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Energy Management of a Hybrid AC/DC Microgrid with Grid Integration

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***Abstract*— In contemporary energy systems, the integration of renewable energy sources has led to the emergence of hybrid AC/DC microgrids as promising solutions for enhancing energy efficiency, reliability, and sustainability. This paper presents an energy management framework tailored for hybrid microgrids encompassing photovoltaic (PV), battery storage, wind, and grid connections. The proposed management system addresses both islanded and grid-connected modes of operation, ensuring seamless transition and optimal utilization of available resources. The management strategy is designed to accommodate the intermittent and variability inherent in renewable sources. In islanded mode, the system optimizes the utilization of locally available resources, prioritizing renewable energy generation to meet the demand while ensuring grid stability through coordinated control of inverters and energy storage systems. During grid-connected operation, the microgrid acts as a flexible entity capable of supplying power to the local load, importing or exporting energy to/from the main grid, and providing ancillary services such as frequency regulation and voltage support. Case studies and simulation results are provided to demonstrate the effectiveness of the proposed energy management system under different operating conditions, including variations in renewable energy availability, load demand, and grid disturbances.**

Keywords— Voltage Control, AC/DC, Hybrid Microgrid, Battery Storage, PV system and Wind Generator.

I. Introduction

In order to decrease CO2 emissions and fossil fuel use, it is best to use renewable energy sources in a micro grid today. People think that the benefits of distributed energy resources are more reliable service, better quality power, and more efficient use of energy by using the waste heat from power production systems. Also, being able to use green energy that doesn't pollute much or at all is becoming more appealing from an environmental protection point of view and is attracting more and more important interests. Also, distributed generation can help the electric company by making the grid less crowded, cutting down on the need for new power plants and transmission lines, and providing other services. [1]. Solar photovoltaic and wind energy have the highest potential to generate power among the various RES sources; however, the output power of solar energy and PV panels is primarily dependent on environmental temperature and solar irradiance, whereas the output power of wind energy is primarily dependent upon wind speed; this results in a continuous vacillation in output power [2], [3], [4], [5]. Consequently, a source of stored energy is required to guarantee continuous power output. In [6], the author examines a droop control system for balancing the load on a PV array-storage system with power from another source. An improved version taking into account a wide variety of power sources has been introduced in [7, 8]. All of these methods work well for systems without a DC bus and loads because they efficiently control the load need and source power generation. Literature [9][10]introduces a control method for a mixedsystem, the focus on optimal sizing and costing analysis of the PV system and battery storage rather than power balancing. AC micro-grids [11][12][13][14] are proposed here to reduce the complexity of the link of RES to existent AC systems. The AC network accommodates a wide variety of load configurations. In order to keep up with the demand, it is necessary to use both AC-DC and DC-DC converters. Integration of dispersed energy resources has been extensively discussed in [15][16].The modeling of a grid-connected hybrid micro grid has been established in this paper by using MATLAB/Simulink.

In addition, coordinated control strategies are designed for the voltage control of hybrid micro grids. This is because one of the most important issues facing all micro grids is maintaining the stability of the dc and ac bus voltages.

Introduction:

In response to the growing demand for sustainable and resilient energy solutions, hybrid AC/DC micro grids have emerged as promising platforms for integrating renewable energy sources and enhancing energy management capabilities. The integration of photovoltaic (PV), battery storage, wind, and grid connections within a single micro-grid framework presents a versatile approach to address the challenges associated with renewable energy intermittency and variability. This paper focuses on the development and implementation of an advanced energy management system tailored for hybrid micro-grids, with a specific emphasis on optimizing operation in both islanded and grid-connected modes.

The transition towards renewable energy sources, driven by environmental concerns and technological advancements, necessitates innovative approaches to energy distribution and management. Hybrid micro-grids offer a flexible and scalable solution that can adapt to diverse operating conditions, including remote off-grid environments and interconnected urban grids. By leveraging a combination of renewable generation, energy storage, and grid interconnection, these micro grids enable efficient utilization of locally available resources while enhancing system reliability and resilience.

The integration of PV, battery, wind, and grid sources within a hybrid microgrid presents unique challenges and opportunities for energy management. In islanded mode, the microgrid operates autonomously, relying primarily on renewable generation and energy storage to meet local demand. Effective coordination of generation and storage assets is essential to ensure system stability and reliability, particularly in the face of fluctuating renewable output and varying load profiles.

Conversely, in grid-connected mode, the micro-grid interfaces with the larger electrical network, enabling bi-directional power flow and participation in grid services. Optimizing energy exchange with the main grid while maintaining grid stability requires sophisticated control algorithms and communication protocols. Moreover, the ability to provide ancillary services such as frequency regulation and voltage support enhances the micro-grid's value proposition and contributes to overall grid stability.

In this particular piece of research, the uncertainty effect of the micro-grid's generators and loads, including both tiny and big deviations, is investigated with regard to its capacity to manage the voltage.

The findings demonstrate that the controllers are both effective and robust in their ability to quickly restore and stabilise the voltage of the micro-grid generation. This has the potential to benefit the electric utility by reducing congestion on the grid, lowering the requirement for new generation and transmission capacity, and providing ancillary services. A proposed system of hybrid micro-grid is depicts in fig.1.

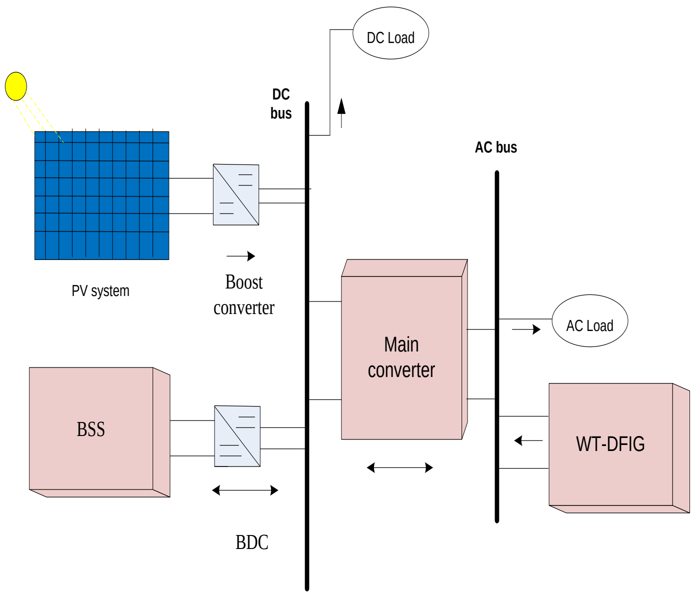

Figure 1 Proposed hybrid microgrid system

II. Hybrid DC-AC Micro-grid Modeling

A. PV Array System

A photovoltaic system typically includes an array of photovoltaic modules Fig.2. depicts the PV array equivalent circuit model. PV current is expressed by equation. Figure 2 depicts the PV array system's internal circuit. For obtaining the current of PV array undermentioned approach is applied.

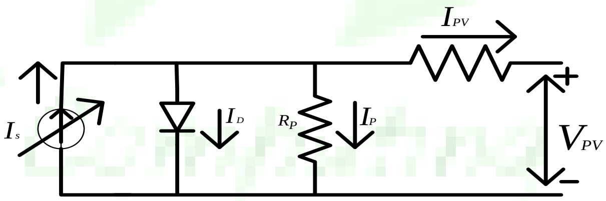

Figure 2 Equivalent circuit of PV system

$$I_S = \left(\frac{\gamma}{\gamma_{ref}}\right)I_{Sref} + \alpha_{ISC}(T_a - T_{ref}) \quad (1)$$

Where, γ represent irradiance level in w/m2, Ta is temperature in kelvin, α_{ISC} is coefficient of short circuit current and I_{Sref} , T_{ref} and γ_{ref} are standard value under test conditions.

Due to the irradiance in PV array, there is variation in the generated power and maximum power point tracking (MPPT). To trace the MPPT, incremental conductance (INC) MPPT method as shown in Fig.3. is performed with an adjustable variable step size. This algorithm itself change the step size to observe the maximum power point (MPP) with step size adaptation coefficient, and a user predefine fix value is not important for the junction of this MPPT method, thus clarify the design of the PV system

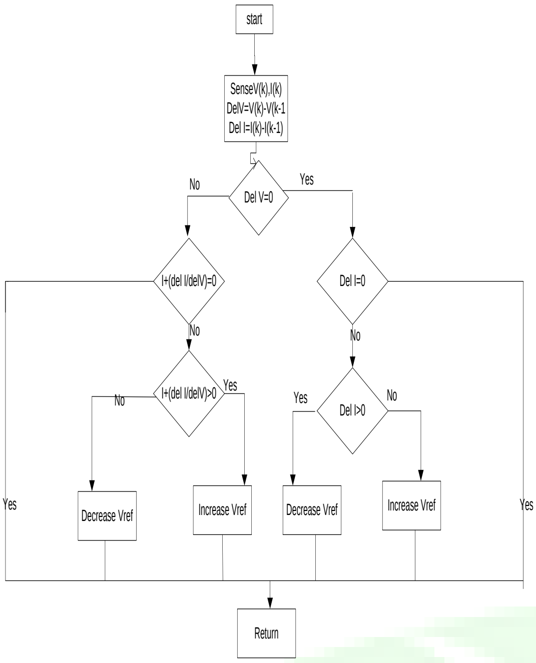

Figure 3.Incremental conductance MPPT algorithm flowchart

B. Modeling of Battery Storage

Renewable energy sources have a lot of promise, but they can be unreliable if we don't have reliable energy storage options.

There are essentially two types of energy storage that are used in power grids. One is a reaction to sudden fluctuations, whereas the other is associated with constant energy flow.. The state of charge (SOC) of the battery is resolved using the method of current integration, where Q(t0) is the initial charge to the battery at time to, α is the discharge/charge efficiency and I is the current.

$$V_B = V_{OC} + R_B . I_B - K \frac{Q}{Q+\int I_B dt} + A.\exp(B \int I_B dt \quad (2)$$

C. Modeling of Wind

The output expression of a WT in terms of ambient wind speed can be obtained by a piecewise function.

$$P(v) = \begin{cases} \frac{P_r(v - v_{ci})}{(v_r - v_{ci})} v_{ci} \le v \le v_r \\ P_{r v_r \le v \le v_{co}} \\ 0 \quad v < v_{ci} or v > v_{co} \end{cases} \quad (3)$$

Where $P_W(v)$ is wind turbine generator output with ambient wind speed v, P_r is power of wind turbine at rated speed and v_{ci} is cut in wind speed , v_{co} is the cut-out wind speed and vr is rated wind speed.

III. ENERGY MANAGEMENT SYSTEM (EMS)

Figure 4 illustrates the control algorithm of a customized hybrid microgrid network using the proposed EMS. In this proposed EMS design, the PV system is linked to the DC bus by a boost converter, and the battery storage unit is linked via a bidirectional converter to handle the charging /discharging process. A main converter is used to connect the DC and AC buses and exchange the power flow smoothly. The mode of operation of the hybrid microgrid is determined by the availability of PV system output power, wind turbine output power, battery power and SOC, as well as the demand for DC and AC loads. As a result, power flow in the hybrid microgrid is always steady. The EMS works based on following equations:

Grid mode:

$$P_{PV} + P_W \mp P_B + P_G = P_{DC}^{Load} + P_{AC}^{Load} \quad (4)$$

Here in the equations P_{PV} stands for the output of the PV system, here P_W is the output power of wind turbine generator, term P_B is the battery power and P_G is grid power(-ve sign here represents charging of battery and +ve sign represents discharging).P_{DC}^{Load} ,P_{AC}^{Load} represent the AC and DC load respectively.

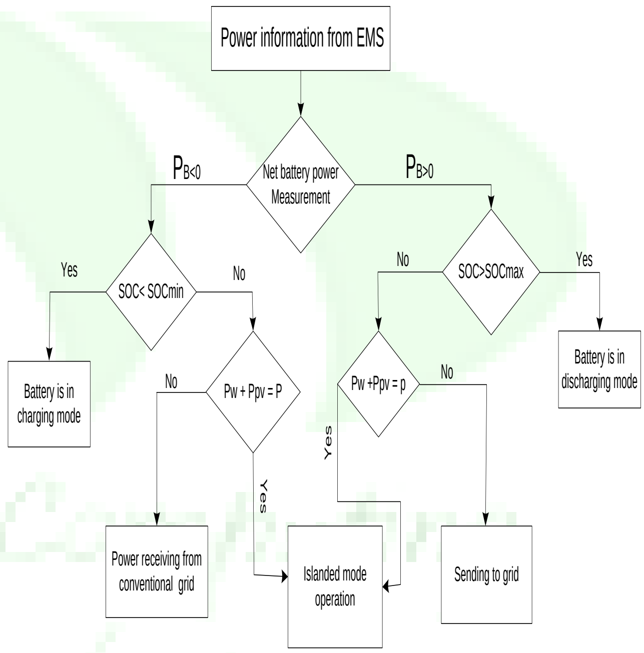

Figure 4: Energy management system for hybrid DC-AC microgrid

IV. RESULTS AND DISCUSSION

With the help of simulation results, the regulations of the hybrid micro grid are validated when subjected to a variety of load circumstances, as well as alternating and direct current sources of energy.

The electricity for the fusion microgrid system is supplied by a photovoltaic array system, a wind turbine generator, and the conventional grid when it is operating in the grid connection mode. The state of charge (SOC) of the battery is lower than the minimum SOC limit (SOC< 30%) when the battery is connected to the grid, as seen in figure 7(d). That the BSS is in a charging condition is necessary. As can be seen in figure 5(a), the grid supply to the fusion microgrid is extremely low between the times of 0 and 10 seconds. At t=10 seconds, the ambient wind speed drops from 12 metres per second to 9 metres per second, resulting in a fall in the output of WT to 20 kilowatts. As can be seen in figures 5(a) and 5(c), the conventional grid is responsible for compensating for power fluctuations that occur in the WT. According to the diagrams shown in figures 5(a) and 5(b), the conventional grid is used to compensate for the volatility in power output of PV array systems. As a consequence of this, the DC bus voltage is kept at a consistent level, as seen in figure 8(b). The DC load requires power supply from the DC microgrid, as well as through the main converter from the AC microgrid, as seen in figures 6(c) and 6(d). As can be seen in figure 7(d), the battery state of charge level continues to rise even when the battery system is operating in grid mode on a continuous basis. Both the battery current and the battery power are displayed in figures 7(b) and 7(c), respectively. The voltage at the battery terminals should remain constant, as seen in figure 7(a).

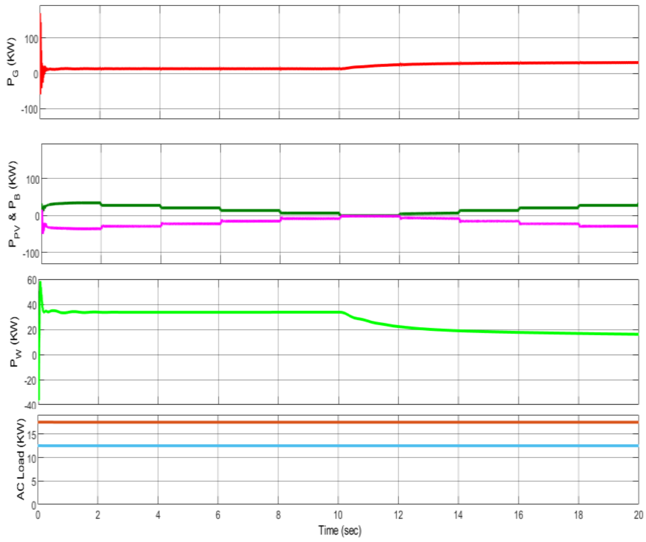

Fig. 5 (a) grid power from hybrid MG. (b) PV system output power and battery power (c) Wind generator output power (d) AC load

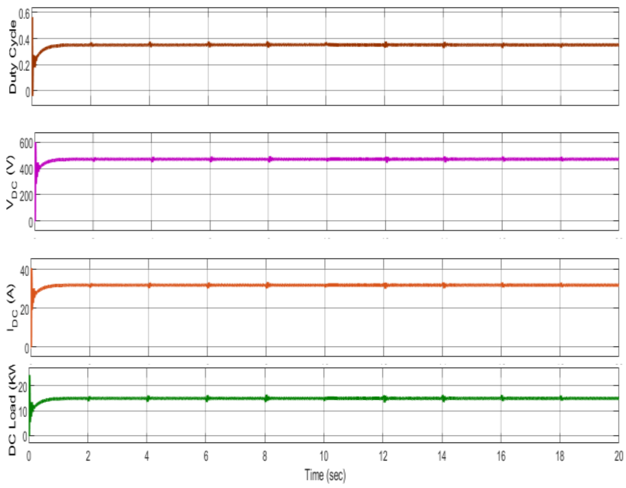

Fig. 6Grid mode of hybrid microgrid (a) duty cycle (b) dc bus voltage (c) dc load current (d) DC load.

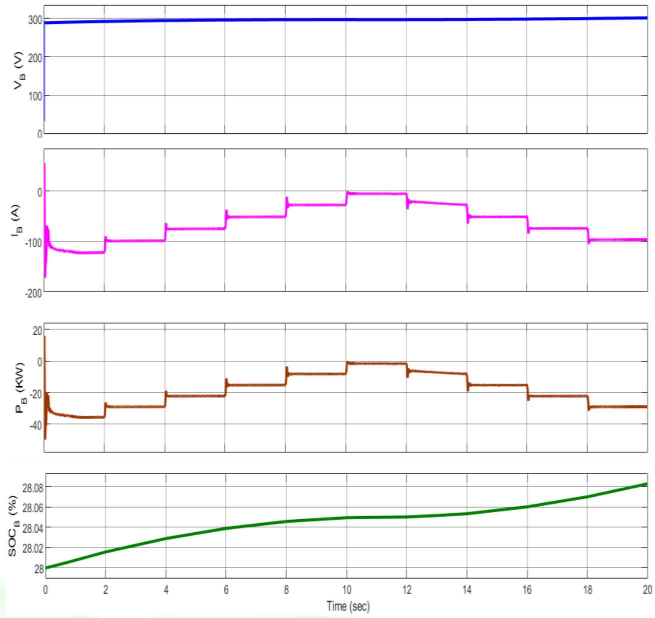

Fig. 7 Grid mode of hybrid microgrid (a) battery terminal voltage (b) battery current (c) battery power (d) battery SOC.

V.CONCLUSION & DISCUSSION

This study, we focus on the controllers among the converters, with the goal of increasing the dynamic voltage stability of the microgrid's dc section while it is connected to the grid. In addition, the ac and dc halves of a DFIG are made to tack onto an MPPT. Research into dc voltage regulation is conducted with both low and high levels of generator and load uncertainty. The results show that the controllers are reliable and effective in restoring and stabilising the dc grid voltage rapidly.

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