OPTIMAL ENERGY MANAGEMENT STRATEGY FOR RENEWABLE ENERGY DC MICROGRIDS

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ABSTRACT

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 paper, a coordinated and multivariable energy management strategy is proposed that employs a wind turbine and a photovoltaic array of a standalone DC microgrid 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 algorithm. Applying to a sample standalone dc microgrid, 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. The control technique is simulated using MATLAB/SIMULINK in PV- wind power generating system with MPPT and case study has been done on the control strategy and verifies the effectiveness of adaptive droop control on output converter voltage

Keyword: - *Microgrid; droop method; maximum power point tracking (MPPT); solar; wind; fuel cell*

1. INTRODUCTION

The demand on electrical energy is increasing day by day. For our future demand the existing energy systems will not be enough. Therefore the search for alternative energy sources has become an important issue. Many researches has been done in the area of unlimited energy resources such as wind power generation and solar energy transformation. Also expensive technologies and global environmental damage techniques has led to a global scenario which point towards generating clean and eco-friendly green energy. In many ways, green energy is having a leading role in the democratized energy production and consumption in the country. Of all the renewable energy sources, solar energy have the least impact on environmental. Electricity produced from photovoltaic (PV) cells does not result in environmental pollution, deplete natural resources, or endanger living being [1].

For many years, the centralized power grid is one way of electricity flow, generated by large, remote power plants and distributed over large distance by transmission lines to homes and industries. In recent years the system's shortcomings are increasing. The traditional grid is highly depends on planet-warming fossil fuels. Due to the upcoming of negative issues there is departing from the traditional system and introduced a new model called Microgrid. A microgrid is independent systems that produce power for a specific entity. A microgrid is defined by the ability to generate power using renewable energy sources near or at the point of consumption independent of other generators. Main applications are in areas having high energy prices or remote areas (such as islands) or facilities, such as military or experimental installations that cannot risk losing power, etc. Microgrid, also named as mini grids, can be operated in islanded or grid connected mode. Compared to AC, DC microgrids are very reliable highly efficient, economic and easy to control.

The main problem faced by the DC Microgrid is that when converters are parallel connected the output voltage from converter won't be constant always. [2]- [8] Main reason for this variation is due to change in load and input power and also feedback voltage and current. Even a small mismatch of output voltage will initiate circulating current and difference in current sharing will cause an overload to the converters and also variation in power sharing. The converter with higher output voltage will give higher power. One of most popular control technique for proper sharing is droop control method. This paper mainly focus on the voltage control and power sharing of the converters using droop index and also maximum power point tracking for better performance.

The droop control method is a decentralized control technique in which each converter is controlled based on the output current [7]. This paper explains the importance of cable resistance in load sharing. In existing methods the droop used for voltage control is fixed which a major drawback [5]. An instantaneous dro op is calculated to overcome this drawback which can improve the voltage control to larger extend.

The droop control method is local control technique that relies on externally or internally added resistance of the parallel connected modules for maintaining relatively equal current sharing. Generally, the droop method is easy to implement, and it does not require any communication system. However, fixed droop method also achieves the equivalent current sharing accuracy but major drawback is its poor voltage regulation whereas in case of instantaneously produced droop, it can adaptively controls the reference voltage of each module.[10]-[12] This will improve the voltage regulation and the current sharing of the traditional method.
The solar cell and wind turbine efficiency depends on factors such as temperature, insolation (radiation), dirt, shadow, wind speed and so on. Due to fast changing climate such as cloudy weather, storm or sunny day there will be changes in irradiance, wind speed and rise in ambient temperature can decrease the PV wind output power. PV – wind system produces energy depending to its operational and environmental conditions. Maximum power point tracking (MPPT) is a concept put forward to improve the efficiency of PV – wind system. All MPPT methods follow goal of maximizing the output power by tracking the maximum on all operating condition. Analysis study and case study of the droop control method for voltage regulation and MPPT method is explained.

A number of phenomena affect the batteries operation during the charging mode [19]:
1) Applying high charging currents, the batteries voltages quickly reach to the gassing threshold; 2) the internal resistor and hence power losses and thermal effects increase at high SOC levels; and 3) batte ries cannot be fully charged with a constant high charging current. The work in [6] limits, as an operational constraint, the maximum absorbed power by the batteries in order to protect them from being overcharged. However, since batteries act as nonlinear loads during the charging mode, it does not necessarily limit the charging currents. Alternatively, the works in [10] restricts the maximum attainable SOC that leads to unused capacities. Depending on the proportion of the power generation to the load demand ratio within standalone DC microgrids, three cases are envisaged: 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. This study focuses on case 3) in which the generated power must be curtailed if it violates the batteries charging rates or if batteries are fully charged. A novel energy management strategy (EMS) is proposed to address, as its control objectives, three aforementioned issues corresponding standalone dc microgrids; 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 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 microgrids:
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 comp utational time to solve the resulting proposed strategy is in permissible range. Unlike dump load-based strategies that only protect the battery from overcharging; the proposed strategy implements the IU charging regime that helps to increase the batteries life span. Moreover, removing dump loads, the overall installation cost is reduced.

2. DESCRIPTION OF PROPOSED SYSTEM

The standalone dc microgrid in Fig. 4.1 is a small-scale microgrid for remote applications. The wind turbine operates at variable speeds and is connected to the electrical generator directly, i.e., the direct-drive coupling. The variable speed operation is more flexible for the power management and MPPT applications [21].

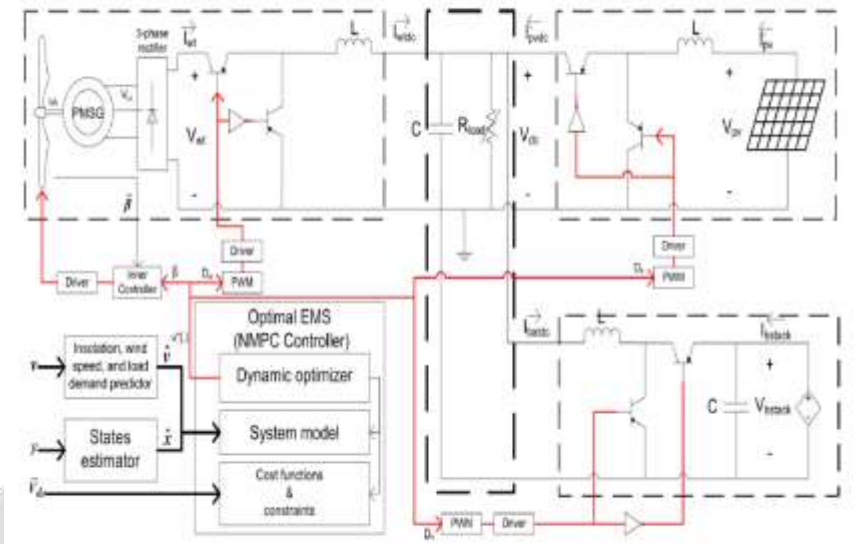

Fig-1: Simplified view of the dc microgrid and the developed NMPC controller.

Furthermore, direct-drive coupling is more efficient and reliable and is more popular for small-scale wind turbines [22]. In spite of high cost, permanent magnet synchronous generators (PMSGs) are the most dominant type of direct-drive generators in the market [22], chiefly due to higher efficiency. From Fig. 4.1, it can be seen that battery bank is connected to the dc bus through a dc-coupled structure, i.e., via a dc-dc converter, which is more flexible in terms of implementing different charging and discharging regimes despite more power losses [19].

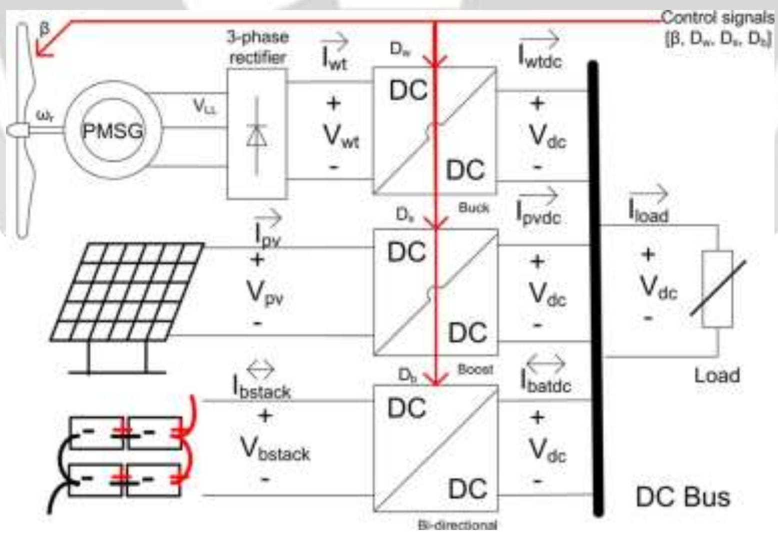

Fig-2: Topology of a small-scale and standalone dc microgrid

The following notations are used to model the standalone dc microgrid in Fig. 1 as DAEs Fig. 4.2 summarizes a modified version of the proposed model in [20]. Since this paper focuses on the case in which there is an excess power greater than or equal to the maximum possible absorbing rate of the battery bank, the hybrid nature of the battery bank operation is ignored for the sake of simplicity. The differential and algebraic states, i.e., and , and the manipulated and non-manipulated control variables, namely, u and v , are detailed later throughout the next sub-sections.

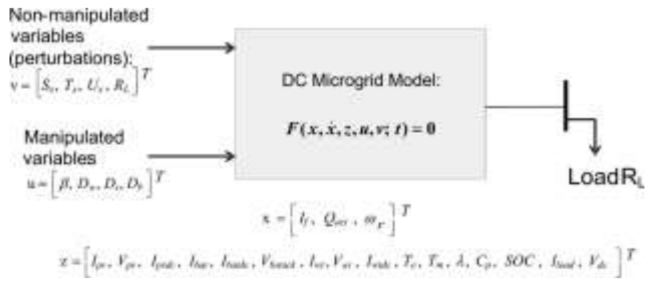

Fig-3: Modified version of the system model in [20] for this paper

$$\mathcal{F}(\mathrm{x}, \dot{\mathrm{x}}, \mathrm{z}, \mathrm{u}, \mathrm{v}) = \begin{bmatrix} f_1(\mathrm{x}, \dot{\mathrm{x}}, \mathrm{z}, \mathrm{u}, \mathrm{v}) \\ f_2(\mathrm{x}, \dot{\mathrm{x}}, \mathrm{z}, \mathrm{u}, \mathrm{v}) \\ .. \\ f_{24}(\mathrm{x}, \dot{\mathrm{x}}, \mathrm{z}, \mathrm{u}, \mathrm{v}) \end{bmatrix} = 0 \qquad (1)$$

where ‘F’ is a set of implicit differential and algebraic functional

3. SIMULATION RESULTS

A Simplified 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 microgrids.

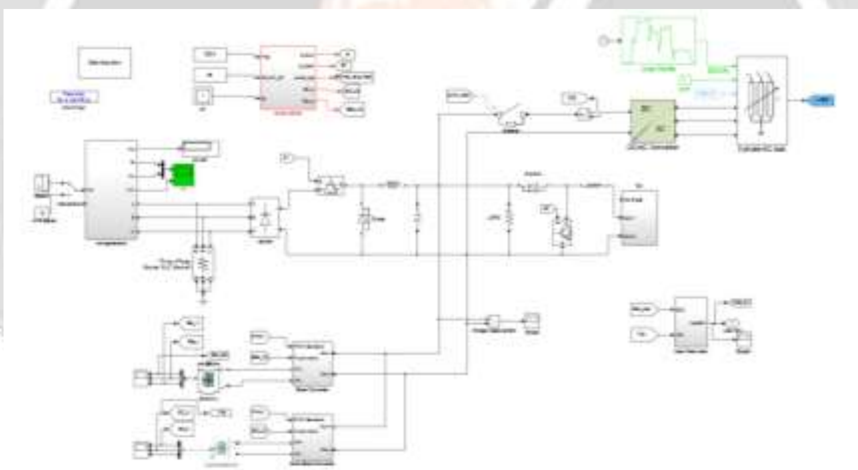

Fig-4: Matlab design of the proposed system

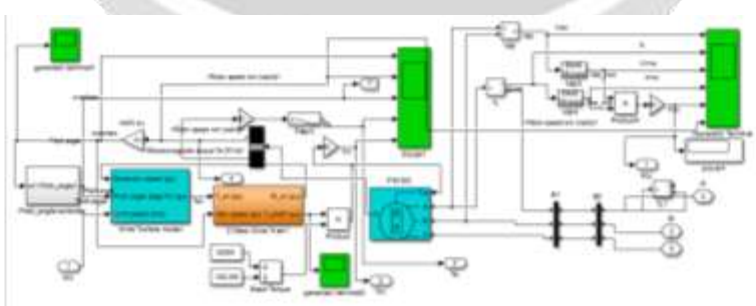

Fig-5: Wind energy generation and pitch angle control

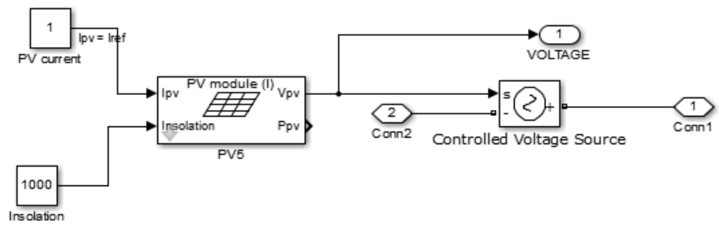

Fig-6: Solar power generation

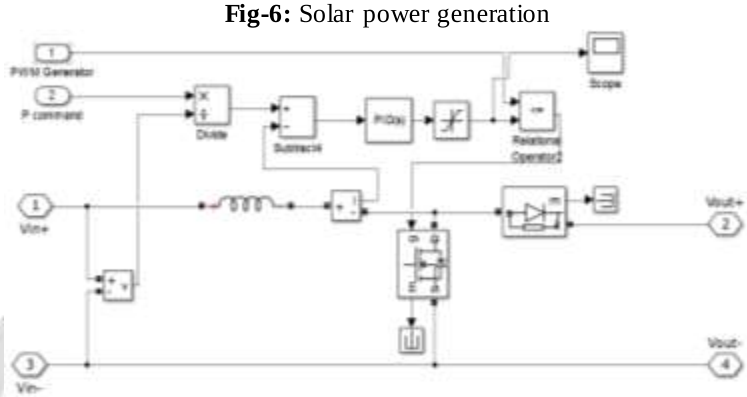

Fig-7: buck/boost converter

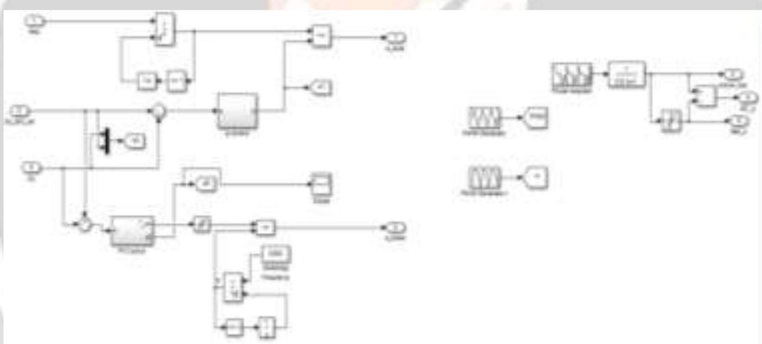

Fig-8: buck/boost control

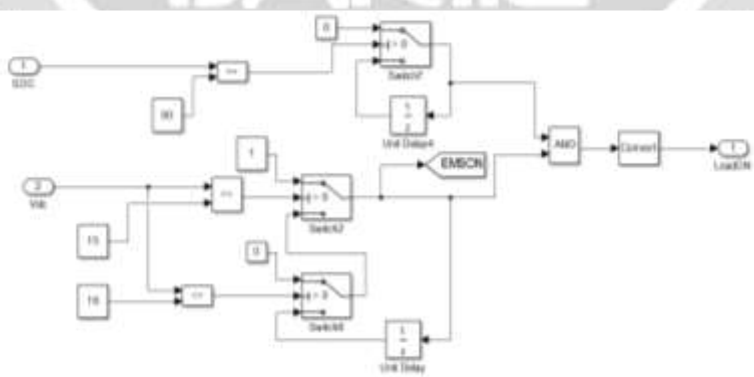

Fig-9: proposed NMPC control

The figures from 6 to 9 represent the implementation of the proposed system using MATLAB design software. Each independent control in here is a co-ordinate control.

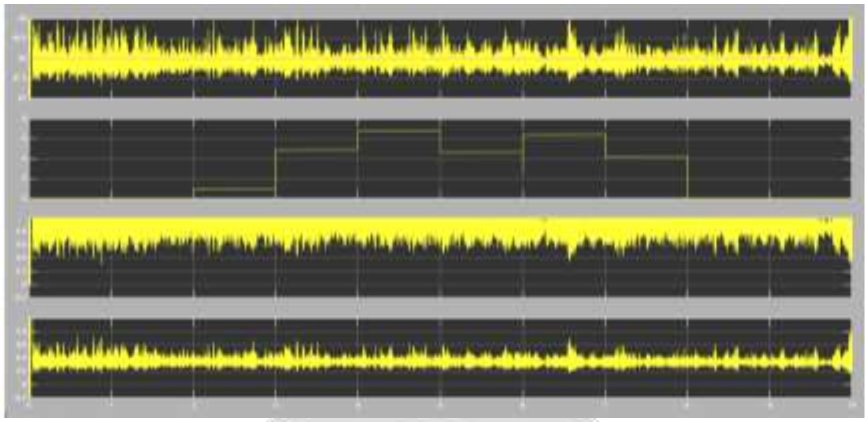

Fig-10: Dc-link voltage, pitch angle variation of wind, duty ratio modulation of solar and wind and battery charging converters

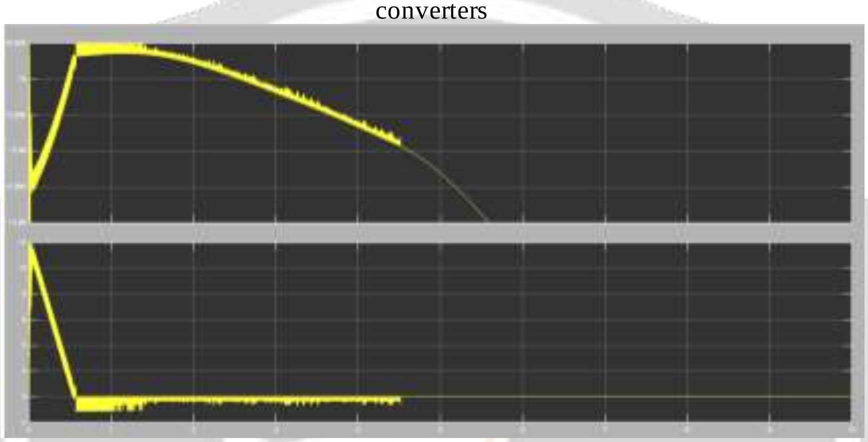

Fig-11: SOC of super capacitor

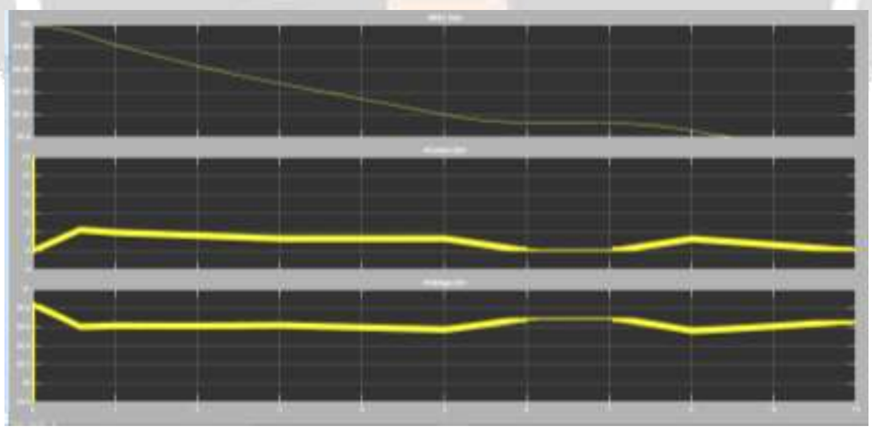

Fig-12: SOC, Voltage and current of battery

The figure 10 represents the maintenance of DC-link voltage as 48V irrespective of source input variations. It shows the variation of wind pitch angle and duty ratios of dc-dc converters for wind, solar and battery systems. The figures 11 and 12 Shows the state of charge of battery and super capacitor.

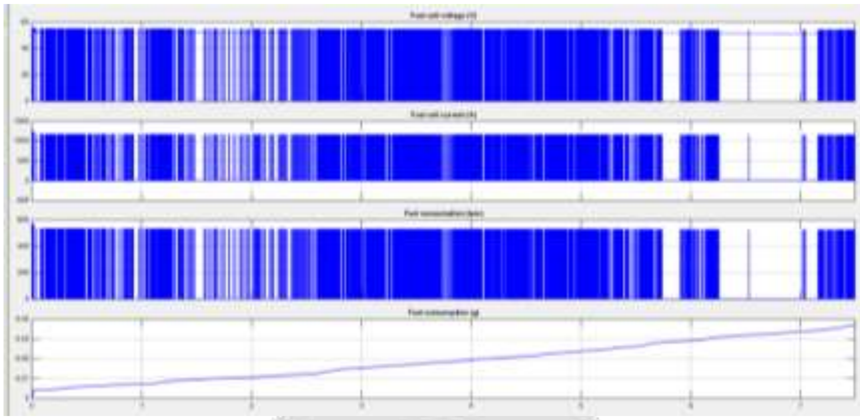

Fig-13: Fuel cell voltage, current and consumption

4. CONCLUSION

An optimal EMS that manages the energy flows across a standalone green dc microgrid, consisting of the wind, solar, and battery branches has proposed. A coordinated and multivariable strategy has been developed to address, as the optimal EMS, three main control objectives of standalone dc microgrids. 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 MPPs 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.

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