Scan to know paper details and author's profile

Solar PV Based Maximum Power Point Tracking Embedded DC Voltage Regulation Incorporating Battery Storage for Micro-Grid Application

M. Juma , C. Msigwa & B. M. M. Mwinyiwiwa

University of Dar es salaam

ABSTRACT

This work deals with reducing the voltage dip to improve the voltage on voltage regulator of solar photovoltaic for the microgrid. In the previous work, results show that voltage regulator managed to regulate dc voltage and maintaining the dc bus voltage at its reference value but there is voltage dip when step load changes and recovering time to response taken about 150msec. To reduce this response time battery energy storage have been incorporated with it. The battery energy storage has been used when stepping load changes or in case there is a mismatch between load demand and power generation in a microgrid. The capacity of the battery used is in less percentage of total installed capacity of the system which reduces the cost of the system. In this paper, Solar PV based Maximum Power Point Tracking (MPPT) provides voltage regulation and storage batteries have been integrated at common dc bus through bidirectional buck-boost Converter. The DC bus voltage was tested at varying solar insolation at constant temperature. Simulation results using MATLAB/SIMULINK software shows that the response time of the DC bus voltage dip has been improved after step load changes. Incorporating the storage battery in Solar PV based maximum PowerPoint Tracking (MPPT) embedded voltage.

Indexterms: maximum power point tracking; solar pv; dc-dc boost converter; voltage regulation; duty cycle, battery, bi-directional buck- boost converter

Classification: FOR code: 850505

Language: English

London Journals Press

LJP Copyright ID: 392893
Print ISSN: 2631-8474
Online ISSN: 2631-8482

London Journal of Engineering Research

Volume 19 | Issue 5 | Compilation 1.0

Solar PV Based Maximum Power Point Tracking Embedded DC Voltage Regulation Incorporating Battery Storage for Micro-Grid Application

M. Juma [α], C. Msigwa [σ] & B. M. M. Mwinyiwiwa [ρ]

ABSTRACT

This work deals with reducing the voltage dip to improve the voltage on voltage regulator of solar photovoltaic for the microgrid. In the previous work, results show that voltage regulator managed to regulate dc voltage and maintaining the dc bus voltage at its reference value but there is voltage dip when step load changes and recovering time to response taken about 150msec. To reduce this response time battery energy storage have been incorporated with it. The battery energy storage has been used when stepping load changes or in case there is a mismatch between load demand and power generation in a microgrid. The capacity of the battery used is in less percentage of total installed capacity of the system which reduces the cost of the system. In this paper, Solar PV based Maximum Power Point Tracking (MPPT) provides voltage regulation and storage batteries have been integrated at common dc bus through bidirectional buck-boost Converter. The DC bus voltage was tested at varying solar insolation at constant temperature. Simulation results using MATLAB/SIMULINK software shows that the response time of the DC bus voltage dip has been improved after step load changes. Incorporating the storage battery in Solar PV based maximum PowerPoint Tracking (MPPT) embedded voltage

Indexterms: maximum power point tracking; solar pv; dc-dc boost converter; voltage regulation; duty cycle, battery, bi-directional buck- boost converter.

Author α: PhD student at the University of Dar es salaam, Tanzania

σ: Department of Electrical Engineering Dar es Salaam Institute of Technology, Tanzania.

ρ: Department of Electrical Engineering University of Dar es Salaam, Tanzania Nomenclature.

ΔD, Dnew, D, Der- Duty Cycle Correction, Corrected duty cycle, Uncorrected duty Cycle and their error.

Vdc, Vref, Vdcer- Sensing dc link voltage, Reference of dc-link voltage and their errors.

Ib, Ibref, Iber - Sensing battery current, reference battery current and their errors.

I. INTRODUCTION

OLDWIDE renewable energy-based micro grids are being considered to provide electricity for the expanding energy demand in the grid distribution network and grid isolated areas. As the use of renewable energy sources (RES) Micro-grids in the isolated mode of operation leads to more technical challenges associated with the operation and control of it as compared to grid-connected as [1]. The energy sources from renewable sources give natural stochastically variable magnitude AC or DC voltages. This leads to a real challenge, especially when it comes to maintaining both micro-grid voltage and frequency within an acceptable range. The solar PV. system is an example of a common source of power in rural Africa, it is intermittent in nature due to the fact that characteristic of the solar cell is dependent upon the insolation, temperature and array voltage. Thus, the output voltage should be regulated and keep a constant dc voltage then inverted to ac load as shown in Fig. 1. Regulation on solar PV based on the MPPT control algorithm of a corrected duty cycle from estimated duty cycle through Boost converter has a voltage dip when step load changes with the response time of about 150msec as [2]. Stand-alone solar power

London Journal of Engineering Research

systems require battery energy storage to supply the power according to the load requirements as shown in [3]- [4]. Power generated at the solar energy system varies according to the solar Irradiance as explained in [5]. Battery energy storage system stores the energy when the load power requirement is lower than the generated power and supply energy when generated power is lower than the required load power due to low solar Irradiance and step load changes. The charging and discharging states of the battery energy storage system (BESS) is controlled by gating pulses applied to the DC-DC bidirectional buck-boost converter [6]-[8]. This helps to maintain power-balance between the generation and load side power which increases system reliability. This paper focuses on stand-alone PV based solar energy system with battery storage to keep a constant dc bus voltage when step load changes and also to maintain the power balance.

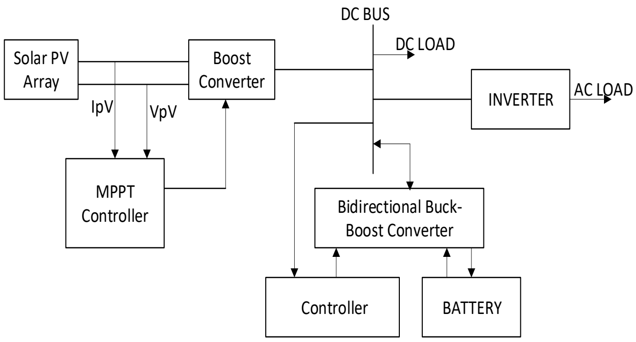


Fig. 1: A standalone Solar PV System

II. REVIEW OF THE METHODOLOGIES FOR MAXIMUM POWER POINT TRACKING (MPPT)

The Perturb and Observe (P&O) and the Incremental Conductance (InCond) algorithms are the most commonly used for MPPT control. The advantages of both methods are simplicity and requirement of low computational power. Other techniques based include fuzzy logic control, neural networks, fractional open-circuit voltage or short circuit current and current sweep. Most of these methods yield a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, rather than an exact output. In this work, the Perturb and Observe (P & O) technique which has been frequently used in PV systems is applied. The flowchart of the P & O algorithm is in [9]-[10]. An MPPT controller is implemented to maximize the output power of the solar PV by adjusting the duty cycle D as shown in Fig. 2.as [11]-[14].

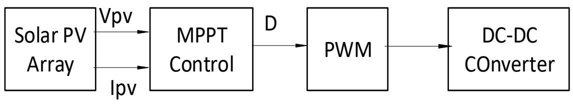


Fig. 2: MPPT Control with direct duty cycle

MPPT control with the direct duty the cycle cannot regulate and keep constant dc voltage as a reference value in this case (750V) due to changing of solar Irradiance with constant temperature when step load changes.

a) DC bus voltage regulation using dc-dc boost converter

A boost converter is used in renewable step up unregulated dc voltage to a higher voltage that required by loads as shown in Fig. 3. The parameters of dc-dc boost converter as calculated in [4] are given by (1) through (5).

In dc-dc boost converter the output voltage is greater than the input voltage as expressed in (1).

$$V_{dc} = \frac{V_{pv}}{1 - D} \qquad (1)$$

Where V_{dc} is the output voltage, D is duty cycle and V_{pv} is the input voltage.

The output current is given by(2) (assuming loss free system)

$$I_{dc} = I_{pv}(1 - D) \qquad (2)$$

Where I_{dc} is output current and Ipv is input current.

In order to operate the converter in continuous current conduction mode, the inductance is calculated such that the inductor current IL flows continuously and never fall to zero as given by (3)

$$L_1 \geq \frac{D(1 - D)^2 R_1}{2f} \qquad (3)$$

Where L1 is the minimum inductance, D is the duty cycle, R_1 is load resistance, and f is the switching frequency of switch Q1 as shown in Fig. 3.

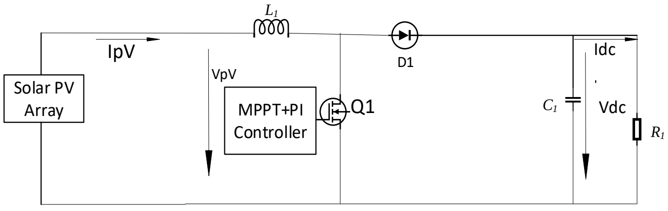


Fig. 3: DC-DC Boost Converter

The output capacitor gives the desired output voltage was calculated as (4).

$$C_1 \geq \frac{D}{\Delta V_o * f * R_1} \qquad (4)$$

ΔV_o is ripple output voltage being 2% as suggested by [3].

b) DC bus Voltage

The minimum DC bus voltage for power transfer should be at least equal to 1.1 of the peak AC line to line voltage as calculated in (5) as has explained in [2],[9].

$$V_{dc} \geq 1.1 \times V_{sab} \times \sqrt{2} \qquad (5)$$

c) Battery Sizing

The proposed system is designed such that it meets an average load of 31.5 kW for 24 hours. Taking additional 20% margin for energy losses during the exchange of energy as suggested by [7]. The battery storage capacity using 20% of installed capacity is about 248 Ampere-Hour (AH).

d) Controller Design of Voltage Regulator

Control strategy has been developed in which the new duty cycle is calculated adjusting an estimated MPPT based duty cycle D with correction by ΔD shown in Fig. 4 as [2].

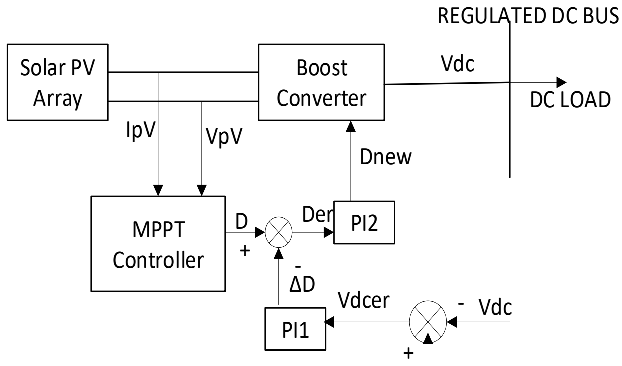


Fig.4: Control of DC-DC Boost Converter for DC voltage regulation

III. BIDIRECTIONAL BUCK-BOOST DC-DC CONVERTER

The bidirectional buck-boost DC–DC converter (BDDC), which connects the battery to the DC bus, is designed to operate as a buck converter while charging the battery and operates as a boost converter for battery discharging mode as shown in Fig. 5. In the bidirectional buck-boost DC–DC converter *L2* is calculated by (6) through (7) [15].

$$L_2 = \frac{D(Vdc - Vb)}{f_s \Delta I_L} \qquad (6)$$

ΔIL = 20% of charging current

$$D = \frac{V_b}{V_{dc}} \qquad (7)$$

Where *D* is duty cycle, *Vb* is Battery voltage and *Vdc* is dc bus voltage

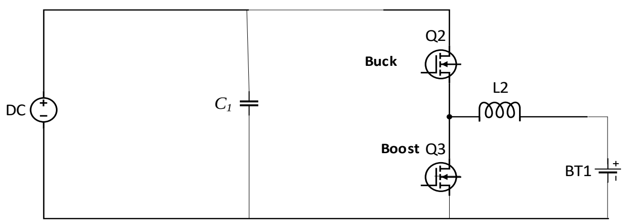
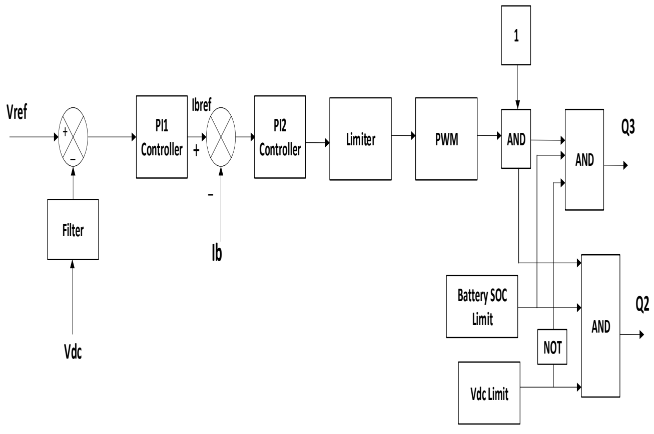


Fig. 5: Bidirectional Buck- Boost Converter

a) Control of Bi directional Buck-Boost DC-DC Converter for Battery Storage

The charging and discharging condition of the battery is identified with the SOC value and the dc bus voltage. In this proposed battery control scheme as shown in Fig.6, if the battery SOC value is higher than the 50% then the BESS is ready to supply power to the load or which is in discharging mode. BESS is in charging mode if the SOC value is lesser than 100% and there is excess energy from solar Pv.



IV. MATHEMATICAL MODELING OF THE CONTROLLER FOR THE DC VOLTAGE REGULATOR AND DIRECTIONAL BUCK-BOOST DC-DC CONVERTER

This mathematical modeling consists of controller of dc voltage regulation and controller bidirectional buck-boost to maintain dc bus voltage.

a) Mathematical modelling of controller for dc voltage regulator

The DC-DC Boost Converter regulates the DC bus voltage through MPPT control and proportional integral (PI) controllers as in presented [2], that have been corrected the duty cycle *D* as shown in Fig. 4, to estimate the new duty cycle. The correction factor od duty cycle is calculated as (8).

$$\Delta D(k) = \Delta D(k-1) + kp_1\{V_{dcer}(k) - V_{dcer}(k-1)\} + ki_1 V_{dcer}(k) \quad (8)$$

Where *kp1* and *ki1* are the proportional and integral gains of *PI1* controller respectively. The sampled kth dc voltage error is given as.

$$V_{dcer}(k) = V_{ref}(k-1) - V_{dc}(k) \quad (9)$$

The new duty cycle of the converter governs by PI2 controller is given as

$$D_{new}(k) = D_{new}(k-1) + kp_2\{D_{er}(k) - D_{er}(k-1)\} + ki_2 D_{er}(k) \quad (10)$$

Where *kp2* and *ki2* are the proportional and integral gains of PI2 controller respectively. The duty cycle error is given by

$$D_{er}(k) = D(k-1) - \Delta D(k) \quad (11)$$

b) Mathematical modelling of directional Buck-Boost DC-DC Converter

In this control technique, the DC bus voltage (Vdc) is detected and compared with the reference DC bus voltage (*Vref*) The error between these two values is applied to PI1 controllers as shown in fig. 6. The reference battery current is given [3] by (12).

$$Ib_{ref}(k) = Ib_{ref}(k-1) + kp_1\{V_{dcer}(k) - (V_{dcer}(k-1)\} + ki_1 V_{dcer}(k) \quad (12)$$

Where *kp1* and *ki1* are the gain of the PI1 controller, respectively. The duty cycle of the Bidirectional Buck-Boost converter is governed by a battery current PI2 controller and it is their error as expressed in (13).

$$D_{dc}(k) = D_{dc}(k-1) + kp_2\{Ib_{ref}(k) - Ib_{ref}(k-1)\} + ki_2 Ib_{ref} \quad (13)$$

Where *kp2* and *ki2* are the gain of PI2 controller, respectively. The battery current error is given as

$$Ib_{er}(k) = Ib_{ref}(k-1) - Ib(k) \quad (14)$$

DC-Link voltage and state of charge (SOC) controls the battery bi-directional buck/boost converter in [9] as shown in Fig. 6. Table 1 gives the parameters of the solar panels used in this study.

Table 1: Data for tested pv array sunpowerspr-315-WHT-D

An Array data	Quantity
Parallel String	10
Series-Connected modules per string	10
Number of cells per module	96
Maximum Power	315W
Voltage at maximum power point	54.7V
Current at maximum power point	5.76A

Table 2: Shows parameters of BESS of Concorde PVX 1080 Lead acid battery used in this study

Table 2: Data for Lead Acid Battery of 12V, 124 AH [16]

Parameter	Value
Initial State of Charge (%)	50
Nominal Voltage	240V
Rated Capacity	248AH
Number of Battery in parallel	2
Number of Battery in series	20

V. SIMULATION RESULTS

Simulations results based on MATLAB/ SIMULINK of Solar PV tested model are presented. Fig.7. shows simulation results on varying solar irradiance between 800W/m2 up to 1000W/m2 when there are step load changes at Constant Temperature. It can be seen that voltage dip have been improved and DC output voltage maintain reference DC bus voltage (750V) after step load changes and variations of solar irradiance. And also, battery voltage, current, and state of charge show battery that is charging and maintain a state of charge limit as shown in Fig.8.

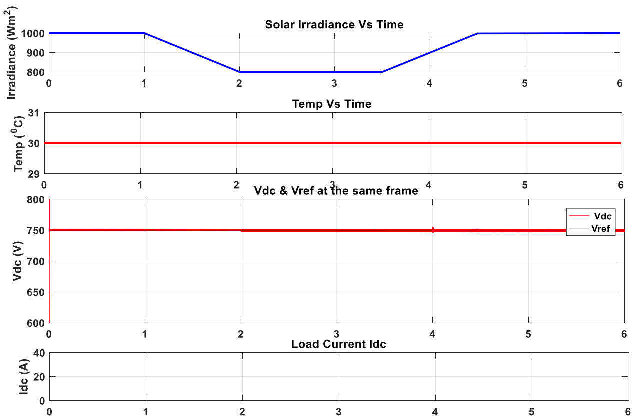


Fig. 7: Solar System under variable load and Varying Solar Irradiance at Constant Temperature when step load changes.

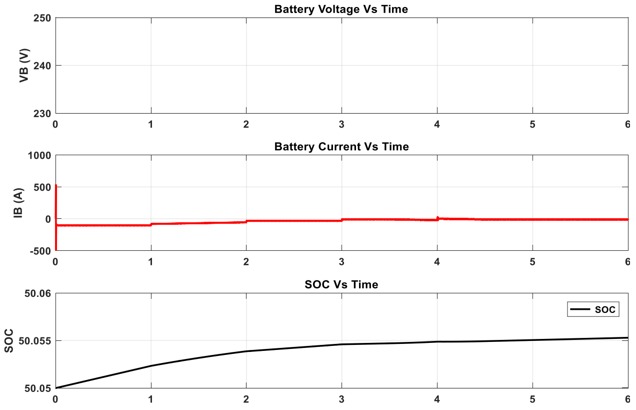


Fig. 8: Battery voltage (VB), Battery current (IB) & Battery SOC%.

a) Comparison of Simulated Results

Fig.9 (a) and (b) show the results for comparison of DC bus voltage without and with battery storage respectively when there are step load changes. Fig.9 (b) shows that the voltage dip of DC bus voltage has improved as compared to fig. 9 (a).

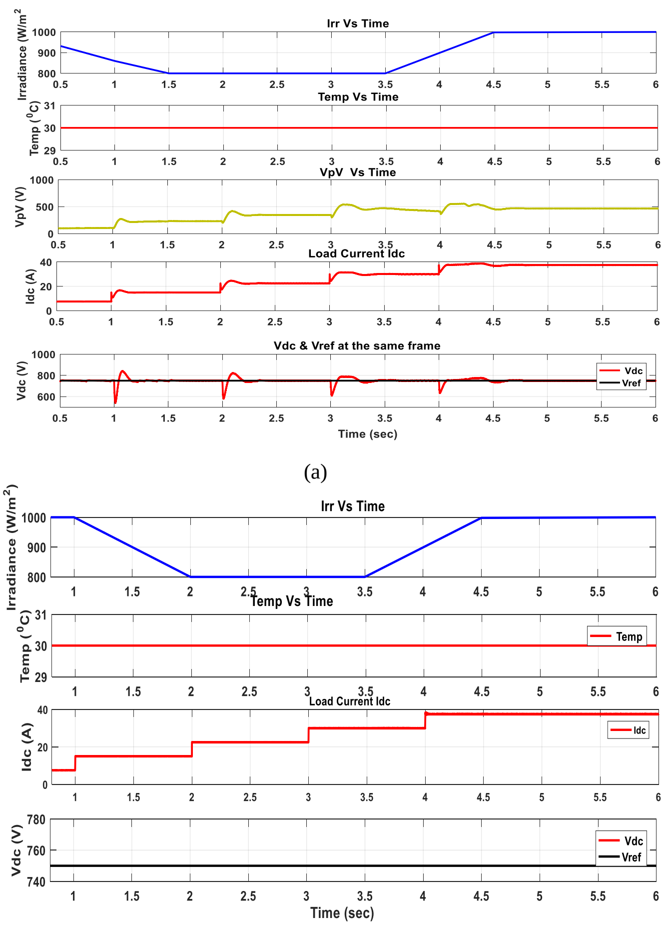


Fig. 9: DC bus voltage Regulation with Step load changes (a) Without BESS (b) With BESS.

VI. CONCLUSIONS

This research work aimed to minimize voltage dip when step load changes on the regulator of solar PV based with Maximum Power Point Tracking (MPPT) and maintaining dc bus voltage at reference value to meet load requirements. This system controller can be used in the hybrid stand-alone system for renewable energy sources and the loads which require standard DC or AC supply. The results of work are important and improve the stability and reliability of renewable energy sources, conversion and integration technologies. The methodologies used in this research work are modeling of the DC voltage regulation with battery storage system in off-line simulations of the model through MATLAB/SIMULINK software. The results obtained shows that the voltage dip of output voltage has been reduced against variation of solar insolation as well as step load changes. The system is suitable for the synthesis of asynchronous DC busbar which can be used to integrate several renewable energy sources with varying characteristics.

APPENDIX

Boost converter calculated parameters are as follows:

Inductor L_1=20mH output capacitor C_1=150µF and Load R1 =20Ω

Controller Parameter of DC Regulator:

PI1; kp1=0.5 and ki1 =15, PI2; kp2=0.25 and ki2=30

Bi-directional Buck Boost Converter Inductors: L2 =1mH.

Controller Parameter of Bi-directional Buck Boost Converter:

PI1; kp1 =0.1and ki1=1, PI2; ki1=1 and ki2=100

ACKNOWLEDGMENT

This research is supported by Royal Society - Development of International Development (DFID), UK under the Africa Capacity Building Program Initiative. It is implemented by ACERA consortium: that is University of Leeds, UK; CREEC-Makerere University, Uganda; Dar es Salaam Institute of Technology (DIT), Tanzania and Marien Nguabi University-Congo Brazzaville.

REFERENCES

1. Mwinyiwiwa B. M. M, "DC bus voltage regulator for renewable energy based micro grid-application", *International Scholarly and Scientific Research & Innovation*, vol. 7, no.12, pp.1629-1633, 2013.
2. Juma M., Msigwa C., Mwinyiwiwa B., Solar PV based on Maximum Power Point Tracking embedded voltage Regulation for micro-grid Application; *International Journal of Innovative Research in Advanced Engineering (IJIRAE)*; vol.06, no.6, pp.552-558, June 2019.
3. Kewat S, Singh B, Hussain I., "Power management in PV-battery-hydro based standalone microgrid", *IET Renewable Power Generation*, vol.12 pp.391-398, 2018.
4. Iqbal M. M, Islam K, "Design and Simulation of A PV System with Battery Storage Using Bidirectional DC-DC Converter Using Matlab Simulink", *International journal of scientific & technology research*, vol.6 no.7, pp. 403-410, 2017.
5. Philip J, Jain C, Kant K, Singh B, Mishra S, Chandra A, Al-Haddad. K, "Control and implementation of a standalone solar photovoltaic hybrid system", *IEEE Transactions on Industry Applications*, vol. 52 no.4, pp 3472-3479, 2016.
6. Adhikari S, Fangxing Li, "Coordinated V-f and P-Q Control of solar Photovoltaic Generators with MPPT and Battery Storage in Micro grids", *IEEE Trans. On Smart Grid*, vol. 5, no.3, pp. 1270-1281, 2014.
7. Tiwari S.K., Singh B.& Goel P.K "Design and Control of Micro-Grid fed by Renewable Energy Generating Sources". *Transaction on industrial Application*, pp.1-9 ,2016.
8. Tamiru D, Avik B, "Design and Analysis of a DC/AC Microgrid with 84Centralized Battery Energy Storage System" International Conference on Power and Embedded Drive Control (ICPEDC) pp. 8779-87, 2017.

9. Madaci B, Chenni R, Kurt E, Hemsa K, "Design and control of a stand-alone hybrid power system", *Energy Publications LLC, International journal of hydrogen energy, Elsevier Ltd*, vol.41 pp.12485 -12496, 2016.
10. Smita A. P, Mamun M, "Integration of Hybrid Renewable Energy and its control in grid connected and islanded mode" *International Conference on Power and Embedded Drive Control (ICPEDC)*, pp. 14-19, 2017.
11. Jin W. C, Shin Y. H, Mun K. K "Hybrid Operation strategy of wind energy storage system for grid frequency *regulation*" *IET Renewable Power Generation*, vol.10 no.3, pp.736-749, 2016.
12. Ahmed S, Benachaiba C "Simulation and Control of Solar Wind Hybrid Renewable Power System" *Proceeding of the International Conference on Systems and control*, University of Batna2, Batna Algeria, May 7-9 pp.51-56, 2017.
13. Fouad M.A, Badr M.A, Ibrahim M.M. "Modeling of micro-grid system components using matlab/simulink". *Global Scientific journal (GSJ)* vol.5 no.5 pp.163-177, May 2017.
14. Laurentiu F. Dan C "Output Analysis of Stand-Alone PV Systems: Modeling, Simulation and Control" *Energy Procedia* vol.112, pp. 595 – 605, 2017.
15. Dileep S. Vani N. "Power quality improvement in standalone battery integrated wind energy system". *International conference on Signal Processing, Communication, Power and Embedded System (SCOPES)* pp.642-647, 2016.
16. Gilbert M. "*Renewable and Efficiency Electrical Power Systems*". ISBN 0-471-28060-7 John Wiley & Sons, Inc. 2004.

This page is intentionally left blank