# Enhanced Profitability of Photovoltaic Plants By Utilizing Cryptocurrency-Based Mining Load

Bilal Eid, *Member, IEEE*, Md Rabiul Islam, *Senior Member, IEEE*, Rakibuzzaman Shah, *Member, IEEE*, Abdullah-Al Nahid, Abbas Z. Kouzani, and M. A. Parvez Mahmud

***Abstract*—The grid connected photovoltaic (PV) power plants (PVPPs) are booming nowadays. The main problem facing the PV power plants deployment is the intermittency which leads to instability of the grid. In order to stabilize the grid, either energy storage device - mainly batteries - or a power curtailment technique can be used. The additional cost on utilizing batteries make it not preferred solution, because it leads to a drop in the return on investment (ROI) of the project. A good alternative, is using a customized load (such as; cryptocurrency-based loads) which consumes the surplus energy. This paper investigating the usage of a customized load – cryptocurrency mining rig - to create an added value for the owner of the plant and increase the ROI of the project. These devices are widely used to perform the required calculations for validating the transactions on the network of the Blockchain. A comparison between the ROI of the mining rig and the battery have been conducted in this study. Based on this study the mining rig has superior ROI of 7.7% - in the case with the lowest ROI - compared to 4.5% for battery. Moreover, an improved controlling strategy is developed to combine both the battery and mining rig in the same system. The developed strategy is able to keep the profitability as high as possible during the fluctuation of the mining network.**

***Index Terms*—Return on investment, Photovoltaic power plants, batteries, blockchain, bitcoin, cryptocurrency.**

## I. Introduction

THE cost of the photovoltaic (PV) systems has been decreased dramatically during the recent years. Moreover the renewable energy incentives from the governments have been increased dramatically, which led to huge investments from the private sector in the PV power plants (PVPPs) [1], [2]. This increases the penetration of PVPPs in the distribution network and creates many instability challenges. The PVPPs are none-dispatchable power sources which require to install an energy storage device – such as; batteries - to store the surplus energy [3], [4]. The batteries absorb the surplus energy, then injects it back to the grid when the power generated from the PVPPs is low or none. Utilizing batteries is a matured and well-known solution. However the cost of the PVPP will be increased, which is not preferred by the investor if there is no potential extra profit out the solution. Another solution is to contribute to the stability of the grid by injecting reactive power via the implementation of the low voltage rid through (LVRT) capability [5]–[7].

Superconducting power devices have been utilized to improve the LVRT capabilities of PV sources. Based on the previous works, the utilization of a superconducting fault current limiter to improve the profitability of the PVPP has received significant attention [5], [6]. The use of a superconducting fault current limiter, especially with a superconducting magnetic energy storage system, the fluctuated output power will be mitigated and this will lead to get incentives from the distribution network operator. The drawback of the LVRT capability implementation is that it requires special regulations approved by the distribution network operator which is not available everywhere [8].

Another option for dealing with the overpowering problem is to create a custom load that can absorb the surplus energy. However, in order to continue to invest in it, this solution must be gainful for the investor with a good return on investment (ROI). A load that has this functionality is the mining rigs that performs calculations required to confirm the transactions on the network of the Blockchain. The growth in blockchain technology is on the rise worldwide because it improves many sectors. Blockchain is deploying the decentralized solutions and peer-to-peer technologies without the necessity for a central authority [9]. The so-called proof-of-work concept is utilized to approve the transactions on the Blockchain network. Since this sector is decentralized, millions of mining machines owners are connected to the blockchain network and performing crypto mining to secure the network and verify the transactions. And in return the mining machine owners are gaining regular rewards from the blockchain's network. These rewards are the so-called crypto currencies such as Ethereum and Bitcoin [10].

The ROI of the PVPP is examined in two different cases in this study. The first case is the battery, while the other is the Cryptocurrency-based mining load. The capital cost of each solution has been calculated along with the running cost and the projected income in each case. Fig. 1 shows a PVPP connected to the grid, during the high solar radiation no ability to injecting to the grid the surplus energy can be injected either to a mining rig or a battery. The controlling communication

Manuscript received March 8, 2021; revised May 26, 2021 and June 18, 2021; accepted June 21, 2021. Date of publication July 13, 2021; date of current version August 17, 2021. *(Correspondence author: Bilal EID.)*

Bilal Eid is with the Electrical and Electronics Engineering Department, Hasan Kalyoncu University, Gaziantep 27410, Turkey (e-mail: bilal.eid@hku.edu.tr).

Md Rabiul Islam is with the Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, NSW 2522, Australia (e-mail: mrislam@uow.edu.au).

Rakibuzzaman Shah is with the Department of Engineering, IT, and Physical Sciences, Federation University Australia, Ballarat, VIC 3353, Australia (e-mail: m.shah@federation.edu.au).

Abdullah-Al Nahid is with the Department of Electronics and Communication Engineering, Khulna University, Khulna 9208, Bangladesh (e-mail: nahid.ece.ku@gmail.com).

Abbas Z. Kouzani and M. A. Parvez Mahmud are with the School of Engineering, Deakin University, Geelong, VIC 3216, Australia (e-mail: abbas.kouzani@deakin.edu.au; m.a.mahmud@deakin.edu.au).

Digital Object Identifier 10.1109/TASC.2021.3096503

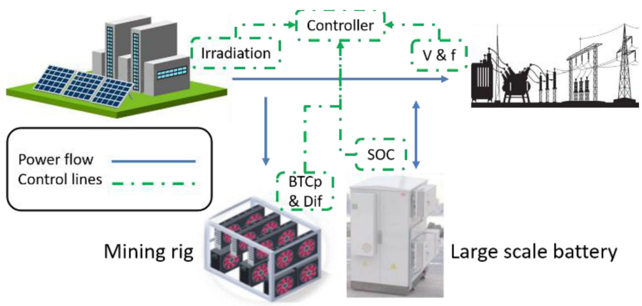


Fig. 1. PV solar power plant connected to the grid with either battery or mining rig.

TABLE I
DATA TO CALCULATE THE PRODUCED ENERGY

| Item | Value |
|---|---|
| Location (latitude/longitude) | 37.131, 37.450 |
| PVPP installed capacity (MWp) | 1 |
| The loss in the system (%) | 14 |
| Tilt angle (°) | 31 |
| Annual PV energy yield (MWh) | 1570.17 |

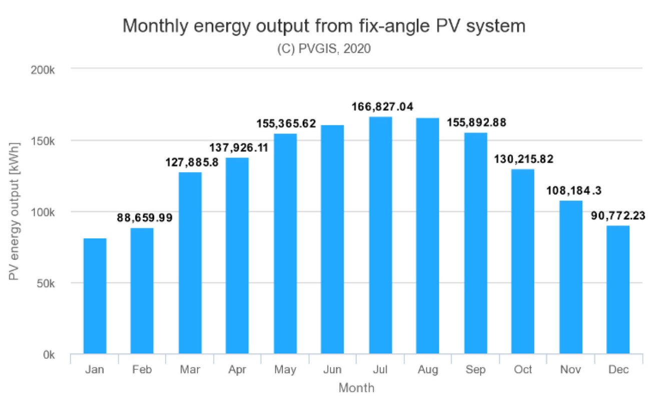


Fig. 2. Monthly energy output from the 1 MW PV plant installed in Gaziantep, Turkey.

channels are shown in dashed green lines. In previous works [8] a superconducting magnetic energy storage system has been used to mitigate the out-power fluctuation which led to get incentives from the distribution network operator.

## II. Battery Sizing and ROI

A PVPP with a total installed capacity of 1 MW dc has been investigated in this study. The total generated energy out of this system is 1570 MWh yearly in Gaziantep, Turkey. Table I. shows the assumptions that have been used to calculate the PVPP energy yield.

As shown in Fig. 2, the average daily produced energy is 5.5 MWh from April to September. By taking the daily surplus energy as a 4% which equals to 225 kWh, therefore, a battery with the same capacity can be used. A BYD outdoor battery model: OSN-P100B225-E-R1 has been proposed. The nominal power of this model is 100 kVA and the capacity is 225 kWh, which is enough for the current case study.

Currently the Turkish government incentive for PVPPs is 0.133$/kWh and the distribution network usage fee are about 0.033$/kWh so the net incentive is about 0.1$/kWh. Thus, by using the above-mentioned battery during the months from April to September, the total generated income, $I_{com}$ is

$$I_{com} = S_c \, G_{inc} D \tag{1}$$

In (1), $I_{com}$ is the annual investment's income, and the daily capacity that can be stored, $S_c$ in [kWh], quantity of days with extra energy, $D$ [days] (which are 180 days) and the incentives from the government, $G_{inc}$ in [$/kWh], therefore the annual income is 4050 $; the BYD OSNP100B225ER1 capital cost ($C_{cost}$) is around 90000 $, therefore the ROI can be expressed as,

$$ROI = \frac{I_{com}}{C_{cost}} 100\% \tag{2}$$

Therefore, the yearly ROI is 4.5%. ROI is well-known tool used in renewable energy sector to evaluate the efficiency of an investment [11].

## III. Mining RIGS and ROI Calculations

In this section the ROI analysis is conducted. The calculation is based on the same amount of energy to be handled daily (the 225 kWh). The peak time of generation last for 2 hours so the surplus energy has to be consumed during this period. Therefore, in order to have an equivalent case study with the battery a mining rig with a rated power of 112 kW has to be used. A mining rig from the well-known manufacturer – Bitmain – has been chosen to conduct the financial analysis in this study.

The model Antminer S19 have been chosen which is recently produced by Bitmain, and which generates 95T H/s [12]. The consumption of this mining rig is 3.25 kWh. Therefore the total devices required to consume the 225 kWh, $N_{rd}$ can be calculated as,

$$N_{rd} = \frac{S_e}{P_c} \tag{3}$$

where $S_e$ is the hourly amount of surplus energy, and the power consumption for each device, $P_c$. Therefore, the number of required devices equals 34.4; which can be rounded to 35 devices. Total hash power, $T_{hp}$ for these 35 devices is,

$$T_{hp} = H_p \, N_d \tag{4}$$

In (4), $N_d$ is the devices' number and $H_p$ is the hash power of each device.

Therefore, 3325 TH/s is the total amount of hash power. And according to databases (such as; cryptocompare.com and whattomine.com) the income from the 3325 TH/s can be calculated as shown in Table II. The table shows different cases for the blockchain mining network. The parameters of each case are summarized in a separated column in Table II. Case 1 is for values from mining network just after the latest Bitcoin halving. In case 2, other parameters have been taken from the network when the 16% increase of network mining difficulty ($D_{if}$) has been occurred. After that, a third case has been selected in early 2021 Bitcoin smashed through $40000 to hit a new record high. These three different parameters have been chosen to show different cases from the BTC blockchain mining network. These

TABLE II
ASSUMPTIONS USED TO CALCULATE THE MINING POWER

| Item | Case 1 | Case 2 | Case 3 | Case 4 |
|---|---|---|---|---|
| Algorithm | SHA-256 | SHA-256 | SHA-256 | SHA-256 |
| Date | 21.05.2020 | 24/11/2020 | 10/01/2021 | assumption |
| Total Hash power (TH/s) | 3325 | 3325 | 3325 | 3325 |
| Network difficulty | 15.138T | 17.597T | 20.607T | 24.728T |
| Total Hash Rate (TH/s) | 93.6 Million | 140 Million | 149 Million | -- |
| BTC block reward | 6.25 | 6.25 | 6.25 | 6.25 |
| Current 1 BTC price (USD) | 9,765 | 19,130 | 39,621 | 20,750 |
| Hourly revenue in (BTC) | 0.00124 | 0.001075 | 0.000932 | 0.000776 |
| Hourly revenue in (USD/h) | 13.4 | 20.56 | 36.64 | 16.1 |

cases reflect real situations and show practical values from the network. In order to show a worst-case scenario case 4 have been assumed. Case 4 shows 20% increasing in $D_{if}$ and 50% drop in Bitcoin price from the peak on 10/01/2021 (41500.00$). In all cases the total hash power is 3325 TH/s and the algorithm that they are mining is SHA-256. The $D_{if}$ is increased gradually from case 1 to 4. The price of Bitcoin is increased from case 1 to 3. However, in case 4, in order to predict a worst-case scenario, the price of Bitcoin have been assumed to be dropped. The hourly revenue from each case in Bitcoin and USD is shown in the last two rows in the Table II.

The proposed mining rigs will be operated daily for 2 hours (the proposed time for high solar irradiation at noon time) and the cost of each device as shown in the Bitmain's website is 1785.00 $ [12].

Therefore, the total capital cost, $C_{cost}$ is,

$$C_{cost} = C_{ind} N_d \tag{5}$$

where $N_d$ is the devices' quantity and $C_{ind}$ is the cost per unit. So, 62475 $ is the total capital cost and the total yearly income, $Y_{inc}$ is,

$$Y_{inc} = H_{OI}\ N_h \mathrm{N}_D \tag{6}$$

where $H_{OI}$ is the operation income per hour, $N_h$ is the daily hours, and $N_D$ are the days (180 days). Therefore, the annual income out of this investment is $ 4824, $ 7400, $ 13190 and $ 5796 in cases 1, 2, 3 and 4 respectively. By knowing that the $C_{cost}$ of the mining rig is $ 62475 from (5). Therefore, the ROI is calculated as,

$$ROI\ = \frac{Y_{com}}{C_{cost}}\ 100\% \tag{7}$$

From (7) the ROI is 7.7%, 11.8%, 21% and 9.2% for cases 1, 2, 3 and 4, respectively.

## IV. COMBINATION OF MINING RIG AND BATTERY

The profitability of bitcoin mining is varying dramatically based on; bitcoin price ($BTC_p$), network total mining hash power ($NT_{hp}$) and network mining difficulty ($D_{if}$). The difficulty is a measure of how difficult is to mine a Bitcoin block due to the number of miners connected to the grid. A network with high difficulty means that more computing power is required to mine

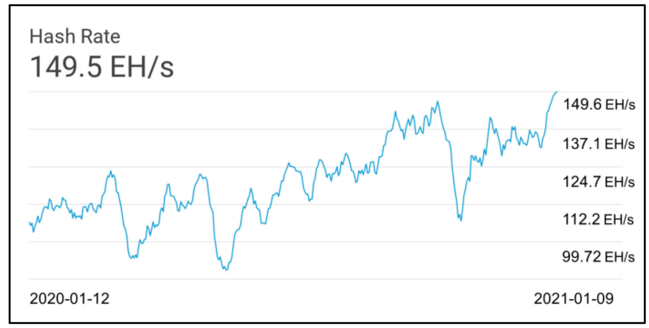


Fig. 3. Bitcoin network total hash power during the last year.

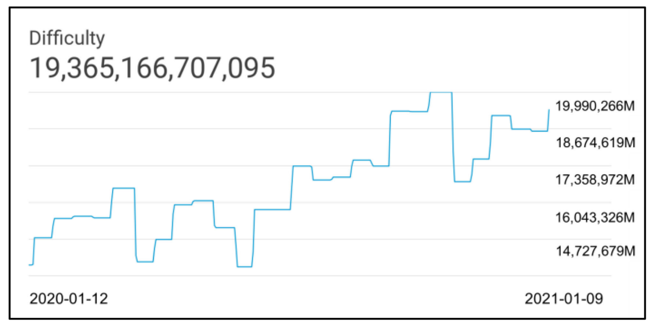


Fig. 4. Bitcoin network mining difficulty during the last year.

the same number of blocks (each block is equivalent to 6.25 bitcoin). Even though high difficulty increases the security of the network against attacks, this will reduce the number of bitcoins generated which will lead to less profitability. The difficulty adjustment is directly related to the $NT_{hp}$ in (TH/s) [13],[14]. $NT_{hp}$ is a key security indicator which increase or decrease based on the number of mining machines connected to the network. The fluctuation of the $NT_{hp}$ and $D_{if}$ during the last year is shown in Fig. 3 and 4 respectively. The value of $D_{if}$ is adjusted every 2016 blocks (which happens approximately in 2 weeks) based on the equation (7) below:

$$New\ D_{if} = \frac{20160\ \times\ Dif_{cur}}{t_{lst2016}} \tag{8}$$

where $Dif_{cur}$ is the current difficulty, 20160 is the time of 2 weeks in minutes and $t_{lst2016}$ time taken to mine last 2016 blocks.

Due to the above-mentioned fluctuation on the profitability of the mining market, combining battery and mining ring in one system is recommended. In this section the profitability of the combination of mining rig and battery for the PVPP is shown. A battery of 50 kVA and energy capacity of 112 kWh along with a mining rig with 1662 TH/s are under investigation. Both loads here are consuming - combined - the same amount of energy studied in sections II and III which wase 4% of 5500 kWh (the 225 kW). The proposed controlling strategy is explained in the section below.

## V. CONTROLLING STRATEGY FOR EFFECTIVE OPERATION

In case the batteries are already installed in the PVPP, an improved controlling strategy is required for effective operation. Fig. 5 shows the flow chart of the controlling strategy. The controlling strategy starts when there is extra energy produced from the PVPP. Then a reference points for $Dif_{ref}$, bitcoin price

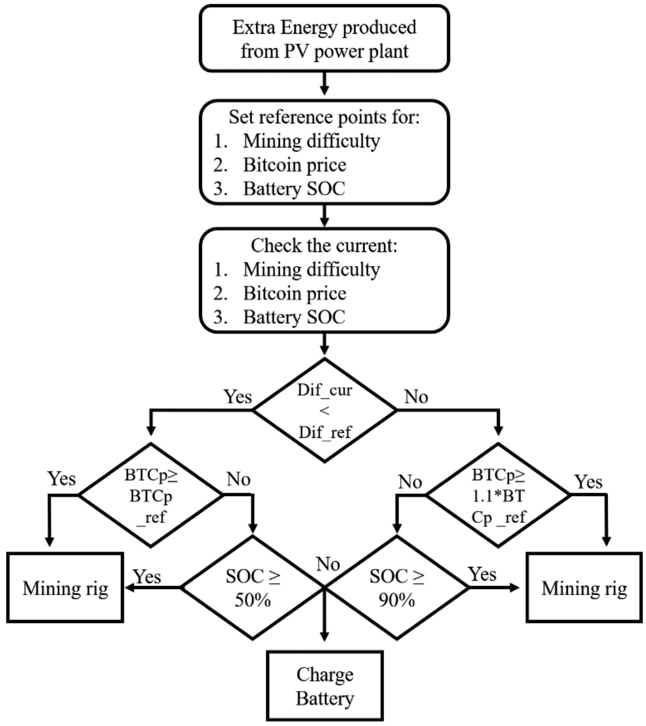


Fig. 5. Developed controlling strategy for system with both battery and mining rig.

($BTC_{pref}$) and battery state of charge (SoC) is set. After that the controller checks the current values of mining difficulty $Dif_{cur}$, $BTC_p$ and SoC. In the first If condition block, if the $Dif_{cur}$ is smaller than $Dif_{ref}$ the controller will check the $BTC_p$. If the $BTC_p$ is bigger than $BTC_{pref}$ then the energy will go to the mining rig to start mining, due to the high profitability of the mining at these conditions. However, if the $BTC_p$ is not bigger than the $BTC_{pref}$ the SoC of the battery will be checked, if it is higher than 50% then the power will supply the mining rig, if lower then it will charge the battery. The controller will enable the left side if the $Dif_{cur}$ is smaller than $Dif_{ref}$ and then the $BTC_p$ will be checked. If $BTC_p$ is bigger or equal to 10% more of the value of $BTC_{pref}$ then the power will supply the mining rig. However, if $BTC_p$ is not bigger than 10% more of the value of $BTC_{pref}$ then the SoC will be checked. Adding 10% here is important, because the incremental of the difficulty will reduce the profitability if there is no incremental in the $BTC_p$ at least 10%. In case that SoC is bigger than 90% then charging the battery in not profitable. However, for any SoC's value less than 90% battery charging is worthy because at this condition the mining is not profitable.

In case the batteries are already installed in the PVPP, the controlling strategy proposed in Fig. 5, is useful to have effective operation. Implementing this controller is increasing the stability of the PVPP by keeping the SoC as high as possible and at the same time suppling the extra power to the mining rig when the profitability is high.

## VI. Results and Discussion

Another important factor to consider is the cash time of use factor (CToU), which means when the income generated from the investment required to be used from the investor. The CToU

TABLE III
A Comparison Between Utilizing Mining Rig (four cases) Vs Batteries.

| | | Mining rig cases 1 to 4 | | | |
|---|---|---|---|---|---|
| Item | Battery | Case 1 | Case 2 | Case 3 | Case 4 |
| Total energy storage/ consumption (kWh/day) | 225 | 227 | 227 | 227 | 227 |
| Power (kW) | 100 | 113 | 113 | 113 | 113 |
| Capital cost $ | 90,000 | 65,380 | 65,380 | 65,380 | 65,380 |
| ROI (%) | 4.5 | 7.7 | 11.8 | 21 | 9.2 |
| CToU | 0.85 | 100 for all cases 1 to 4 | | | |

is calculated as,

$$CToU = Y_{wt} \times G_{avr} \tag{9}$$

where $Y_{wt}$ is the number of years for the investor to wait before he really wants to spend the generated income, and $G_{avr}$ is the average growth within the period. The investors in PV solar systems are long term investor and expected to have $Y_{wt}$ equals to 5 years. The possibility of growth for BTCp is very high due to the halving in Bitcoin reward occurs each 4 years. Each halving sharply reduces Bitcoin's inflation rate and increases the BTCp. Based on the previous halvings in 2012, 2016 and 2020 the $G_{avr}$ for the bitcoin was between 1000% to 2000%. However, if the yearly interest rate will be used as $G_{avr}$ for the returns from the battery storage system, it is 17% yearly interest rate in Turkey based on the Turkish Central Bank on 10/01/2021. Therefore, the CToU is 100 and 0.85 for mining rig and battery $G_{avr}$ respectively. The CToU show a very high change for the investor to get better ROI during the investment period in mining rig compared with the batteries.

A comparison between the batteries and the mining rig is summarized in Table III. The advantages and disadvantages of each solution is explained. It is shown that the mining rig has less capital cost than the battery. In addition, the ROI of the mining rig is better than the ROI of the battery this makes the mining rig a favorable investment option.

## VII. Conclusion

A deep financial analysis for ROI of PVPP has been explained in this study. With the intention of avoiding power curtailment during the high solar irradiation, either mining rig or battery can be deployed to maintain the stability of the system and generate extra income. The capital cost of the two alternatives is noticeably high. The battery's revenue coming from the incentives whereas the mining rig from the distributed rewards that comes from the verification processes on the network of the Blockchain. In this study it is illustrated that the ROI of the battery is 4.5% whereas for the mining rigs are 7.7% 11.8%, 21% and 9.2% for cases 1, 2, 3 and 4 respectively. An innovative controlling strategy to combine both the mining rig and the battery has been proposed. It is clearly shown that the controller maintains a high SoC for the battery and generates the maximum possible profit from the mining rig. The CToU factor has been investigated and showed the superiority of mining rig in ROI. These outcomes show that deploying mining rigs are more profitable option for the investors in the PVPPs.

## REFERENCES


[1] A. C. Duman and Ö. Güler, "Economic analysis of grid-connected residential rooftop PV systems in Turkey," *Renew. Energy*, vol. 148, pp. 697–711, Apr. 2020.

[2] F. Polzin, F. Egli, B. Steffen, and T. S. Schmidt, "How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective," *Appl. Energy*, vol. 236, pp. 1249–1268, Feb. 2019.

[3] J. W. Shim, Y. Cho, S.-J. Kim, S. W. Min, and K. Hur, "Synergistic control of SMES and battery energy storage for enabling dispatchability of renewable energy sources," *IEEE Trans. Appl. Supercond.*, vol. 23, no. 3, Jun. 2013, Art. no. 5701205.

[4] L. Chen *et al.*, "SMES-Battery energy storage system for the stabilization of a photovoltaic-based microgrid," *IEEE Trans. Appl. Supercond.*, vol. 28, no. 4, Jun. 2018, Art. no. 5700407.

[5] W. Guo *et al.*, "Overview and development progress of a 1-MVA/1-MJ superconducting fault current limiter-magnetic energy storage system," *IEEE Trans. Appl. Supercond.*, vol. 26, no. 3, Apr. 2016, Art. no. 5200905.

[6] L. Chen *et al.*, "Comparison of superconducting fault current limiter and dynamic voltage restorer for LVRT improvement of high penetration microgrid," *IEEE Trans. Appl. Supercond.*, vol. 27, no. 4, Jun. 2017, Art. no. 3800607.

[7] B. M. Eid, N. Abd. Rahim, J. Selvaraj, and B. W. Williams, "Electronically coupled distributed generation modeling and control strategies for microgrid applications," *Appl. Math. Inf. Sci.*, vol. 10, no. 4, pp. 1343–1353, Jul. 2016.

[8] M. Sufyan, N. A. Rahim, B. Eid, and S. R. S. Raihan, "A comprehensive review of reactive power control strategies for three phase grid connected photovoltaic systems with low voltage ride through capability," *J. Renew. Sustain Energy*, vol. 11, no. 4, Jul. 2019, Art. no. 042701.

[9] P. Siano, G. De Marco, A. Rolan, and V. Loia, "A survey and evaluation of the potentials of distributed ledger technology for peer-to-peer transactive energy exchanges in local energy markets," *IEEE Syst. J,* vol. 13, no. 3, pp. 3454–3466, Sep. 2019.

[10] M.-C. Yuen, K.-M. Lau, and K.-F. Ng, "An automated solution for improving the efficiency of cryptocurrency mining," in *Proc. Int. Conf. Commu. Syst. Net. (COMSNETS)*, Bengaluru, India, Jan. 2020.

[11] N. A. Rahim, M. F. Mohammed, and B. M. Eid, "Assessment of effect of haze on photovoltaic systems in Malaysia due to open burning in Sumatra," *IET Renew. Power Gen.*, vol. 11, no. 3, pp. 299–304, Feb. 2017.

[12] bitmain, "bitmain product antminer S19," [Online]. Available: https://shop.bitmain.com/product/detail?pid=00020200526110631700Bro7L3Qe0673, 2020.

[13] J. Derks, J. Gordijn, and A. Siegmann, "From chaining blocks to breaking even: A study on the profitability of Bitcoin mining from 2012 to 2016," *Electron. Markets*, vol. 28, no. 3, pp. 321–338, Aug. 2018.

[14] A. Ozisik, G. Bissias, and B. Levine, "Estimation of miner hash rates and consensus on blockchains," Jun. 2017. Accessed: Jan. 17, 2021. [Online]. Available: https://people.cs.umass.edu/~brian/status-reports.pdf