An Optimal Energy Management Strategy for Standalone DC Micro grids

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Abstract-**The proposed system mainly deals with implementation of Energy Management System (EMS) to DC micro grid using maximum power point tracking (MPPT) algorithm. A coordinated and multivariable EMS is proposed that employs a wind turbine and a photovoltaic array as controllable generators by adjusting the pitch angle and the switching duty cycles and a storage system consisting of batteries. In order to realize constant current, constant voltage (IU) charging regime and increase the life span of batteries, the proposed EMS require being more flexible with the power curtailment feature. The proposed strategy is developed as an online nonlinear model predictive control (NMPC) algorithm based on individual MPPTs of the system.**

Index Terms- **Battery Management, Maximum Power Point Tracking (MPPT), Nonlinear Model Predictive Control (NMPC), Power Sharing, and Voltage Regulation.**

I. INTRODUCTION

In the future, distribution networks will consist of several interconnected smart micro grids that have the capability to locally generate, consume, and store energy[1]. A micro grid can be operated as an extension of a main power grid, i.e., in grid-connected mode, or as a standalone network without a connection to the main power grid. The most common applications of standalone dc micro grids are in the field of avionic, marine, industrial areas , as well as in electrification of remote areas. In the case of ac systems , the need of synchronization is very essential for several generators[2],[3]. The dc micro grids are more efficient than ac micro grids because the dc generators and storage batteries do not need ac-dc converters for being connected to dc micro grids [4],[1]. Voltage regulation, proper power sharing, and battery management are more severe in standalone dc micro grids that consist of only solar and wind energy sources and lead to the necessity of more developed control strategies.

The main control objective is to find out the stability of dc micro grid that can be obtained from the stability of dc bus voltage level [5],[6],[7]. The voltage level of grid-connected dc micro grids can be regulated by the use of grid voltage source converters (G-VSCs) [8],[9]. Battery banks are the effective slack terminals for standalone dc micro grids [6] and their energy absorbing capacities are usually limited regarding a number of operational constraints. To regulate the voltage level of standalone dc micro grids, the works in [2]and [6] presents load shedding strategies for the insufficient power generation or energy storage. The works in [10]–[12],presents strategies that decrease the renewable power generations of standalone dc micro grids if the storage battery bank cannot absorb the excess generation. These curtailment strategies restrict the batteries charging rate by absorbing maximum power; however, the maximum charging current must also be limited. They do not curtail the power of each generator in proportion to its rating.

To prevent circulating currents between generators and overstressing conditions [13], load demands must be shared accurately between all slack DGs in proportion to their ratings [7], [14]. Standalone dc micro grids are usually located in areas where the power sharing between DGs can be easily managed by centralized algorithms that are less affected by two main issues: 1) the absolute voltage level of a standalone micro grid is shifted as the result of the load demand variation; 2) batteries in charging mode are nonlinear loads causing distortions to the grid voltage.

Operational constraint, the maximum absorbed power by the batteries in order to protect them from being over charged. Therefore batteries act as nonlinear loads during the charging mode. Depending on the proportion of the power generation to the load demand ratio within standalone DC micro grids, three cases are possible.

1) Power generation and load demand are balanced;
2) Load demand exceeds power generation causes dc bus voltage to drop in absence of any load shedding; and
3) Power generation is higher than load demand leads batteries to be overcharged and bus voltage to climb.

Energy management strategy (EMS) is proposed, as its control objectives, three aforementioned issues corresponding standalone dc micro grids; i.e., dc bus voltage regulation, proportional power sharing, and battery management. In contrast to the strategies available in literature in which renewable energy systems (RESs) always operate in their MPPT mode, the proposed multivariable strategy uses a wind turbine and a PV array as controllable generators and curtails their generations if it is necessary. The proposed EMS is developed as an online novel NMPC strategy that continuously solves an optimal control problem (OCP)and finds the optimum values of the pitch angle and three switching duty cycles. It simultaneously controls four variables of micro grids:

1) Power coefficient of the wind turbine.
2) Angular velocity of the wind generator.
3) Operating voltage of the PV array and
4) Charging current of the battery bank.

It is shown that, employing new available nonlinear optimization techniques and tools, the computational time to solve the resulting NMPC strategy is in permissible range. The proposed strategy implements the IU charging regime that helps to increase the batteries life span.

II. PROPOSEDCONTROL STRATEGY

Fig.1. shows the Topology of a small-scale and standalone dc micro grid with connected loads. The mathematicalmodel of stand- alone green dc microgrids is described ashybrid differential algebraic equations (hybrid DAEs). Thebelow figure Fig.2 summarizes a modified version of theproposed model. Since this paper focuses on the case inwhich there is an excess power greater than or equal to themaximum possible absorbing rate of the battery bank thefollowing notations are used to model the standalone dc.

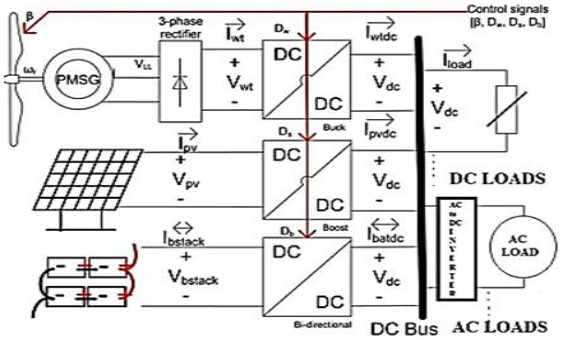

Fig.1.*Topology of a small-scale and standalone dcmicrogrid with connected loads*

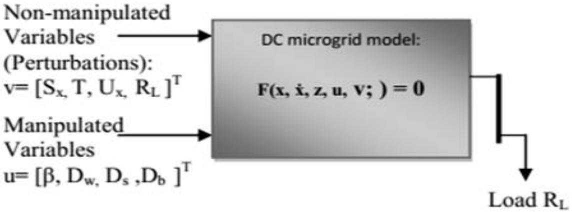

Fig 2 *Modified version of the system model*

$X = [I_f, Q_{act}, \omega_r]^T$ …………………… (1a)

$z =$
$[I_{pv}, V_{pv}, I_{pvdc}, I_{bat}, I_{batdc}, V_{batdc}, I_{wt}, V_{wt}, I_{laod}, ..]^T$
(1b)

Where F is a set of implicit differential and algebraic functionals fi for i € [1, 2, 3 …24]. The first two constraints f1 and f2 are due to the fact that in standalone dc micro grids the sum of the generated, stored, and consumed powers is always zero:

$f_1 = V_{dc}(I_{pvdc} + I_{wtdc} + I_{batdc} + I_{load})$…… (2a)

$f_2 = V_{dc} - I_{load}R_L$…………………… (2b)

A. Wind Branch

Wind turbines (WTs) convert the kinetic energy of wind to mechanical power. In order to generate the maximum power by a WT at variable wind speed, it is necessary to employ a maximum power point tracking (MPPT) control strategy [11]. A wind turbine can be connected to an electrical generator directly or through a gear-box. In order to convert the three-phase output of a PMSG to dc voltage, it is essential to deploy a three-phase rectifier. A general structure, which consists of a full-bridge diode rectifier connected in series to a dc-dc converter, is common due to lower cost. Performance of the wind turbines is measured as the power coefficient curve with respect to the tip speed ratio and pitch angle. Equation (3) shows the power coefficient curve of three-blade wind turbines.

$$f_3 = C_{p,norm} - \frac{1}{c_{p,max}} \times \left(C_1\left(\frac{c_2}{\lambda_1} - C_3\beta - C_4\right)\exp\left(-\frac{c_5}{\lambda_1}\right) + C_6\lambda\right) \qquad (3a)$$

$$f_4 = \lambda - \frac{Rad\ X\ \omega_r}{U_x} \qquad (3b)$$

$$f_5 = \lambda_1 - \left(\frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}\right)^{-1} \qquad (3c)$$

Where λ and β, respectively, are the tip speed ratio and pitch angle. Rad is the radius of the blades and $c_{p,max}$ isthe maximum achievable power coefficient at the optimumtip speed ratio of λ_{out} .

Energy management strategies of micro grids must estimate the dc bus voltage level deviation from its set point in about every 5–10 sec. It means that except the angular velocity of the generator all other fast voltage and current dynamics can be ignored. It is also assumed that there are no mechanical and electrical losses through the power train and therefore the electromagnetic power given is equal to the output electrical power of the wind branch. Equation shows that the PMSG is connected directly to turbine, which rotates at low speed, and therefore needs to have multiple pole pairs P. Hence, the electrical frequency is P times faster than the mechanical angular velocityω_r. The shaft inertia J(Kg.m^2) and the combined viscous friction coefficient F(N.m.s) of PMSG are given by the manufacturers. For energy management strategies, the average model of the buck converter is replaced with the steady-state equations for the continuous conduction mode (CCM).

B. Battery Branch

There are different types of batteries applicable to the Backup/storage purposes across micro grids. Among all the lead-acid batteries have some advantages for hybrid renewable energy system (HRES) applications. Lead-acid batteries are widely available in many sizes and are appropriate for small to large applications. Furthermore, the normalized cost of this type of batteries is reasonable and it is mature in concepts, mathematical model and technology. In fact, the performance characteristics of lead-acid batteries are well understood and modeled.

C. Solar Branch

PVs are among the popular renewable energy components to harvest solar energy. A PV cell, as the fundamental PV element, is a P-N junction that converts solar irradiance to the electrical energy. Normally, manufacturers provide PV modules, also known as PV panels, which consist of several PV cells connected together in series. A PV cell is a non-linear component that its operation is characterized by a set of current-voltage curves at different insolation levels and junction temperatures. The equivalent electrical circuit of the PV module is used to mathematically model the solar branch, consisting of a PV array and a boost converter [13].

D. Maximum Power Point Tracking

Maximum power point tracking (MPPT) is a technique used commonly with wind turbines and photovoltaic (PV)solar systems to maximize power extraction under all conditions. The MPPT technique is also useful for the operation of battery. Depending upon the MPPT technique charging and discharging modes of operations of batteries are controlled. It is useful in protecting the battery from over charging, and to implement the IU charging regime of the battery that helps to increase the life span of batteries. The output power induced by the pv modules and wind turbine are influenced by number of factors which are solar radiation, temperature, wind speed etc. To maximize the power output from the system it is necessary to track the maximum power points of the individual energy sources. There are several methods to track the mpp's of the system among them P&O is the commonly used method.

E. Power Conversion

In order to supply different types of variable dc and variable ac loads connected to the isolated standalone dc micro grid, and depending on the energy supplying sources and storage systems it is necessary to convert the energy to maintain the dc bus voltage regulation. Depending upon the load connected and the energy sources the energy conversion is either DC-DC or DC-AC[14]. And only the AC-DC conversion is needed at wind turbine through bridge rectifier to connect dc bus.

III. SIMULATION AND RESULTS

To evaluate the performance of the developed optimal EMS, Two test scenarios are carried out. They are

1.) Scenario I: Constant current charging mode.
2.) Scenario II: Constant voltage charging mode.

1) Scenario I: Constant Current Charging Mode:

This scenario covers the following three different cases which are run successively:

Case I: Wind turbine and PV array generate enough power at their MPPs to sup-ply load demands and charge battery bank with its nominal charging current.

Case II: The generated power is just enough to supply the load demands and therefore battery bank is not charged oris charged with the current less than its nominal charging current.

Case III: The generated power is more than the required power to supply the load demands and charge battery bank with its nominal charging current. Each case lasts for 5minutes and therefore the total period of the simulation time is15 minutes. In order to calculate the optimal control variables every 5seconds, the developed NMPC controller runs exactly 60 times as per each case.

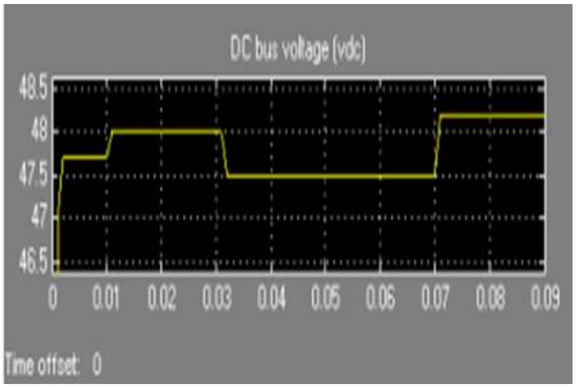

Fig.4 (a) *Dc bus voltage*

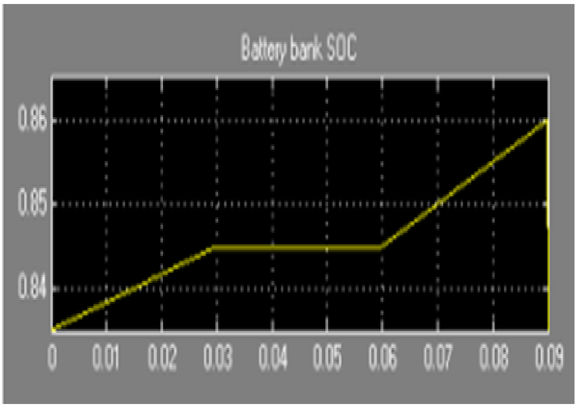

Fig.4 (b) *Battery bank soc*

From Fig. 4(a), it can be seen that after t = 300 s, when there is not enough generated power to charge battery, controller reduces the dc bus voltage level. However, att = 600s the voltage level returns back to the nominal value of 48.0V. So the controller makes the dc bus voltage level within the permissible range i.e. 48.0 ±0.96V even when there is a significant change in load demand variations and change in wind speed which changes power generation from wind system. From Fig.6(c), it can be seen that this strategy helps the battery to be charged up to high SOC values.

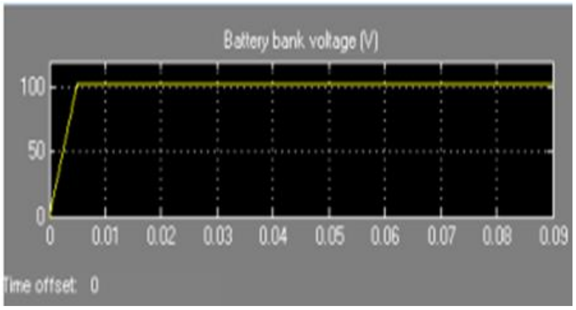

Fig.5 (a) *Battery bank voltage*

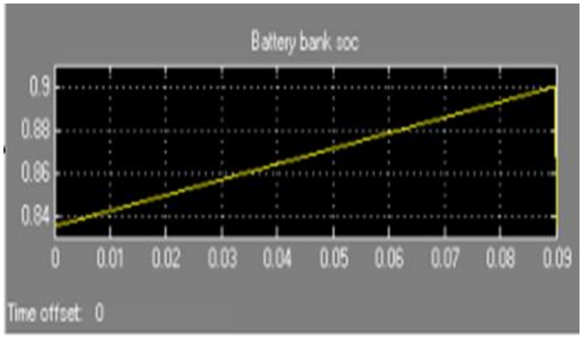

Fig.5 (b) *Battery bank soc*

From Fig. 5(a) it can be seen that the battery bank voltagereaches certain value i.e. a safe margin of the gassingvoltage after some time and remains constant. This doneby the controller which reduces the charging currentgradually with respect to the safe margin of the gassingvoltage in order to maintain the battery bank voltageconstant. Fig. 5(b) indicates that the battery can be fullycharged with the constant current-constant voltage regimewith no risk of exceeding the gassing voltage.

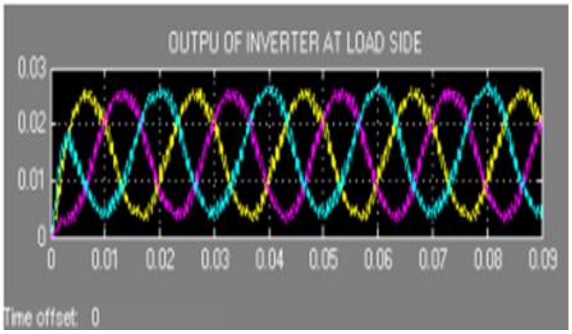

Fig. 6 *output current of the inverter at load side*

From the Fig. 6 it shows the 3-phase current output of the inverter which is used to supply the Ac dump loads at the standalone DC micro grid installed at the remote and rural areas. This output current is applied either directly to the loads or through a transformer depending upon the loads connected.

IV. CONCLUSION

These targets are the voltage level direction, relative power sharing, and battery administration. With a specific end goal to address these destinations, the created EMS at the same time controls the pitch edge of the breeze turbine and the exchanging obligation cycles of three dcdc converters. It has been demonstrated that the created controller tracks the MPPs of the breeze and sun powered branches inside the ordinary conditions and diminishes their eras amid the under load conditions. The gave adaptable era abridgement system understands the consistent present, steady voltage charging administration that conceivably builds the life expectancy of the battery bank.

REFERENCES

[1] J. M. Guerrero, M. Chandorkar, T. Lee, and P. C. Loh, “AdvancedControl Architectures for Intelligent Microgrids-Part I: Decentralizedand 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 smartgrid architecture,” IEEE Trans. SmartGrid, 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 Microgrids-Part II: Power quality,energy storage, and AC/DC microgrids,” IEEE Trans. Ind. Electron.,vol. 60, no. 4, pp. 1263–1270, 2013.

[4] N. Eghtedarpour and E. Farjah, “Control strategy for distributed integration of 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 microgrid with 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 toensure proportional load sharing and improve voltage regulation inlow-voltage DC microgrids,” 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 microgrids 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 gridintegration,” 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 coordination control,” IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 278–286,2011.

[11] H. Kanchev, D. Lu, F. Colas, V. Lazarov, and B. Francois, “Energymanagement and operational planning of a microgrid with a PV-basedactive gen. for smart grid applications,” IEEE Trans. Ind. Electron.,vol. 58, no. 10, pp. 4583–4592, 2011.

[12] H. Ghoddami, M. B. Delghavi, and A. Yazdani, “An integrated windphotovoltaic-battery system with reduced power-electronic interfaceand fast control for grid-tied and off-grid applications,” Renew. Energy,vol. 45, no. 0, pp. 128–137, 2012.

[13] J. M. Guerrero, J. C. Vasquez, J. Matas, L. G. de Vicua, and M. Castilla,“Hierarchical control of droop-controlled AC and DC microgrids-ageneral approach toward standardization,” IEEE Trans. Ind. Electron.,vol. 58, no. 1, pp. 158–172, 2011.

[14] P. H. Divshali, A. Alimardani, S. H. Hosseinian, and M. Abedi, “Decentralized cooperative control strategy of microsources for stabilizingautonomous VSC-Based microgrids,” IEEE Trans. Power Syst., vol.27, no. 4, pp. 1949–1959, Nov. 2012.

[15] P. C. Loh, D. Li, Y. K. Chai, and F. Blaabjerg, “Autonomous operationof hybrid microgrid with AC and DC subgrids,” IEEE Trans. PowerElectron., vol. 28, no. 5, pp. 2214–2223, 2013.

[16] T. L. Vandoorn, B. Meersman, L. Degroote, B. Renders, and L. Vandevelde, “A control strategy for islanded microgrids with DC-Linkvoltage control,” IEEE Trans. Power Del., vol. 26, no. 2, pp. 703–713,Apr. 2011.

[17] T. L. Vandoorn, B. Meersman, J. D. M. De Kooning, and L. Vandevelde, “Analogy between conventional grid control and islanded microgrid control based on a global DC-Link voltage droop,” IEEE Trans.Power Del., vol. 27, no. 3, pp. 1405–1414, Jul. 2012.

[18] H. Kakigano, Y. Miura, and T. Ise, “Distribution voltage control for DCmicrogrids using fuzzy control and gain-scheduling technique,” IEEETrans. Power Electron., vol. 28, no. 5, pp. 2246–2258, 2013.

[19] H. Fakham, D. Lu, and B. Francois, “Power control design of abattery charger in a hybrid active PV generator for load-followingapplications,” IEEE Trans. Ind. Electron., vol. 58, no. 1, pp. 85–94,2011.

[20] A. M. Dizqah, A. Maheri, K. Busawon, and P. Fritzson, “Acausal modelling and dynamic simulation of the standalone wind-solar plant usingmodelica,” in Proc. 2013 15th Int. Conf. Computer Modelling and Simulation (UK-Sim), 2013, pp. 580–585.