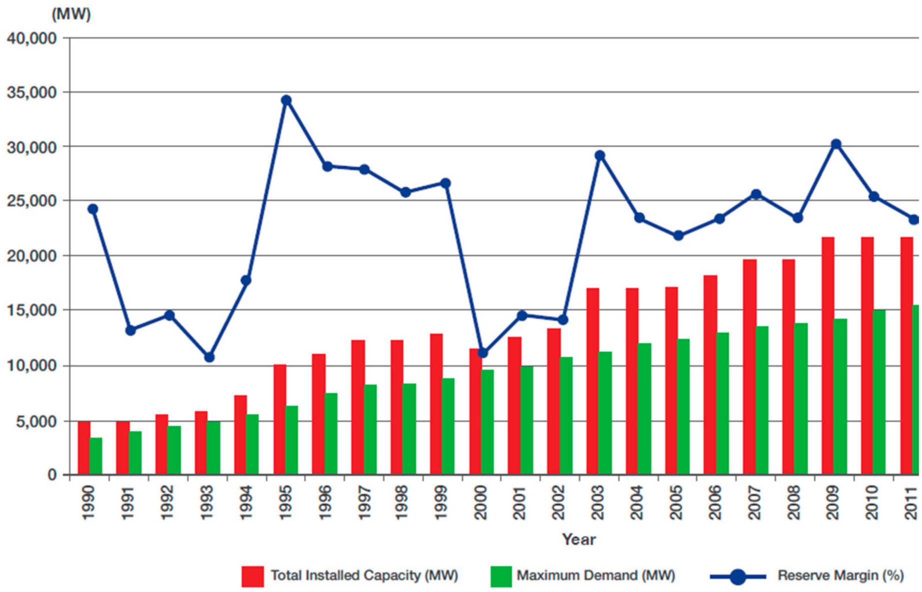

Figure 1. Peninsular Malaysia electricity sector 1990–2015 [26].

Implementation of renewable energy (RE) projects is expected to reduce the maximum demand and will significantly contribute to the overall generation mix in Malaysia. Based on Figure 2, in terms of capacity, by the year 2020, it is expected that the cumulative annual growth rate of RE capacity, which consists of mini hydro, biomass, biogas, and solar PV plants will be more than 11% or 2080 MW of installed capacity [27]. The latest forecast of generation fuel mix includes the contribution from RE plants due to the sizable output that is expected in the future. The RE share in the overall fuel mix is projected to gradually increase up to 20% of total energy generated in 2020.

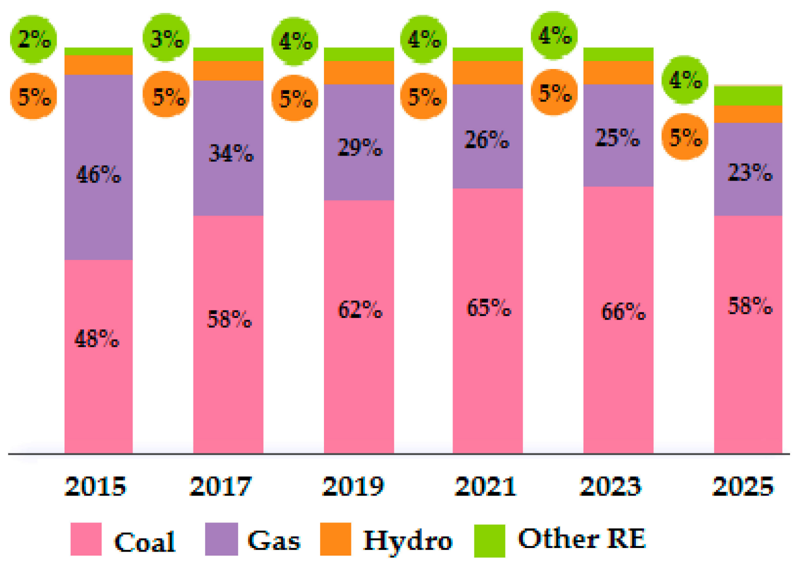

Figure 2. Power generation mix in Malaysia 1992–2025 [27].

Typically, the peak demand charge may contribute up to 20% to the expensive electricity bills that are caused by the use of open-cycle gas power plants. Therefore, utility companies habitually charge the energy users at a premium price under Time-of-Use (TOU) based on their highest demand captured in a month apart from the energy consumption charges. MD is captured by taking the demand over the consecutive period of 30 m intervals throughout the month. However, MD charges increase the operating cost of the commercial and industrial sectors, which affect their competitiveness in the market.

Table 1 shows the electricity tariff rates for various types of commercial and industrial customers in Malaysia. According to the electricity tariff rates, for category C1 and E1, MD charges are captured in between 8.00 a.m. and 10.00 p.m., apart from the flat rate for net consumption charges. For category C2 and E2, net consumption will be charged based on peak and off-peak periods. The timeline between 8.00 a.m. to 10.00 p.m. and 10.00 p.m. to 8.00 a.m. are assigned for peak hours and off-peak hours respectively apart from MD charges.

Table 1. Tariff rate for commercial and industrial customer in Malaysia.

Tariff	Unit	C1 [a]	C2 [b]	E1 [c]	E2 [d]
Peak	RM (USD)/kWh	0.0	0.365 (0.08)	0.0	0.365 (0.08)
Off-peak	RM (USD)/kWh	0.0	0.224 (0.05)	0.0	0.219 (0.05)
Net consumption	RM (USD)/kWh	0.365 (0.08)	0.0	0.337 (0.08)	0.0
Maximum Demand (MD)	RM (USD)/kW	30.3 (6.82)	45.1 (10.2)	29.6 (6.7)	37.0 (8.3)

[a] C1 represents the medium voltage general commercial [20]; [b] C2 represents the medium voltage peak/off-peak commercial [13]; [c] E1 represents the medium voltage general industrial [20]; [d] E2 represents the medium voltage peak/off-peak industrial [26].

Most tariffs are designed to help customers to limit their electricity usage during peak hours. Based on Figure 3 and Table 2, the load profile data for the month of November 2015 for C1 category customer (Malaysian institution) has revealed that the MD of 1290 kW was captured on 25 November 2015 at 9.00 a.m., which came up to RM 39,087.00 apart from the total net consumption of RM 129,330.45. Table 2 shows that the total electricity bill is RM 168417 for the month of November 2015, where 23% and 77% charges are maximum demand and net consumption respectively.

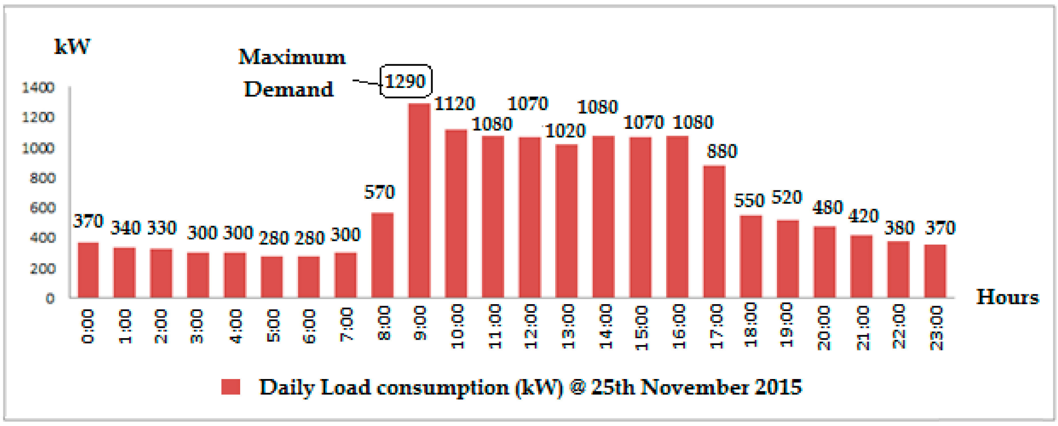

Figure 3. Load consumption data on Malaysian institution for month of November 2015.

Table 2. Electricity billing data for Malaysian Institution.

Customer:	Nilai University, Malaysia		
Duration of Bill:	1 November 2015–1 December 2015 (30 days)		
Tariff Category:	C1 (Commercial)		
Block Tariff	**Usage (kWh/kW)**	**Rate**	**Total Amount [RM (USD)]**
Net consumption	354,330.00	0.365 (0.08)	219,330.45 (49,560.61)
MD consumption	1290.00	30.3 (6.82)	39,087.00 (8832.22)

Consumers are able to use RE, especially solar PV with a battery storage system to shave the MD throughout the peak period, thus reducing the electricity price [28]. In November 2016, Sustainable Energy Development Authority (SEDA), Malaysia, announced the introduction of Net-Energy Metering (NEM) to address the overwhelming demand for solar PV. NEM allows for the self-consumption of electricity that is produced by solar PV system users, while selling the excess energy to the utility company. NEM is a policy that allows connecting the consumers' own rooftop solar PV generation system to the utility grid and gain credits on their bills in excess of their electricity consumption. The term, net-energy metering, denotes the measurement of the bi-directional flow of electricity in the utility system by feeding the grid when additional power is generated. The power is then consumed from the grid later on when the production is lower than the consumption. For low voltage connection, the credit rate is at MYR 0.31 (USD 0.07)/kWh and for medium voltage connection, rate is MYR 0.238 (USD 0.05)/kWh, respectively [29]. Solar PV technology is pertinent to the NEM and it is the only technology that allows the public to play their part in addressing climate change by engendering the clean energy, therefore decreasing the energy usage of the electricity that is produced by fossil fuel powered generators.

2.2. Grid-Tied Solar PV System

Malaysia, in a strategic geographic location, has good solar insolation of 1400 to 1900 kWh/m^2/year [30]. Under Standard Test Conditions (STC) of 1000 W/m^2 of solar radiation and an ambient temperature of 25 °C, reference PV cells are used to measure the maximum irradiance. However, the actual maximum solar irradiance will be achieved below 800 W/m^2 since PV module temperature and ambient temperature under Malaysia climate condition will contribute to the deterioration of measured value [31]. In order to avoid large variations in solar electricity production, it is necessary to include energy storage and releasing it in peak consumption periods for bringing very short fluctuations and for maintaining the continuity of power supply [32]. In Malaysia, apart from the back-up power supply, energy storage is an entirely new concept for peak load shaving in the commercial and industrial sector. Among the challenges that are holding back the widespread use of energy storage systems is the cost. Despite declining prices for energy storage, it remains higher than the price per unit of current obtained from the grid.

According to Energy Commission of Malaysia, as per Figures 4 and 5, solar PV generation contributes the highest load compared to other RE technologies since 2012. Under Feed In-tariff (FiT) scheme, as of 2016, a total of 298.9 MW was generated through RE installation and 64% of the RE generation was from solar PV system. Based on the 2011 Renewable Energy Act, Malaysia has mandated the adoption of a renewable energy feed-in tariff (FiT) mechanism. Since 2011, the predominant policy framework for clean energy development in Malaysia has given strong ground for the substantial deployment of renewable energy and energy efficiency.

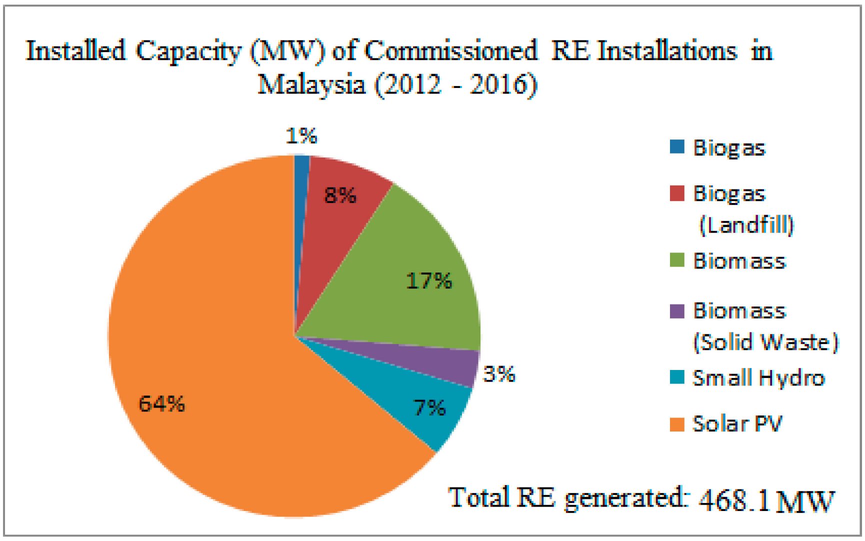

Figure 4. Installed renewable energy (RE) capacity 2012–2016 in Malaysia [20].

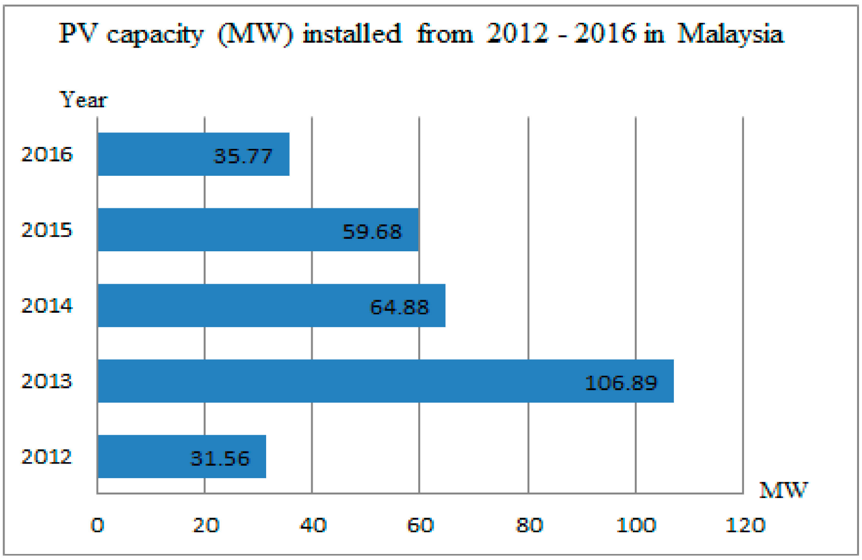

Figure 5. Photovoltaic (PV) installed capacity (MW) from 2012–2016 in Malaysia [29].

Previously, all of the grid-tied photovoltaic projects in Malaysia were based on Feed In-tariff (FiT) scheme. The Feed-in Tariff (FiT) system obliges Distribution Licensees (DLs) to purchase the electricity generated by renewable resources from Feed-in Approval Holders (FIAHs) at the specified FiT rate. The DLs will pay for renewable energy that is supplied to the electricity grid for a particular period. As of 2014, the FiT payment rated at MYR 0.7194/kWh up to MYR 1.0411/kWh depending on the RE installed capacity. In November 2016, net energy metering (NEM) scheme has complemented the current Feed-in Tariff (FiT) mechanism for the commercial and industrial sectors. However, a solar PV project under FiT quota that is applicable for the community category only, such as educational institutions, place of worship, and care centers.

3. Review of Peak Shaving Approach

3.1. Use of Battery Storage During Peak Demand

The general concept is that the battery system will absorb power from the grid throughout off-peak rate period or while solar PV is producing excess energy and release the power at peak hours [33]. This particular concept is able to level the demand profile, reduce peak demand, and overvoltage, as well as reverse power flow issues prompted by greater solar PV penetration. A proven steady reduction in maximum demand derives a significance for the utility in delaying the expansion of electricity network, especially on capital expenditure [34]. As a means to mitigate the sudden changes in PV outputs and to support the evening peak load in residential systems, a strategy of charging and discharging BES units was proposed [35]. One of the important attributes that affects the storage capacity and lifetime of the battery is its size. A smaller battery may have a shorter lifetime due to the increasing stress, while a larger battery in contradiction, have a longer life cycle by reducing its depth of discharge of the cycles [36].

Performances of BESS rely on both internal and external parameters. Generally, internal parameters are uncontrollable and are determined by the manufacturer, such as manufactured technology, design, and material. On the other hand, external parameters are more manageable and have a larger effect on the life cycle of the battery. Examples of external parameters are the degradation, such as charge/discharge rates, linear state of charge (SOC), and depth of discharge (DOD) [28]. Some of the most commonly known battery storage technologies are lead-acid, lithium-ion (Li-ion), sodium-sulfur (NaS), Nickel–cadmium (NiCd), and Nickel metal hydride (NiMH) batteries. In comparison to other batteries, lithium-ion batteries demonstrate an excellent energy preservation ability with slight internal power losses, longer life cycle, and small self-discharge rate [37].

Jargstorf et al. studied the ability of battery storage to smoothen the maximum power demand that is requested by an end user. They performed a thorough analysis of end-user reactions and the related grid upgrade costs, i.e., residential tariffs reflectivity [38,39]. The study states that a capacity tariff does not assure the reduction of the final cost for the distribution system operator, however, the user could lessen the upgrading cost when PV injection is added. One of the important elements to minimize the stress of PV generators to the distribution network system is by the reduction of the maximum PV power exported to the grid. However, it needs dedicated battery schedules and forecasting techniques to have the accessible battery capacity when excess PV power is available.

Kein Huat Chua et al. [40] stated that the reducing the electricity price using lead-acid battery storage system to decrease the maximum demand is economically feasible. By year 2020, the value of Li-ion batteries is predicted to drop from USD 600/kWh to USD 200/kW. The decrease in the value is about one-third of the existing price, thus, providing a great prospect for energy storage to be accepted in mitigating the peak demand. David Parra et al. [41,42] presented a time-dependent model to compare and optimize the lead acid and Li-ion battery in terms of the total cost (storage medium, inverter, balance-of-plant, maintenance) and battery life cycle (calendar and cycle losses). The study confirmed that simple retail tariffs, where the electricity bill is constant throughout the day, is the best possible option for consumers who have PV-coupled battery systems that only perform PV energy time shift.

Park et al. [43], formulated a method to determine the battery charging current from the grid and the PV array by considering the battery capacity and internal resistance, the efficiency of power converter, effect of the rate capacity, and the maximum power tracking point of the PV array. The experimental outcomes show that the proposed algorithm able to effectively reduce the electricity bill by up to 28% in comparison to previous state-of-the-art battery management policies. It has been observed that, the PV module impedance, effect of battery rate-capacity, converter loss, and storage limit for giving solar irradiance, load profile and billing policy have been taken into account in the proposed framework.

All of the cases described previously verifies that the integrated PV with battery storage system is able to accomplish the functions of load shifting, grid power quality control, and peak shaving under the nominal load state and unstable output power from a solar cell array. This is under the assumption that the optimal battery capacity is available to cater for load demand during peak-hours and off-peak hours, respectively. For instance, with reference to Table 1, BESS can be configured to discharge in between 8.00 a.m. until 10.00 p.m. under category C1 electricity tariff so that normalized power can be achieved with the intention to set the new MD limit at the minimal level, as observed in Figure 6. The battery storage system alone will not be feasible since the high capacity of the battery storage system is very costly. Hence, the integration of PV system in parallel to the BESS will be the best option.

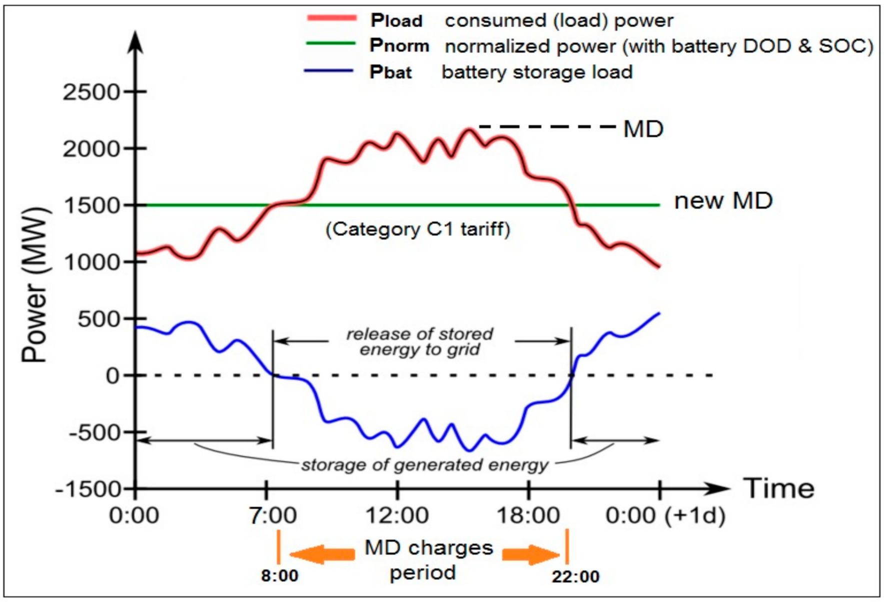

Figure 6. Typical battery storage operation under Malaysia electricity tariff.

3.2. Peak Shaving via Solar PV—Battery Storage System

In order to mitigate the impacts of PV intermittency, increase PV penetration, and deliver numerous benefits for utilities, customers, and PV owners, the hybrid battery energy storage (BES) and solar PV system has been used as one of the most feasible solutions in grid-connected applications. However, the intermittent solar irradiance logically suggests the adoption of battery storage system to meet the maximum demand and to compensate the gap between the energy accessibility and the load demand. The hybrid PV-BES system can be either a DC-coupled or an AC-coupled system. The hybrid system coupled with DC consists of a battery bank which is connected to the intermediate DC link straight through a bi-directional converter. In the case where the batteries are supposed to be charged from both PV array and the grid, the grid converter could be bi-directional. Meanwhile, in an AC-coupled system, both PV array and battery bank are linked to the AC bus through a bi-directional battery converter and an inverter, respectively [44].

In recent times, some of the existing energy storage technologies and literatures demonstrate their applicability and economic viability of the PV load management. A hybrid PV-battery system was established to enhance the efficiency of electrical system. For reliable peak load shaving in a grid-connected PV-battery system, an optimal battery charging and discharging program is very critical. In [45], the authors suggested an approach to identify the size of BES units for power arbitrage and peak shaving utilized in a PV system that is connected to grid. Additionally, another method has been proposed to size BES units for the increasing PV penetration in a housing system to control the voltage and lessen the peak power along with the annual cost [46].

Several studies have been reported on optimal energy management for PV systems that are connected to grid, coupled with energy storage. The studies encompass resolving optimization problems subject to some limitations, predicting the day-ahead forecasts of load profile, PV power production profile, and the energy rates. The probability method has been developed to optimize the solar PV systems by taking into account a probability function, expressed as the probability of losing load (load demand more than energy source) in terms of battery capacity, solar PV energy output, and load demand. Therefore, the determination of an optimal battery storage is based on the consistency of the solar PV irradiance and the optimal solar PV array size is analyzed using the worst month method [47]. Teleke et al. [48], developed a PV system model to enhance its size based on a well-defined solar energy potential and load. The RE source's output is leveled by the hourly dispatch of the net injected power to the utility grid using the battery energy system Nevertheless, when both the performance of the control system and suitable sizing of BES are evaluated, using the typical 1-week solar and wind data as input is considered unreliable.

Li and Danzer used dynamic programming to determine predictive charge control strategies for different objectives (i.e., maximizing battery life, maximizing self-sufficiency) [49]. Gravitational Search Algorithm was demonstrated as an effective tool for peak consumption reduction and electricity generation cost minimization [50]. The imperialist competition algorithm was used in energy management system (EMS) to provide multiple optimum solutions [51]. When considering the demand response of customers in the microgrid, a further decrease of energy cost of up to 30% was achieved [52]. The above studies obtained short-term power scheduling based on forecasted weather and load data. Shimada and Kurokawa [53] modeled yearly energy bill savings for a solar PV system using variety of battery capacities. They identified the amount of nighttime charging required to reduce the cost of energy bought by the customer from the electric utility during the following day using an approximate insolation forecast and a load forecast.

Marco Bortolini et al. presented a technical and economical model for the design of a grid- connected solar PV with battery system. The authors related the study to the hourly irradiation and the temperature trend for the installation site by taking into account the hourly energy demand profile for a reference year [54]. On the other hand, Moshövel et al. established a management strategy referring to the weather forecasts for relieving the grid with battery storage systems. The analysis revealed that there are higher potential to relieve the grid using storage system management leads, instead of a system that only maximizes self-consumption [55].

Yann Riffonneau et al. presented a predictive control system that relates to co-locate solar PV and BES. The system initializes by predicting temperature, load profile, irradiance and the cost of energy. The optimal peak reduction in the system is achieved through dynamic programming [56]. Similarly, Jayasekara et al. achieved peak shaving objectives by setting out to schedule customer-side solar PV and BES. The system functions to provide a 24-h load profile forecast by first estimating load a day ahead and filtering the forecast with a Fourier series. Apart from this, Arghandeh et al. [57] developed the scheduling system to produce a charge, discharge schedule by optimizing an objective function using a gradient-based heuristic method. The objective function comprises the price of acquiring energy when charging, saving prices during discharging, load profile predictions, local marginal costs estimates, feeder losses, as well as energy storage system limitations.

Nottrott et al. suggested a cost-benefit analysis and an energy dispatch schedule optimization strategy. The model contains, as input, level of irradiation, the temperature, and the energy demand profiles in view of the system lifespan. These datas are accounted hourly in the whole reference year of analysis to assess a proper PV system power size and the BES system capability [58]. The battery sizing methods in Gitizadeh et al. [59] and Khalilpour et al. [60] rely on the correct forecasting data. The methods throw little light on the real condition, operation when forecasting data cannot be certain. In other words, the optimal scheduling cannot be guaranteed.

Scheduling systems developed by Sanseverino et al. [61] and Grillo et al. [62] depend on price signals over the use of TOU tariffs, day-ahead energy market data, an hour ahead market data, and spot prices optimize the charging and discharging of battery energy storage (BES). Utilization of day-ahead, hour-ahead, and spot price markets provides the scheduling systems a precise image of the load on the grid. The norm behind these systems is to maximize revenue or minimize the price rate of the BES.

Iromi Ranaweera and Ole-Morten Midtgård [63] proposed an EMS to maximize the everyday economic benefits while limiting the power injection to the grid with time-dependent grid feed-in. The day-to-day operative charge that comprises the energy rate and the battery degradation price is considered as the objective function. The storage is able to level demand and minimize the peak demand from the grid. In addition, in some cases, the electricity bill can also be reduced with the storage [64–67]. Jochen Linssen et al. developed Battery-Photovoltaic-Simulation (BaPSi) model to run techno-economic study of PV-battery systems. The model considers the variation in environment to determine the solar PV sizing and storage capacity. The combination of total charges for the electricity supply along with the related technical and economic output parameters are calculated for each system [68].

Ming Jin et al. [68], developed micro grid optimal dispatch with demand response (MOD-DR) using the concept day-ahead dispatch, in according to the electricity tariff and renewable availability. The method has a time-shifting capability of storage, consequently attaining effective operation. Hanna et al. [69], developed an operational battery dispatch control algorithm using linear programming for a combined photovoltaic-battery storage system that uses load and solar forecast to mitigate peak demand of a metered load. Geem and Yoon [70] proposed an efficient harmony search algorithm for charge scheduling of an energy storage system (ESS) with renewable power generators, under time-of-use pricing and demand charge policy. The summary of the reviewed paper on Table 3 shows the techniques used for peak shaving, load leveling and load shifting using solar PV-battery system [71].

Table 3. Summary of energy management techniques using solar PV-battery system.

Techniques	Concept	Highlights	Ref.
Choice-diffusion model	Peak demand management	Used to experiment and compare electricity price tariff scenarios to projected future usage of solar PV and battery options.	[34]
Battery Charging/Discharging strategy	Peak shaving	Used for rooftop PV impact justification and peak load support by managing the available capacity of battery energy storage systems.	[35]
Simulation model framework	Energy management	It focuses on the collaboration of electricity tariff, PV generation and battery storage. This is done using the sub-models such as load flow model, Grid tariff model, Grid-user model and Investment model.	[40]
Forecast management strategy	Battery management	Optimization of PV-battery energy management is based on persistence forecasts of solar irradiation and household load demand.	[55]
Time-dependent model	Selection of battery system	Used to analyze the solar PV-battery sizing based on the dynamic electricity tariff model and technical model of the battery system.	[42]
Electricity bill optimization algorithm	Battery management	The algorithm schedules the battery charging and discharging mode for given solar irradiance and load profile for arbitrary grid electricity price.	[43,53]

Table 3. *Cont.*

Techniques	Concept	Highlights	Ref.
Linear programming (LP) model	Peak net load management	The LP leverages solar PV output and load forecasts to reduce peak loads subject to elementary dynamical and electrical constraints of solar PV-battery system	[59,70]
Multiobjective optimization method	Energy management	It is recommended to visualize the trade-offs between three objective functions such as voltage regulation, peak load reduction, and annual cost.	[46]
Gravitational search algorithm	Energy management	This algorithm is applied to achieve maximum efficiency and to improve economic dispatch as well as attaining the best performance of energy storage system	[50]
Technical and economic model	Peak shaving and load shifting	The proposed model is based on a power flow control to meet the energy load profile with PV-BES system and to determine the PV array size and the battery capacity that reduces the Levelized Cost of the Electricity (LCOE).	[54]
Dynamic programming (DP)	Peak shaving	Optimization is achieved based on batteries ageing parameters and "day-ahead" approach of energy management.	[56]
Innovative management strategy	Peak shaving and load leveling	Optimum daily energy profiles for each battery storage unit are calculated based on one day ahead energy forecasts.	[38,58]
Mixed Integer Programming (MIP) model	Energy management	Battery sizing highly depends on the exact pricing structure during battery charging and discharging period and real assumptions of battery ageing is essential to estimate the financial benefits of battery capacity in solar PV-battery system	[59]
BaPSi (Battery-Photovoltaic-Simulation) model	Energy management	The analysis exposes a considerable influence of the load profile on the modelling results concerning the total costs and optimal system configuration in terms of PV and battery sizing.	[67]

4. Maximum Demand Shaving Strategies

The main focus of all the reviewed articles is to determine the optimal combination of PV system size and battery capacity. Apart from the influence of interest rates, the maximum possible energy savings, especially peak demand reduction via optimal PV and battery system, need to be determined for a higher return on investment. Based on the studies, as per Figure 7, to achieve a high maximum demand reduction, solar PV, and battery system relies on a few criteria, such as load profile, technical and economic aspects, and electricity tariff. In terms of load profile, the load consumption data from two to three years of the commercial or industrial will be sufficient to reveal the consistency of the load pattern in terms of maximum demand and total kWh during off-peak and peak hours.

Besides that, technical and economic aspects on solar PV and battery mainly on solar irradiance, PV inverter efficiency, battery efficiency in terms of SOC and DOD should be considered for optimal sizing. Based on Figure 7, the normalized load ($\mathbf{P_{load\_normalized}}$) will be obtained with new maximum demand (new MD) when PV load generation ($\mathbf{P_{PV}}$) is supplied for self-consumption with the support of battery system during peak hours. Key elements that influence the maximum demand shaving via PV-battery storage system are as follows:

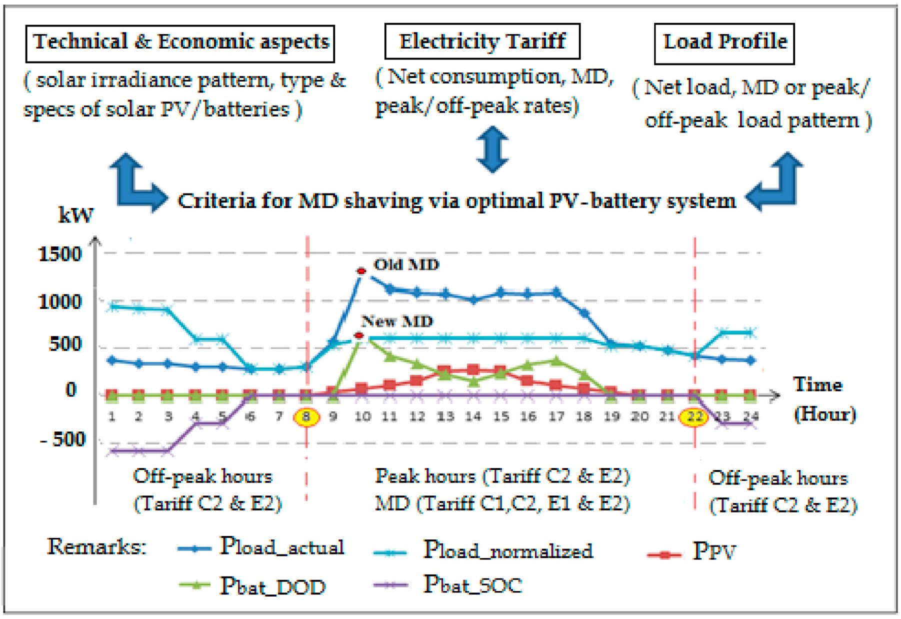

Figure 7. Criteria for maximum demand (MD) shaving optimal PV-battery system.

4.1. Influence of Different Solar Irradiance Patterns

Due to the sporadic behavior of the solar PV system, combining the solar PV system and battery storage system is necessary for the stable operation and to cater for load shaving during peak demand. Accurate measurement is required to forecast the solar irradiation pattern to optimize the PV self- consumption and to integrate with a battery system into efficient energy management for commercial buildings and industries in Malaysia. The proposed optimization algorithm assumes that the actual PV generation and load follow the predetermined pattern. However, electrical power generation and load are not likely to follow the similar pattern daily. Hence, the proposed algorithm should be combined with some prediction algorithm in practice.

4.2. Influence of Load Profile

The simulations underlying the load profile, which shows the consumer behavior, play a vital role in the PV-Battery design and the operational profile of the battery system. Load pattern and load consumption data for one to two conservative years will be sufficient to pre-specify demand in terms of kWh for optimization of the PV-battery system. Based on the ratio of the peak hour to the off-peak hour electricity charges, the grid-connected battery system may either supply power to the load or charge the battery during off-peak hours. Control methods that integrate forecasts are able to outperform to decrease the peak demand through the solar PV-battery system by incorporating an expectation of future demand, albeit with a level of uncertainty that must be considered.

4.3. Influence of Battery Capacity

The investment rate of capacity (in USD/kWh), the investment rate for power rating (in USD/kW), replacement cost (in USD/kWh), operation and maintenance (O&M) cost (in USD/kW-year), total efficiency (in percent), permissible depth of discharge (in percent), and lifetime (in the number of charge/discharge cycles) are among the most imperative considerations in optimal battery storage planning. As a mean to minimize the power consumed from the grid at peak hours, it is important to decide when and how much to charge the battery from the grid or PV throughout off-peak hours, in order to satisfy the requirement of shaving limits. The regular approach to planning the size of a facility is to break down only the critical operating periods. The effect of different battery system peak configurations and the allied control algorithm, , on real low voltage networks in worst-case loading conditions, is evaluated to form the reliable configuration of battery charging and discharging operation for limiting the maximum demand.

4.4. Influence of Control Algorithm of PV-Battery System

The key features associated to the control of solar PV-battery system, includes: (1) control of intermittent PV irradiance for efficient energy distribution and relieving the peak load; (2) control of battery energy storage system for peak load shaving; and (3) use of PV-battery control method for operative response to the utility network. Based on the Malaysian electricity tariff scheme, control algorithm should be integrated according to the MD timeframe so that battery capacity in terms of the ampere-hour (Ah) will be charged during off-peak hours and discharged during peak hours to cater for MD limit settings.

5. Conclusions

The PV system functions to fulfill the energy demand, while the energy surplus will be sold to the grid via the net metering system. The local consumption of PV produced energy could be boosted by battery capacity at times of peak demand when and it is not enough or does not exist. Alternatively, battery energy dispatch schedule of the battery will also increase income by using the stored energy to deliver for the loads since the cost of the MD electricity bill is high during peak hours of the day. Electricity will be imported from the grid throughout off-peak hours to charge the battery at a net load below maximum demand limit setting for using it throughout the peak hours of the day in the presence of intermittent solar irradiance as well as without PV generation.

Even though there is an extra investment cost for the battery system, by scheduling the battery operation in a smart way, the overall benefits of the system are mainly focused on reducing the maximum demand tremendously. The intricacy of controlling the system upsurges when the overall capacity of such sources becomes significant. Hence, utilities will need to adopt energy storage solutions to help integrate these renewable sources into the grid, and will contribute to filling the gap between local production and demand in energy.

6. Future Works

Future work will focus on maximum demand reduction modelling for commercialization and industries in Malaysia based on important criteria, such as load profile, technical/economic aspects, and electricity tariff scheme. Analysis of technical and economic aspects will mainly focus on solar PV and battery systems, such as solar irradiance pattern under Malaysian climate, technical specifications of PV, battery, converter, and etc. Besides that, the control algorithm of battery charging and discharging configuration mode according to the electricity tariff scheme will be integrated into the maximum demand reduction model. With a proposed model, an optimization of solar PV-battery will be developed via MATLAB (2014a, MathWorks, Natick, MA, USA) tool. MATLAB optimization is able to generate the optimal sizing of solar PV and battery system at designated MD limits for maximization of PV self-consumption with higher maximum demand savings.

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