Optimal Economic Dispatch of Grid-Interactive Renewable Prosumers with Hybrid Storage and Peer to Peer Energy Sharing Capabilities

Kanzumba Kusakana
Dept. of Electrical, Electronic and Computer Engi., Central University of Technology, Bloemfontein, South Africa
Email: kkusakana@cut.ac.za

Abstract—**Currently, there is few research works focusing on the optimal power dispatch of hybrid renewable energy systems operating in conjunction with hybrid energy storage systems, precisely the combination of pumped hydro storage and battery storage systems. Moreover, there is a lack of studies that focusing on analysing the potential energy cost reduction resulting from the economic power dispatch applied to hybrid energy systems combining grid-interactive renewable energy sources with hybrid energy storages under the peer to peer energy sharing scheme. Given the fact that each of these concepts has the potential benefit of reducing the operation energy cost; this study proposes an optimal energy management model of two grid-interactive prosumers operating in a peer to peer energy sharing mode to supply the loads both from the hybrid renewable sources and hybrid storage systems whilst minimizing the cost of energy purchased from the national grid. Simulation were conducted using different scenarios linked to the internal power sharing pricing structures. The results showed that the proposed arrangement has the potential to reduce substantial energy cost; decrease the reliance of the prosumer from the grid as well as reducing the need of having a larger storage.**

Index Terms—**Economic dispatch; grid interactive, hybrid renewable energy sources, hybrid storage systems, peer to peer energy sharing**

I. Introduction

Over the past two decades, the use of renewable energy sources such as solar, wind or hydropower has significantly increased for electricity generation in both isolated and grid-connected applications [1]. These renewable energy sources (RESs) are environmental friendly and can be deployed from micro to large scale as alternatives to fossil fuels [2]. One common challenge with the use of RESs is their reliance on the variable resources and climatic conditions, making their power generated too unreliable to continuously meet the load demand requirements, which can lead to excess or under generation [3].

Given the different characteristics as well as complementarity of different RESs, hybrid energy systems (HESs) have been implemented to solve the unbalance problem between the load demand and the supply from RESs. These HESs can incorporate different RESs and/or energy storage systems (ESSs), with the ability of increasing the availability of power supply [4]. Given the number of existing energy sources as well as storage systems, different HESs topologies can result in combining the different available generation and storage technologies to assist the power balance between the supply and the demand.

Generally, isolated RESs employ battery storage systems (BSSs) to solve the power unbalance problem between generation and supply [5]. Given their short production time and their ability to be easily deployed in any site, batteries have been the storage system of choice for isolated RES [6]. The current trend in the energy storage system research filed has shown an increased interest in the use pumped hydro storage systems (PHSs).

This ESS is well known, requires low maintenance, has a long lifespan, can produce high energy density, is environment friendly and has high roundtrip conversion efficiency; these characteristics makes PHS well suited to support the fluctuation of RESs such as isolated hydrokinetic (HKT), PV and wind energy conversion systems [7]-[13]. However, some of the challenges observed when operating existing PHSs are the fairly low power and energy density, which necessitates either large water flows and/or large net height between the upper and lower reservoirs, as well as the slow response rate when balancing lower power deficits [14]. Therefore, PHSs can be used in hybrid configurations with other ESSs to take advantage of the resultant energy storage capabilities and further support the stochastic power generated from RES.

Like renewable energy systems, the different storage technologies currently available have their own technical properties. Therefore, they can also be combined in hybrid storage system (HSS) topologies this hybridization provides excellent characteristics which cannot be offered by a single ESS [15]. Many research works published in the last decade looked at the operation control of hybrid storage systems with topologies such as battery-supercapacitor, fuel cell-battery-supercapacitor, fuel cell-supercapacitor or battery-pumped hydro storage.

The subsequent compiled literature reveals that very few studies have analysed the optimal energy management of integrated PHSs with other ESSs to

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Corresponding author: K. Kusakana (email: kkusakana@cut.ac.za).

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support RESs. Guezgouz *et al*. [16] presented an energy management model for an HES composed of a PV and wind supported by a HSS (PHS-BES). The work opened a path to the concept of HSSs operating in conjunction with non-dispatchable RESS such as PV or wind supplying isolated loads. Bhayo *et al*. [17] analysed a HES composed of a PV, a BSS, a hydro system and a PHS for optimal energy management, considering the excess generated power. The results have demonstrated that integrating a rainfall-based hydropower system with an optimally sized water storage situated at a specific net water head can resulted in a substantial reduction of the PV size as compared to system without rainfall-based hydropower system. Javed *et al*. [18] proposed a novel operating strategy for a hybrid PHS-BSS operating with an isolated RES. The results obtained based on energy output analysis have shown that during peak power demand periods, PHS comes into operation when the minimum SOC is almost reached, while low power shortages are met by the BSS. Abdelshafy *et al*. [19] presented an energy management model to minimize the cost as well as the CO_2 emissions of a grid-connected double storage system consisting of a PHS-BSS supplied by a HES. The research findings have demonstrated the techno-economic and environmental effectiveness of the proposed model. Kumar and Biswas [20] studied the feasibility of combining a PHS and a BSS supplied by a PV. The results revealed that utilizing a small BSS with PHS can significantly reduce the upper reservoir size, which can subsequently decrease the excess energy generated. Ma *et al*. [21] analysed the combination of BSS and PHS for the RES suppling a microgrid in an isolated island in Hong Kong. Several options have been analysed i.e. advanced deep cycle BSS, conventional BSS, PHS without BSS, and PHS combined with BSS. Sensitivity analysis revealed that PHS becomes even more cost-effective by increasing the upper reservoir capacity. Bento *et al.* [22] proposed an optimal dispatch model for a grid connected/stand-alone HES, supplying power to an industrial prosumer using a HES made of BSS and PHS. Different scenarios were analysed to highlight the techno-economic effectiveness of the developed model.

As compared to standalone systems, the optimal economic power dispatch between the sources, load and storages become more complex when HES are connected to the grid with a bi-directional power flow, and demand response strategies, such as variable time of use tariff, are implemented. As solutions to this challenge, different innovative approaches can be implemented to minimize the energy cost supplied to the demand while increasing the penetration of RESs. The first solution is to use the grid connection to sell the excess power generated from RESs during periods when the load demand is lower than the available supply. The consumer can also make use of the available ESS to store the excess power from the renewable sources during off peak demand time and use it later during peak load demand. This option enables the consumers to have full control of the bi-directional power flow between their installations and the grid (buying and selling). This type of arrangement is referred to as grid-interactive system [23]. Due to the incorporation of energy storage, an added benefit of the grid-interactive systems is that the users can take advantage of the time-of-use (TOU) electricity tariff, through peak shaving, to further minimize the total cost of energy purchased from the grid. However, this solution is influenced by the magnitude of the incentive linked to the feed-in tariff (FIT) implemented. Also, given the fact that RESs such as PV and wind have achieved grid parity, most of regulatory frameworks are gradually ending feed-in tariffs, which were previously used to support the integration of these technologies [24].

The second proposed solution is based on taking advantage of the fact that it is very unlikely that different load demands can display the same profile at the same time. Therefore, different small RESs producers, in close proximity, can assist each other in balancing their excess energy generated with other consumers that are in deficits or those who would like to reduce their reliance from the utility. The involved energy customer and producers can independently participate in energy trading with each other and the grid. This novel next-generation energy management concept is defined as Peer-to-Peer (P2P) energy sharing and has benefits such as the RESs usage maximization, energy cost reduction, peak load shaving, prosumer empowerment and lifecycle cost minimization. [25]. Similar trading arrangements are applied in concepts such as Bitcoin, Airbnb or Uber.

P2P energy sharing is an innovative scheme for trading energy between consumers who also can produce their own electricity; they are referred to as "prosumers" [26]. In the traditional energy trading scheme, there is a bilateral energy trading between the utility and the prosumers; where the excess of energy generated by a prosumer can only be fed back to the grid for an imposed tariff which is generally lower than the price of the kWh purchased from the grid. On top of trading with the utility, the P2P energy sharing scheme enables prosumers to further trade their energy generated among themselves. Prosumers can agree on a pricing mechanism linked to the internal energy transactions.

Several recent research works, related to the optimal P2P energy sharing between renewable prosumers, have been described in the literature. Zhang *et al*. [26] conducted a survey of existing P2P projects with the focus on comparing their similarities and differences based on the business aspect. Zepter *et al*. [27] developed a framework to incorporate local P2P energy transactions from solar, wind and battery in wholesale markets, using a stochastic linear programing approach. Alam *et al*. [28] analysed the best sharing arrangement of distributed energy resources comprising PV, battery and electric vehicles to minimize the community's operation cost using a mixed integer linear programing approach. Ira *et al*. [29] performed a comparison analysis between an aggregator and a centralized market from residential prosumers with PV and battery, using two stage stochastic cost optimization approach. Kusakana [30] analysed P2P energy transactions between isolated prosumers generate electricity from a HKT, a diesel generator and a pumped hydro storage scheme using a nonlinear optimization approach. Nguyen *et al.* [31] assessed the economic benefits of P2P between prosumers with rooftop PV and battery storage systems, using a mixed integer linear programing approach. Lüth *et al*. [32] performed an analysis of P2P energy trading comparing centralized to decentralized energy storage on a renewable energy prosumer community, using a linear programming approach. Liu *et al*. [33] proposed an energy sharing model for residential PV prosumers using a bi-level programming approach of supply demand ratio and flexibility demand. El-Baz *et al*. [34] developed a trading model framework for a microgrid composed of a solar PV, micro-CHP, electric vehicle and heatpump, including near real-time pricing, nonpredictive bidding strategies according to individual component type as well as probabilistic solar PV generation prediction. An *et al*. [35] proposed a P2P electricity sharing model based on the minimum and maximum electricity trading charges to guarantee the profitability of the involved residential PV prosumers.

Considering the different studies discussed and summarised above, it can be noticed that, currently there is few research works focusing on the optimal power dispatch of HRES operating in conjunction with HSSs, precisely the combination of PHS and BSS. Moreover, there is a lack of studies that focusing on analysing the potential energy cost reduction resulting from the economic power dispatch applied to HESs combining grid-interactive RESs with HSSs under the P2P energy sharing scheme. Given the fact that each of these concepts has the potential benefit of reducing the operation energy cost, this study proposes an optimal energy management model of two grid-interactive prosumers operating in a P2P energy sharing mode to supply the loads both from RESs (PV and HKT) and storage systems (BSS and PHS) whilst minimizing the cost of energy purchased from the national grid. The main contributions of this study can be highlighted as:

A new HES architecture is proposed, integrating PV and HKT as RES, as well as BSS and PHS as ESSs.

- An optimal energy management model is developed to minimize the energy costs of the grid-interactive prosumers operating with P2P energy sharing capabilities. The model looks at the variable demands, variable resources, applicable ToU, Feed-in tariff as well at the different internal energy sharing pricing structures to minimize the total operation energy cost.
- The impact of the P2P energy sharing of the BSS and PHS operating range is also analysed as compared to the case without P2P.
- Unlike in many microgrid-based studies, the energy costs are computed for each prosumer, not as a community. This gives a clear picture of how each prosumer benefit from the available storage, grid-interactivity as P2P energy sharing. This shows assists to demonstrate how does P2P energy sharing performs in comparison with grid interactive for the proposed set-up.

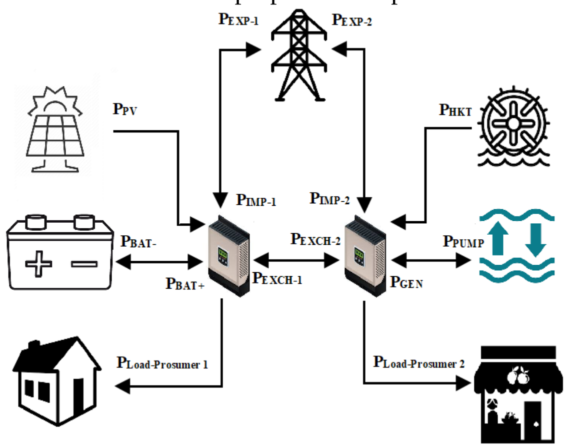

Fig. 1. Proposed system power flows.

II. Description of the Proposed System

The studied HES is composed of two grid-interactive prosumers: one has PV and a BSS while the other is composed of a HKT and a PHS as shown on Fig. 1.

Additionally, these prosumers are connected to each other by power lines to operate in a P2P energy sharing mode, this results in a HES with a HSS. The two prosumers can be in different operating modes such as generating power, storing energy, purchasing power from the grid, selling power to the grid or exchanging power with the other prosumers; therefore, an optimal energy management strategy is needed to minimize the total energy cost of each prosumer.

The various power flows in the considered arrangement given on Fig. 1 may be defined as follows: P_{PV}: Power produced by the prosumer 1's PV, P_{BAT+}: Power output from the prosumer 1's battery, P_{BAT-}: Power input to the prosumer 1's battery, $P_{IMP\text{-}1}$: Power imported from the grid to the prosumer 1, $P_{IMP\text{-}2}$: Power imported from the grid to the prosumer 2, $P_{EXP\text{-}1}$: Power from the prosumer 1 exported to the grid, $P_{EXP\text{-}2}$: Power from the prosumer 2 exported to the grid, $P_{EXCH\text{-}1}$: Power to the prosumer 1 procured from prosumer 2, $P_{EXCH\text{-}2}$: Power to the prosumer 2 procured from prosumer 1, P_{HKT}: Power produced by the prosumer 2's HKT, P_{GEN}: Power from the PHS's turbine-generator set, and P_{PUMP}: Power to the PHS's motor-pump system.

III. Model Development

A. Objective Function

The developed model aims to minimize the overall net energy cost of each prosumers. For each prosumer taken individually, the net energy cost results from maximizing the revenue generated and minimizing the spending under the Time of Use. This is modelled as:

$$f = \sum_{j=1}^{N} (\rho_j \times P_{IMP-i(j)} + \theta_j \times P_{EXC-IN-i(j)} - (\delta \times P_{EXP-i(j)} + \theta_j \times P_{EXC-OUT-i(j)})) \times \Delta t \quad (1)$$

where f is the cost function linked to the developed model to be implemented, i is the considered prosumer (1 or 2), ρ_i is the energy charge structure from the grid defined by the applicable ToU tariff, δ is the flat feed-in tariff structure for energy sold to the grid, θ_j is the cost of energy allocated to the internal power sharing between prosumers, j is the selected j^{th} sample interval where the optimization is taking place, N is the overall number of sample intervals, and Δt is the duration of each sampling interval.

B. Load Balances

Using the diagram given in Fig. 1, for each optimization period, the load balance derived from the power controller on each prosumer's side can be modelled as:

$$P_{Load-1(j)} = P_{PV(j)} + P_{BAT+(j)} + P_{IMP-1} + P_{EXC-1(j)} - (P_{BAT-(j)} + P_{EXP-1(j)} + P_{EXC-2(j)}) \quad (2)$$

$$P_{Load-2(j)} = P_{HKT(j)} + P_{GEN(j)} + P_{IMP-2} + P_{EXC-2(j)} - (P_{PUMP-(j)} + P_{EXP-2(j)} + P_{EXC-1(j)}) \quad (3)$$

where $P_{Load-i(j)}$ is the prosumer's load demand in each considered optimization interval.

C. State Variables

For any considered ESS, the State of Charge (SoC) is basically the ratio of the available energy (charge or volume) at a sampling time j over the maximum capacity of storage system (battery or upper reservoir). The SoC dynamic of the BSS and PHS can be respectively modelled using (4) and (5):

$$SoC_{BAT(j)} = SoC_{BAT(0)} \times (1-\gamma) + \frac{\Delta t}{E_{BAT}} \times \left(\eta_{ch} \times \sum_{i=1}^{j} P_{BAT-(j)} - \frac{\sum_{i=1}^{j} P_{BAT+(j)}}{\eta_{disc}} \right) \quad (4)$$

$$SoC_{PHS(j)} = SoC_{PHS(0)} \times (1-\alpha) + \frac{\Delta t}{E_{PHS}} \times \left(\eta_{ch} \times \sum_{i=1}^{j} P_{PUMP(j)} - \frac{\sum_{i=1}^{j} P_{GEN(j)}}{\eta_{disc}} \right) \quad (5)$$

D. State Variables

For all the considered optimization sample (j), the sum of power flows originating from any power source incorporated in the system must be less or equal to the instantaneous power generated by the considered power source.

$$P_{PV-Load-1(j)} + P_{PV-BAT-(j)} + P_{PV-EXP-1(j)} + P_{PV-EXCH-2(j)} \le P_{PV(j)}^{\max} \quad (6)$$

$$P_{BAT-Load-1(j)} + P_{BAT-EXP-1(j)} + P_{BAT-EXCH-2(j)} \le P_{BAT+}^{Rated} \quad (7)$$

$$P_{IMP-1-Load-2(j)} + P_{IMP-1-BAT(j)} \le P_{IMP-1}^{\max} \quad (8)$$

$$P_{HKT-Load-2(j)} + P_{HKT-PUMP-(j)} + P_{HKT-EXP-2(j)} + P_{HKT-EXCH-1(j)} \le P_{HKT(j)}^{\max} \quad (9)$$

$$P_{GEN-Load-2(j)} + P_{GEN-EXP-2(j)} + P_{GEN-EXCH-1(j)} \le P_{GEN}^{Rated} \quad (10)$$

$$P_{IMP-2-Load-2(j)} + P_{IMP-2-PUMP(j)} \le P_{IMP-2}^{\max} \quad (11)$$

E. Exclusive Power Flows

This condition is applied to the power flows that cannot occur simultaneously in the same considered sampling interval. Considering Fig. 1, this condition is applied to the branches and components experiencing bidirectional power flows; the following exclusive power flows on the operation strategy are considered:

$$P_{BAT+(j)} \times P_{BAT-(j)} = 0 \quad (12)$$

$$P_{IMP-1(j)} \times P_{EXP-1(j)} = 0 \quad (13)$$

$$P_{EXCH-1(j)} \times P_{EXCH-2(j)} = 0 \quad (14)$$

$$P_{GEN(j)} \times P_{PUMP(j)} = 0 \quad (15)$$

$$P_{IMP-2(j)} \times P_{EXP-2(j)} = 0 \quad (16)$$

$$P_{IMP-1(j)} \times P_{EXCH-2(j)} = 0 \quad (17)$$

$$P_{IMP-2(j)} \times P_{EXCH-1(j)} = 0 \quad (18)$$

$$P_{EXP-1(j)} \times P_{EXCH-1(j)} = 0 \quad (19)$$

$$P_{EXP-2(j)} \times P_{EXCH-2(j)} = 0 \quad (20)$$

F. Final Fixed State

To allow for the repeatability of the optimization algorithm; the respective SoC of the battery and the PHS at the beginning and of the simulation horizon must be equal to the one at the end. These can be modelled as:

$$\sum_{j=1}^{N} (P_{BAT+(j)} + P_{BAT-(j)}) = 0 \quad (21)$$

$$\sum_{j=1}^{N} (P_{PUMP(j)} + P_{GEN(j)}) = 0 \quad (22)$$

G. Solver Selection

The problem can be treated as a non-linear optimization problem due to the product of the variables in (12) to (20); the optimization problem can be solved using "*fmincon*" solver from MATLAB (R2019b) optimization toolbox [36].

IV. Simulation Results and Discussion

A. Baseline 1: Loads Exclusively Supplied by the Grid

The HRES is supplied from the grid using the applicable Eskom Ruraflex — Local Authority tariff structure for 2019/2020. The ToU pricing periods, the rates per kWh for the different seasons as well as the flat feed-in tariff in Mangaung municipality were given in [10]. Fig. 2 can also be used to represent the profiles of the power exclusively supplied from the grid to the two demands.

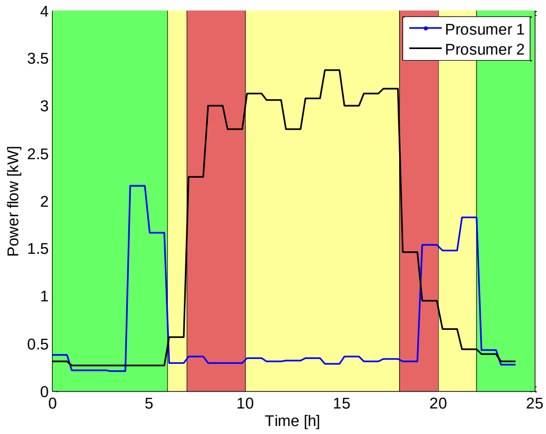

Fig. 2. Prosumers' daily demand profile.

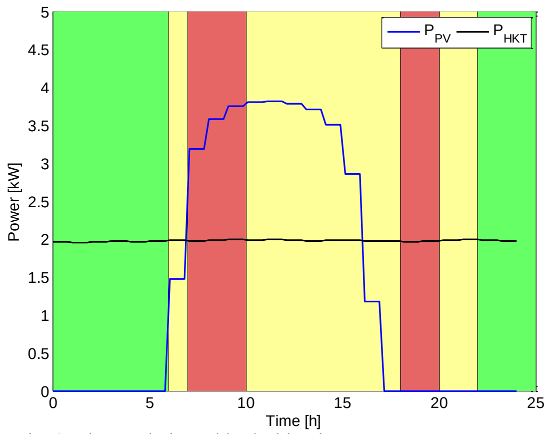

Fig. 3. Photovoltaic and hydrokinetic systems' output power.

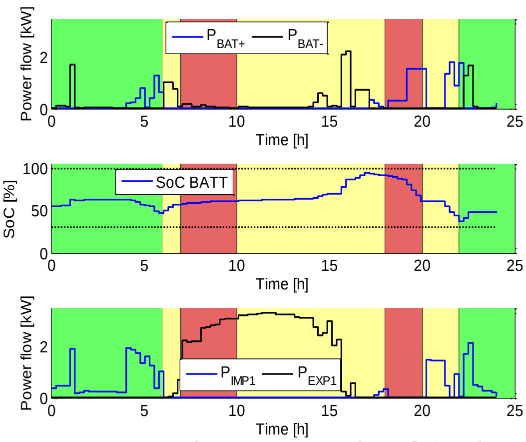

Fig. 4. Prosumer 1 optimal economic power dispatch (Baseline 2).

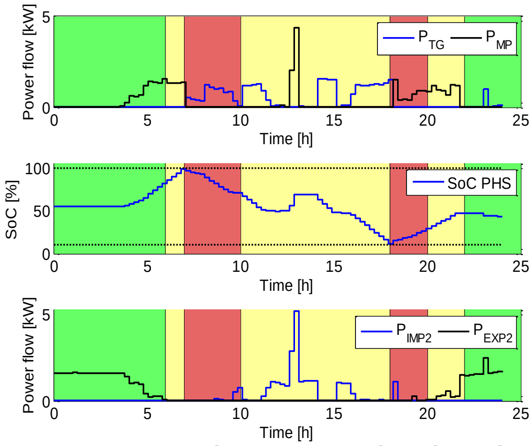

Fig. 5. Prosumer 2 optimal economic power dispatch (Baseline 2).

B. Prosumer Component Sizing

Prosumer 1 has a 3.72kWp dual axis solar tracking with a Pylon 9.6kWh Lithium battery and a Lynx Axpert 5kVA 48V inverter. Prosumer 2 has a 2kW Hydrokinetic system with a 5kW, Water Motor-Pump, a 5kW Water Turbine-Generator and a 136m^3 Upper reservoir situated at 170m height.

Fig. 3 shows the power generated by the PV (owned by prosumer 1) and the by HKT system (owned by prosumer 2). Fig. 4 and Fig. 5 respectively present the simulation results for prosumer 1 under the grid-interactive scenario. The focus is on maximizing the use of the PV and HKT on each prosumer's side while maximizing the power sold to the grid and minimizing the power purchased from the grid. The resultant optimal power flows and the battery as well as the PHS SoCs are indicated for the different pricing periods (green: off-peak; yellow: standard; red: peak).

C. Baseline 2: Optimal Grid-Interactive HRES Prosumers without P2P

In this case the operation of each prosumer is analyzed individually. Each prosumer will optimally manage its power generation, storage as well as integration with the grid with the aim of reducing the net energy cost.

D. Optimal Grid-Interactive HRES Prosumers with P2P

In this case, the operation of the two grid-interactive prosumer, where the P2P transactions are incorporated, is analyzed based on the different pricing structures applied to the internal energy sharing. The renewable energy resources, the size of the components as well as the grid structure remain the same as in the case without P2P.

The impact of the following P2P cost structures on the prosumers' operation costs will be analyzed:

- Case 1: P2P energy transaction as 65% of ToU.
- Case 2: P2P energy transaction as flat tariff similar to off-peak ToU.
- Case 3: P2P energy transaction is free.

Fig. 6 to Fig. 11 show the different magnitudes of the powers exchanged (P_{EXC1} and P_{EXC2}) between the two prosumers using the P2P scheme for the Case 1, Case 2 and Case 3 respectively. The change in magnitude in the powers exchanged is due to the different energy pricing structures allocated to the P2P transactions; therefore, the two prosumers tend to maximize the power exchanged through this arrangement.

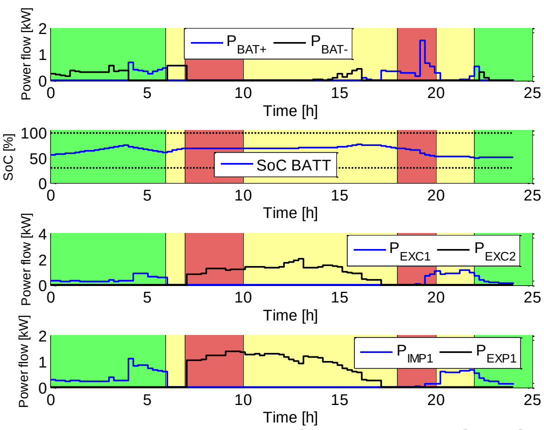

Fig. 6. Case 1: Prosumer 1 optimal economic power dispatch.

TABLE I: PROSUMERS' DAILY ENERGY SCENARIOS COST SUMMARY

Power flows	Energy cost (ZAR)				
	Baseline 1	Baseline 2	Case 1: P2P 65% of ToU	Case 2: P2P flat tariff off-peak ToU	Case 3: P2P free
P_{IMP1}	81.96	29.24	15.95	9.54	5.5
P_{EXP1}	-	47.53	19.43	6.56	10.16
P_{EXC1}	-	-	14.8	21.77	-
P_{EXC2}	-	-	58.21	70.79	-
P_{IMP2}	324.84	36.39	35.3	6.65	7.56
P_{EXP2}	-	22.71	13.14	16.5	14.13
Prosumer 1 Net cost = P_{IMP1} -P_{EXP1} +P_{EXC1} -P_{EXC2}	81.96	18.29	-46.89	-46.04	-4.66
Prosumer 2 Net cost = P_{IMP2} -P_{EXP2} -P_{EXC1} +P_{EXC2}	324.84	13.68	65.57	39.17	-6.57
Total as a microgrid (Net cost 1 + Net cost 2)	406.8	31.97	18.68	-6.87	-11.23

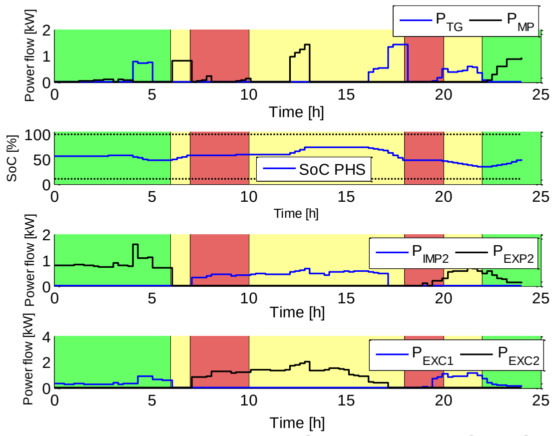

Fig. 7. Case 1: Prosumer 2 optimal economic power dispatch.

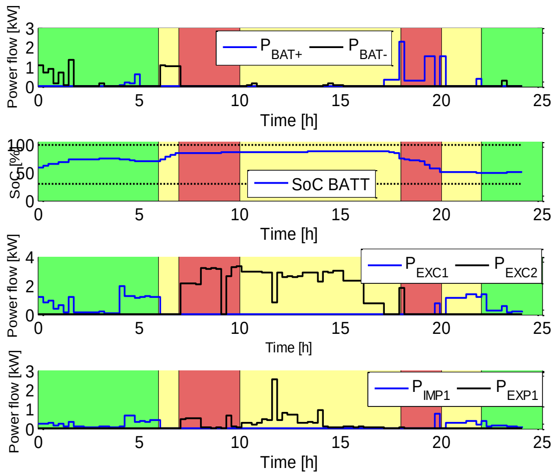

Fig. 8. Case 2. Prosumer 1 optimal economic power dispatch.

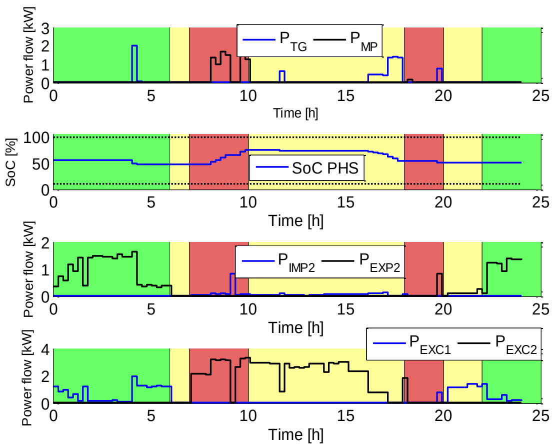

Fig. 9. Case 2: Prosumer 2 optimal economic power dispatch.

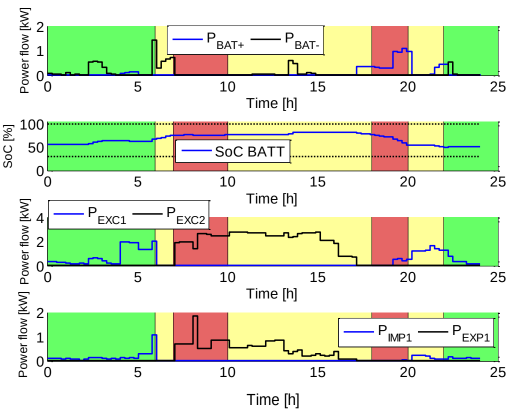

Fig. 10. Case 3. Prosumer 1 optimal economic power dispatch.

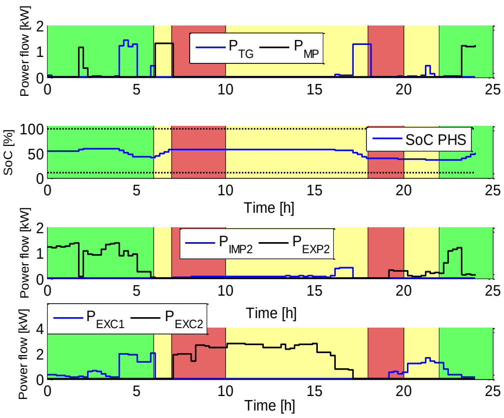

Fig. 11. Case 3. Prosumer 2 optimal economic power dispatch.

Fig. 6 to Fig. 11 also show that the pricing structures also have an influence on the grid-interaction; both the powers exported and imported (P_{EXP1} and P_{IMP1}), the PHS powers (P_{TG} and P_{MP}) as well as the battery power flows (P_{BAT+} and P_{BAT-}) are different in the 3 Cases even if the resources and the prosumer load demands are the same.

Looking at each prosumer individually, Case 1 is favorable for prosumer 1 while Case 3 is favorable for prosumer 2. However, looking at the microgrid as a unit, Case 3 is the most beneficial.

V. ECONOMIC ANALYSIS

The daily energy cost savings of each prosumers partaking in the P2P energy sharing scheme are computed and compared with the grid only and grid-interactive HRES cases taken as baseline 1 and baseline 2, respectively. In Table I, the different components of the net energy cost are shown for each prosumers.

As compared to using the grid as sole power source, prosumer 1 can achieve a daily energy cost reduction of 157% in Case 1 (P2P energy transaction as 65% of applicable ToU); of 156% in Case 2 (P2P energy transaction as flat tariff similar to off-peak ToU) and 105.7% in Case 3 (Free internal power sharing). Prosumer 2 can achieve a daily energy cost reduction of 79.81% in Case 1; 87.94% in Case 2 and 102% in Case 3. The total daily cost saving of the two prosumers as a microgrid is 95.40% in Case 1; 101.68% in Case 2 and 102.76% in Case 3.

As compared to using the grid-interactive HRES, prosumer 1 can achieve a daily energy cost reduction of 356.36% in Case 1; of 351.72% in Case 2 and 125.47% in Case 3. However, prosumer 2 experiences an increase on the daily energy cost of 379.21% in Case 1; and increase of 186.33% in Case 2 and a decrease of 148% in Case 3. The total daily cost saving of the two prosumers as a microgrid is 41.57% in Case 1; 121.49% in Case 2 and 135.12%.

VI. Conclusion and Scope for Future Work

In this study an optimal economic dispatch model of two grid-interactive prosumers operating in a P2P energy sharing mode is proposed. The prosumers were both supplied from a HES (PV and HKT) and a HSS (BSS and PHS) and the cost of energy purchased from the national grid was the main function to be minimized. When comparing the grid-interactive without P2P (baseline 2) with the 3 cases where the P2P is included; the following can be noticed:

- The use of the P2P decreases the prosumer reliance from the grid. The magnitudes of the power imported from the grid is lower in the grid-interactive with P2P energy sharing as compared to the baseline 2 (without P2P).
- It can be seen from the 3 cases that where the P2P is implemented, the dynamic of the respective SoC linked to the battery and PHS have smaller amplitudes as compared to the baseline 2 (without P2P). Additionally, the magnitudes of the peak powers drawn from the battery and PHS (turbine) are lower in the cases of the P2P. This means that smaller storage systems' sizes can be considered in the case of the P2P and the initial cost of the HRESs on the prosumers' side can be significantly reduce.

For future work, a multiobjective optimization model combining the system's sizing to the internal pricing mechanism should be developed. Additionally, further a Life Cycle Cost analysis should be performed to compare the energy cost saving potentially achievable when the P2P energy sharing scheme is implemented.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

K. Kusakana conducted the research; analyzed the data; wrote the paper and approved the final version.

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Kanzumba Kusakana is a professor in electrical engineering and Head of the Electrical, Electronic and Computer Engineering Department at the Central University of Technology, Free State. He is well-received as a professional development short course instructor in South Africa based on his technical, consulting experience and academic qualifications. With over 150 publications in journal, conference proceedings and book chapters, his current research looks at small scale renewable power generation as well as optimal energy management; which support the UNESCO Sustainable Development Goals. He received his doctorate degree in Electrical Engineering in 2015 from the Central University of Technology, Free State, South Africa. He also holds a degree in Electromechanical Engineering from the University of Lubumbashi (2006); a degree in Electrical Power Engineering from Tshwane University of Technology (2009), as well as an MBA in Energy Management (2019) from the Cyprus Institute of Marketing (BVI).