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PERFORMANCE COMPARISON OF MICROGRID SYSTEM USING NMPC AND FUZZY CONTROLLER

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Abstract-- **As the demand of Electricity is increasing day by day and is already more than the production of Electricity whereas reserves of fossil-fuel are depleting, there is a strong need to shift for other sources which are renewable energy sources. Regarding this, DC micro grids and their energy management of these renewable energy sources have gained more importance which is discussed in this paper. The main objective of the proposed system is to provide uninterrupted power supply to the load systems which are located at isolated sites of remote and rural areas. The proposed system mainly deals with implementation of Energy Management System (EMS) to DC microgrid 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. The entire designed system is modeled and simulated using MATLAB/Simulink Environment.**

Index Terms—**Battery Management, Maximum Power Point Tracking, Nonlinear Model Predictive Control, Power Sharing, and Voltage Regulation.**

INTRODUCTION

Isolated DC microgrids are gaining lot of interest from researchers in recent past[1]–[4] over counter parts available due to their merits in relieving from complexity control, synchronization issues, harmonics and reactive power[5]. In developing/undeveloped countries, domestic consumers, data center and telecommunication systems in remote locations are served by local DC grids instead of conventional grid since utility connection is not feasible or uneconomical [6]–[8]. Unlike to grid connected DC microgrid [9], there is no utility available in autonomous DC microgrids (ADCMGs) to balance power between generation and consumption. Thus effective coordination and control plays key role in ADCMGs to meet optimal energy management and efficient utilization of resources and storage units [10].

Control schemes based on centralized controller provide the optimal operation among various units by acquiring the information from them and manage the data centrally [11]. But system reliability is degraded due to high dependence on central controller and communication link. Droop control [12] is a basic decentralized control method which works based on local information but lacks with optimum utilization of resources of microgrid. To overcome above drawbacks, a distributed control strategy based on DC bus signaling method (DCBSM) was introduced in [13]. But it fails to consider the over-charging and discharging of battery. In [14], state of charge (SoC) of battery is included in primary level control based on DCBSM. Secondary level control is designed for adjusting bus voltage as per the reference voltage. As the battery alone regulates the bus voltage, reliability of system degrades. In [15], decoupling the operating regions in primary level control is proposed using DC bus voltage levels. And, coordination among various storage devices is achieved in secondary level through communication. However, excess generation is inefficiently managed by using dump loads. Multilevel energy management strategy is proposed in [16], where hybrid storage devices are utilized to suppress both low and high frequency components during power variations. During over charging or discharging conditions, the hybrid storage devices are poorly managed if the communication fails among control levels. Papers [17], [18] proposes the different control modes based on bus voltage deviation for regulating the DC microgrid under variable generation and storage. These papers utilize bus voltage for indicating status of DC microgrids. Both the papers consider the utility grid and assigns slack role to

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different sources (i.e. utility grid side converter or storage converter) in each mode based on conditions of DC microgrid and utility grid. Distinct control loops are employed under each mode for optimizing the system performance which requires frequent switching between control loops that causes switching transients and also increases burden on control processor. Besides this, excess power beyond the battery charging rate and grid side converter rating is not explored in [17]. Although it is considered by [18], but the deviation of bus voltage is more than 10% of nominal value in islanded mode which affects the sensitive loads connected. Power line signaling method is proposed in [19] to overcome problem of limited number of operating modes based on fixed voltage deviation in DCBSM. It dispatches the status of batteries and other sources in terms of distinct frequency signals superimposed on bus voltage.

A possible solution to overcome the above mentioned drawback is to use the APC as a power interface between the renewable energy sources and the AC bus of the Microgrids as shown in Fig. 1. The APC has proved to be an important alternative to compensate current and voltage disturbances in power distribution systems [6], [7]. Different APC topologies have been presented in the technical literature [8], but most of them are not adapted for Microgrids applications.

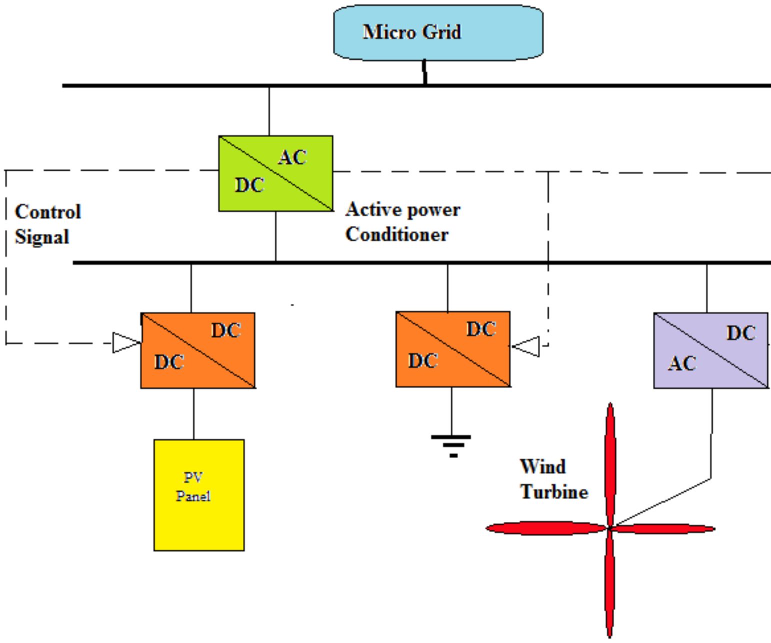

Figure 1. APC for Microgrid applications

MICROGRID STRUCTURE

The Microgrid structure assumes an aggregation of loads and micro sources operating as a single system providing both power and heat. The majority of the micro sources must be power electronic based to provide the required flexibility to insure controlled operation as a single aggregated system. This control flexibility allows the Microgrid to present itself to the bulk power system as a single controlled unit, have plug-and-play simplicity for each micro source, and meet the customers' local needs. These needs include increased local reliability and security.

Key issues that are part of the Microgrid structure include the interface, control and protection requirements for each micro source as well as Microgrid voltage control, power flow control, load sharing during islanding, protection, stability, and over all operation. The ability of the Microgrid to operate connected to the grid as well as smooth transition to and from the island mode is another important function.

Figure 2 illustrates the basic Microgrid architecture. The electrical system is assumed to be radial with three feeders – A, B, and C – and a collection of loads. The micro sources are either micro turbines or fuel cells interfaced to the system through power electronics. The Point of Common Coupling (PCC) is on the primary side of the transformer and defines the separation between the grid and the Microgrid. At this point the Microgrid must meet the prevailing Interface requirements, such as defined in draft standard IEEE P1547.

The sources on Feeder A & B allow full exploration of situations where the micro sources are placed away from the common feeder bus to reduce line losses, support voltage and/or use its waste heat. Multiple micro sources on a radial feeder increase the problem of power flow control and voltage support along the feeder when compared to all sources being placed at the feeder's common bus, but this placement is key to the plug-and-play concept. The feeders are usually 480 volts or smaller. Each feeder has several circuit breakers and power and voltage flow controllers. The power and voltage controller near each micro source provides the control signals to the source, which regulates feeder power flow and bus voltage at levels prescribed by the Energy Manager. As downstream loads change, the local micro source's power is increased or decreased to hold the total power flow at the dispatched level.

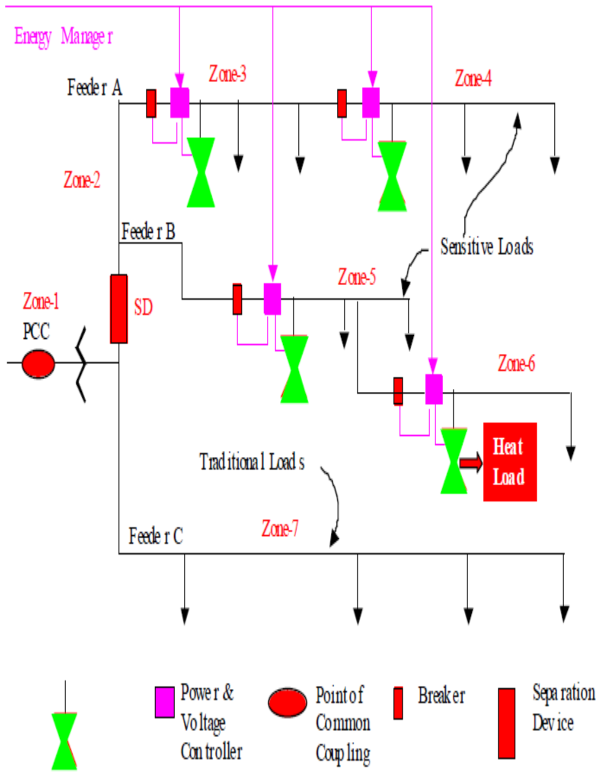

Fig.2 Microgrid Architecture

SYSTEM STRUCTURE

System contemplated in this paper is as shown in Fig. 3 which consists of two ADCMGs spatially apart from each other with considerable line resistance between them. Each ADCMG consists of one photovoltaic (PV) source and battery as equivalent to group of sources from renewable sources and storage devices family respectively in order to simplify the analysis for the proposed PCMS between the ADCMGs. As most of DC loads are of constant power loads (CPL) which are integrated through DC-DC converter. Hence, CPLs can able to maintain fixed power irrespective of variations in DC bus when its voltage oscillations lie within the sustainable range. PV source is interfaced to DC bus through boost converter and bidirectional buck-boost DC-DC converter is utilized for connecting the battery storage. Interconnection of two ADCMGs is realized by considering DABC as interfacing unit which provides galvanic isolation and high power feeding capability in both directions along with large conversion ratios through high frequency transformer. Two full H-bridge converters are connected to either side of the transformer to produce the high frequency AC from DC. Besides, this topology recognized as DABC and widely employed in transferring the power from low to high voltage DC.

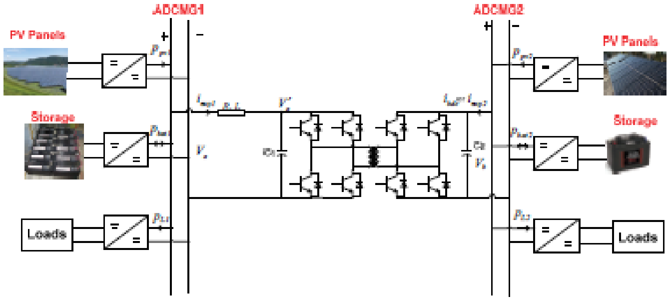

Figure 3: System architecture for interconnection of two ADCMGs.

POWER CONTROL AND MANAGEMENT STRATEGY

Source and storage units of ADCMGs are operated based on bus voltage levels in the grid by making bus voltage as information carrier between the units for proper coordination and management. Loads are managed depending on the state of charge (SoC) of battery and power condition of ADCMG which is expressed in terms of bus voltage deviation. SoC of battery can be regulated by limiting the charging and discharging currents. Voltage levels envisioned throughout the analysis are in compliance with the paper.

CONTROL LOOPS

PV control loop:

PV source always remain at MPP except in zone irrespective of change in load and power import/export so that maximum renewable power is extracted and utilized efficiently. PV control loop of ADCMG1 is shown in Fig. 4 and the same is followed for PV source in ADCMG2. PV source can be operated in two modes, one as MPP mode and other as bus voltage regulation mode. First one consist of two loops in which outer loop is mainly for tracking MPP voltage (MPP V) through perturb and observe (P&O) method and provides voltage reference as input to inner loop. Inner loop works at faster speed for tracking the given reference through PI controller and produce the duty cycle (pv1 δ) as its output.

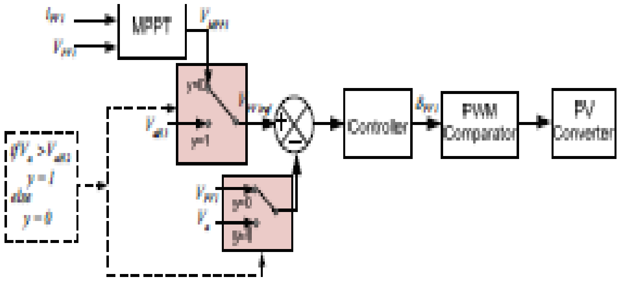

Fig. 4. Control loop of PV source in ADCMG1.

Battery control loops

Battery is operated either in charging or discharging modes based on their cut in thresholds. Battery control loop of ADCMG1 is shown in Fig. 5. Each mode employs two loops in which inner loop is common for both the modes. No mode will be active until the bus voltage crosses its predefined threshold value due to saturation of controller. Outer voltage loop mainly tracks bus voltage reference and produces the current reference as output, and that is fed to inner loop for tracking the reference effectively. In discharging mode, top outer loop gives the positive reference current (I_{bid1}) by regulating bus voltage (V_a) at V_{aL1} as load dominates, which is fed to discharging rate limiter and then checked against its cut off limit (V_{bid}) to ensure the optimal utilization and extended battery's life. Cut off limit of ${}_1$ $SoC = 20\%$ is expressed in terminal voltage (V_{bat1L})[33]. In this mode, bottom outer loop is inactive. During charging mode, bus voltage is regulated at ${}_{aH1}$ V through bottom outer loop and produces negative current as reference to inner loop. Here bus voltage always try to rise above the threshold limit (V_{aH1}) in generation dominating scenario.

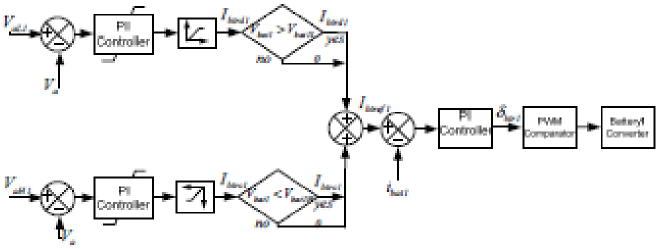

Fig. 5. Control loop of battery in ADCMG1.

Load control

Constant power load is developed in this paper by feeding resistive load through the buck converter. Buck converter control is similar to conventional control scheme. Load shedding is performed based on DC bus voltage and battery status as shown in Fig. 6. If the battery voltage falls below cutoff value VbatL2 (equivalent to SoC=30%) then load shedding is initiated to preserve the battery to feed the essential loads effectively. Similarly if the bus voltage decreases below the lower threshold (VaL2) then load shedding is activated because power deficit exceeds discharging rate of battery. Simultaneously if both occurs during worst scenario, then also it triggers the load shedding.

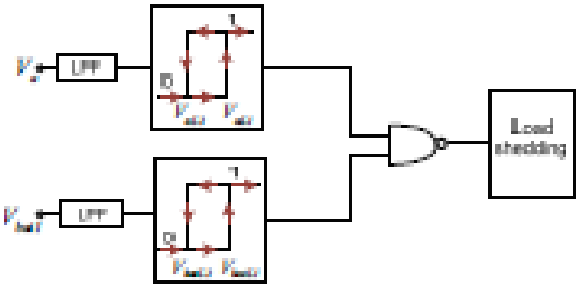

Fig. 6. Load shedding control

SIMULATION RESULTS

Simulation of the system shown in Fig. 3 is carried out on real time digital simulator (RTDS) platform to validate the developed PCMS. System is implemented in RSCAD/RTDS environment. Specifications of system components like PV, battery and load in both the ADCMGs are detailed in results. Two practical DC grid voltage ratings are chosen to prove the applicability of PCMS. Load is classified as fixed and variable loads based on its existence throughout certain period. Nonessential loads/variable loads are shed according to the requirement and other type is fed continuously. Proposed PCMS is explored under various operating scenarios of ADCMGs including extreme conditions of battery and grid like over charging and discharging, overload and under load scenarios of ADCMG. Operation of individual ADCMGs is illustrated using PCMS under different zones and it is followed by bidirectional power transfer between ADCMGs considering aforementioned conditions.

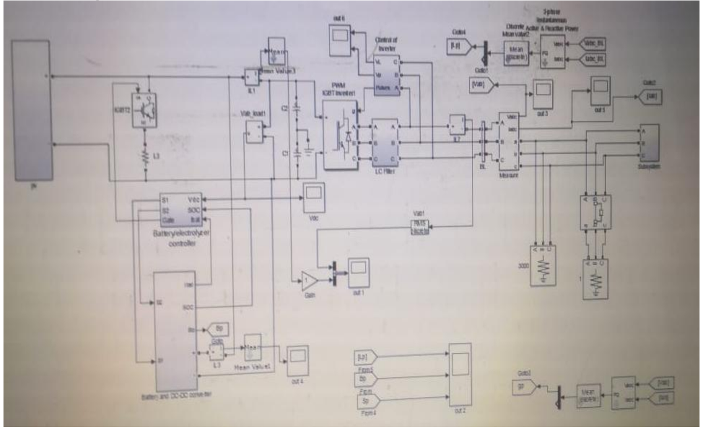

Fig. 7. Simulation Diagram for Proposed System

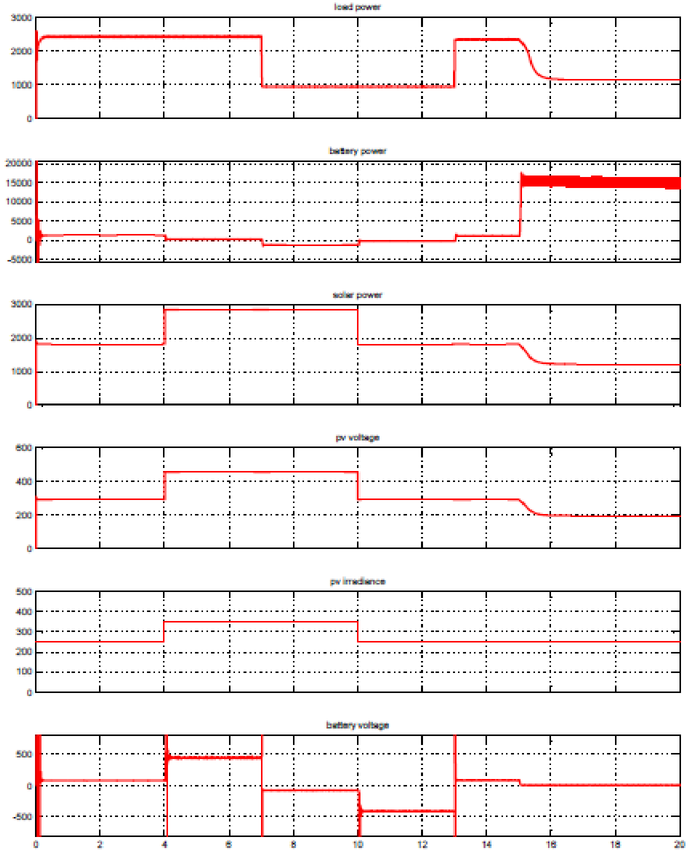

Fig. 8. Simulation Result for proposed system

Various operating regions of ADCMG1 is shown in Fig. 8. Battery terminal voltage is kept just above the lower cut off limit to compile all zones including extreme conditions within the single window. Cutoff limits for each zone are selected with difference of 10V [34] and bus voltage deviation for all zones lie within the ±5% of bus nominal voltage. It is observed from the figure that generated power is equal to load demand from 0 to *t1* that indicates the operating zone-1, during which bus voltage is allowed to vary between boundaries.

CONCLUSION

A coordinated and multivariable online NMPC strategy has been developed to address the optimal EMS, which deals with 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. The simulation results have been shown its ability to achieve all control objectives.

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