PID CONTROL OF HYBRID AC/DC MICROGRID INVOLVING ENERGY STORAGE AND PULSED LOADS

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ABSTRACT—In this paper presents PID control of hybrid AC/DC micro grids involving energy storage and pulsed loads. Grid isolated hybrid microgrid applications require special considerations due to the intermittent generation, online energy storage control and pulsed loads. In this work, we introduce a comprehensive frequency and voltage control scheme with pid for a hybrid AC/DC micro grid consisting of a synchronous generator, solar generation emulator and bidirectional (AC/DC and DC/DC) converters. A bidirectional controlled AC/DC converter, with an active and reactive power decoupling technique is used to link the AC bus with the DC bus while regulating the system voltage and frequency and tuning with PID controller. A DC/DC boost converter with a maximum power point tracking (MPPT) function is implemented to maximize the intermittent energy generation from solar generators. Current controlled bidirectional DC/DC converters are applied to connect each lithium-ion battery bank to the DC bus. Lithium-ion battery banks act as energy storage devices that serve to increase the system resiliency by absorbing, or injecting, power. Simulation results are presented for verification of the introduced hybrid AC/DC power flow control scheme.

INDEX TERMS—Micro grid, energy management, pulsed load, energy storage, battery bank, synchrophasor, PID.

I. INTRODUCTION

HYBRID power systems are gaining popularity due to increasing microgrid deployments featuring renewable power systems connected to low voltage AC distribution systems. Furthermore, DC grids are resurging due to the development of new semiconductor technologies and sustainable DC power sources such as solar energy. There has also been an increase in DC loads, such as plug-in electric vehicles (PEVs) and light emitting diodes (LEDs), connected to the grid to save energy and decrease greenhouse gas emissions. This growth has been motivated by environmental concerns caused by conventional fossil fueled power plants.

At the same time, various utility grids and some hybrid micro grids are increasing the penetration of renewable energy resources. The intermittent nature of wind and solar power can quickly add up to system-wide instability that can force generators to ramp up and down wildly, push grid protection gear into states it’s not meant to handle, or force the wind and solar generator to shut off altogether. Hybrid power systems face far more challenges when operating in islanded mode than they do in grid connected mode. During islanded mode, the AC side can no longer be viewed as an infinite bus, which results in load variations adversely affecting the frequency and voltage of the system. If the system has a high penetration of renewable power, the situation can be even worse. At any time, reactive and active power flow should be balanced between the AC and DC sides to maintain stability on both sides of the grid.

To the best knowledge of the authors, a realistic coordinated, hybrid AC/DC micro grid control considering pulsed load mitigation with energy storage has not yet been studied. In this paper, a real-time coordinated control of a grid-isolated, hybrid AC/DC micro grid, involving energy storage and pulsed loads is studied. This microgrid can be viewed as a PEV parking garage power system or a ship power system that utilizes sustainable energy and is influenced by pulsed load. We introduce a comprehensive frequency and voltage control scheme for a hybrid AC/DC microgrid consisting of a synchronous generator, solar generation emulator and bidirectional (AC/DC and DC/DC) converters. A bidirectional controlled AC/DC converter with active and reactive power decoupling technique is used to link the AC bus with the DC bus, while regulating the system voltage and frequency.
inverter based distributed energy resources, distribution line and load models, synchro phasor, intelligent electronic devices (IED) protection setup, SCADA systems and human machine interface (HMI).

A DC/DC boost converter with a maximum power point tracking (MPPT) function is implemented to maximize the intermittent energy generation from solar generators. Current controlled bidirectional DC/DC converters are applied to connect each lithium-ion battery bank to DC bus.

II. PHOTOVOLTAIC INVERTER

The PV power generation system consists of following major blocks:
1. PV unit
2. Inverter
3. Grid
4. MPPT

Analytical models are essential in the dynamic performance, robustness, and stability analysis of different control strategies. To investigate these features on a three-phase grid-connected PV system, the mathematical model of the system needs to be derived. The modeling of the proposed system includes:
1. Photovoltaic Cell and PV array Modeling
2. Three-phase inverter model
3. Three-phase fundamental transformations modeling

In this chapter, the operation and role of each of these components will be described and their mathematical model will be derived.

![Fig.2 Equivalent circuit diagram of the PV cell](image)

\[ \text{i}_p = \text{I}_L - \text{I}_r \left[ \exp(\text{v}_p + \text{R}_p \text{i}_p) - 1 \right] - \text{v}_p + \frac{\text{R}_p \text{i}_p}{\text{R}_h} \]

2.1 MPPT: (Maximum Power Point Tracking)

The P&O algorithm requires few mathematical calculations which makes the implementation of this algorithm fairly simple compared to other techniques. For this reason, P&O method is heavily used in renewable energy systems.

2.2 Perturb and Observe algorithm

At present, the most popular MPPT method in the PV systems is perturb and observe. In this method, a small perturbation is injected to the system and if the output power increases, a perturbation with the same direction will be injected to the system and if the output power decreases, the next injected perturbation will be in the opposite direction.

The Perturb and observe algorithm operates by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle.

If the PV array operating voltage changes and power increases, the control system moves the PV array operating point in that direction, otherwise the operating point is moved in the opposite direction.

In the next perturbation cycle, the algorithm continues in the same way. The logic of algorithm is shown in Fig.2.2. A common problem in perturb and observe algorithm is that the array terminal voltage is perturbed every MPPT cycle, therefore when the maximum power point is reached, the output power oscillates around the maximum power point resulting in power loss in the PV system.

![Fig.3 Flow chart of perturb and observe](image)

DC-DC Converter Basics

A DC-to-DC converter is a gadget that acknowledges a DC info voltage and produces a DC yield voltage. Normally the yield delivered is at an alternate voltage level than the info. Also, DC-to-DC converters are utilized to give clamor confinement, force transport regulation, and so on. This is a synopsis of a portion of the prevalent DC-to-DC

BUCK CONVERTER

In this circuit the transistor turning ON will put voltage Vin toward one side of the inductor. This voltage will tend to bring about the inductor current to rise. At the point when the transistor is OFF, the present will keep coursing through the inductor however now moving through the diode.

We at first accept that the current through the inductor does not achieve zero, in this way the voltage at Vx will now be just the voltage over the leading diode amid the full OFF time. The normal voltage at Vx will rely on upon the normal ON time of the transistor gave the inductor current is persistent.
III. HYBRID AC/DC MICROGRID CONFIGURATION

The Fig. 5 shows the DC side of the hybrid microgrid configuration, where a photovoltaic (PV) emulator, battery banks, and loads are connected. The AC and DC sides are linked through a bidirectional three phase AC/DC converter and a transformer. The system features constant and pulse loads on both the AC and DC sides. The PV emulator is connected to the DC bus as the DC energy source through a DC/DC boost converter with MPPT functionality. Five 50Ah lithium-ion battery banks with 51.8V terminal voltage are connected to the DC bus through five bi-directional DC/DC boost converters. The rated voltages of DC and AC sides are 300V and 208V phase to phase respectively. The system can be operated in either grid-connected mode or islanding mode. To maximize the utilization of the renewable sources, the PV emulator can be operated in on/off maximum power point modes based on the whole system power.

Energy balancing is handled by controlling the DC/DC boost converter. In grid-connected mode, the proposed system can be viewed as a PEVs car park system. The five batteries can be viewed as five PEVs that can play the role of energy storage. By controlling the charging process of the PEVs in the car park, the hybrid microgrid can limit the PEVs’ charging impact to the utility grid, and at the same time, provide some ancillary support to the utility grid through V2G services, via frequency regulation, reactive power compensation, and spinning reserve. In islanded mode, the proposed system can be viewed as a ship power system with solar panels. The bi-directional AC/DC converter can take control of the AC side frequency and voltage amplitude. The DC bus voltage is regulated by controlling the charging and discharging of the battery banks, which also means controlling the current flow through the bidirectional DC/DC converter.

**PV Panel Emulator:**

The PV panel can be viewed as a current source in parallel with a diode. In this paper, the Sun Power SPR-305-WHT solar cell, with 305W maximum output power, is used. 33 cells are used in the configuration of 11 parallel strings, with 3 serially connected cells per string. Fig. 6 shows the non-linear P-V and I-V electric characteristics of a single Sun Power SPR-305-WHT solar cell. Under different solar irradiations, the maximum power points of the power-voltage curves are associated with different output voltages. Also, under certain solar irradiance, the output of the PV panel is varying with different terminal voltages.

Equations (1)-(3) show the mathematical model of the PV panel with its output currentIpv and output voltage Vpv. Related parameters are shown in Table.
Lithium-ion Battery Banks and Pulsed Load:

An accurate battery cell module needed to regulate the DC bus voltage in islanding mode. The battery terminal voltage and SOC need to be estimated during operation. A high fidelity electrical model of lithium-ion battery model, with thermal dependence, is used. The pulse load can be connected to both the AC and DC side. On the DC side, the pulse load can usually be viewed as a purely resistive load. On the AC side, the pulse load can be either a resistive or inductive load, such as an induction motor. However, those inductive loads are commonly connected to the AC side through power electronic drives, such as back-to-back converters. In this way, the inductive load can be converted and act as a resistive load. In this paper, only 18 ohm resistive loads are used, and the programmable load is designed accordingly.

COORDINATED CONTROL OF CONVERTERS:

Three types of converters are utilized in this proposed hybrid microgrid as shown in Fig. 1. These converters must be actively controlled in order to supply uninterrupted power with high efficiency and quality to pulse loads on the AC and DC sides during grid-connected and islanding modes. The coordinated control strategies for converters are discussed.

Boost Converter Control with MPPT

To maximize the utilization of renewable energy from the PV farm, the boost converter should be operated on MPPT mode when the hybrid microgrid is connected to the utility grid.

Table parameters for photovoltaic panel

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{oc}$</td>
<td>Rated open circuit voltage</td>
<td>64.3 V</td>
</tr>
<tr>
<td>$I_{sc}$</td>
<td>Photocurrent</td>
<td>5.9992 A</td>
</tr>
<tr>
<td>$I_{mppt}$</td>
<td>Module reverse saturation current</td>
<td>$1.733 \times 10^{-5}$</td>
</tr>
<tr>
<td>$q$</td>
<td>Electron charge</td>
<td>1.602 $\times 10^{-19}$ C</td>
</tr>
<tr>
<td>$A$</td>
<td>Ideal factor</td>
<td>1.59</td>
</tr>
<tr>
<td>$k$</td>
<td>Boltzman constant</td>
<td>$1.38 \times 10^{-23}$ J/K</td>
</tr>
<tr>
<td>$R_s$</td>
<td>Series resistance of a PV cell</td>
<td>0.0879598 $\Omega$</td>
</tr>
<tr>
<td>$R_{sh}$</td>
<td>Parallel resistance of a PV cell</td>
<td>993.51 $\Omega$</td>
</tr>
<tr>
<td>$a$</td>
<td>Short-circuit current</td>
<td>3.96 A</td>
</tr>
<tr>
<td>$e_0$</td>
<td>SC current temperature coefficient</td>
<td>$1.7 \times 10^{3}$</td>
</tr>
<tr>
<td>$T_0$</td>
<td>Reference temperature</td>
<td>300.18 K</td>
</tr>
<tr>
<td>$i_{mppt}$</td>
<td>Reverse saturation current at $T_0$</td>
<td>2.07893 $\times 10^{-9}$ A</td>
</tr>
<tr>
<td>$e_{gap}$</td>
<td>Energy of the band gap for silicon</td>
<td>1.16 eV</td>
</tr>
<tr>
<td>$n_{q}$</td>
<td>Number of cells in parallel</td>
<td>528</td>
</tr>
<tr>
<td>$n_{o}$</td>
<td>Number of cells in series</td>
<td>480</td>
</tr>
<tr>
<td>$S$</td>
<td>Solar radiation level</td>
<td>0–1000 $W/m^2$</td>
</tr>
<tr>
<td>$I$</td>
<td>Surface temperature of the PV</td>
<td>350 K</td>
</tr>
</tbody>
</table>

Bi-Directional DC/DC Converter Control:

Battery banks in the microgrid can be used as an energy buffer, and the charging/discharging rates can be controlled based on the status of the output power from the PV farm and the power flow in the AC side. In islanded mode, the boost converter of the PV farm can be operated in on-MPPT or off-MPPT, which is based on the system’s power balance and the SOCs of the battery banks. In most cases, this boost converter can operate in the on-MPPT mode since the variation ratio of the solar irradiance is much lower compared to the power adjustment ability of the small size AC generator. Therefore, for a constant load either on the AC or DC side, the PV should supply as much power as possible to maximize its utilization. However, if the battery banks’ SOCs are high, (near fully charged) and the PV’s maximum output power is larger than the total load in the hybrid microgrid, the PV should be turned to off-MPPT to keep the system power in balance. In this paper, a perturbation and ob-server (P&O) method is used to track maximum power point.
The bi-directional DC/DC converters are used to connect the battery banks to the DC bus. The hardware setup of a battery bank, bi-directional DC/DC converter together with the measurement circuit, and control driver circuit is shown in Fig.8. In grid-connected mode, these converters only regulate the battery banks charging rates.

![Fig.8. The control block diagram for bi-directional DC/DC converter](image)

Based on the SOCs of the battery banks and the power flow conditions in the AC side, the charging/discharging current references are generated to regulate the current flow in the converters.

Each battery has its own bi-directional DC/DC converter, which means they can have different charging rates. The battery banks can inject power to, or absorb power from, the DC bus. Also, they can transfer energy between different battery banks if necessary. In this case, only one closed current control loop with PI controller is enough to regulate the current. The bi-directional DC/DC converters of the battery banks play an important role in islanding mode to regulate the DC bus voltage. A two-loop control is used to regulate the DC bus voltage. The control scheme for the bi-directional DC/DC converter is shown in Fig.8.

The outer voltage controlled loop is used to generate a reference charging current for the inner current controlled loop. The error between the measured DC bus voltage and the system reference DC bus voltage is set as the input of the PI controller, and the output is the reference current. The inner current control loop compares the reference current signal with the measured current flow through the converter and, finally, generates a PWM signal to drive the IGBTs to regulate the current flow through the converter. For example, when the DC bus voltage is higher than the reference voltage, the outer voltage controller generates a negative current reference signal. The inner current control loop adjusts the duty cycle to force the current flow from the DC bus to the battery, which results in charging of the battery. In this way, the energy transfers from the DC bus to the battery, and the DC bus voltage, then decreases to the rating value. If the DC bus voltage is lower than the normal value, the outer voltage control loop generates a positive current reference signal, which regulates the current flow from the battery to the DC bus. Because of the extra energy injected from the batteries, the DC bus voltage increases to the rating value. If several energy storage systems are connected to the common DC bus of the hybrid power system individually through their own bidirectional DC-DC converter, a conventional PID controller could not be used to regulate the DC bus voltage. If all of them are used to regulate the DC bus voltage, they may conflict with each other and cause instability problems. However, if only one of them is used to regulate the DC bus voltage, distributing power flow becomes unclear to the other controllers, which may cause SOC unbalance between energy storage systems. Therefore, droop control is used to regulate and dispatch power flow for multiple lithium-ion bat-tery modules on the DC side of the hybrid power system. With the SOC information, the five battery modules are ranked based on their SOC. With the SOC rank and the measured DC bus voltage, a central aggregator calculates and assigns the droop coefficient to each battery module. Each bidirectional DC-DC converter can generate its charging rate with the droop coefficient.

**Bi-Directional AC/DC Converter:**

In grid-connected mode, the AC side can be viewed as an infinite bus; therefore, the deviation of the voltage amplitude and frequency can be ignored. In this case, the bi-directional AC/DC converter only needs to regulate the DC bus voltage. In order to operate in unit power factor, reference iq can be set as 0.

The controller only needs to control the id, which controls the active power flow through the converter. The control block diagram for bi-directional AC/DC converter in grid-connected mode is shown in Fig.8. As discussed earlier, a two-loop controller is used to regulate the DC bus voltage. Based on the error between the DC bus reference voltage and measured voltage, the outer voltage control loop generates the id reference, which is used to regulate id in the bi-directional converter. In d-q co-ordinates, Id is controlled to regulate the active power flow through the inverter, and Iq is controlled to regulate the reactive power flow through the inverter. In the AC side, the active and reactive power flow will influence the frequency and voltage amplitude respectively.
In islanded operation mode, the frequency and voltage amplitude of the three phases AC side are volatile. The bi-directional AC/DC inverter is used to regulate the active and reactive power by controlling the id and iq, respectively. The control scheme for the bi-directional AC/DC inverter is shown in Fig. 9. Two-loop controllers are applied for both frequency and voltage regulation. For frequency control error between measured frequency and reference frequency is sent to a PI controller which generates the id reference.

Fig. 9. The control block diagram for bi-directional AC/DC converter in islanded mode

To control the voltage amplitude, the error between the measured voltage amplitude and the reference voltage amplitude is sent to a PI controller to generate iq reference.

Equations (4) and (5) show the AC side voltage equations of the bi-directional AC/DC inverter in ABC and d-q coordinates, respectively. Where (Va, Vb, Vc) are AC side voltages of the inverter, and (Ea, Eb, Ec) are the voltages of the AC bus. (Δa, Δb, Δc) are the adjusting signals after the PI controller in the current control loop.

\[
L_{ac} \frac{di_a}{dt} + R_{ac} i_a + \frac{c}{L_{ac}} \int i_a dt = V_a - V_d + \Delta_a
\]  
\[
L_{dc} \frac{di_d}{dt} + R_{dc} i_d + \frac{c}{L_{dc}} \int i_d dt = V_d - V_e + \Delta_d
\]

When the pulse load is connected or disconnected to the AC side, the frequency or voltage amplitude changes. After detecting the deviation using the phase lock loop (PLL) or voltage transducer, Id and Iq reference signals are adjusted to regulate power flow through the bi-directional AC/DC inverter. Because of the power flow deviation, the DC bus voltage is also influenced. The DC bus voltage transistor senses the voltage variation in DC bus, and the bi-directional DC/DC converter regulates the current flow between the battery and the DC bus. In the end, the energy is transferred between the battery and the AC side to balance the power flow.

For further frequency and voltage regulation, a droop control is implemented for solving the microgrid primary control problem as shown in Fig. 10. Synchronous generator and grid-tie inverter adjust their power output according to the no-load speed setting with respect to the system frequency. The power output for any given system frequency can be controlled. The no-load frequency of a given generator can be set to obtain any desired power output according to its droop slope R.

\[
f_{NL} = P(f_{NL} - f_{FL})/\left(P_{max} - P_{min}\right) + f_{NL}
\]  
\[
f_{NL} = -P \cdot R + f_{NL}
\]

Here, R is typically formulated with the maximum and minimum power outputs of the DG, Pmax and Pmin. The no-load and full-load frequencies, INL and IFL, are normally chosen as the bounds which the system frequency must not cross. The secondary level control covers the residual frequency error and puts back the frequency value to 60 Hz.

Fig. 10. Droop control implementation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C_p</td>
<td>Solar panel capacitor</td>
<td>100 μF</td>
</tr>
<tr>
<td>L_p</td>
<td>Inductor for solar Panel boost converter</td>
<td>1 mH</td>
</tr>
<tr>
<td>C_d</td>
<td>DC bus capacitor</td>
<td>6000 μF</td>
</tr>
<tr>
<td>L_d</td>
<td>AC filter inductor</td>
<td>1 mH</td>
</tr>
<tr>
<td>R_m</td>
<td>Inverter equivalent resistance</td>
<td>0.5 kΩ</td>
</tr>
<tr>
<td>L_b</td>
<td>Battery converter inductor</td>
<td>3.3 mH</td>
</tr>
<tr>
<td>R_b</td>
<td>Resistance of L_b</td>
<td>6.5 Ω</td>
</tr>
<tr>
<td>f</td>
<td>Rated AC grid frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>V_d</td>
<td>Rated DC bus voltage</td>
<td>100 V</td>
</tr>
<tr>
<td>V_m</td>
<td>Rated AC bus p-p voltage (rms)</td>
<td>268 V</td>
</tr>
<tr>
<td>n_l/m</td>
<td>Transformer ratio</td>
<td>1:1</td>
</tr>
</tbody>
</table>

IV. SIMULATION RESULTS
In the proposed system, instead of PI control, we are using PID controller for efficient performance of micro grid. A hybrid AC/DC micro grid with solar energy, energy storage, and pulse load is proposed. This micro grid can be viewed as a PEV parking garage power system or a ship power system that utilizes sustainable energy and is influenced by pulse load. The power flow control of these devices serves to increase the system’s efficiency, stability, and robustness.

**Grid connected mode:**

![Simulink block of PID control of micro grid in grid connected mode](image1)

Fig.11. simulink block of PID control of micro grid in grid connected mode

This block represents PID control of ac/dc hybrid micro grid involving energy storage energy and pulsed connected mode of operation. In existing system we had used PI controller for controlling circuit. In this proposed system we are used PID controller for the increment of grid efficiency by the control of stability, uncertainties. In this we have provide MPPT for maximum power tracking purpose .The PID control circuit shown in below figure.

![PID controller circuit](image2)

Fig 12. PID controller circuit

![Solar irradiance levels](image3)

Fig 13 : solar irradiance levels

![Power generated from the generator](image4)

Fig14 : The power generated from the generator

The hybrid micro grid is stable in both its AC and DC side. Another simulation was done for the hybrid micro grid under same islanding mode operation without DC side support. When the 10 kW resistive pulse load was connected to the AC bus, the
total load in the AC side was 14 kW which exceeded the generator’s output limitation by 0.2

Fig 15: the AC side frequency variation
Fig. 15 shows the AC side frequency variation. The AC/DC bi-directional inverter was enabled at 0.1s and the AC side frequency was stable at 60 Hz in less than 0.4 second. When the resistive pulse load was connected at t=2.2s, the frequency dropped to 58 Hz and returned to 60 Hz in less than 1 second. When the pulse load was disconnected from the AC side, the frequency increased to 62 Hz and returned to steady state in less than 0.5s

Fig 16: the PV output power

The PV farm output power variance is shown in Fig.16 When the 10kW pulse load is connected to the DC bus, those five battery banks cooperated together to regulate the voltage, therefore the DC bus voltage kept stable with a maximum variance of 17V during the transient response

6.hybrid microgrid performance in islanding mode:

the above fig 15 and below fig 16 and fig 17 shows the islanding of hybrid AC/DC micro grid during the synchronized operation, the islanded power system was delivering some amount of power to remote system. The islanding occurs at 138th second, which results over frequency in the area. The export power becomes zero. The primary control recovers the system frequency to until 155th second and settles at that point. Similar to previous scenario , the phase angle difference between power systems is no longer close to zero. At 167th second, the secondary control is enabled to draw power from the system to charge the energy storage systems. Since the imbalance power is not high that much, the system frequency reaches to nominal value very fast at 168th second. It is clearly seen that since system frequency is regulated, the oscillation of the generators becomes stable and start to swing coherently.

Fig 17: grid connected operation

Fig 18: phase angle difference
V. CONCLUSION

In this project, a coordinated power flow control method of multi power electronic devices is proposed for a hybrid AC/DC microgrid operated in both grid-connected and islanded modes. The microgrid consists of a PV module, battery bank and a synchronous generator that supply energy to its DC and AC side. Battery banks are connected to the DC bus through bi-directional DC/DC converter. The AC side and DC side are linked by the bi-directional AC/DC inverter. The control algorithms are tested with the harsh influence of pulse loads and islanding conditions. The simulation and experimental results show that the proposed microgrid with the control algorithm can greatly increase the system stability and robustness.

REFERENCES


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