IET Smart Grid

Research Article

Advanced power routing framework for optimal economic operation and control of solar photovoltaic-based islanded microgrid

eISSN 2515-2947
Received on 31st August 2018
Revised 4th February 2019
Accepted on 19th February 2019
E-First on 21st March 2019
doi: 10.1049/iet-stg.2018.0202
www.ietdl.org

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Abstract: Energy sharing through a microgrid (MG) is essential for islanded communities to maximise the use of distributed energy resources (DERs) and battery energy storage systems (BESSs). Proper energy management and control strategies of such MGs can offer revenue to prosumers (active consumers with DERs) by routing excess energy to their neighbours and maintaining grid constraints at the same time. This paper proposes an advanced power-routing framework for a solar-photovoltaic (PV)-based islanded MG with a central storage system (CSS). An optimisation-based economic operation for the MG is developed that determines the power routing and energy sharing in the MG in the day-ahead stage. A modified droop controller-based real-time control strategy has been established that maintains the voltage constraints of the MG. The proposed power-routing framework is verified via a case study for a typical islanded MG. The outcome of the optimal economic operation and a controller verification of the proposed framework are presented to demonstrate the effectiveness of the proposed power-routing framework. Results reveal that the proposed framework performs a stable control operation and provides a profit of 57 AU$/day at optimal conditions.

Nomenclature

P	active power
Q	reactive power
ω	angular frequency
f	frequency
$*$	reference values for corresponding variables
D_P, D_Q	droop coefficients of active and reactive power controller
$P_{t,h}^{s}$	power supplied to house *h* during *t*
$P_{t,h}^{d}$	power demand of house *h* during *t*
t	index of time periods
h	index of houses
j	index of PV systems
ΔT	duration of time periods (hours)
$P_{t,j}^{g}$	POWER generation of PV system
H_S	set of smart houses (with PV facility)
H_T	set of traditional houses (without PV facility)
G	set of PV generation units
λ_t	per-unit cost for traded energy during period *t*
SoC_t	state of charge of the CSS during period *t*
E_{cap}	maximum storage capacity of the CSS
η_{ch}	charging efficiency of the CSS
η_{dis}	discharging efficiency of the CSS

1 Introduction

Renewable-energy technologies are getting progressively more popular for both off-grid and interconnected-grid utilisation. Of all the renewable energy technologies, solar photovoltaic (PV) is the favoured and most promising one due to its increased efficiency, availability, low cost, small maintenance, reliability, robustness, and clean production [1–8]. The inconsistency of PV production demands the integration of a battery energy-storage system in the local grid or microgrid (MG) to achieve hybrid operation [9–13]. The combination of PV panels, energy storage, and local loads forms a conventional MG system [14]. These MGs play a crucial role in satisfying the load demand of isolated localities, such as rural villages, islands, enclaves, and exclaves by smart energy sharing with cost-efficient operation [15–17], smooth control and management [2, 18, 19]. In addition, the surplus power from the MGs can be routed to a neighbour's home when the load demand of the PV owners is fulfilled and the central storage reaches its charge limit. Thus, the wasted energy can be utilised by a simple method of local power routing, which offers both revenues for the owners and much-needed power for the neighbours [20–22]. Consequently, from both a technical and an operational point of view, the MG, due to its small size, short transmission distance, easy maintenance, robust control, and economic operation, can be a good option for energy sharing.

In islanded operation of an MG framework, the main aim is to reduce the generation, operation, and maintenance costs and system losses during sharing to optimise the prosumers' revenue. This can be achieved by a systematic priority formation through various optimisation techniques. Non-linear programming (NLP) is a favoured approach to maximise the profit, while satisfying the operational constraints of the storage system. It has been utilised in some recent studies to achieve required objectives such as load-sharing optimisation [23], best-case scenario development for energy generation scheduling [24], optimal load scheduling [25], and off-grid power management hierarchical structure formation [26]. None of the previous optimisation-based research highlights maximisation of the profits of energy trading from a stakeholder's viewpoint of an MG framework through maximum power routing to consumers, while fulfilling the constraints of the central storage system (CSS).

On the other hand, an incompetent control mechanism of voltage regulation during energy sharing is the foremost hindrance to the advancement of MG frameworks [27, 28]. The limitations associated with renewable resources, like low inertia, and storage requirements, make the control of the proposed islanded MG more challenging [29]. Additional complexity arises when load sharing happens between PV owners and powerless neighbours in the MG framework to ensure overall power balancing [30, 31], state of charge (SoC) regulation [32], and voltage balancing [33]. Researchers have proposed several decentralised control schemes for the smooth operation of islanded MGs with distributed generation and battery energy storage [34–36]. A frequency-based power-management system is highlighted in [37], but is not applicable for frameworks with isolated battery energy-storage systems. Another similar method proposed by W. Dan *et al.* in [38] is also not compatible for systems with an isolated BESS, while in [39], the technique is updated by applying the droop-control approach for a particular solar/BESS-based hybrid structure. Moreover, regulating the voltage and frequency level of an MG bus is a way of power stabilisation during energy routing [40, 41]. Power balancing in an MG framework can also be achieved by utilising the previously proposed charging and discharging algorithm [42], and using the PI controller of previous work [43] to regulate the deviation between the DC-bus and the central-storage currents. However, in [30], a unique architecture of power management is proposed which is applicable for regulating power flow in an MG. The major drawback of this approach is that it is not possible to apply in current frameworks, as it requires real-time data to adjust the power routing unit.

Recently, Fernandez *et al.* developed a game-theoretic energy-sharing model to provide cost savings for a smart neighbourhood in Sydney [44]. Their model helps to cut down the energy cost by using central storage during the peak time instead of consuming energy from the main grid. Therefore, about 9.17 and 9.68% more cost saving in summer and winter, respectively, was achieved by the proposed Nash game-theory-based approach than the non-cooperative method. On the other hand, this research presents all revenues as cost savings of prosumers, as they sell excess energy to consumers which would have been wasted. Moreover, no prosumers are competing among each other at NLP-based profit optimisation, presented here. Another recent work by Nizami *et al.* has considered the revenue sharing among all consumers [45], whereas this research has taken into account the profit maximisation from a prosumer's perspective. Moreover, this research provides stable control operation of the proposed framework. The contribution by Akter *et al.* provided an energy-sharing model for a residential MG considering hierarchical energy management for three different cases following the participation of PV units and BESSs [46]. Their work dealt with a rule-based mechanism for the intelligent energy management. However, this work offers the state-of-the-art approach through NLP-based optimal economic operation of an MG framework for the maximum profit of prosumers, and robust control operation of the proposed system.

The main focus of this work is to ensure maximum utilisation of the available solar power and battery storage resources in a community. This paper proposes a novel energy-sharing framework for a remote locality where an MG is the only means of meeting the prosumers' load demand and routing excess energy to their neighbours to fulfil their much-needed energy demand. Here, an NLP-based optimisation model is presented for the day-ahead scheduling of maximum available power routing after fulfilling prosumers' and consumers' load demands, and the constraints of CSS for an off-grid remote MG framework. In the NLP formation, the optimisation focuses on boosting the PV owners' revenue by maximum power routing to neighbouring consumers after meeting their own load demands. Optimal economic operation of the proposed framework has been developed and applied to improve the MG's effectiveness. Furthermore, the power-routing framework is verified to be a stable control operation with proper voltage regulation utilising a droop controller in the power-control loop of the inverter. Therefore, the key contributions of this paper can be summarised as follows:

i. A smart load-sharing framework for an off-grid remote community is developed. This framework provides cost-effective performance for the smart houses as it routes surplus energy to nearby traditional houses without wasting it.
ii. An NLP-based optimisation model is developed and applied for the day-ahead scheduling of excess power routing for an optimal profit to stakeholders using the proposed MG framework.
iii. A novel off-grid power-routing management strategy is proposed that measures the instant load demands and PV generation, and routes the desired power to specific loads through priority formation utilising local and central controllers, while the prosumers are provided the highest priority.
iv. The proposed MG framework is verified by a droop controller through a real-time voltage control method, which provides stable DC and AC bus voltages and ensures better performance of the grid.

In the light of the above, the remainder of the paper is organised as follows. The power-routing framework is introduced in Section 2. The optimisation-based energy-sharing model is discussed in Section 3. Section 4 control strategy depicts the power-routing control strategy of the proposed framework. The results and discussions to validate the profit optimisation and controller performance are highlighted in Section 5, and concluding remarks on the research outcomes are presented in Section 6.

2 Power routing framework

The power-routing framework follows the concept of a solar home system (SHS), where small-scale commercial loads (such as a poultry farm) are interconnected with the own consumptive load [29]. Thus, the energy remaining after meeting the household load demand is utilised through an autonomous off-grid arrangement. In an MG framework, a number of small-capacity generators and battery energy storage systems (BESSs) are usually interconnected to a supply chain that provides electricity to several clients, where energy-sharing takes place among suppliers and consumers. A benefit of this situation is that homes in an island or rural area where no central grid is available can share energy using the MG framework. Moreover, a group of 10–20 houses in an urban zone can interconnect and share extra renewable energies among themselves by this kind of system [47], in which the MG s may connect or disconnect with the central grid for a time based on demand. This can reduce the pressure on the central grid. Furthermore, it is economical as the shared energy rate is cheaper than grid power [48]. However, the MG power quality is required to be maintained properly, following its distinctive features, control strategies, and power-management system. In the proposed system, a small cluster of houses within a short radius are interconnected to share electricity through the islanded off-grid arrangement. A few of them have a PV power-generation facility. The surplus power in the MG is routed to the neighbouring powerless houses after meeting the demands of prosumers by this framework.

Fig. 1 represents the conceptual architecture of the power-routing framework in a remote off-grid locality. The houses with PV systems are considered as prosumers and represented by smart houses, whereas a traditional house represents a consumer without any PV facility. The PV generation units of smart houses are connected to a DC bus via DC/DC boost converters and the power generated from the PV systems is stored in a CSS (CSS). The outputs of the CSS are connected to the MG controller (MGC) which controls the MG inverter. The MGC and LC controls are based on hierarchical-control strategies for effective power routing and stable operation. The main task of the MGC is to gather the power requirements measured by the local measuring units and route the desired power to specific loads. Generator and traditional houses are connected to the AC bus. The generator is utilised to supply power in an emergency situation when PV generation and CSS capacity is not enough to fulfil the energy demands of prosumers and consumers.

The overall power-routing process is represented in Fig. 2. Prosumers are prioritised during power dispatch. After fulfilling their total demand, the remaining power is routed to neighbouring traditional houses of the cluster according to the energy-sharing optimisation model. For a square deal, a uniform distribution is used among the traditional houses. All of them follow a prepaid payment method based on a unit energy price in buying electricity from the grid, and the total revenue is distributed among the eight prosumers by curtailing their consumption cost. The power meter

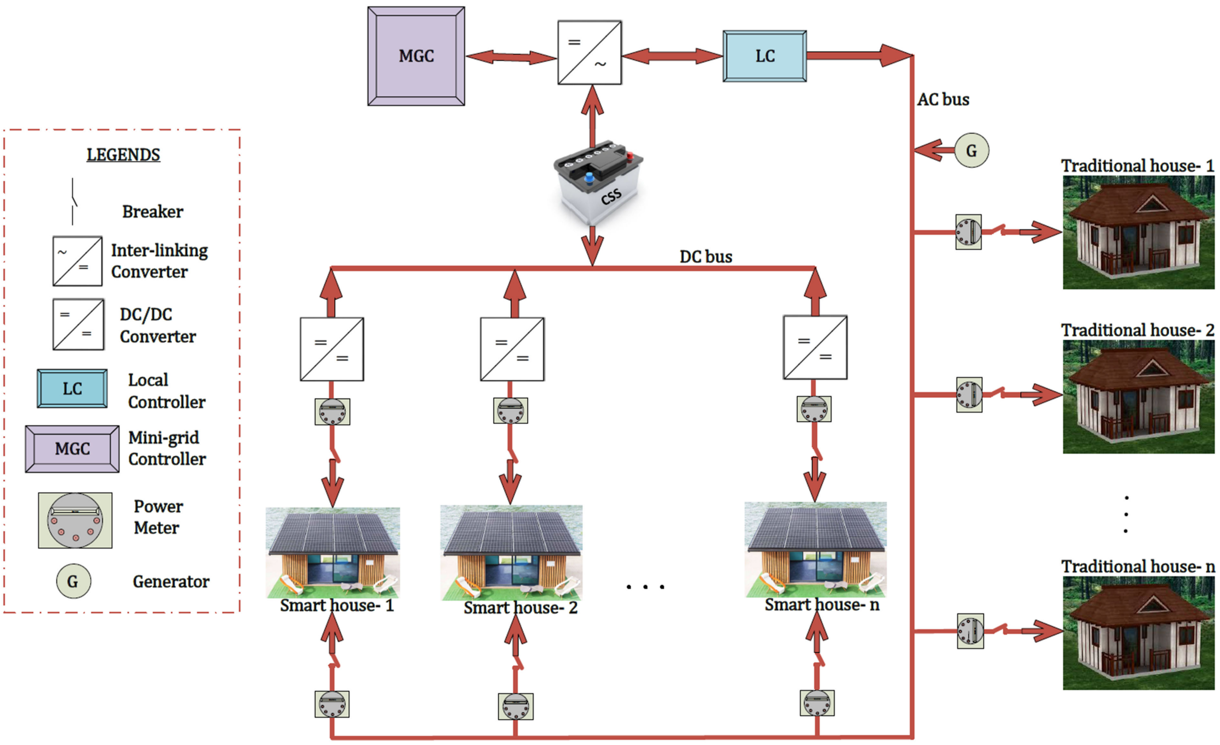

Fig. 1 *Conceptual architecture for the power routing framework*

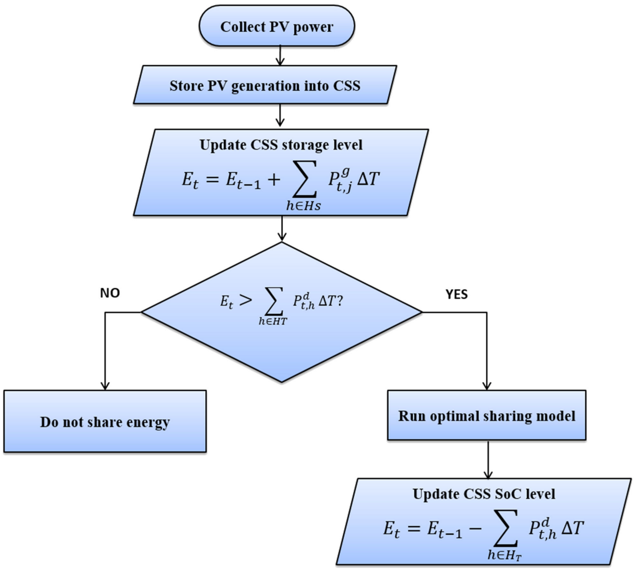

Fig. 2 *Power routing management strategy*

plays a vital role in power-flow calculations, payment information sharing, and management. The optimisation model for the energy sharing is described in Section 3. A modified control strategy is used with droop control that satisfies the voltage constraints for the energy sharing. The control strategy is discussed in Section 4.

3 Optimisation-based energy-sharing model

The main idea is to develop a power-routing framework that allows prosumers to utilise their excess PV generation by trading it with traditional consumers. Therefore, it will only sell energy to a consumer if there is any excess power in the MG. However, in an emergency when there is not enough power from both PV and CSS, the prosumers and consumers will draw energy from the generator. As the objective is to develop optimal power routing from a prosumers' perspective, only the profits of prosumers are considered. Generator activity is neglected as it does not have any role in profit maximisation from PV generation. However, this case study is aimed to show that the PV generation and CSS size are more than enough to fulfil the prosumers' demand and route the excess power. For the efficacy of the proposed model, it checks how much excess energy would be available to route for making optimal profit for prosumers after fulfilling their power demand and the battery-related constraints. The NLP-optimisation considers day-ahead forecasts of demand and PV generation to determine the power trading.

To fulfil the main objective of the energy-sharing model, maximising the profits of energy trading while satisfying the operational constraints of the CSS, the sharing model is formulated as a non-linear optimisation problem, expressed as:

$$\max_{P^s_{t,h},\, \lambda_t} \sum_{t \in T,\, h \in H} P^s_{t,h} \Delta T \lambda_t \tag{1}$$

subject to:

$$P^s_{t,h} = P^d_{t,h} \quad \forall h \in H_S \tag{2}$$

$$0 \le P^s_{t,h} \le P^d_{t,h} \quad \forall h \in H_T \tag{3}$$

$$\sum_{h \in H_T} P^s_{t,h} \Delta T \le SoC_t E_{cap} + \sum_{j \in G} P^g_{t,j} \Delta T \quad \forall t \tag{4}$$

$$\mathrm{SoC}_{\min} \le \mathrm{SoC}_t \le \mathrm{SoC}_{\max} \tag{5}$$

$$\lambda_{\min} \le \lambda_t \le \lambda_{\max} \tag{6}$$

$$\mathrm{SoC}_t = \mathrm{SoC}_{t-1} + \frac{\sum_{j \in G} P^g_{t,j} \eta_{ch} - \left(\sum_{h \in H} P^s_{t,h} / \eta_{dis}\right)}{E_{cap}} \tag{7}$$

Here, the objective function of (1) maximises the profits from energy trading. The optimisation variables $P^s_{t,h}$ represent the power supplied to house $h \in H$ during period $t \in T$ and λ_t indicates the per-unit cost for traded energy during $t \in T$. The duration of the time period is represented by ΔT. The load demand of houses $h \in H$ during period $t \in T$ is represented by $P^d_{t,h}$ and (2) and (3) indicate that the energy demand of smart houses $h \in H_s$ has the maximum priority in the energy-sharing model, whereas energy is traded with traditional houses $h \in H_T$ only after supplying the

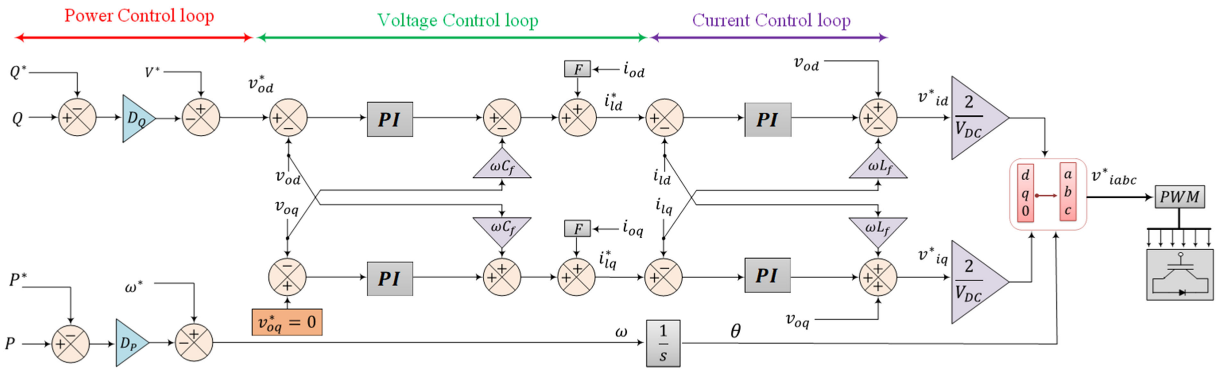

Fig. 3 *Inverter control structure*

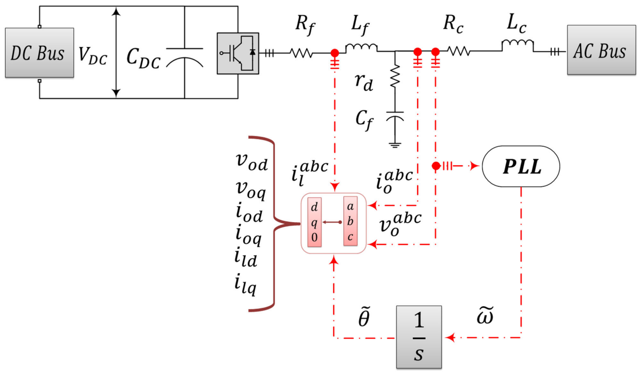

Fig. 4 *Inverter circuit diagram with LCL filter*

smart-house demand. As the objective is to develop optimal power routing from a prosumer's perspective, only the profits for prosumers are considered.

The energy-balance constraints in (4) and (5) ensure that energy is traded with traditional houses $h \in H_T$ only when there is excess energy stored in the CSS or if there is excess PV generation. Here, $P^g_{t,j}$ represents the power generation of the PV system $j \in G$ during $t \in T$. SoC_t indicates the SOC of the CSS during $t \in T$ and E_{cap} is the maximum storage capacity of the CSS. (5) and (6) indicate the upper and lower bounds for SoC_t and λ_t. The linear dynamics of the CSS state of charge is indicated in (7). Here, η_{ch} and η_{dis} indicate the charging and discharging efficiency of the CSS.

4 Power-routing control strategy

The MG power-routing strategy follows an ordered control operation of the DC-to-DC converter and DC-to-AC inverter control to obtain a stable performance throughout the period. The overall control method for effective energy sharing is described below.

4.1 DC-to-DC converter control

Here, the power supplied to each house ($P^s_{t,j}$) is determined from the optimisation model discussed in Section 3. Depending on the shared information, a control signal is sent either to discharge the CSS to supply a house load or to shed some or all of the house load. A PI controller is utilised following previous work in [43] to find the difference between the DC bus and CSS currents. Overall, the active power of the DC bus is regulated using the designed DC-to-DC converter controller.

4.2 DC-to-AC inverter control

This converter control maintains the output voltage of the DC bus at the CSS. The $P - V_{DC}$ droop-based control method is utilised to balance the active and reactive powers of the system. The total amount of PV generation and the total load supplied by the CSS at any instant are calculated as follows:

$$P^g_{total,t} = \sum_{j \in G} P^g_{t,j} \tag{8}$$

$$P^s_{total,t} = \sum_{i \in H_T} P^s_{t,j} + \sum_{i \in H_S} P^s_{t,j} \tag{9}$$

Multiple houses share their power to achieve the MG operation. As a result, to ensure robust power-sharing among multiple houses, with stable voltage and frequency regulation in the MG, a droop-control method is adopted in the power-control loop of the inverter. The conventional P/f and Q/V droop-control schemes are adopted to achieve the control objective. The droop-control schemes can be expressed as [49]:

$$\begin{aligned} \omega &= \omega^* - D_P(P - P^*) \\ V &= V^* - D_Q(Q - Q^*) \end{aligned} \tag{10}$$

where $\omega = 2\pi f$ and f is the frequency of the system. V^*, ω^*, P^* and Q^* are reference values for voltage, angular velocity, active power, and reactive power, respectively. D_P and D_Q are the droop coefficients. The inverter-controller structure is illustrated in Fig. 3. The AC and DC buses shown in Fig. 4 are interfaced through four-quadrant inverters and LCL filters. The filtered current (i_o^{abc}), the voltage (v_o^{abc}), and the output current (i_l^{abc}) in an abc reference frame are fed into an abc-dqo converter, which results into their corresponding dqo components. The synchronisation is carried out utilising a phase-locked loop (PLL), which generates the necessary synchronising angle for the abc-dqo converter. Overall, the inverter controller includes a power-control loop, a voltage-control loop, and a current-control loop. The detailed specification of the control parameters is summarised in Table 1. The power-control loop is designed with the conventional droop-control scheme that maps the output power from each house with the droop coefficients and with the optimisation-based energy-sharing unit. A decoupled control with a feed-forward technique is adopted for the voltage and current control loops. The main objective of the voltage-control loop is to generate reference values for i_d and i_q, which are i_d^* and i_q^*, respectively. The current-control loop generates the necessary reference signal for the associated pulse-width modulator (PWM), which controls the inverter. The detailed configuration of the inverter controller along with its small-signal model can be found in [50, 51].

5 Simulation and results

5.1 Simulation setup

The proposed method has been run through a simulation case study considering a MG framework in a remote islanded area of Bangladesh (Kutubdia) having an area of about 1000 m2 where no electricity facility exists. A total of 20 houses are considered, out of which eight are considered to be smart houses with PV generation units. The overall test model has a CSS with a maximum charging capacity of 90%, eight DC/DC converters having an output of 700 V DC, and a DC/AC converter (240 V). Fig. 5 reveals the average

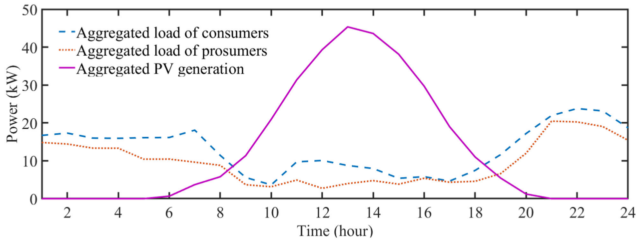

Fig. 5 *Aggregated PV generation and load profile of prosumers and consumers*

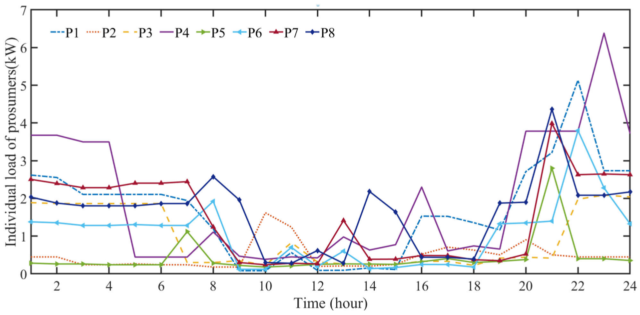

Fig. 6 *Individual load profiles of prosumers*

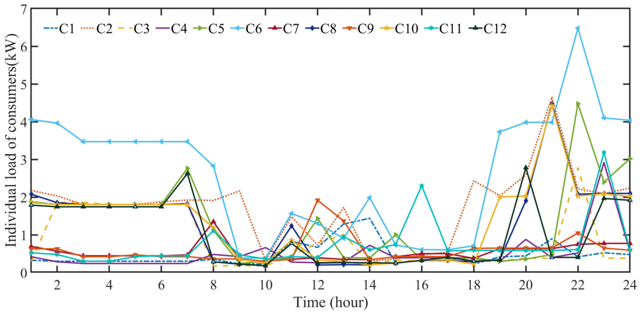

Fig. 7 *Individual load profiles of consumers*

daily aggregated load of the prosumers and consumers used for the case study. Figs. 6 and 7 show the individual load demands of all eight prosumers and 12 consumers, respectively. The electricity demands of both prosumers and consumers are a maximum at night time and a minimum at noon. The peak individual and aggregated loads of prosumers are about 6 and 20 kW, respectively, whereas the maximum individual and aggregated load demands of consumers are considered as approximately 6.5 and 24 kW, respectively. The aggregated load demand of consumers is higher than for prosumers as the number of consumers is 1.5 times that of prosumers in the proposed MG framework.

The solar irradiation profile of the location is depicted in Fig. 8. At mid-day, the maximum irradiation value of about 0.8 kW/m^2 is achieved. The irradiation value is zero until 5 am then increases gradually up to mid-day and starts to fall steadily after that time. At night no solar production is possible due to zero irradiation, although the maximum loads appear at night time for both prosumers and consumers. Therefore, the considered CSS with a capacity of 180 kWh has to play a vital role in energy storage and supply during night time, prioritising the prosumers' load demands.

Table 1 Control-system parameters

Parameter	Value
nominal AC bus RMS voltage:	240 V
nominal DC bus voltage:	700 V
damping resistor, r_d	$2 \times 10^{-3}\,\Omega$
L_f and C_f	250×10^{-6} H, 0.0169 F
ω^*	314.16 rad/s
power controller	
D_P and D_Q	3.14×10^{-5} rad/s/W 1.36×10^{-4} V/VAR
voltage controller	
k_p and k_i	7 and 800
current controller	
k_p and k_i	0.3 and 20
DC/DC converter	
k_p and k_i	0.2 and 1.1

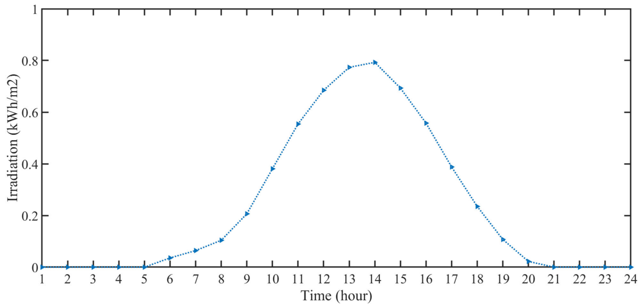

Fig. 8 *Solar irradiation profile at the microgrid location*

5.2 Results of energy-sharing model

Upon running the simulation, the non-linear problem discussed in (1)–(7) of section: optimisation model has been optimised. The objective function is optimised with respect to the considered constraints using MATLAB. Figs. 9 and 10 show the power demand and supply from the CSS for all the smart houses and traditional houses of the community, which is obtained from the simulation operation of the energy-sharing model. It is evident that all of the prosumers' hourly load demands are fulfilled. All the hourly loads of the consumers could not be supplied by the CSS of the MG framework due to the unavailability of energy in the CSS, especially in the early morning and late night time. At these times, when PV generation and CSS storage are not enough to route power to the consumers, the demand would be supplied by the generator. As the objective is to develop optimal power routing from a prosumer's perspective, only the profits of prosumers are considered. Generator activity is neglected as it does not have any role in profit maximisation by the available routed power, the main objective of this study. However, this case study ensures that in a typical day there is excess energy and prosumers make some profit by trading it. The SoC profile of the CSS is highlighted in Fig. 11. The minimum and maximum charge limits of the CSS are maintained as 10 and 90% over the whole day. At the beginning of the day, the charge level was about 53%, which reduced gradually until 10 am to supply load demands with zero PV power generation in the morning. As of high PV penetration at 10 am to 7 pm the storage increases rapidly to 90%, and after that gradually falls down to 33% at midnight as the CSS supplies power to the consumers' and prosumers' houses.

The hourly profit of the MG framework due to excess energy routing to the consumers is depicted in Fig. 12. The profit evaluations reveal that the greatest revenue rate occurred around mid-day, as the CSS got the highest storage at that time due to peak PV generation. The profit is zero for the first 9 h of the day, as the CSS is unable to supply power due its small storage and zero PV production. At night time, a moderate profit with an hourly rate of an average 3 AU$ is achieved by stakeholders through this proposed NLP-based optimal power-sharing framework. The average rate of trade is considered as 0.5231 AU$. The amount of total daily excess energy for routing is found to be ~109.57 kWh, which would have been wasted if not shared. Therefore, the total revenue of a typical day is about 57.32 AU$ (20,635.2 AU$/yr) with the proposed framework.

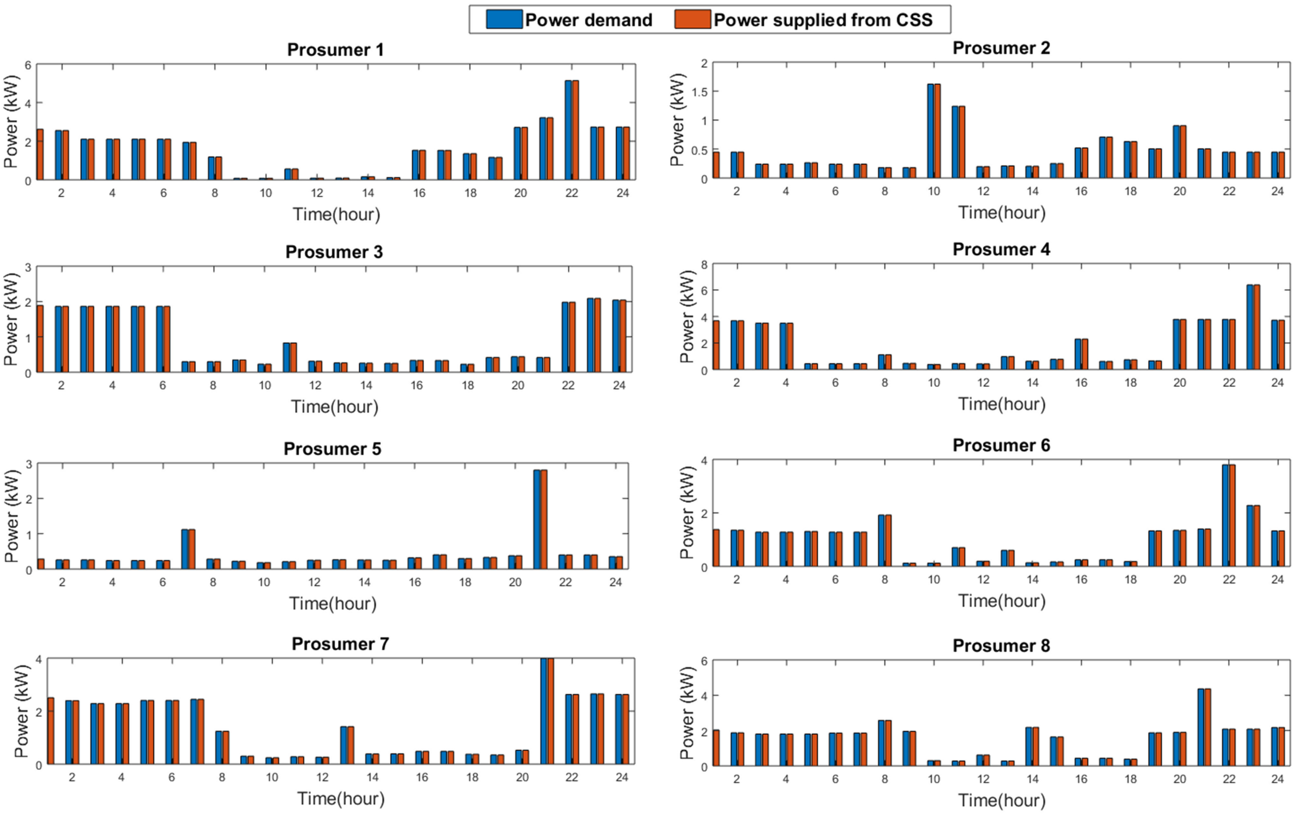

Fig. 9 *Hourly prosumers' demand and supply status*

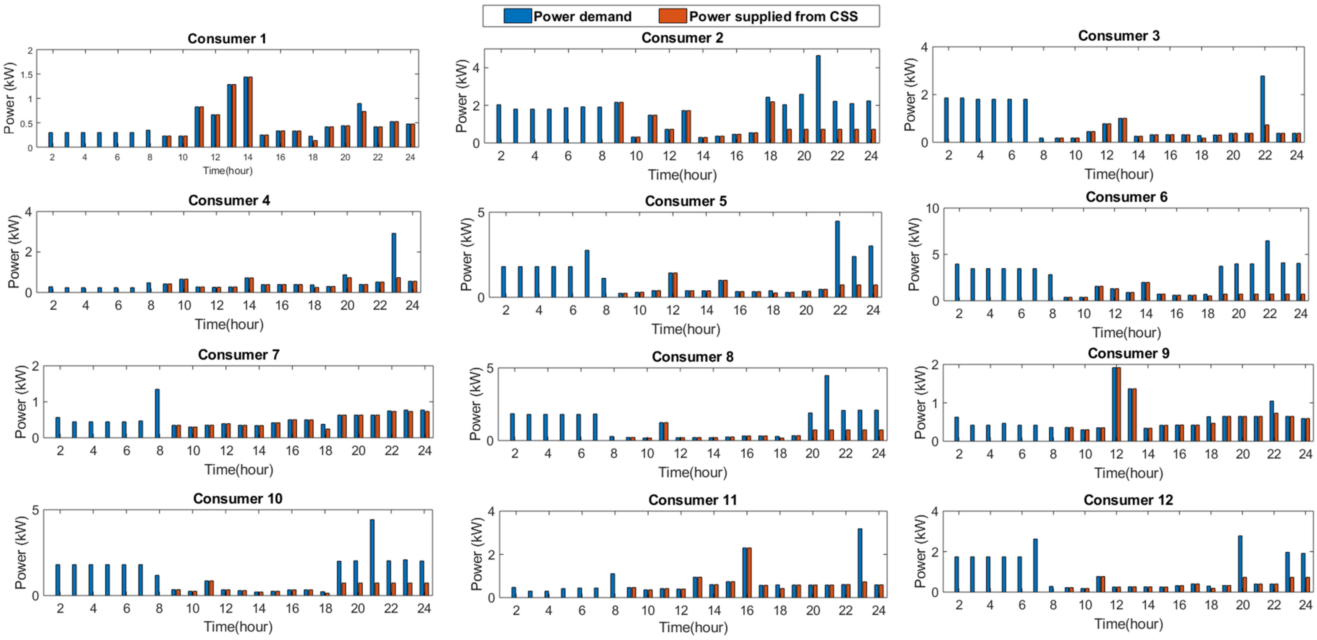

Fig. 10 *Hourly consumers' demand and supply status*

5.3 Controller operation outcomes

The proposed method is evaluated in simulation-based case studies. Real-life irradiation values are used for the PV generation. The output power generated from the 8 PV panels of the prosumers are utilised to meet their load demand and then any excess energy is routed to 12 neighbouring loads. The robustness of the designed controller is tested on an hourly basis assuming that the inverter provides similar behaviour at every hour. During the moment of energy dispatch, the inverter should provide stable operation, which is checked by the controller. The AC and DC loads of each house are connected to individual AC and DC buses of the MG. As a result, to ensure stable operation of the MG during various power-dispatch schedules the control operation is carried out, and thus both the AC and DC bus voltages are regulated. The bus voltage profiles of the proposed method of controller operation for a selected time period are depicted in Fig. 13. It is observed that both the AC and DC bus voltages were quite stable throughout the period except for initial fluctuations. The community storage plays a vital role in regulating both bus voltages. In particular, during this control operation, the community storage acts as a slack bus that can support the DC bus voltage through the DC/DC converter. The AC bus voltage is regulated using four-quadrant operation of the interconnecting inverter. As both AC and DC loads are supplied accordingly by the PV and the community storage, both bus voltages are well regulated.

The acceptable frequency operating range for the continuous uninterrupted MG operation is about 50 Hz. It is shown in Fig. 14

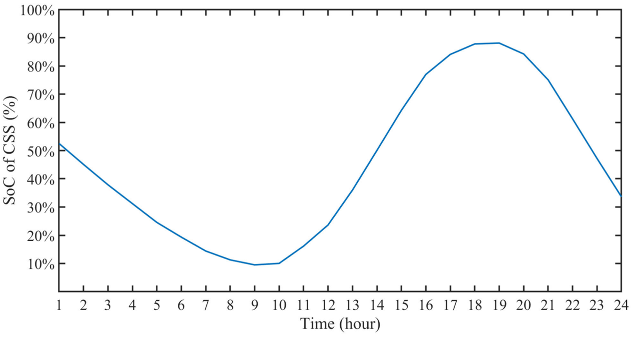

Fig. 11 *%SoC of the central storage system*

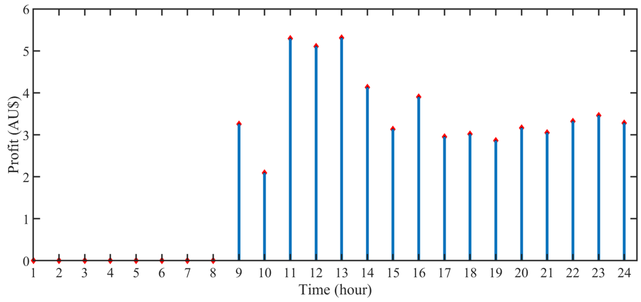

Fig. 12 *Hourly profit from the microgrid framework*

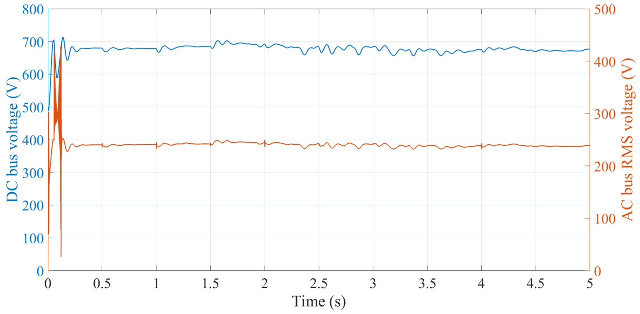

Fig. 13 *AC and DC bus voltages*

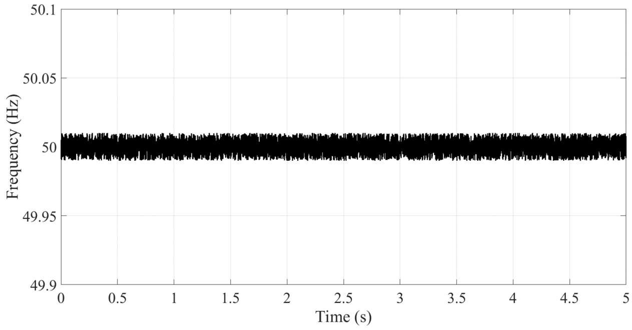

Fig. 14 *AC bus frequency*

that the frequency at the AC side of the MG is regulated within the operating range for diverse optimal power scheduling due to the robust nature of the droop-based inverter controller.

6 Conclusion

Here, a new power-sharing approach by a PV/CSS hybrid-source-based remote-area MG framework is proposed. This method performs all the necessary tasks such as load sharing among eight PV owner units and 12 neighbour units, battery charging and discharging, and PV power curtailment with proper communication among the units. To ensure the efficacy of the MG system, we (i) developed a novel energy-sharing framework, (ii) optimised based on profit maximisation for cost-efficient operation, and (iii) verified that a typical droop-controller-based control method gave stable functioning. This research work is novel in developing an NLP-based optimisation model for day-ahead scheduling of available power routing using the proposed smart-power-routing framework, which routes any excess energy to neighbour loads and so utilises energy that would have been wasted, and provides revenue to the owners. The efficacy of the proposed method of economic optimising and stable control operation under different load, PV generation, and central storage conditions is validated by simulation, with results presented to demonstrate its effectiveness. From the simulation results, it is evident that the non-linear-programming-based techno-economic optimisation gives a maximum revenue of 57 AU$/day to the prosumers. Furthermore, the designed controller is shown to have excellent performance, with accurate power-sharing and voltage-regulation capabilities. The future direction of this research is directed towards consideration of the national grid and other renewable-energy sources in the system and finding an optimised power-routing scheme for obtaining a successful power solution in the whole country, reducing the pressure on the national grid.

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