ENERGY MANAGEMENT SYSTEM OF HYBRID MICROGRID WITH ENERGY STORAGE

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ABSTRACT. The economic scheduling of the generation units is playing a significant role in the energy management of the hybrid stand alone microgrid. Energy storage is an increasingly important part of the renewable energy sector because of the need to store power during peak production times for use in off-peak periods. This paper describes an energy management system (EMS) for an islanded microgrid (MG) comprising wind energy conversion system (WECS), photovoltaic (PV), energy storage (ES) system, and microturbine (MT) for calculating the battery charging price (BCP) factor. To reach this objective, firstly the battery system has been modeled using the presented equations then various scenarios is applied by technically limited such as the power, voltage and current applied to charge and discharge of the battery.

Keywords: The isolated Microgrid, stand alone mode operation, Energy Management system (EMS), Energy storage (ES).

Nomenclature

C^{WT} :	WECS' cost coefficient ($€/kWh$);
P_t^{WT} :	The available wind power limitations (kW);
C^{PV} :	PV' cost coefficient ($€/kWh$);
P_t^{PV} :	The PV's power (kW);
P_t^{MT} :	The power output from the MT unit (kW);
C^{MT} :	MT' cost coefficient ($€/kWh$);
BCP	The battery charching price factor (€);
P_t^{ES}	The battery's power (kW);
$P_t^{ES,c}$	The battery's power during charging (kW);
$P_t^{ES,d}$	The battery's power during discharging (kW);
$\overline{P}^{ES,c}$	Maximum instantaneous power of charge (kW);
$\overline{P}^{ES,d}$	Maximum instantaneous power of discharge (kW);
V_{oc}^{ES}	Battery open circuit voltage (V);
R_t^{ES}	Internal resistance of battery (Ω) ;
$I_t^{ES,c}$	The charging current at time t (A) ;
δ_t	The hourly self-discharge rate
C^{ES}	Capacity at $+25^{\circ}C$ (Ah)
SOC_I^{ES}	Initial state of charge (SOC) at T (kWh);
SOC_t	Battery state-of-charge (SOC);
SOC_{Min}	The minimum of SOC;
SOC_{Max}	The maximum of SOC;
V_t^{ES}	Battery terminal voltage (V) ;
V_{Float}	The float charge voltage (V) ;
$\overline{I}_t^{ES,c}$	The maximum of continuous charge current (A);
$\overline{I}_t^{ES,d}$	The maximum of continuous discharge current (A);
$\overline{P}^{ES}$	The Maximum delivered power by converter (W);
P_t^n	The load demand at each time step (kW);
P_t^{EWH}	The EWH power (kW);
$\overline{P}^{EWH}$	The maximum EWH power (kW);
P_t^{Supp}	The overall power demand of the hybrid system (kW)
D_t^e	The power demanded by the load at time t ;
Δt	The energy management time step (30 min)

1. INTRODUCTION

The EMS makes decision to generate and dispatch of electric power and heat based on load profiles, weather conditions, the offer price of electricity and heat by each of distributed energy resources (DER), the cost of fuel, environmental regulations, finnily local and national government policies. Thus, energy management include technical and economical issues, which recomend how much optimal investment planning in sitting, sizing and technology selection of

DERs could bring best power quality and relability to supply to the customers at optimal price. The main objective of EMS is to acheve an economically feasible microgrid and so it has a vital role to play in maximization of above benefits [1].

In [2], an on-line EMS for a hybrid fuel cell (FC)/ES distributed generation system is presented. The presented architecture in subsequent sections consists in three layers which thier duties were to capture the possible operations modes, power splitting between ES and FC using fuzzy controller and the regulation of these sub-systems to each other, respectively. In [3] an EMS for controlling a microgrid is presented. The objective of this paper was to manage the power flows for minimizing the electricity generation costs, and avoiding the loss of energy produced by renewable energy sources. Lu and Francois [4] describe an EMS for a microgrid (PV, MT) based on the day-ahead power scheduling, considering the power prediction and load forecasting. The proposed system provides the real-time power set-points for microsources and coordinates the droop controllers for the primary frequency control. Lagorse et al. [5] propose an EMS to control the energy flow in the microgrid which is composed by PV, ES, FC, supercapacitor and load. The ES is guided by fuzzy-logic rules. Logenthiran & Srinivasan [6] describe a three-step efficient method for the optimal generation scheduling of a microgrid in island operation mode. This microgrid is composed by PV, WECS, thermal units and ES. The first step is to set up an initial feasible solution for thermal unit commitment, considering the use of renewable energy to meet the load. A real time PSO-based energy managment of a stand alone hybrid microgrid is presented in [7]. In this paper, the developed EMS promotes energy sustainbility by ensuring an optimal balance between generation units and also by incorporating desirable energy objectives into the EMS decision-making process. The presented paper focuses on EMS of a low voltage stand-alone WECS-PV-MT-ES system to supply the load requirements. An EMS aiming is proposed to determine the best dispatch of an aggregated group of different kinds of DG with the final goal of calculating the BCP in the MG under various operation conditions.

The paper is organized as follows. The energy storage has been modeled in section 2. The related equations to calculate price in ES is formulated in section 3. The EMS, as well as the battery charging price is also presented in section 4 for a stand-alone MG. Section 5 is dedicated to the presentation of the obtained results from visual C language. Finally, the paper is concluded in Section 6.

2. PROBLEM FORMULATION

A. FORMULATION OF THE BATTERY BANK

Lithium-ion batteries were used as energy storage in this study. The used model of battery in this simulation is SYNERION 24M which its characteristic is summarized in table 1. Usually, two properties of the battery are closely related to the hybrid system's performance which are included $\mathrm{SOC_t}$ and $\mathrm{V_{Float}}$.

Table 1

The nominal charactristic of the battery syste

Parameter	Value	Mesure unit used
V_t^{ES}	24	V
C^{ES}	84	Ah
V_{Float}	26	V
V_{Cutoff}	21	V
$\bar{I}_t^{ES,c}$	34	A
$\bar{I}_t^{ES,d}$	160	A

A.1. State of charge

The battery's SOC during the charging process is given by the following relation [8]:

$$SOC_{(t+1)} = SOC_t.(1-\delta_t) + \frac{I_t^{ES,c}.\Delta t.\eta_c}{C^{ES}} \tag{1}$$

Furthermore, $\mathrm{I_t^{ES,c}}$ in the conditions that the power generated by the hybrid system exceeds the load demand are as follows:

$$I_t^{ES,c} = P_t^{Extra} \Big/ V_t^{ES}, \tag{2}$$

$$P_t^{Extra} = \left(P_t^{WT} + P_t^{PV}\right) - P_t^n, \tag{3}$$

Meanwhile, the charged quantity of the battery is subject to the following constraints:

$$P_t^{Extra} \le \bar{P}^{ES,c}, \tag{4}$$

$$SOC_{(t+1)} \le SOC_{Max}, \tag{5}$$

$$\mathrm{if}: \mathrm{I_t^{ES,c}} \le \underbrace{\max\left\{0, \min\left[\bar{\mathrm{I}}^{ES,c}, \frac{\mathrm{C^{ES}.(SOC_{Max} - SOC_t)}}{\Delta t}\right]\right\}}_{\mathrm{ml}} \rightarrow \mathrm{I_t^{ES,c}} = \mathrm{ml}, \tag{6}$$

$$V_t^{ES} \le V_{Float}, \tag{7}$$

When the power generated by the hybrid system cannot meet the load demand completely if the necessity conditions are satisfied which will be stated in the following as a result the discharge process, SOC can be computed as follows:

$$SOC_{(t+1)} = SOC_t.(1-\delta) - \frac{I_t^{ES,d}.\Delta t}{C^{ES}}, \quad (8)$$

Where

$$I_t^{ES,d} = \frac{P_t^{Stg}}{V_t^{ES}}, \quad (9)$$

$$P_t^{Stg} = P_t^n - (P_t^{WT} + P_t^{PV}), \quad (10)$$

Meanwhile, the discharged quantity of the battery is subject to the following constraints:

$$P_t^{Stg} \le \bar{P}^{ES,d}, \quad (11)$$

$$SOC_{(t+1)} \ge SOC_{Min}, \quad (12)$$

$$if \;\; I_t^{ES,d} \ge \underbrace{\max\left\{0, \min\left[\bar{I}^{ES,d}, \frac{C^{ES}.(SOC_t - SOC_{Min})}{\Delta t}\right]\right\}}_{m2} \rightarrow I_t^{ES,d} = m2, \quad (13)$$

$$V_t^{ES} \ge V_{Cutoff}, \quad (14)$$

A.2. Floating charge voltage of battery

The terminal voltage of a battery is expressed in terms of V_{oc}^{ES} and the voltage drop across the internal resistance of the battery which will be calculated as follows.

$$\text{Charging mode}: V_t^{ES} = V_{oc}^{ES} + I_t^{ES,c} \cdot R_t^{ES}, \quad (15)$$

$$\text{Discharging mode}: V_t^{ES} = V_{oc}^{ES} + I_t^{ES,d} \cdot R_t^{ES}, \quad (16)$$

Both quantities of V_{oc}^{ES} and R_t^{ES} with changing of SOC_t will be changed and their characteristics curves can be achieved in the manual of the used battery and by using interpolation method, the value of these quantities at the moment can be calculated. Detailed discussion of this subject is beyond the scope of this paper and has not been carried out theoretically in detail.

3- CALCULATION OF MICRO-SOURCES' PRICE

The studied MG comprises two renewable energy sources (PV and WECS), and a CHP unit that are connected along with a battery storage system. The generation costs taken into consideration are as follows:

- Levelized costs for wind generator ($C_{WT} = 0.083$) and CHP unit ($C_{MT} = 0.152$);
- The penalty cost for PV system ($C_{PV} = 0.112$). It is assumed that the penalty cost with the wind (0.074 €/kWh) will never be used as the system always uses the maximum wind power available (due to the fact that wind energy has the minimum cost) [9];

$$p_{battery} = 0.007 + p_{av.ch}, \; [€/kWh] \quad (17)$$

$$p_{av.ch} = \frac{\sum_{i=1}^{N} p_i \cdot P_i \cdot \Delta t}{\sum_{i=1}^{N} P_i \cdot \Delta t}, \; [€/kWh] \quad (18)$$

Where $p_{av.ch}$ represents the mean value of the charging price and may be calculated by (18). being i the number of charging interval; P_i the power delivered in the interval i; ρ_i the price of the energy in the interval i and Δt the length of the charging interval.

$$BCP = p_{battery} \times \Delta t \times P_t^{ES,c}, \quad (19)$$

4. PROPOSED ENERGY MANAGEMENT SYSTEM

The flowchart of the proposed EMS is demonstrated in Fig. 1; which accounts the following cases:

1- The calculating of battery charging price according to equation (17);
2- The determining of power required by auxiliary electric water heater (EWH);
3- The rate of produced power by MT during 24-hours operation of the system;
4- The produced power by battery during charging and discharging

As shown in Fig. 1, the battery has six states which included charging mode, discharging mode, over charging protection mode, over discharging protection mode, full charging mode and full discharging mode. The variables such as the initial values for the energy sources, their cost coefficient, the value of load and the battery characteristics will be loaded after start of the EMS program. The following limit states shall be considered to prolong battery life in the EMS algorithm:

1- The charging/discharging power limit

$$\begin{cases} if: P_t^{Extra} \leq \overline{P}^{ES,c}, \\ else: P_t^{Extra} = \overline{P}^{ES,c}. \end{cases} \quad (20)$$

and

$$\begin{cases} if: P_t^{Stg} \leq \overline{P}^{ES,d}, \\ else: P_t^{Stg} = \overline{P}^{ES,d}. \end{cases} \quad (21)$$

2- The lower/upper voltage limit

$$V_{Cutoff} \leq V_t^{ES} \leq V_{Float}, \quad (22)$$

3- lower/upper current limit during charging/discharging

$$\begin{aligned} & if: I_t^{ES,c} \leq \overline{I}^{ES,c}, \\ & else: I_t^{ES,c} = \overline{I}^{ES,c}. \end{aligned} \quad (23)$$

and

$$\begin{aligned} & if: I_t^{ES,d} \leq \overline{I}^{ES,d}, \\ & else: I_t^{ES,d} = \overline{I}^{ES,d}. \end{aligned} \quad (24)$$

The following scenarios have been investigated for the proposed algorithm:

A.1. Scenario 1 (Fully Charged Mode)

If the maximum available power from the WECS and PV is greater than demand and battery is full charge, the surplus power can be supplied to a useful dump load, e.g., EWH to preheat water, as proposed in Fig. 2. Therefore, the following two cases can be happened in this scenario:

$$if \quad SOC_t = SOC_{Max},$$

$$\left.\begin{aligned} P_t^{Extra} &= \left(P_t^{WT} + P_t^{PV}\right) - P_t^n, \\ P_t^{EWH} &= P_t^{Extra}, \end{aligned}\right\} \rightarrow D_t^e = P_t^n + P_t^{EWH},$$

$else$: Charging and over charging protection mode.

(25)

Two cases which can occur during battery charging procedure depend to value of battery voltage including the following:

$$V_t^{ES}, Eq.(15),$$

$$if\ V_t^{ES} \geq V_{Float}, \rightarrow \text{Over charging protection mode.}$$

$$else: \ \text{Charging mode.}$$

A. 2. Scenario 2 (Charging Mode)

If the battery has capability to be charged i.e. the following condition should be provided as a result the surplus power mentioned in the Scenario1 can be stored in the battery. In this way, the reliability of the whole system and energy sustainability will be enhanced. In this scenario, it should be investigated the following instruction:

$$I_t^{ES,c}\left(Eq.(2)\right),$$

$$if: \ I_t^{ES,c} \geq \overline{I}^{ES,c} \rightarrow \begin{cases} I_t^{ES,c} = \overline{I}^{ES,c}\left(Eq(6)\right), \\ SOC_{(t+1)}\left(Eq.(1)\right), \end{cases}$$

$$else: \ SOC_{(t+1)}\left(Eq.(1)\right),$$

$$if: \ SOC_{(t+1)} \geq SOC_{Max} \rightarrow \begin{cases} SOC_{(t+1)} = SOC_{Max}, \\ \overline{I}^{ES,c}\left(Eq.(1)\right), \\ P_t^{ES,c}\left(Eq.(2)\right), \end{cases}$$

The calculation of the charging price (Eq. (26)).

$$else: \ I^{ES,c}\left(Eq.(1)\right) \rightarrow P_t^{ES,c}\left(Eq.(2)\right),$$

The calculation of the charging price (Eq. (26)).

The price of electricity to charge the battery is also considered inside of this Scenario as follows:

$$if: \ P_t^n \leq P_t^{WT} \rightarrow \begin{cases} \rho_{av.ch} = F_t^{WT}, \\ F_t^{ES} = 0.007 + \rho_{av.ch}. \end{cases}$$

$$else: \begin{cases} \rho_{av.ch} = ((F_t^{WT}.P_t^{WT}.\Delta t) + (F_t^{PV}.(P_t^{ES,c} - P_t^{WT}).\Delta t)) / \\ \quad ((P_t^{WT}.\Delta t) + ((P_t^{ES,c} - P_t^{WT}).\Delta t)). \\ F_t^{ES} = 0.007 + \rho_{av.ch}. \end{cases}$$

(26)

A. 3. Scenario 3 (Over Charging Protection Mode)

In this case, the following contrivances to save battery operation should be considered:

$$\begin{cases} SOC_t = SOC_{Max}, \\ I_t^{ES,d}\left(Eq.(9)\right), \end{cases}$$

$$if: \ I_t^{ES,d} \geq \overline{I}_t^{ES,d} \rightarrow \begin{cases} I_t^{ES,d} = \overline{I}_t^{ES,d}\left(Eq.(13)\right), \\ SOC_{(t+1)}\left(Eq.(8)\right), \end{cases}$$

$$else: \ SOC_{(t+1)}\left(Eq.(8)\right),$$

$$if: \ SOC_{(t+1)} \leq SOC_{Min} \rightarrow \begin{cases} SOC_{(t+1)} = SOC_{Min}, \\ I_t^{ES,d}\left(Eq.(8)\right), \\ P_t^{ES}\left(Eq.(9)\right). \end{cases}$$

$$else: \begin{cases} I_t^{ES,d}\left(Eq.(8)\right), \\ P_t^{ES}\left(Eq.(9)\right). \end{cases}$$

In this case, it should be calculated the price of electricity to charge the battery same as the previous scenario. If the requested power by load is bigger than the summation of the produced power by WECS and PV therefore there are three possible dispatch scenarios in this condition. The shortage power available will be calculated using the following equation:

$$P_t^{Stg} = \left(P_t^{WT} + P_t^{PV}\right) - P_t^n. \quad (27)$$

The first scenario is that if the battery is full discharge as a result whole of the requested power should be meet by MT. Two case studies include discharging mode and over discharging mode which will be explained future in the following.

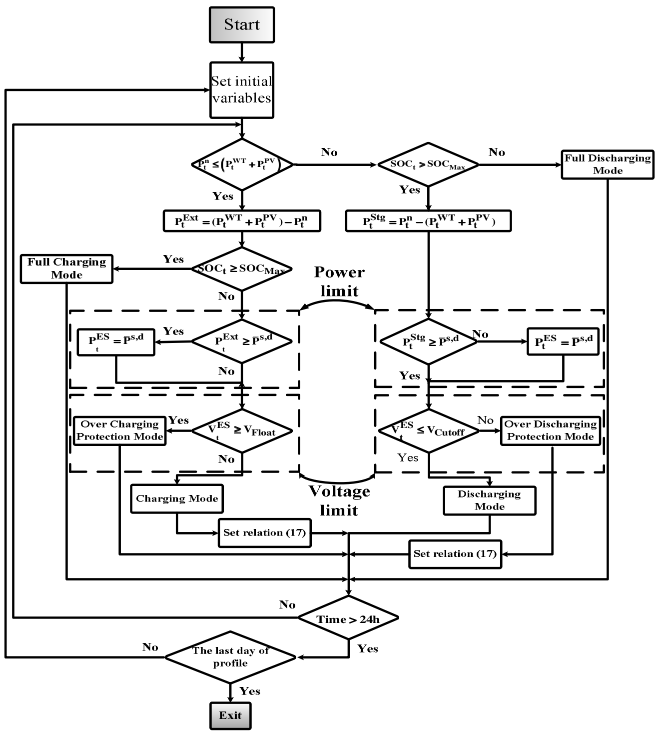

Fig. 1. Proposed energy management strategy for the WECS-PV-ES- MT system

A. 4. Scenario 4 (Fully Discharged Mode)

MT is dispatched to cover the difference between the load and the total power from the WECS and PV while the ES cannot discharge more. If the total power from the WECS and PV is less than demand and also battery is in the fully discharged mode $SOC_t < SOC_{Min}$, MT needs to be used to meet the demand. The output power from MT will be as follows:

$$P_t^{MT} = P_t^n - \left(P_t^{WT} + P_t^{PV}\right). \quad (28)$$

Before going to next scenarios, the amount of battery discharge should be checked firstly using relations (20) and (21) so that the extra power doesn't damage our ES system. As it is shown in relation (22), after discharge if V_t^{ES} is less than V_{Cutoff} therefore the battery should not be discharged more and the gotten power from battery must be returned to ES so much that relation (22) would be sure to confide completely. Two cases which can occur during battery discharging procedure depend to value of battery voltage including the following:

$$V_t^{ES}\left(Eq.(16)\right),$$

$$if: V_t^{ES} \le V_{cutoff} \rightarrow \text{Over discharging protection mode.}$$

$$else: \text{ Discharging mode.}$$

A. 5. Scenario 5 (Discharging Mode)

In cases that the summation of the produced power from the WECS and PV is not enough to meet the demand, and also SOC_t is bigger than SOC_{Min}, and also as it explained before if $V_t^{ES} \ge V_{Cutoff}$, the battery can be used to supply load. The following equations can be written for this scenario:

$$I_t^{ES,d}\left(Eq.(9)\right),$$

$$if: \ I_t^{ES,d} \ge \overline{I}_t^{ES,d} \rightarrow \begin{cases} I_t^{ES,d} = \overline{I}_t^{ES,d}\left(Eq.(9)\right), \\ SOC_{(t+1)}\left(Eq.(8)\right), \end{cases}$$

$$else: \ SOC_{(t+1)}\left(Eq.(8)\right),$$

$$if: SOC_{(t+1)} \le SOC_{Min} \rightarrow \begin{cases} SOC_{(t+1)} = SOC_{Min}, \\ I_t^{ES,d}\left(Eq.(8)\right), \\ P_t^{ES}\left(Eq.(9)\right) \\ P_t^{MT} = P_t^{Stg} - P_t^{ES}. \end{cases}$$

$$else: \begin{cases} \left.\begin{matrix} I_t^{ES,d}\left(Eq.(8)\right), \\ P_t^{ES}\left(Eq.(9)\right), \end{matrix}\right\} \rightarrow P_t^{MT} = P_t^{Stg} - P_t^{ES}, \\ D_t^e = P_t^n, \\ P_t^{Supp} = P_t^{WT} + P_t^{PV} + P_t^{ES,d}. \end{cases}$$

A. 6. Scenario 6 (Over Discharging Protection Mode)

As said in the pervious paragraphs, it is noteworthy that the battery cannot be discharged when the condition presented in (24) isn't valid. The following equations are investigated in this scenario:

$$\begin{cases} SOC_{(t+1)} = SOC_{Min}, \\ I_t^{ES,c}\left(Eq.(1)\right), \end{cases}$$

$$if:\ I_t^{ES,c} \geq \overline{I}^{ES,c} \rightarrow \begin{cases} I_t^{ES,c} = \overline{I}^{ES,c}\left(Eq.(6)\right), \\ SOC_{(t+1)}\left(Eq.(1)\right), \end{cases}$$

$$else:\ SOC_{(t+1)}\left(Eq.(1)\right),$$

$$if:\ SOC_{(t+1)} \geq SOC_{Max} \rightarrow \begin{cases} SOC_{(t+1)} = SOC_{Max}, \\ I_t^{ES,c}\left(Eq.(1)\right), \\ P_t^{ES,c}\left(Eq.(2)\right), \\ P_t^{MT} = P_t^{Stg} - P_t^{ES,c}. \end{cases}$$

$$else: \begin{cases} I_t^{ES,c}\left(Eq.(1)\right), \\ P_t^{ES,c}\left(Eq.(2)\right), \\ P_t^{MT} = P_t^{Stg} - P_t^{ES,c}. \end{cases}$$

5. ALGORITHM IMPLEMENTATION AND RESULTS

The stand-alone WECS-PV-MT-ES system in this study is shown in Fig. 2. The total aggregate hourly average load demand is shown in Fig. 3. Actual wind data is used in this case study is obtained from the online records of the weather station at Museu de Badalona, Badalona, affiliated with the Generalitat de Catalunya Weather Network [10]. The hourly average wind speed data, recorded at a height of 6m, was chosen for the 24-hour simulation study. Fig. 4 shows the output power of the WECS corresponding to the wind speed profile presented in [11]. Actual PV data is used in this case study, obtained from the online records of the Manresa, Barcelona, affiliated with the IREC [12] by using of Kipp & Zonen, CMP3 pyranometer . The PV output is also shown in Fig. 4.

Fig. 5 shows the SOC of the battery for the aforementioned six scenarios. The initial battery SOC is assumed to be 50% in order to show charge/discharge pattern clearly. As shown in Fig. 3, during the periods 01:30-14:30, 04:00-04:30 and 13:30-16:30, the summation of available wind power and PV is higher than the main load demand; thus the surplus power will be used to charge ES system. As shown in this figure, the battery charging power is limited to 4 kW for the existence limitations in converter output. Likewise, as seen in Fig. 4, battery will be discharged when the WECS plus PV cannot meet the power demand (00:00-01:30, 02:30-04:00, 04:30-05:00, 05:30-06:30 and 17:30-21 h). In the rest of the hours, the battery remains idle. Fig. 4 also shows the MT output power profile for the six scenarios explored in the previous section. In most cases, the MT produces power when the available wind power, PV and battery are not sufficient to meet the demand. Under the proposed EMS, when the battery SOC is 20%, the MT will turn on and the remainder of power will supply by it and in the rest of time, MT will is off (Fig. 4, 00:00–06:00, 13:30–18:30 h).

As seen in Fig. 3, the scenarios 1, 2 and 3 to deliver the excess power to a useful dump load (e.g., an auxiliary EWH) is used during 15:00 -17:30 h. The load and generation profile used to proof the algorithms are shown in Fig. 6. All shown and used powers are active powers. The explained stand-alone hybrid system covers completely the necessary power by load as shown in this figure. The proposed algorithm solves the hourly dispatch; the real time power balancing should be done by a different ancillary service unit if it indeed needs to meet. The market price of WECS is significantly lower than the market price of the other micro-sources, as a result the WECS is the preferred dispatched power in this MG and always the full available power is generated.

Fig. 7 depicts the calculated results of the energy storage price during discharging with respect to the extended EMS algorithm applied to the MG. As seen in this figure, The ES can be discharched during 00:00-1:30, 02:30-04:00, 04:30-05:00, 05:30-06:30 and 17:30-21 and how much its proposed offer can be acceptable during this time will be investigated in the next work.

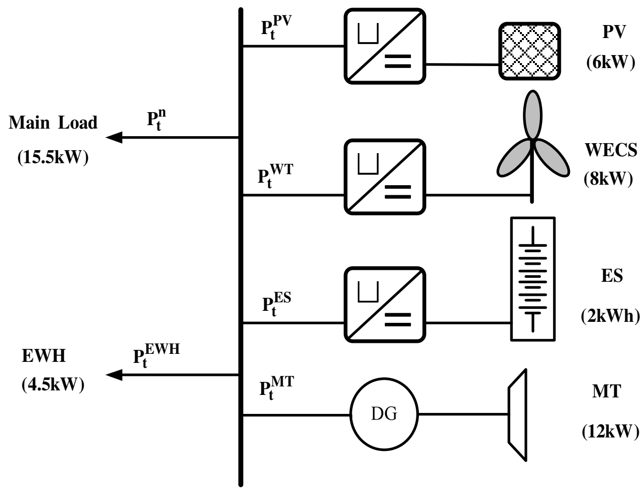

Fig. 2. Configuration of the proposed system.

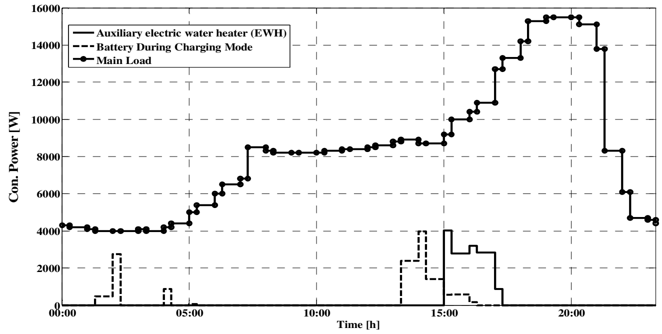

Fig. 3. Hourly main load, 1-day-storage battery bank during charging mode and auxiliary electric water heater

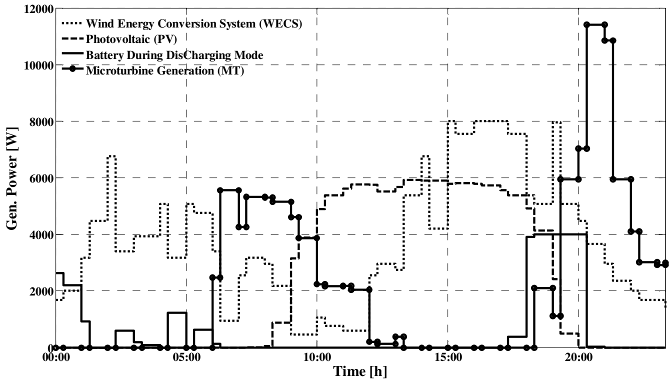

Fig. 4. Hourly WECS, PV, MT and ES system during 1-day-storage battery bank in the discharge mode

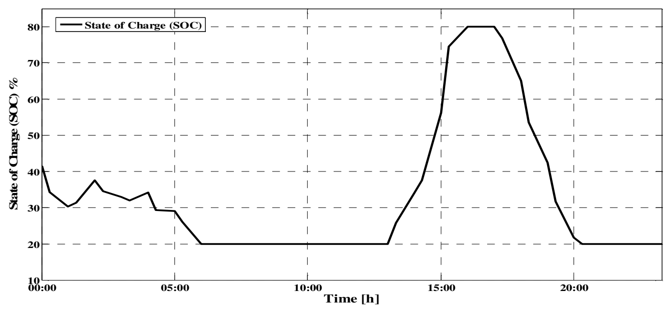

Fig. 5. SOC of battery during 1-day-storage battery bank in the charge and discharge mode

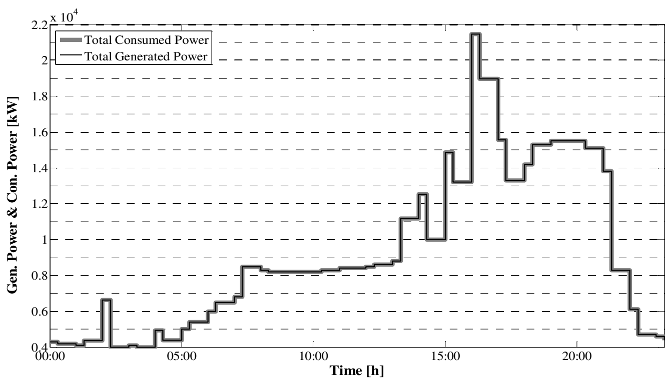

Fig. 6. Hourly load and power production during a day.

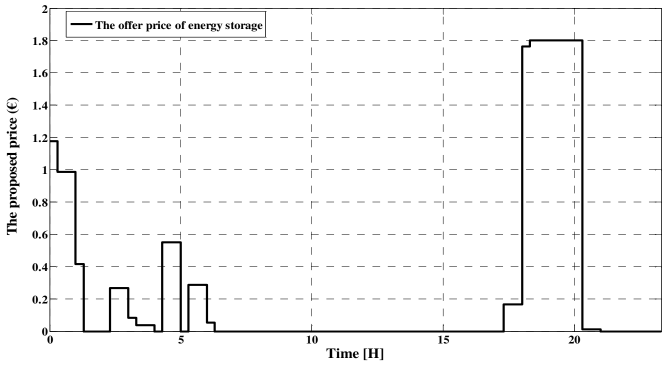

Fig. 7. The proposed price by energy storage during twenty-four work of system

6. CONCLUSIONS

This paper presents an original EMS for a stand-alone MGs hybrid system to calculate BCP factor. Firstly, energy management of a stand-alone hybrid WECS-PV-MT-ES system was presented by using the proposed algorithm. Then, a formula is presented to obtain BCP factor by using the proposed offering prices of renwable producers. In this equation, both offer quantities and prices of PV and WECS are treated as decision variables to calculate the final consumption energy by ES. Simulation results on a small, four-unit test system demonstrate that the proposed algorithm can locate a global solution of the related problem.

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