ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

A Multivariable Optimal Energy Management Strategy for Standalone DC Micro-Grids



Sai Suprajitha
M.Tech Student
Department of EEE
Malineni Lakshmaiah Engineering College,
Singaraya Konda, Ongole.

Sivasai Jonnadula, M.Tech
Assistant Professor
Department of EEE
Malineni Lakshmaiah Engineering College,
Singaraya Konda, Ongole.

J.Alla Bagash
HoD,
Department of EEE
Malineni Lakshmaiah Engineering College,
Singaraya Konda, Ongole.

ABSTRACT

Due to substantial generation and demand fluctuations in standalone green micro-grids, energy management strategies are becoming essential for the power sharing and voltage regulation purposes. The classical energy management strategies employ the maximum power point tracking (MPPT) algorithms and rely on batteries in case of possible excess or deficit of energy. However, in order to realize constant current-constant voltage (IU) charging regime and increase the life span of batteries, energy management strategies require being more flexible with the power curtailment feature.

In this project, a coordinated and multivariable energy management strategy is proposed that employs a wind turbine and a photovoltaic array of a standalone DC micro-grid as controllable generators by adjusting the pitch angle and the switching duty cycles. The proposed strategy is developed as an online nonlinear model predictive control (NMPC) algorithm. Applying to a sample standalone dc micro-grid, the developed controller realizes the IU regime for charging the battery bank.

The variable load demands are also shared accurately between generators in proportion to their ratings. Moreover, the DC bus voltage is regulated within a predefined range, as a design parameter.

INTRODUCTION

With the depletion of fossil fuels and skyrocketing levels of CO2 in the atmosphere, renewable energy sources continue to gain popularity as a long-term sustainable energy source. However, two major limitations exist that prevent widespread adoption: availability and variability of the electricity generated and the cost of the equipment. Figure 1.1 illustrates the future of hybrid distribution system which demonstrates the integration of renewable energy sources into DC microgrid and current AC distribution system. DC electrical systems are gaining popularity due in part to high efficiency, high reliability and ease of interconnection of the renewable sources compared to alternating current (AC) systems.

DC micro-grids have been proposed to improve point-of load energy availability and to integrate disparate renewable energy sources with energy storage. Various renewable energy sources such as photovoltaic (PV) systems have natural DC couplings; therefore, it is more efficient to connect these sources directly to DC microgrid by using DC/DC converters. A DC microgrid system with distributed PV and wind generation and employing centralized battery storage, illustrated in Figure 1.1, is an attractive technology solution for communities to "go-green" while simultaneously ensures reliable electricity. DC distributed generation (DG), grid-tied PV-wind systems with centralized battery backup, illustrated in Figure 1.1, have been proposed for community-scale micro-grids such as the Pecan Street project in Austin Texas and other communities. The focus of this dissertation is Model Predictive Control (MPC) for optimal sized photovoltaic (PV), DC Microgrid, and multi-sourced hybrid energy systems. The main considered applications are:

1. Maximum Power Point Tracking (MPPT) by MPC.
2. Droop predictive control of DC Microgrid.
3. MPC of grid-interaction inverter.
4. MPC of a capacitor-less VAR compensator based on a matrix converter (MC).

The considered applications have direct impact on efficiency and performance of renewable energy systems. This dissertation firstly investigates an optimization technique base on a Multi-Objective Genetic Algorithm for the hybrid distribution system illustrated in Figure 1.1. The proposed methodology employs a techno-economic approach to determine the system design optimized by considering multiple criteria including size, cost, and energy availability. The variability of a high-penetration PVscenario also studied when incorporated into the microgrid concept. Emerging (PV) technologies have enabled the creation of contoured and conformal PV surfaces, theeffect of using non-planar PV modules on variability also analyzed.

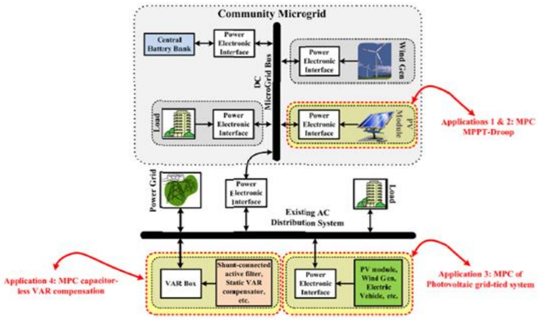

Fig1.1: hybrid distribution system

OBJECTIVE OF THESIS

Literature has investigated predictive control applications in power electronics as early as the 1980's for high-power systems with low switching frequency. The useof higher switching frequencies was not possible at that time due to the large calculation time required for the control algorithm. During last couple of decades by improvement of high speed and powerful microprocessors, interests in predictive control in power electronics considerably increased. Power electronics converters are nonlinear system with finite number of switching devices. Characteristics of power converters and drives such as nonlinear behavior, finite number of switching states, and constraints lead to the application of model predictive controls. In addition, predictive control techniques are coincident by the characteristics of present day control platforms such as discrete-time implementation and model knowledge based. Predictive controllers can be divided into four main methods, these classification of predictive controllers are illustrated in Figure 1.2. The main difference between these methods of control is that the model predictive control and deadbeat control with continuous control set are working with a modulator, thus they have fixed switching frequency. However the hysteresis based and trajectory based predictive controller generating the switching signals directly and therefore they have variable switching frequency. The main focus of this dissertation is model predictive control as highlighted in Figure 1.2. The main characteristics of all of the predictive controllers are to use the system (power converter) model to predict the future behavior of the controlled variables. This information is utilized by the controller algorithm to determine the optimal actuation by predefined optimization criteria.

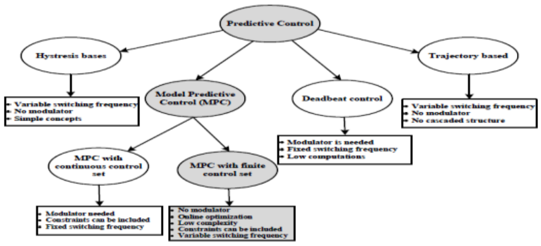

Fig1.2: Classifications of predictive controllers

MICROGRID

A micro-grid is a network consisting of distributed generator and storage devices used to supply loads. A distributed generator (DG) in a micro-grid is usually a renewable source, such as combined heat and power (CHP), photovoltaic (PV), wind turbine, or small-scale diesel generator. DGs are usually located near the loads, so that line losses in a micro-grid are relatively low. A micro-grid can work with a host grid connection or in islanded mode. When grid connected, DGs supports the main grid during peak demand. However, if there is a disturbance in the main grid, a micro-grid can supply the load without the support of the main grid. Moreover, a micro-grid can be reconnected when the fault in the main grid is removed. Furthermore, as in any technology, micro-grid technology faces many challenges. Many considerations should be taken into account, such as the control strategies based on of the voltage, current, frequency, power, and network protection.

NEED FOR A MICROGRID

A micro-grid is used for many reasons. It is a new paradigm that can meet the increase in the world’s electrical demand. It can also increase energy efficiency and reduce carbon emission, because the DGs commonly use renewable sources or a small-scale back-up diesel generator. By using a micro-grid, the critical loads will be ensured to be supplied all the time. Economically, extending the main grid is expensive, so a micro-grid can be used to supply the load instead. Moreover, the main grid is supported by DGs; therefore, overall power quality and reliability will improve. Also, by using a micro-grid, the main grid generators will supply less power. Having a generator of the main grid that runs with less fossil fuels is beneficial. Another economic reason is that the DGs are located near the load, and thus line losses are kept to a minimum. A micro-grid can be used to supply energy to remote areas or in places where the host grid is both inefficient and difficult to install. For example, in some areas, the load demand is so low that the load can be supplied entirely by small-scale DGs. Therefore, a micro-grid is the suitable choice for supplying the load demand. Moreover, some areas have harsh geographic features, making the main grid difficult to connect. Using a micro-grid is the best solution to provide power to these areas. In summary, the most important issues that make the micro-grid technology important are:

- Load demand has increased worldwide.
- Micro-grids use renewable sources, so they have less impact on the environment.
- Extending the main grid is not only costly but also difficult.
- A micro-grid can supply critical loads even if it is disconnected from the main grid.

MICROGRID STRUCTURE AND COMPONENTS

The fig.2.1 shows the structure of a micro-grid. This structure is based on renewable energy sources. The main grid is connected to the micro-grid at the point of a common coupling. Each micro-grid has a different structure (number of the DGs and types of DGs), depending on the load demand. A micro-grid is designed to be able to supply its critical load. Therefore, DGs should insure to be enough to supply the load as if the main grid is disconnected. The micro-grid consists of micro sources, power electronic converters, distributed storage devices, local loads, and the point of common coupling (PCC).

The grid voltage is reduced by using either a transformer or an electronic converter to a medium voltage that is similar to the voltage produced from the DG.

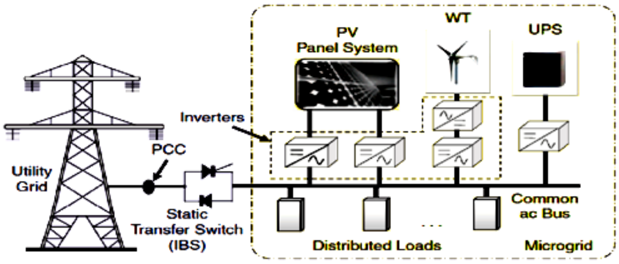

Fig2.1: Micro-grid Structure based on renewable energy sources

VARIOUS LOADS ON MICROGRID

The load of the micro-grid can be houses, hospitals, banks and malls. These loads can be classified into two types. The first type is called critical load, examples of which are a hospital or a bank's computer system. As indicated by the examples, critical load should be supplied with an uninterruptible energy source that has high power quality. The second type is called uncritical load, examples of which are park lights or air conditioners or streetlights.

Uncritical loads can be disconnected when there is a shortage of power supply or if the main grid is disconnected. Uncritical loads are usually supplied by a current source, such as PV, or storage devices. Disconnecting the uncritical load is used in many micro-grid applications when operating in islanded mode. The loads of a micro-grid are usually supplied by both the grid and the micro-grid. However, if the grid is disconnected, two issues arise related to micro-grid load.

CONTROL SYSTEM

The control system is an important component of the micro-grid operation because it ensures that the system works correctly. For example, if it is working optimally, the carbon emission will be reduced as generators will run with less fossil fuel. Moreover, the transfer from one mode to other is conducted safely. A micro-grid commonly requires a micro-source controller (MC) and a central controller (CC). Each type of control system is discussed in the following subsections.

MICRO-GRID OPERATION

A micro-grid being a plug and play power unit does have different operational modes. More specifically, a micro-grid that is an integral part of a bulk grid system can only have the following modes of operation.

Grid Connection Mode

The grid connection mode is the normal operation status of the micro-grid. In this mode, the load is supplied by both the grid and the micro-grid. The voltage of the grid is determined by the PCC. The voltage of the grid should be in the same phase as the voltage generated by the DG.

Therefore, in the grid connection mode, the voltage and frequency of the DG are controlled by the grid voltage and frequency.

Islanded Mode

When the grid experiences a fault or disturbance, the main grid is disconnected from the micro-grid by the PCC switch. In this situation, the micro-grid loads are supplied only by the DGs.

Thus, the voltage amplitude and frequency are regulated by the DGs, and the DGs are responsible for the stability of the system by providing nominal voltage and frequency for the micro-grid.

Voltage and frequency management

The primary purpose is to balance the system against losses disturbances so that the desired frequency and power interchange is maintained that is why, voltage and frequency inner loops must be adjusted and regulated as reference within acceptable limits.

Supply and demand balancing

When the system is importing from the grid before islanding, the resulting frequency is smaller than the main frequency, been possible that one of the units reaches maximum power in autonomous operation. Besides, the droop characteristic slope tries to switch in vertical as soon as the maximum power limit has been reached and the operating point moves downward vertically as load increases.

Power quality

Power quality must synthesize quality of supply and quality of consumption using sustainable development as transporting of renewable energy, embedded generation, using high requirements on quality and

ISSN No: 2348-4845
International Journal & Magazine of Engineering,
Technology, Management and Research
A Peer Reviewed Open Access International Journal

reliability by industrial, commercial and domestic loads/costumers avoiding variations as harmonic distortion or sudden events as interruptions or even voltage dips.

After the primary control is applied in islanded mode, a small deviation in the voltage and frequency can be observed in the micro-grid. This deviation must be removed to ensure the full and stable operation of the micro-grid in islanded mode. DGs are responsible for the stability of the system by providing nominal voltage.

Transition between grid connection and islanded mode
In this situation, the voltage amplitude and frequency should be controlled to be within the acceptable limits to ensure the safe transition from one mode to another. At this stage, the static switch adjusts the power reference to the desired value. After the primary control is applied in islanded mode, a small deviation in the voltage and frequency can be observed in the micro-grid. This deviation must be removed to ensure the full and stable operation of the micro-grid in islanded mode.

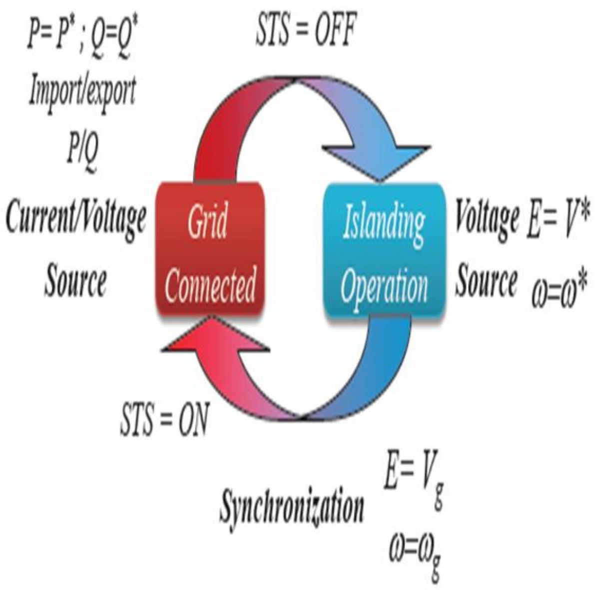

Fig2.2: Transition between grid connection and islanded mode

GRID CONNECTED PHOTOVOLTAIC SYSTEM

Grid connected photovoltaic (PV) energy conversion systems are getting more and more observation in last decade, mainly due to cost reduction of PV modules and government incentive, which has made this power source and technology ambitious among other power source. Photovoltaics' is the field of technology and research related to other devices which directly the PV effect. Photovoltaic effect involves the creation of voltage in a material upon exposure to electromagnetic radiation.

The photovoltaic effect was first noted by a French physicist, Edmund Becquerel, in 1839, who establish that certain materials would manufacture little amounts of electric current when reveal to light. In 1905, Albert Einstein detail the nature of light and the photoelectric effect on which PV technology is based, for which he later won a Nobel prize in physics. The first PV module was built by Bell Laboratories in 1954.

The solar cell is the fundamental building block of the PV technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes the most useful and their conductivity may easily be modified by introducing impurities into their crystal open frame network. For an example in the fabrication of a PV solar cell, silicon, which has four valence electrons, is towards to increase its conductivity. On one side of the cell, the degradation, which are phosphorus atoms with 5 valence electrons (N-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers.

On the different side, atoms of boron with 3 valence electrons (P-donor) generate a greater accord than silicon to attract electrons. Because the P-type silicon is familiar contact with the n-type silicon a p-n junction is initiate and a diffusion of electrons occurs from the region of high electron absorption (the n-type side) into the region of low electron absorption (p-type side). When the electrons are spread across the p-n junction, they recombine with holes on the p-type side.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

However, the spreading of carriers does not occur for an unspecified time, because the polarity of charge directly on either sides of the junction start an electric field. This electric field forms a diode that position current to flow in only one direction. Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell and the electrodes are prepared to be connected to an external load. When photons of illumination drop on the cell, they transfer their power to the charge carriers. The electric field across the joint different photo-generated positive charge carriers (holes) from their negative counterpart (electrons). In this way an electrical current is removing once the circuit is closed on an externalload.

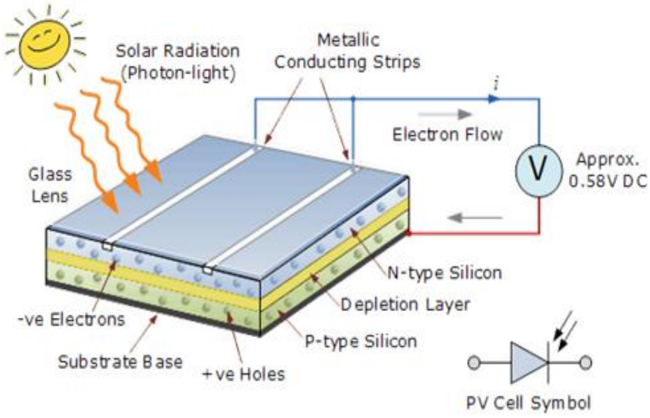

Fig3.1: Block diagram of photovoltaic system

PHOTOVOLTAIC ARRAY MODEL

A photovoltaic array consists of a number of photovoltaic modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The photovoltaic array will be any size from a few hundred watts to hundreds of kilowatts, even though the larger systems are frequently divided into some electrically independent sub arrays each feeding into their own energy ordering of the system.

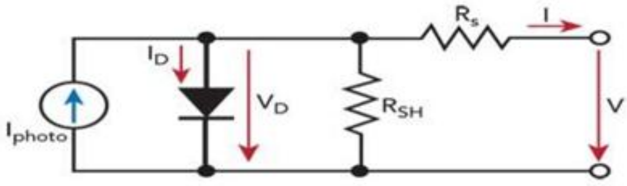

Fig.3.2Equivalent circuit of solar cell

A number of solar cells electrically attached to each other and mounted in a single support structure or frame is called a ‘photovoltaic module’. Modules are designed to supply electricity at a certain potential, such as a normal 12 volt system. The current generated is straightly based on the intensity of illumination reaching the module. Several modules will be wired together to form an array. The PV modules and arrays generate direct-current electricity. They can be attached to the both series and parallel electrical arrangements to generate any necessary voltage and current.

MATHEMATICAL MODEL OF PHOTOVOLTAIC ARRAY

The photovoltaic arrays consist of series and parallel connected PV modules. For each PV module, there are series and parallel connected PV cells. The PV cell is usually described by the equivalent circuit as shown in fig. It can be seen that one current source anti parallel with a diode, a parallel and a series resistance are included in the equivalent circuit. The basic equation for the photovoltaic cell can be obtained by the Kirchhoff’s current law:

$$I=I_{SC}-I_d-I_{sh} \quad \text{...eq. (3.1)}$$

The diode current I_d and the shunt branch current I_{sh} can be expressed as

$$I_d=I_o\left[exp\left(\frac{v+IR_{sr}}{nKT_c/q}\right)-1\right] \quad \text{.... eq. (3.2)}$$

$$I_{sh}=\frac{v+IR_{sr}}{R_{sh}} \quad \text{.... eq. (3.3)}$$

In eq. (3.1), I_{sh} is defined as the photo current. The value of I_{sc} under reference conditions will be determined by seeing the data sheet of the photovoltaic cell. The photocurrent under unreasoned conditions can be expressed as:

$$I_{sc}=I_{scR}\frac{R}{R_R}\left[1+\alpha_T(T_c-T_{CR})\right] \quad \text{...eq. (3.4)}$$

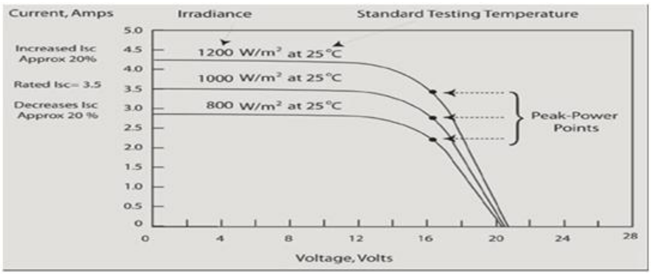

Fig.3.3 I-V curve of photovoltaic array

Where I_{scR} is the short circuit current at the reference solar radiation R_R and the reference cell temperature which are selected as 1KW/m^2 and 25°C separately. The parameter ∝_T is the temperature coefficient of photo current.

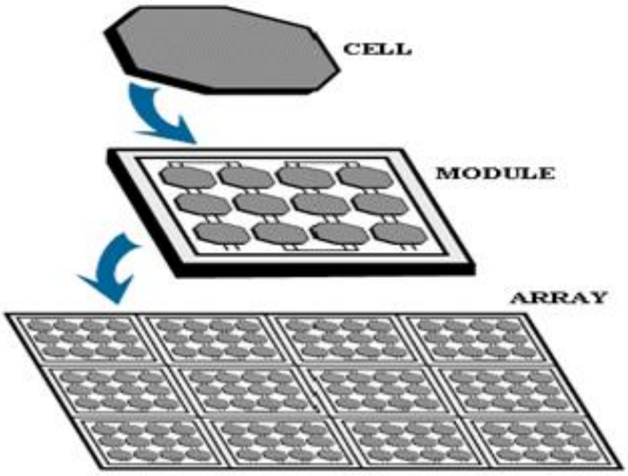

Fig.3.4 Model of photovoltaic array

And the current I_O is the dark current which is the only function of cell temperature.

$$I_O = I_{OR}\left(\frac{T_C^3}{T_{CR}^3}\right) exp\left[\left(\frac{1}{T_{CR}} - \frac{1}{T_C}\right)\frac{q e_g}{nK}\right] \quad \text{.... eq. (3.5)}$$

In eq. (3.5), I_{OR} is the reference dark current. The different parameters become visible from eq. (3.2) to (3.5) are the electron charge q, the Boltzmann constant K, the band-gap energy of the PV celle_g, and the diode perfect factor n which is used to adjust the characteristic I-V curves.

The output voltage and energy for each cell is separately small. In order to increase the voltage level and output energy from the photovoltaic cells will be attached in series and parallel to form one photovoltaic array.

CONTROL TECHNIQUES

MAXIMUM POWER POINT TRACKING

Maximum power point tracking is a technique that solar inverters use to get the most possible power from the PV array. Any given PV module or string of modules will have a maximum power point: essentially, this defines current that the inverter should draw from the PV in order to get the most possible power (power is equal to voltage times current).A maximum power point tracker (or MPPT) is a high efficiency DC to DC converter that presents an optimal electrical load to a solar panel or array and produces a voltage suitable for the load.

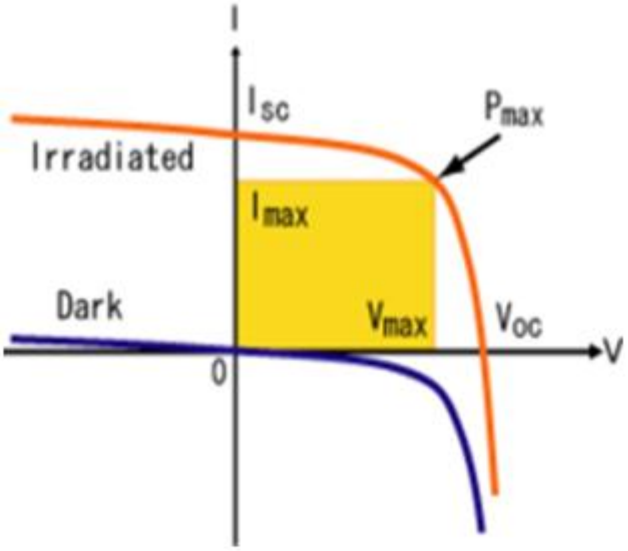

Fig.4.1 Curve for a Solar Cell, Showing the Maximum Power Point Pmax.

PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, and the maximum power point (MPP) occurs at the knee of the curve, where the resistance is equal to the negative of the differential resistance (V/I = -dV/dI). Maximum power point trackers utilize some type of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

Traditional solar inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows though all panels in the string. But because different panels have different IV curves, i.e. different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some panels will be performing below their MPP, resulting in the loss of energy.

Some companies (see power optimizer) are now placing peak power point converters into individual panels, allowing each to operate at peak efficiency despite uneven shading, soiling or electrical mismatch.

MPPTs can be designed to drive an electric motor without a storage battery. They provide significant advantages, especially when starting a motor under load. This can require a starting current that is well above the short-circuit rating of the PV panel. A MPPT can step the panel's relatively high voltage and low current down to the low voltage and high current needed to start the motor. Once the motor is running and its current requirements have dropped, the MPPT will automatically increase the voltage to normal. In this application, the MPPT can be seen as an electrical analogue to the transmission in a car; the low gears provide extra torque to the wheels until the car is up to speed.

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different.

FRACTIONAL OPEN-CIRCUIT VOLTAGE

The method is based on the observation that, the ratio between array voltage at maximum power VMPP to its open circuit voltage V_{OC} is nearly constant.

$$V_{MPP} = K_1 V_{OC} \quad \ldots(4.1)$$

This factor k1 has been reported to be between 0.71 and 0.78. Once the constant k1 is known, VMPP is computed by measuring V_{OC} periodically. Although the implementation of this method is simple and cheap, its tracking efficiency is relatively low due to the utilization of inaccurate values of the constant k1 in the computation of VMMP.

FRACTIONAL SHORT-CIRCUIT CURRENT

The method results from the fact that, the current at maximum power point IMPP is approximately linearly related to the short circuit current I_{SC} of the PV array.

$$I_{MPP} = K_2 I_{SC} \quad \ldots(4.2)$$

Like in the fractional voltage method, k2 is not constant. It is found to be between 0.78 and 0.92. The accuracy of the method and tracking efficiency depends on the accuracy of K2 and periodic measurement of short circuit current.

PERTURB AND OBSERVE

In P&O method, the MPPT algorithm is based on the calculation of the PV output power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. So, the duty cycle of the dc chopper is changed and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. To solve this problem, a variable perturbation size that gets smaller towards the MPP.

However, the P&O method can fail under rapidly changing atmospheric conditions. Several research activities have been carried out to improve the traditional Hill-climbing and P&O methods. A three-point weight comparison P&O method that compares the actual power point to the two preceding points before a decision is made about the perturbation sign. Reference proposes a two stage algorithm that offers faster tracking in the first stage and finer tracking in the second stage.

INCREMENTAL CONDUCTANCE

The method is based on the principle that the slope of the PV array power curve is zero at the maximum power point.

$$(dP/dV) = 0. \text{ Since } (P = VI), \text{ it yields}\ldots \quad (4.3)$$

$$\Delta I/\Delta V = -I/V \text{ , at MPP}$$

$$\Delta I/\Delta V > -I/V \text{ , left of MPP} \quad \ldots(4.4)$$

$$\Delta I/\Delta V < -I/V \text{ , right of MPP} \quad \ldots(4.5)$$

The MPP can be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV). The algorithm increments or decrement the array reference voltage until the condition of equation (4.a) is satisfied. Once the Maximum power is reached, the operation of the PV array is maintained at this point. This method requires high sampling rates and fast calculations of the power slope.

To understand how MPPT works, let's first consider the operation of a conventional (non-MPPT) charge controller. When a conventional controller is charging a discharged battery, it simply connects the modules directly to the battery. This forces the modules to operate at battery voltage, typically not the ideal operating voltage at which the modules are able to produce their maximum available power. The PV Module Power/Voltage/Current graph shows the traditional Current/Voltage curve for a typical 75W module at standard test conditions of 25°C cell temperature and 1000W/m2 of insulation. This graph also shows PV module power delivered vs module voltage. For the example shown, the conventional controller simply connects the module to the battery and therefore forces the module to operate at 12V. By forcing the 75W module to operate at 12V the conventional controller artificially limits power production to »53W.

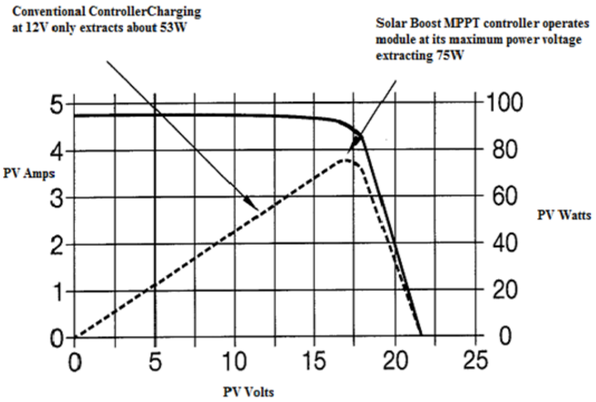

Fig.4.2 PV Module Power Delivered Vs Module Voltage.

Rather than simply connecting the module to the battery, the patented MPPT system in a Solar Boost charge controller calculates the voltage at which the module is able to produce maximum power. In this example, the maximum power voltage of the module (VMP) is 17V. The MPPT system then operates the modules at 17V to extract the full 75W, regardless of present battery voltage. A high efficiency DC-to-DC power converter converts the 17V module voltage at the controller input to battery voltage at the output.

If the whole system wiring and all was 100% efficient, battery charge current in this example would be V-module¸ V-battery, X I-module, or 17V ¸ 12V x 4.45A = 6.30A. A charge current increase of 1.85A or 42% would be achieved by harvesting module power that would have been left behind by a conventional controller and turning it into useable charge current. But, nothing is 100% efficient and actual charge current increase will be somewhat lower as some power is lost in wiring, fuses, circuit breakers, and in the Solar Boost charge controller.

Actual charge current increase varies with operating conditions. As shown above, the greater the difference between PV module maximum power voltage VMP and battery voltage, the greater the charge current increase will be. Cooler PV module cell temperatures tend to produce higher VMP and therefore greater charge current increase. This is because VMP and available power increase as module cell temperature decreases as shown in the PV Module Temperature Performance graph.

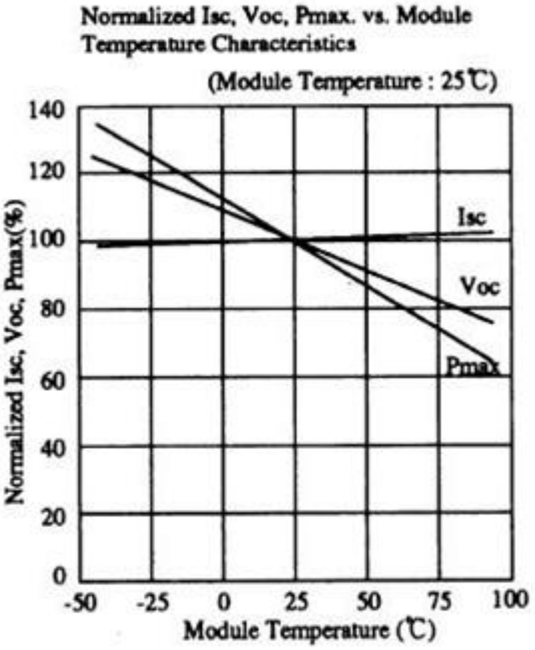

Fig.4.3 Normalized Isc, VOC ,Pmax, Vs Module Temperature Characteristics.

Modules with a 25°C VMP rating higher than 17V will also tend to produce more charge current increase because the difference between actual VMP and battery voltage will be greater. A highly-discharged battery will also increase charge current since battery voltage is lower, and output to the battery during MPPT could be thought of as being "constant power".

SIMULATION RESULTS

The simulation results have shown its ability to achieve all control objectives. The issue of considering the discharging mode of the battery operation, which shifts the problem to the class of hybrid dynamical systems, is currently being investigated. The linear load demand is also less than or equal to 12 KW. Two test scenarios are carried out to evaluate the performance of the developed optimal EMS.

SIMULATION CIRCUIT OF CONSTANT CURRENT CHARGING MODE

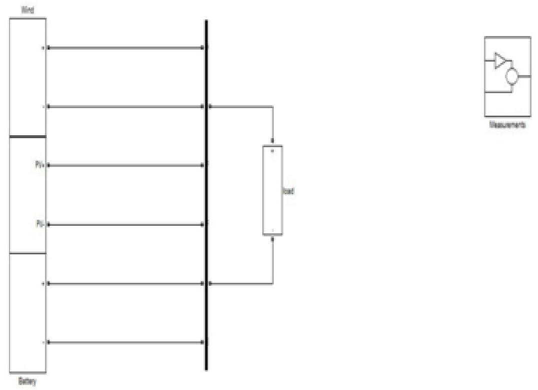

Fig5.1: simulation circuit of constant current charging mode

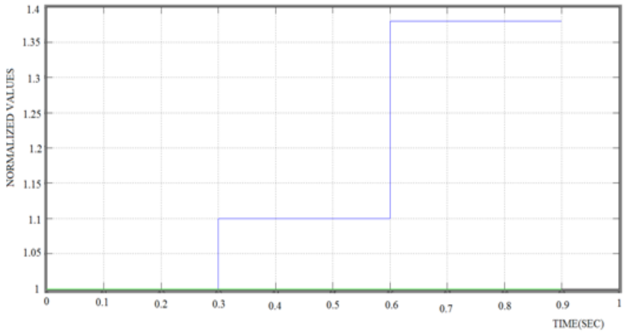

Fig5.2(a)

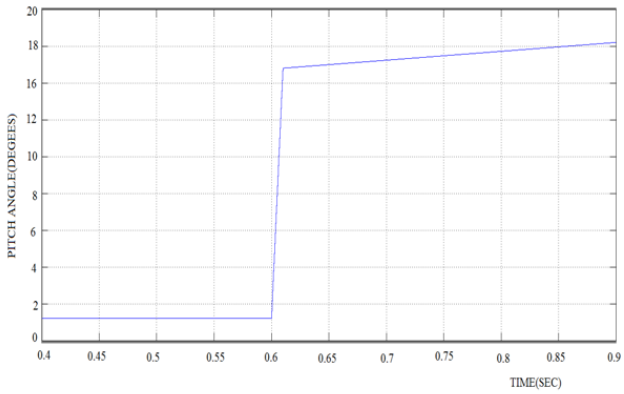

Fig5.2(b)

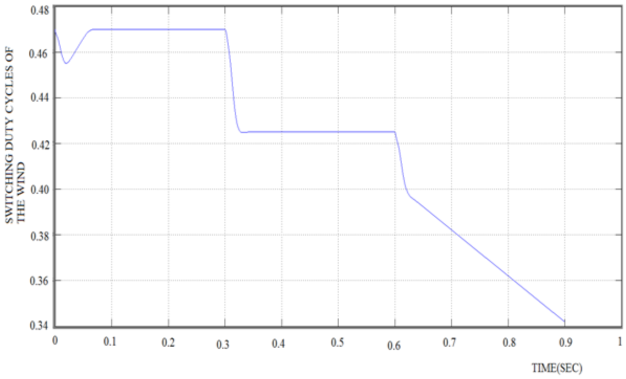

Fig5.2(c)

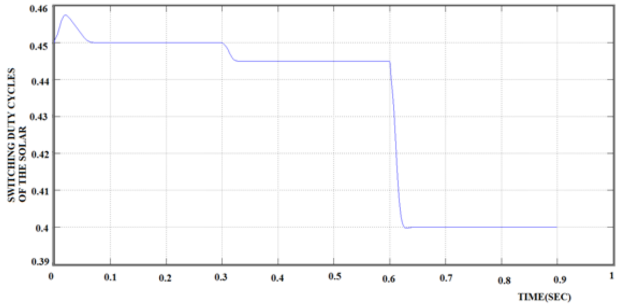

Fig5.2(d)

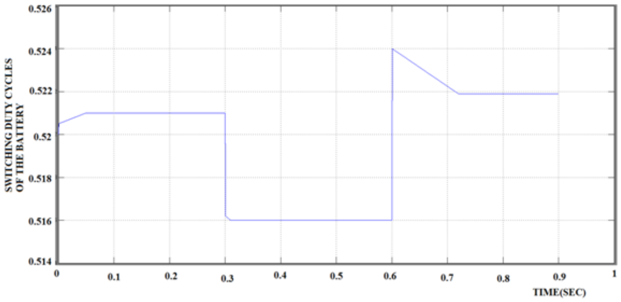

Fig5.2(e)

Fig5.2: (a) Normalized amounts of non-manipulated inputs and the optimal (b) pitch angle, and switching duty cycles of the (c) wind, (d) solar, and (e) battery branch converters in Scenario I.

Fig. 5.2(a) illustrates the normalized wind speed, insulation, and load demand inputs to the system. Wind speed starts at the rating value of the generator and sharply increases by 37.5% at t=600s. Load demand is below the nominal value, except between 300 to 600 s. Moreover, solar irradiance is constant during the simulation only for results clarification. Fig. 5.2(b)–(e) depicts the calculated optimal control variables. The wind branch operates at MPPT mode up to seconds with a calculated pitch angle of zero asgiven in Fig. 5.2(b). Fig. 5.2(c) shows the calculated buck converter duty cycle that adjusts the rotational speed of the wind turbine at its nominal value. NMPC strategies, which are also called as the receding horizon control, continuously solve an OCP over a finite-horizon using the measurements obtained at as the initial values. Then the first optimal value is applied as the next control signal. Comparing with the conventional methods, NMPCs are inherently nonlinear and multivariable strategies that handle constraints and delays.

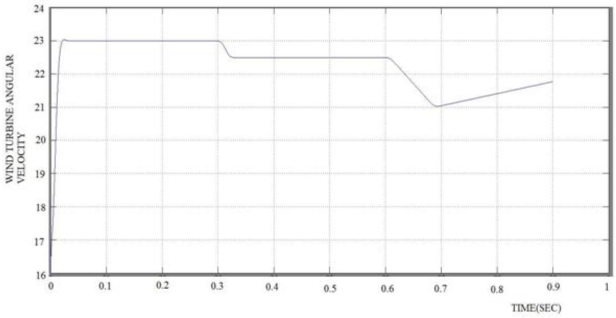

Fig 5.3(a)

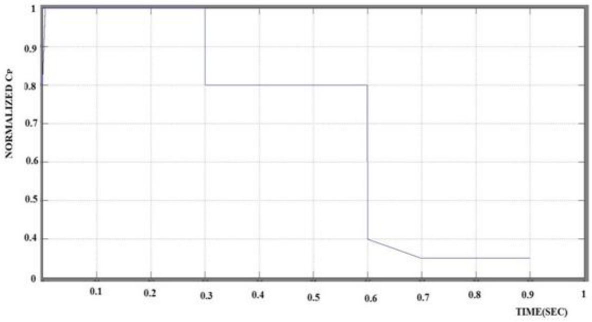

Fig5.3(b)

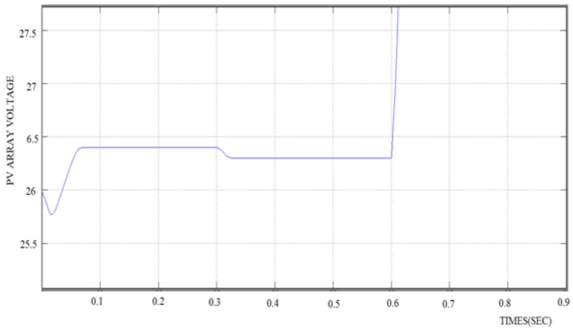

Fig5.3(c)

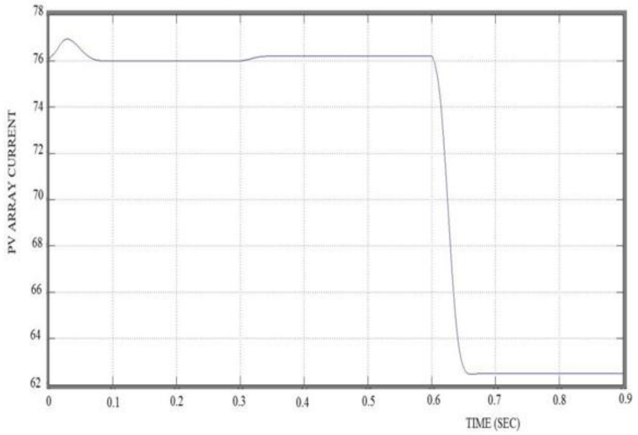

Fig5.3(d)

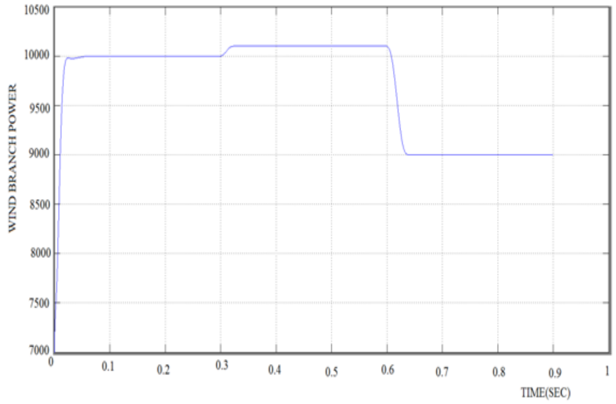

Fig5.3(e)

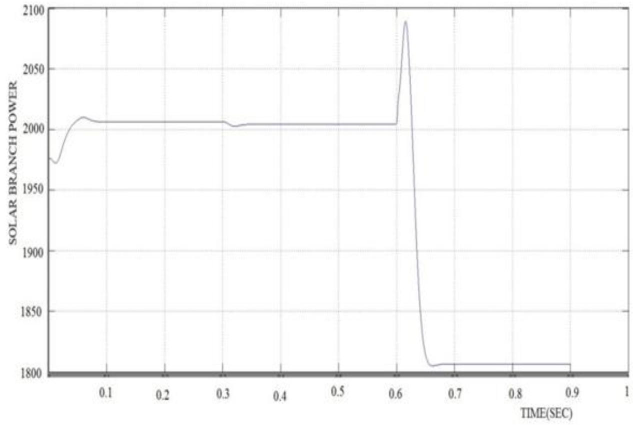

Fig5.3(f)

Fig5.3: Different variables of the wind and solar branches: the wind turbine (a) angular velocity and (b) power coefficient; the PV array (c) voltage and (d) current; and (e)-(f) the generated power by each branch in Scenario I.

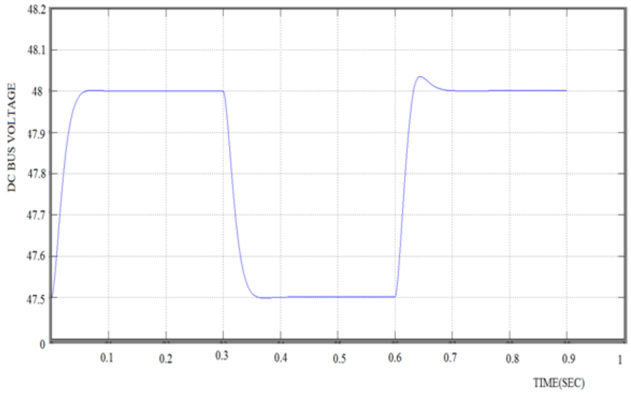

Fig5.4(a)

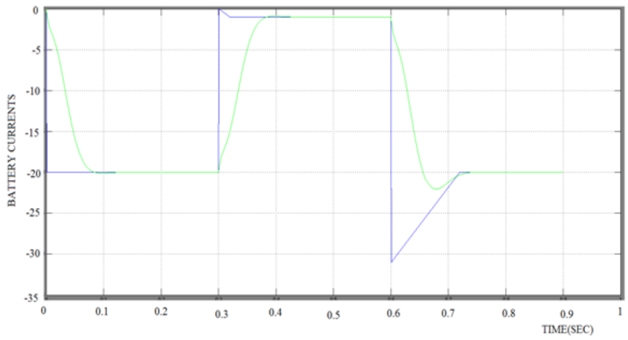

Fig5.4(b)

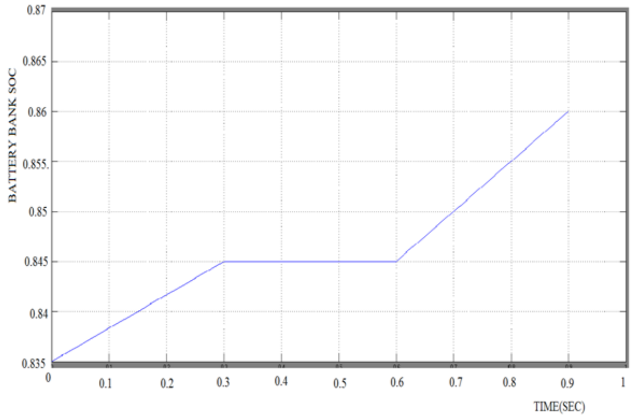

Fig5.4(c)

Fig5.4: (a) The dc bus voltage of the micro-grid, the (b) charging current, and (c) SOC of the battery bank in Scenario I.

Applying these optimal control variables to standalone dc micro-grid, different variables of the wind and solar branches are depicted in Fig. 5.3. Fig 5.4 illustrates the resulting dc bus voltage and the battery bank SOC and charging currents. the calculated buck converter duty cycle that adjusts the rotational speed of the wind turbine at its nominal value, as given by Fig. 5.3(a). Fig. 5.3(b) indicates that the resulting power coefficient reaches to its maximum value. Fig. 5.3(a) and (b) illustrates a combination of the speed and power coefficient variations that curtails the generation down to 9.039KW after t=600s, as given by Fig. 5.3(e). Fig. 5.3(c) and (d) illustrates that though the PV array initially operates at its MPP. In spite of significant wind speed and load demand variations, Fig. 5.4(a) depicts that the dc bus voltage level stays within the permissible range. From Fig. 5.4(a), it can be seen that after t=600s, when there is not enough generated power to charge battery, controller reduces the dc bus voltage level. However, at t=600s the voltage level returns back to the nominal value of 48v. Fig. 5.4(b) depicts that the charging current of the battery bank remains constant at its nominal value, In Fig. 5.4(c), it can be seen that this strategy helps the battery to be charged up to high SOC values.

CONCLUSION

In this project, we developed a novel optimal EMS that manages the energy flows across a standalone green dc microgrid, consisting of the wind, solar, and battery branches. A coordinated and multivariable online NMPC strategy has been developed to address, as the optimal EMS, three main control objectives of standalone dc micro-grids. These objectives are the voltage level regulation, proportional power sharing, and battery management. In order to address these objectives, the developed EMS simultaneously controls the pitch angle of the wind turbine and the switching duty cycles of three dc-dc converters.

It has been shown that the developed controller tracks the MPPT of the wind and solar branches within the normal conditions and curtails their generations during the under-load conditions. The provided flexible generation curtailment strategy realizes the constant current-constant voltage charging regime that potentially increases the life span of the battery bank. It is important to note that the proposed strategy can be employed as a centralized implementation of the primary and secondary levels in the hierarchical architecture. The simulation results have shown its ability to achieve all control objectives. The issue of considering the discharging mode of the battery operation, which shifts the problem to the class of hybrid dynamical systems, is currently being investigated.

REFERENCES

[1] J. M. Guerrero, M. Chandorkar, T. Lee, and P. C. Loh, "AdvancedControl Architectures for Intelligent Micro-grids-Part I: Decentralized and Hierarchical Control," IEEE Trans. Ind. Electron., vol. 60, no. 4,pp. 1254–1262, 2013.

[2] R. S. Balog, W. W. Weaver, and P. T. Krein, "The load as an energyasset in a distributed DC smart grid architecture," IEEE Trans. Smart Grid, vol. 3, no. 1, pp. 253–260, 2012.

[3] J. M. Guerrero, P. C. Loh, T. L. Lee, and M. Chandorkar, "AdvancedControl Architectures for Intelligent Micro-grids-Part II: Power quality,energy storage, and AC/DC micro-grids," IEEE Trans. Ind. Electron.,vol. 60, no. 4, pp. 1263–1270, 2013.

[4] N. Eghtedarpour and E. Farjah, "Control strategy for distributed integrationof photovoltaic and energy storage systems in DC micro-grids,"Renew. Energy, vol. 45, no. 0, pp. 96–110, 2012.

[5] D. Chen and L. Xu, "Autonomous DC voltage control of a DC micro-gridwith multiple slack terminals," IEEE Trans. Power Syst., vol. 27,no. 4, pp. 1897–1905, Nov. 2012.

[6] L. Xu and D. Chen, "Control and operation of a DC microgrid withvariable generation and energy storage," IEEE Trans. Power Del., vol.26, no. 4, pp. 2513–2522, Oct. 2011.

[7] S. Anand, B. G. Fernandes, and M. Guerrero, “Distributed control to ensure proportional load sharing and improve voltage regulation inlow-voltage DC micro-grids,” IEEE Trans. Power Electro., vol. 28, no.4, pp. 1900–1913, 2013.

[8] B. Zhao, X. Zhang, J. Chen, C. Wang, and L. Guo, “Operation optimization of standalone micro-grids considering lifetime characteristicsof battery energy storage system,” IEEE Trans. Sustain. Energy, to bepublished.

[9] T. Zhou and B. Francois, “Energy management and power control of ahybrid active wind generator for distributed power generation and grid integration,” IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 95–104,2011.

[10] X. Liu, P. Wang, and P. C. Loh, “A hybrid AC/DC microgrid and its coordinationcontrol,” IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 278–286,2011.