NOVEL CONTROL METHOD FOR INTERMITTENT RENEWABLE SOURCE IN DC MICROGRID

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ABSTRACT: Distributed resources have important portion in power supply, especially in microgrids. Most of these resources are intermittent. Control of microgrid with these intermittent DG resources is one of the main challenges to reach the dispatchable energy resource. Integrating Energy Storage System (ESS) with these DG resources can make them dispatchable.

Optimal use of ESS will be considered in this paper to overcome intermittent behavior of DGs. This optimal strategy will make constraints on ESS parameters such as State of Charge (SOC) and charge/discharge current. For optimizing the life time of the battery, SOC will be forced to keep between 30% to 100%. Also maximum values will be set for charging and discharging currents and control strategy was designed so that battery current would not exceed from these limits. This control strategy was implemented with power forecasting algorithm. The output power of PV will be predicted hourly with the use of daily solar irradiation. With use of proposed control algorithm, the difference between actual power and load consumption will be compensated by storage system or upstream network. The designed control strategy can ensure microgrid stability. The effectiveness of this control strategy has been tested with actual PV system data and it has been shown that the ESS can completely remove the PV output power fluctuation with low deviation and smooth transition.

Keywords: DC microgrid; New control strategy; Forecasting power; DG; Battery; Photovoltaic system

INTRODUCTION

A microgrid consists of interconnected distributed energy resources capable of providing sufficient and continuous energy for a significant portion of internal load demand. Microgrid system is used for example in houses, ships and etc. [1]

The idea of distributed generation (DG) has reached much acceptance during the last decades due to the 1) High cost of energy, 2) Environmental concerns, and 3) Major advances in DG technologies [1]. Besides the advantages of renewable energy sources, solar and wind resource usually has unsteady condition due to affect by the natural and meteorological conditions. These conditions make renewable sources output power, intermittent naturally and cause variation in output power and common bus voltage fluctuation. Fig. 1shows the typical power output of a solar PV system in one month. The figure shows that the power output can have rapid variation during the day, using such highly intermittent energy source have a negative impact on microgrid [4], [5]

To overcome these contingencies, Energy Storage Systems (ESSs) are used with DGs. [2]

DGs are widely use in microgrid such as rural networks or computer stations. In most cases these loads are important and should be fed when required. So it is necessary to make DG's dispatchable.

The growth of power electronic device and increasing the Capacity of ESS are the main reasons to increasing usage of DC microgrid in many conditions.

Also DC microgrid can create power systems which are more efficient and more compatible with the fast growing in segment of the load.

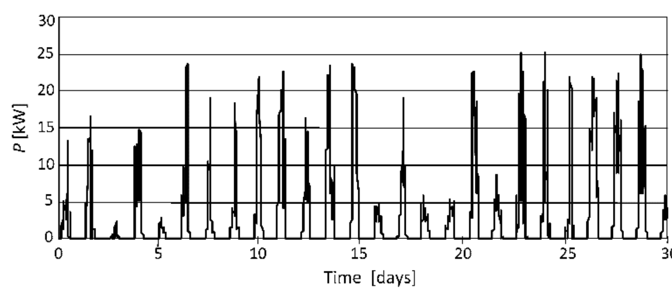

Fig 1. Typical solar power output in one month

A DC microgrid has higher efficiency from generation and storage system point of view. Also DC micro grid has more reliability. Moreover because DC power has no phase to match, the connection to the load is simplified and more economical to sending power. ESS's are commonly used with DG's for smoothing and dispatching of DG based micro grid system, power. ESS's are expensive and important components of these systems. So they should be controlled in a manner that reach power smoothness and dispatching purpose and at the same time battery life time observation should be considered.

Different Control strategies and power sharing methods in AC microgrid with and without storage system integration had been studied by many researchers

In paper [6] DC microgrid has been studied without the storage system. In this paper, DC droop control with DC link voltage and output power is used for control of microgrid. Because the lack of storage system, this control strategy can't respond to the big changes in the load and also output power will have rippled and fluctuations.

In paper [7], storage system was used for compensation of voltage and frequency ripple in microgrid. In [8], Voltage control and power sharing with dc side impedance were discussed in most papers, the DG sources are considered as a constant value or step change output [9], [10]. The intermittent nature of DGs is neglected in many papers.

In paper [11], stand-alone Photovoltaic generation systems with energy storage are developed and also grid connected mode has been taken into account.

In past studies PV dynamics and battery life time are neglected. Also a comprehensive algorithm which is considered all features has not introduced till now.

In this paper battery is used as a storage system, the dynamics of Photovoltaic will be considered.

In this paper with use of appropriate cost function, output power of Photovoltaic system will be predict in next hour and then with proposed control algorithm power difference between load and Photovoltaic will be compensated with an energy storage system. Although this process could be implemented in any intermittent systems, but in this paper PV system has been examined.

When the battery compensates power difference of load and PV system, it should be controlled in an optimal way to guaranty its life time. The designed algorithm which based on the battery SOC will increase battery lifetime and optimize its usage, and at the same will assure that battery will respond so, the load fed suitably with minimum ripple and fluctuation and also microgrid remains stable. In this algorithm battery SOC and Current will remains in specified limits. This algorithm will describe in section ш. In critical situation when the battery has low SOC level and PV can't supply the loads, Micro grid will connect to upstream network to keep it stable. In this paper, battery capacity and loads are chosen so that, this mode will be occurred in simulation.

In Section 2 battery dynamic model, PV module and microgrid configuration are briefly described. Also some parameters of battery have been defined. Section 3 presents the forecasting algorithm and introduces the proposed control strategy for the BESS. Simulation results are given in Section 4.

2- Basic Control Design Issues

In this section, the battery parameters and dynamic model will be discussed. Also PV and microgrid model will be given.

1) ***State of Charge (SOC):***the state of charge of a battery indicates the available capacity of battery in use. By knowing the amount of energy left in the battery compared with initial energy, it is possible to indicate how much longer battery will continue to recharge again. To avoid loss of battery life ,SOC should be kept in specified limit.[30% to 100%]. The controller shall be designed to keep battery charge/discharge current properly to satisfy mentioned limit.

2) ***State of Health (SOH*):**SOH of battery shows general condition of battery and its ability to deliver certain energy compared with fresh battery. Because of Non-Return physical and chemical change during operation time of battery, SOH will be deteriorated**.**

3) ***Depth of Discharge (DOD):***the amount of active chemical transformed with each charge/discharge cycle will be proportional to Depth of Discharge. The relation between cycle life and DOD has been shown in Fig 2. DOD is the inverse of SOC(100%= empty , 0% = Full) and use when discussing the lifetime of battery after repeated use[12].

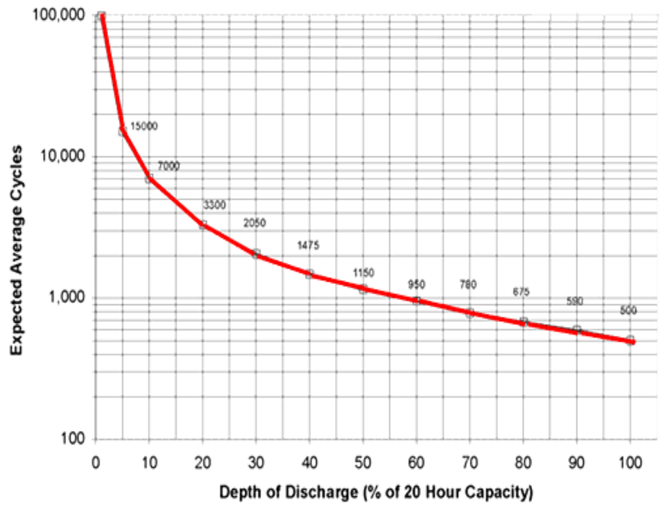

Fig 2. Relation between the cycle life and the depth of discharge [12]

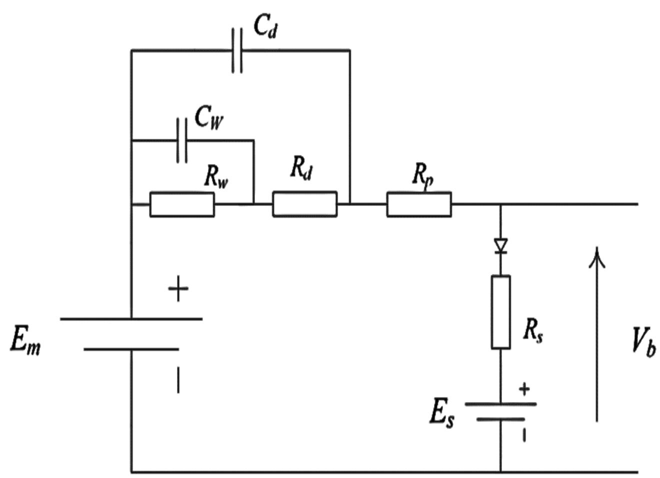

Fig 3. Fourth order battery dynamic model [13]

The fourth model of battery is shown in the Fig3. The main drawback of this model, are fourth order equations due to consideration of the paralleled R-C blocks in the circuit and therefore it takes more time for the computation. Another drawback is that a number of empirical parameters are contained in the model. [13]

For these problems we use an improved model for battery model in simulation. This model is simple but meets most requirements for a good battery model. It contains most non-linear characteristics and is linked to the state of charge. Most elements included in this model are the functions of the state of charge or the open circuit voltage, which is also related to the state of charge. The improved model is shown in the Fig4. [14]

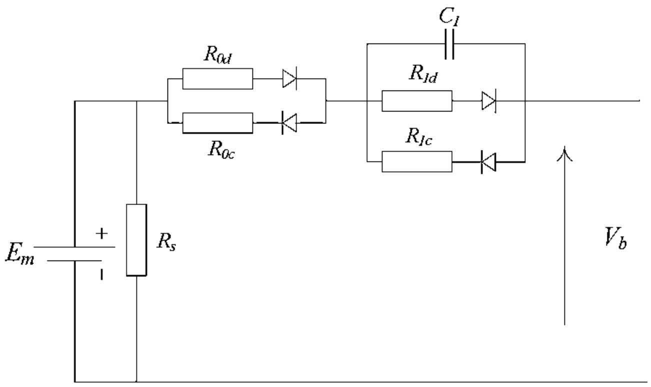

Fig 4. Improved battery model [14]

An ideal PV cell is modeled by a current source in parallel with a diode. However none solar cells are ideal and thereby shunt and series resistances are added to the model as shown in Fig 5.   is the intrinsic series resistance whose value is very small.   Is the equivalent shunt resistance which has a high value. [15], [16]

The proposed PV arrays converter is a transformer-less boost converter that operate with the MPPT method under real data for varying levels of irradiation and temperature.

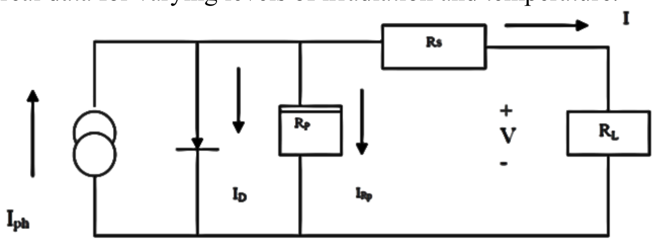

Fig 5. Equivalent circuit of PV cell

In Fig. 6, proposed DC microgrid configuration is shown. The proposed dc microgrid consists of photovoltaic generation (as intermittent DGs), energy storage elements such as batteries, dc loads and grid-tied converters.

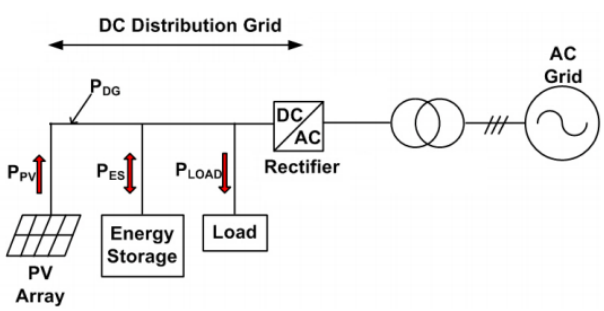

Fig 6. Proposed DC microgrid configuration

3- Dg Control Algorithm

The controller will optimally generate control signals for battery converter. This controller is extracted from [17], [18]. The cost function is assumed for this control strategy is according to (1). The period of control signal which applied to the battery converter should be appropriately selected. Then J is selected and inputted to the cost function, continuously. The control strategy schematic has been shown in Fig7.

$$J(u) = \int_0^t \left(P_{BESS,ref}(t) - P_{BESS}(t)\right)^2 \quad (1)$$

$$J(u) = \int_0^t (y_{ref}(t) - y(t)) \quad (2)$$

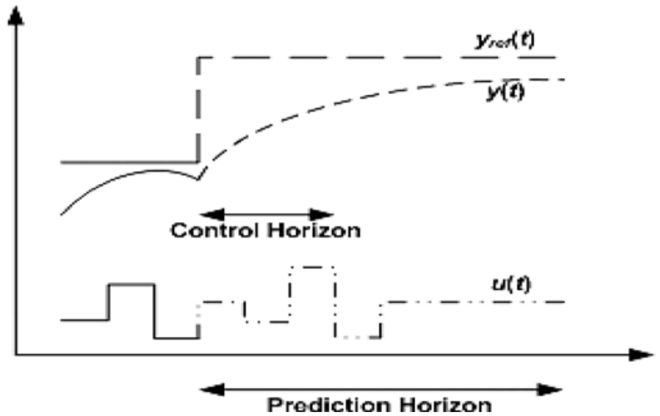

Fig 7. Proposed DC microgrid configuration

As mentioned before, the most common challenge for renewable source is intermittent power output that makes DGs undispatchable. In other words, the goal of this control method is to overcome this problem by charge/discharge battery and use upstream network, and as a result a dispatchable resource will be reached.

DC microgrid voltage must be kept in certain range with acceptable ripple. An abnormal DC voltage causes problems in the system and makes system collapse. Fixed voltage indicates power balance between source and consumer. Two modes are considered for microgrid:

Mode1: microgrid works in islanding mode. In this mode the photovoltaic and battery tasks are providing the shortage of power. Hence battery should smooth photovoltaic output.

Mode 2: Photovoltaic output power and battery can't support load and also battery SOC is in the lowest range. In this situation, rectifier will connect upstream network to microgrid. In this condition we assumed that no fault will occur in upstream network when the grid is connected.

Before describing the proposed control algorithm, battery limitation should be demonstrated. To have optimal battery lifetime, the battery limitations are as follows:

$$SOC_{min} \leq SOC(t) \leq SOC_{m} \quad (3)$$

$$i_{max,disch} \leq i_{battery}(t) \leq i_{ma} \quad (4)$$

Where SOC_{r} and SOC_{n} represent the minimum and maximum limits of battery SOC, respectively. Battery current is positive when battery discharge, i_{ma} and $i_{max,d}$ represent the maximum allowable charge and discharge current of a battery.

In order to have stable microgrid, DC link voltage should have restricted fluctuation so for this purpose the microgrid DC link voltage limitation should be as follows:

$$0.95V_{microgrid,pu} \le V_{pu} \le 1.05V_{microgri} \quad (5)$$

If we considered the dynamic behavior of DGs, the output power of DG's is intermittent and affected by many parameters such as natural and meteorological conditions.

In this paper we introduce algorithm to dispatch the power of DG's with battery. This algorithm is based on hourly prediction of the DG's output and then specifies a set point for controller to charge/discharge the battery to enable power dispatch. If the difference of load power and actual DG power assume to be $\Delta p = p(load) - p($then the proposed algorithm is as below:

If: $\Delta_{]}$ **0;**

- for : $SOC_{min} < SOC < SOC_{,}$

Then: $P_{bat}=$ (Discharging mode)

- for : $S=$ SOC

- if 0.98 V $(nom$V then the power variation is low and battery can compensate it and will allow to decrease the SOC to min 20%: then **P (battery) =**

- if voltage not in 0 .98 V $(nom$ V Range then:

$= P_{recti}$

For improving reliability, it prefers to charge the battery from the rectifier path by the upstream network due to the low level of battery SOC, so we have:

$P_{recti}=$

- for : $S =$ $SOC_{,}$

$P_{battery}$ =(Discharge mode)

If $:\Delta p$ **;**

- for :SOC(min) SOC SOC(max)

$P_{battery}$ =(Charge mode)

- for : SOC = SOC(min)

$P_{battery}$ =(Charge mode);

- for : SOC = SOC(MAX)

$= P_{inve}$

P_{inve}: Power Flows from microgrid to network if considered

$P_{battery} = 0$

If: = 0 No action required.

In above algorithm SOC (min) set to 30% and SOC (max) set to 100%. Now we define limits for battery current as below:

- $If \quad i_{max,charge} < \frac{P_{Battery}}{V_{Battery}} < i_{max,discharge}$

For $V_{dc} > 1.05\ pu \rightarrow i_{Bat} = i_{max,cha}$

For $V_{dc} < 0.95\ pu \rightarrow i_{Bat} = i_{max,discha}$

For 0.95 $< V_{dc} < 1.05\,pu \rightarrow i_{Bat} = \frac{P_{Bat}}{V_{Bat}}$

- $If \quad i_{max,discharge} \ge \frac{P_{Bat}}{V_{Bat}}$

$i_{Bat}= i_{max,discha}$

- $If \quad i_{max,charge} \le \frac{P_{Bat}}{V_{Bat}} \quad i_{Bat} = i_{max,cha}$

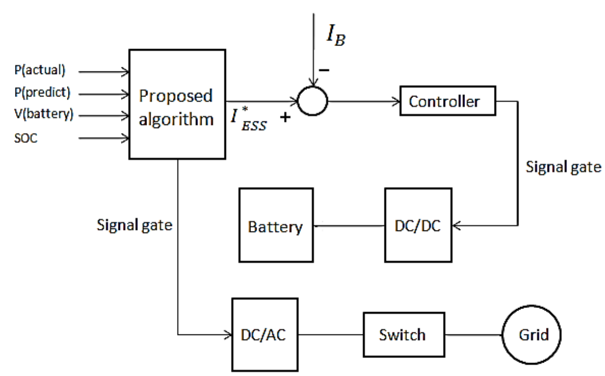

Fig 8. Proposed control algorithm block diagram

4- Simulation

For testing the proposed algorithm, we choose Matlab Simulink and simulate it with real data. Proposed output power of the PV system is shown in Fig 9. For setting the output of battery and rectifier, P_{set} is extracted from forecasting algorithm in the next hour. The average of output errors between real data and forecasting data is near zero and in the worst condition about 2% from P_{set} that compute by forecasting algorithm.

The size of the battery energy system is choosing 15-kWh according to output power of PV and the load ripple of the system. The output of the rectifier is selected 125% of battery output because of properly use of the rectifier for charging batteries. We use the improved fourth order dynamic model of a battery for simulation. Limit for battery SOC is between 30-100 % of charge and output current limit is$\pm 30\ A$.

The three phase rectifier connected to the network has two internal and external controlling loop. The internal loop for current and the external is for voltage [19]. Simulation running has been done in 24 hours data in the Matlab software with e^{-3} step size.

P_{total} Curve shown in the Fig 9. As we see in the Fig 9 the provided algorithm can support P_{total}(demonstrates the load power) with low deviation. The dashed line in this Figure shows the real solar output and the filled line is P_{set} that indicates the PV output with low deviation which forecasted in one hour. In 9:46 the battery SOC became 30% and because of $V_{pu} \leq 98\%$ grid rectifier is activated to compensate the power shortage. At 11:00 the rectifier switch is opened due to severe solar radiation and battery start to charge. Finally at 18:00 two hours before sunset, battery started discharging.

As we mentioned for increase battery lifetime, SOC should be kept between 30-100% which algorithm could suitably establish this constraint as we can see in Fig 10. In Fig 11 battery output current demonstrated. According to Fig 10 and 11 our limitations are considered.

Under the condition that battery is completely full and output power of solar modules are higher than loads demands, according to the proposed algorithm the MPPT control of solar will be switched off and the solar output will support the load and sends the extra power to upstream network.

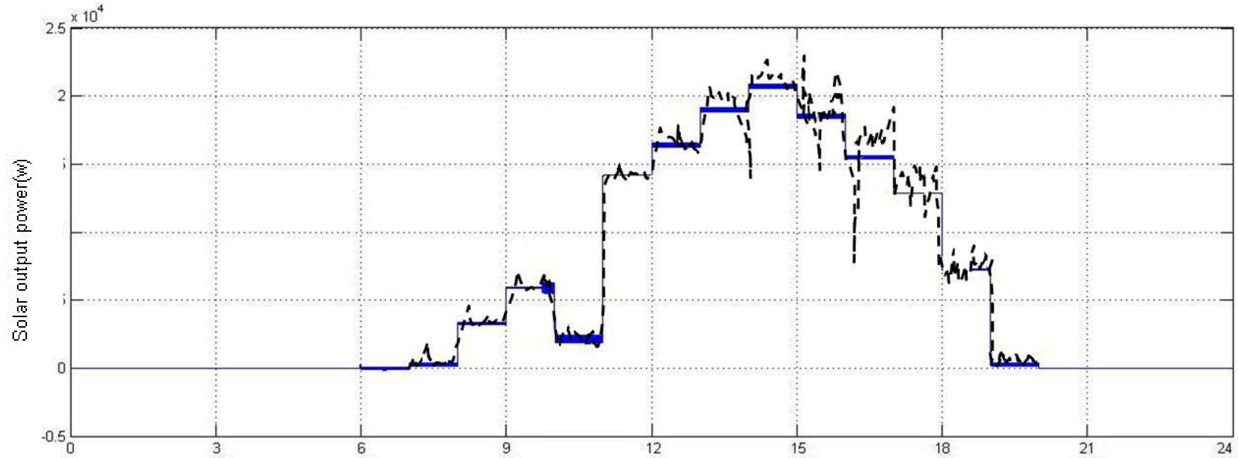

Fig. 9.Solar cell output power set (line), dash line is the real solar power

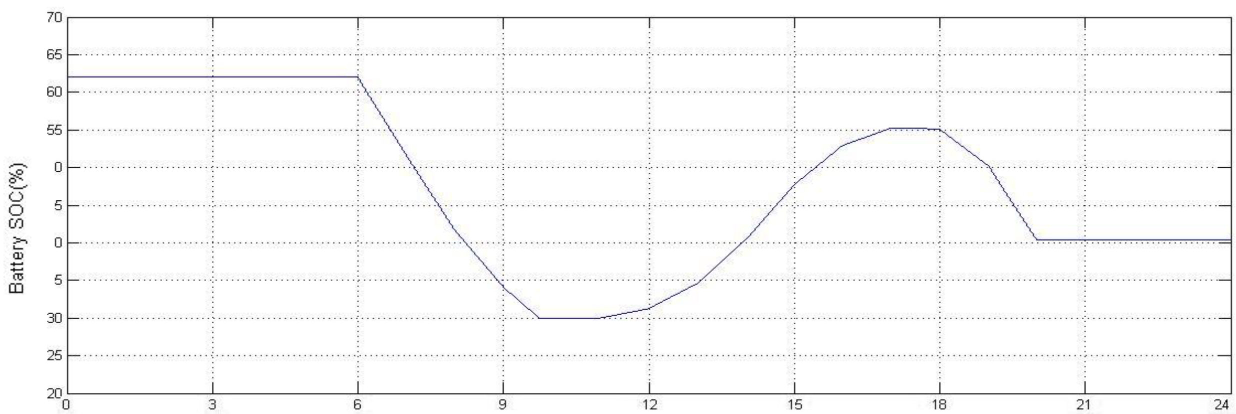

Fig. 10.Battery per hour

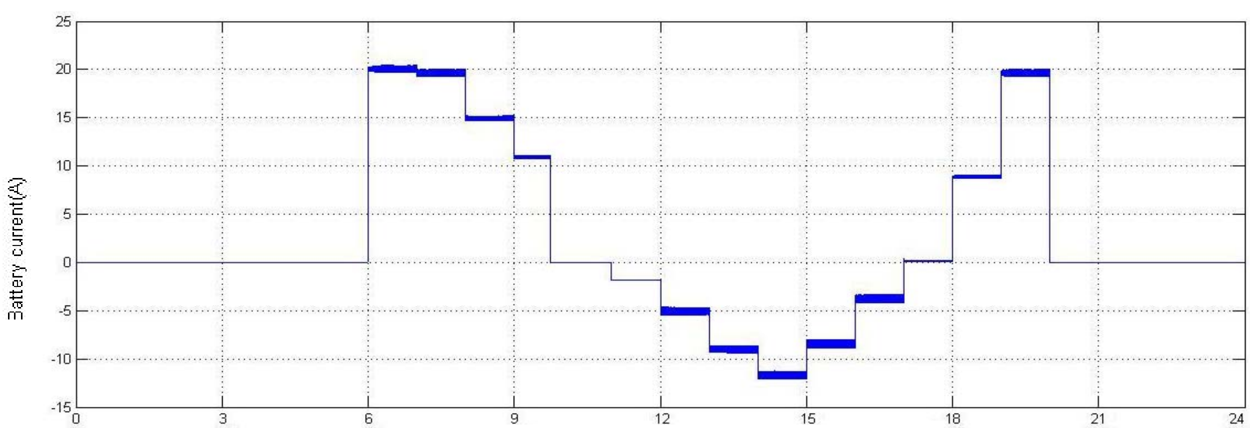

Fig. 11.Battery output current per

5- CONCLUSION

In this paper, a control algorithm is presented to control intermittent DG in dc microgrid. This algorithm was simulated with actual PV data in 24 hours. The results show, the proposed algorithm works in efficient way which satisfies the load and it has shown that the ESS can completely remove the PV output power fluctuation with lower than 2% deviation and smooth transition.

Also the dispatchable aim of DG has been reached. Furthermore the dc voltage ripple is remaining in acceptable limit.

The simulation results indicate that the battery constraints have been satisfied as battery SOC that must be between 30% to 100% for optimizing lifetime of the battery, and level of the battery charge and discharge current was in permissible range. When the ESS and DG's can't able to supply microgrid loads, the rectifier will act and compensate not supplied loads according to the algorithm.

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