# Voltage Control of a Hybrid AC/DC Microgrid in Grid-Connected Operation Mode

M. Akbari, M.A. Golkar, and S.M.M. Tafreshi
Electrical and Computer Engineering Department
K.N. Toosi University of Technology
Tehran, Iran
mohsenakbari@ieee.org , golkar@eetd.kntu.ac.ir , tafreshi@eetd.kntu.ac.ir

*Abstract*— **The stability of dc and ac bus voltage is of the most important issues in all microgrids including ac, dc or ac/dc hybrid microgrids. In this paper, a hybrid ac/dc microgrid is proposed to reduce processes of multiple reverse conversions in an ac or dc microgrid and to facilitate the connection of various renewable ac and dc sources and loads to power system. Also, all control schemes used among all converters are developed in order to improve the voltage stability of the dc grid. Results are achieved considering the uncertainty of the generators and loads existed in microgrid verifying the robustness of the controllers to restore and stabilize quickly the voltage of the dc grid.**

***Keywords- grid-connected mode; hybrid ac/dc microgrid; voltage control***

## I. INTRODUCTION

Nowadays, it is preferred to integrate renewable energies in the microgrid in order to reduce the $CO_2$ emission and the fossil fuel consumption. The benefits of distributed energy resources are seen to be higher reliability of service, better quality of power supply, and greater efficiency of energy use by utilizing the available waste heat from power generation systems. In addition, the ability to use renewable energy with little or no pollution is becoming increasingly attractive for environmental protection considerations and attracts increasingly important interests. Furthermore, distributed generation can benefit the electric utility by reducing congestion on the grid, reducing the need for new generation and transmission capacity, and offering ancillary services [1].

The ac microgrids [2]–[6] have been proposed to facilitate the connection of renewable energy sources to conventional ac systems. However, dc power from some distributed generators, such as photovoltaic (PV) panels or fuel cells, has to be converted into ac using dc/dc boosters and dc/ac inverters in order to connect to an ac grid. In an ac grid, embedded ac/dc and dc/dc converters are required for various home and office facilities to supply different dc voltages [7].

Recently, dc microgrids are resurging due to the development and deployment of renewable dc power sources and their inherent advantage for dc loads in commercial, industrial and residential applications [8]–[11]. However, ac sources have to be converted into dc before connected to a dc grid and dc/ac inverters are required for conventional ac loads.

Multiple reverse conversions required in individual ac or dc grids may add additional loss to the system operation and will make the current home and office appliances more complicated [7].

The smart grid concept is currently prevailing in the electric power industry. The objective of constructing a smart grid is to provide reliable, high quality electric power to digital societies in an environmentally, friendly and sustainable way. One of most important futures of a smart grid is the advanced structure which can facilitate the connections of various ac and dc generation systems, energy storage options, and various ac and dc loads with the optimal asset utilization and operation efficiency [7]. To achieve those goals, power electronics technology and control schemes play the most important roles to interface different sources and loads to a smart grid.

In [7], [12]-[14] hybrid ac/dc microgrids are proposed to reduce processes of multiple reverse conversions in an individual ac or dc microgrid and to facilitate the connection of various renewable ac and dc sources and loads to power system. So in this paper, a hybrid ac/dc microgrid is proposed and studied.

Since in all the microgrids the stability of dc and ac bus voltage is of the most important issues; so in this paper, modeling of a grid-connected hybrid microgrid has been established by using MatLab/Simulink, and also coordinated control strategies are designed for the voltage control of hybrid microgrid.

In this study, the uncertainty effect of the generators and loads including the small and large deviations on voltage control of the microgrid is studied. The results verify the efficiency and robustness of the controllers to restore and stabilize quickly the voltage of the microgrid.

## II. SYSTEM CONFIGURATION AND RESOURCES MODELING

### *A. Proposed Hybrid Microgrid Configuration*

A hybrid microgrid as shown in Fig. 1 is proposed and modeled in MATLAB/Simulink.

PV array is connected to dc bus through a dc/dc boost converter to simulate dc sources. A capacitor $C_{pv}$ is used to suppress high frequency ripples of the PV output voltage [7].

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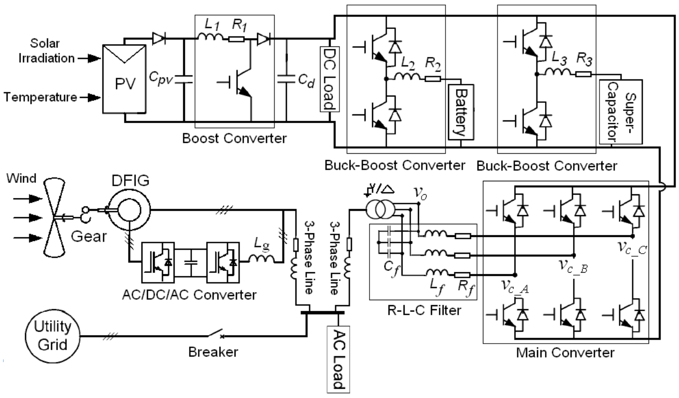


Figure 1. A compact representation of the proposed hybrid microgrid

Also, a wind turbine (WT) with DFIG is connected to an ac bus to simulate ac sources. In addition, a battery and a super-capacitor as the energy storages are separately connected to dc bus through bidirectional (buck-boost) dc/dc converters. dc and ac loads are also connected to dc and ac buses, respectively. The dc load was considered as a pure resistive load, but the connected ac load was included constant-impedance (resistance-inductance), constant-capacitance, and constant-power (induction motor) loads. The rated voltages for dc and ac parts are 400 V and 400 V rms, respectively. A 3-phase bidirectional dc/ac main converter with R-L-C filter connects the dc part to the ac part through an isolation transformer. Furthermore, Two similar ac lines are considered with impedance 0.0024+j*0.000212 Ω.

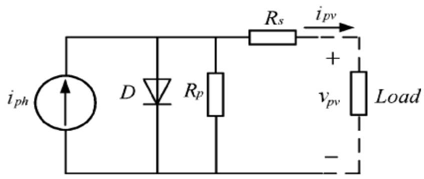


Figure 2. Equivalent circuit of a solar panel

### B. *Modeling of Energy Resources*

#### 1) *PV Array*

Fig. 2 shows an equivalent circuit of a PV panel modeled by a controlled current source. $i_{pv}$ and $v_{pv}$ are terminal current and voltage of the PV panel, respectively. The current output of the PV panel was modeled by formula shown in [7]. Also, 40 kW PV panel parameters, used in study, were extracted from [7].

#### 2) *Battery and Super-Capacitor Storages*

Although renewable resources are attractive, they are not always dependable in the absence of energy storage devices. The utilization of energy storage units in power systems can be classified into two categories. One is in response to fast transients and the other is related to steady-state energy exchanging. Super-capacitors are good candidates for the former application and batteries are suitable for the latter one. Currently, the mixed use of fast and slow energy storage units is gaining popularity for interconnection of renewable generation [15].

In this study, a 65 Ah, 200 V nickel-metal-hydride (NiMH) battery was used together with a super-capacitor storage. The battery was modeled using a controlled nonlinear voltage source in series with a constant resistance as shown in [16].

One of the important parameters to represent state of a battery is state-of-charge (SOC) defined as [16]:

$$SOC\,\% = 100\left(1 - \frac{it}{Q}\right) \tag{1}$$

where *it* is the extracted capacity and *Q* is the maximum capacity of battery storage. The battery SOC is between 0%, for an empty battery, and 100%, for a fully charged battery.

Also, in modeling of the present 500 F super-capacitor storage, it was assumed that it is an ideal capacitance, i.e. its resistance was exactly considered to zero.

#### 3) *Wind Turbine Generator*

In this study, DFIG was considered as a wound rotor induction machine, which needs to excite at both the stator and rotor terminals. Modeling of DFIG is well shown in SimPowerSystem Library of MatLab software. The 50 kW DFIG parameters, used in this study, were extracted from [7].

## III. CONTROLLERS

In a hybrid microgrid, when ac bus is directly connected to the utility grid, the magnitude of dc bus voltage can be regulated by the parallel inverters and microsources and storages located in dc part. And the magnitude and frequency of ac bus voltage are the same with the utility grid. The controllers designed for microgrid study are described in the following sub-sections.

#### 1) *Boost Converter Controller*

In grid-connected mode, the control objective of the boost converter is to track the maximum power point (MPPT) of the PV panel. To achieve this objective, P&O method proposed in [17]-[18] was used.

#### 2) *Coordinated Control of Battery, Super-Capacitor and Main Converter*

Battery has high energy density whereas it has relatively slow charging and discharging speed. On the other hand, super-capacitor has high power density and fast response. The mixed use of these energy storage units can make them complimentary to each other. Based on the above characteristics of battery and super-capacitor, a hybrid control scheme was designed as shown in Fig. 3.

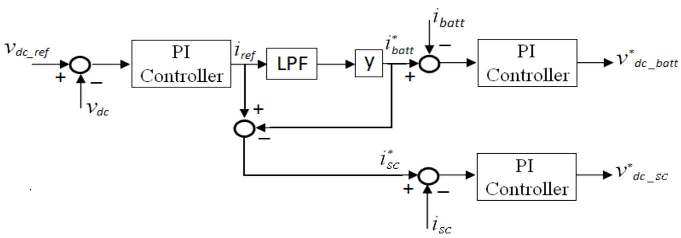


Fig. 3. Coordinated control scheme of the battery and super-capacitor storages

In this scheme, the dc part voltage is coordinately controlled by battery and super-capacitor storages. First, the measured dc part voltage $v_{dc}$ is compared with its reference $v_{dc\text{-}ref}$ and the difference is sent to a proportional-integration (PI) controller to get the current reference $i_{ref}$. Then $i_{ref}$ is split into two parts. One is the battery current reference $i^*_{batt}$ which is obtained by applying a low-pass filter (LPF) with a cut-off frequency 25 Hz and a coefficient $y$ (equal to 0.8 in this study) to $i_{ref}$. The other one $i^*_{sc}$ is the difference between $i_{ref}$ and $i^*_{batt}$. By this means, the high frequency part of the dc part disturbance and somehow low frequency part will be mitigated by super-capacitor and the remained low frequency part of the disturbance is smoothed by battery. The current references $i^*_{sc}$ and $i^*_{batt}$ will be used in the constant current control of the buck-boost converters shown in Fig. 1.

But, the battery has limits on SOC value. If SOC value is reached to its bounds, then the battery will be out and main converter will do the battery task to smooth remained low frequency part of the dc part disturbance. In other words, $i^*_{batt}$ will be displaced by $i^*_{fd}$. The upper and lower bounds of battery SOC are considered 90% and 60%, respectively. Also, the main converter was designed to provide a pre-defined reactive power. The proposed control scheme and detailed schematic of main converter are shown in Figs. 4 and 5, respectively.

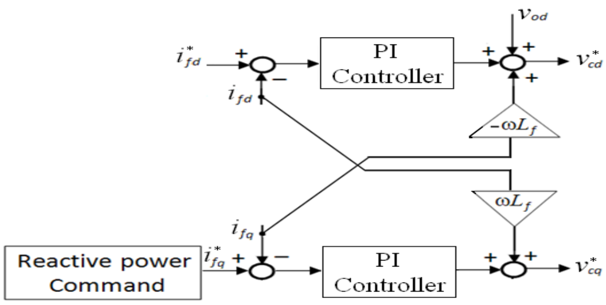

Figure 4. Control scheme of main converter in grid-connected mode

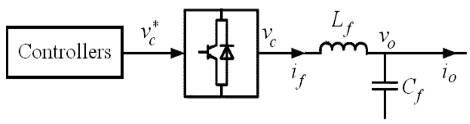

Figure 5. Detailed schematic of the main converter

*3) DFIG Controller*

DFIG has several controllers that are: rotor-side converter controller, grid-side converter controller, pitch controller and torque controller. The objectives of the rotor-side converter are to manage the stator-side active and reactive powers. The DTC scheme proposed in [7] was selected as the control method for the rotor-side converter in this study. The rotor rotational speed was obtained through the MPPT algorithm, based on algorithm proposed in [19], to track the MPPT of WT.

The grid-side converter was designed to regulate the voltage of its own dc-link capacitor. In addition, this model allows using grid-side converter to generate or absorb reactive power. This control system is illustrated in Fig. 6. The voltage of the dc-link is controlled by $i_{dg}$, while the reactive power is controlled by $i_{qg}$.

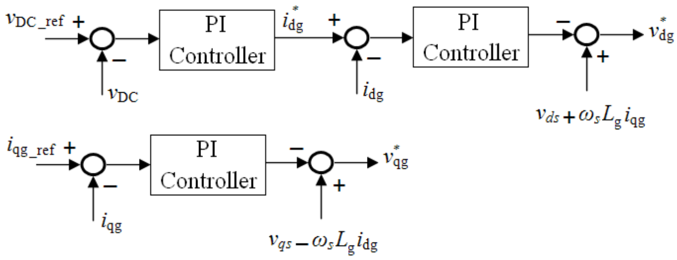

Figure 6. Grid-side converter control block diagram

Also, pitch control scheme proposed in [20] was used for DFIG. The controller enforces the rotor speed related to MPPT as a reference speed. Also, pitch compensation was done in this scheme. When the available wind power is less than rated, the blades are fixed to maximize the mechanical power, and when the available wind power is above the equipment rating, the blades are pitched to reduce $P_{\text{mech}}$ delivered to the shaft down to the mechanical power 1.0 pu.

Furthermore, the torque control scheme proposed in [20] was accomplished by using rotor speed reference. The torque controller output was used in rotor-side converter controller to calculate the d-axis current reference.

## IV. DYNAMIC SIMULATIONS

In this section, simulations performed in MatLab/Simulink are shown to verify the used controllers. The magnitude and frequency of ac bus voltage are the same with the utility grid and therefore constant. However, the voltage response of the dc grid under the different disturbances is shown in Fig. 7. In time 10 s, dc load is increased from 16 kW to 32 kW. Then in time 15 s, the irradiation surface of PV panel is decreased to 200 W/m2. In time 20 s, this surface is increased to the former condition. Finally, in time 25 s, dc load is decreased from 32 kW to 16 kW. In addition, irradiation surface and wind speed were assumed randomly as shown in Figs. 8-9, respectively. It can be seen that the designed controllers are well robustness to give a stable dc grid voltage and to restore the voltage quickly.

Also, the generated power of PV panel and DFIG, and the current waveform of battery and super-capacitor storages are shown in Figs. 10-13, respectively.

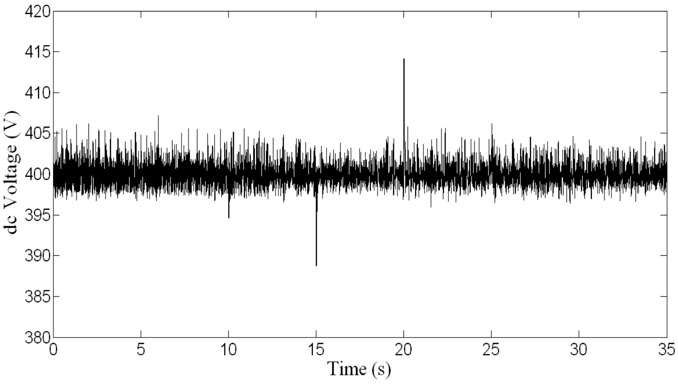


Figure 7. The voltage waveform of the dc grid

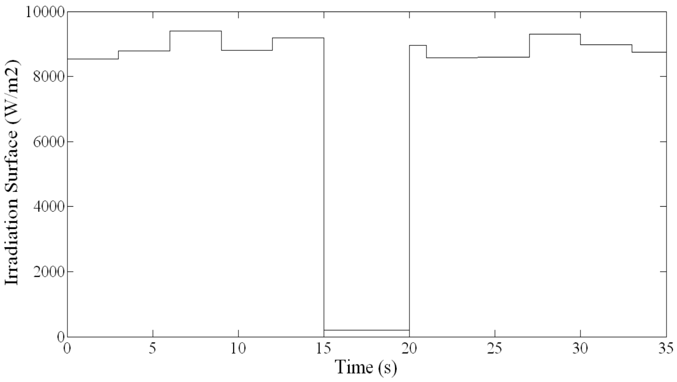


Figure 8. The simulated irradiation surface

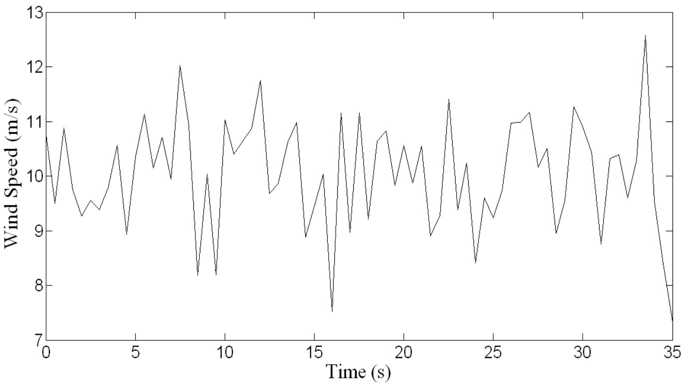


Figure 9. The simulated wind speed

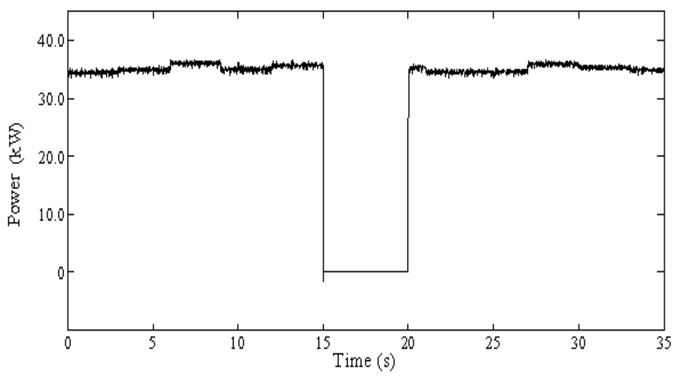


Figure 10. The generated power of the PV panel

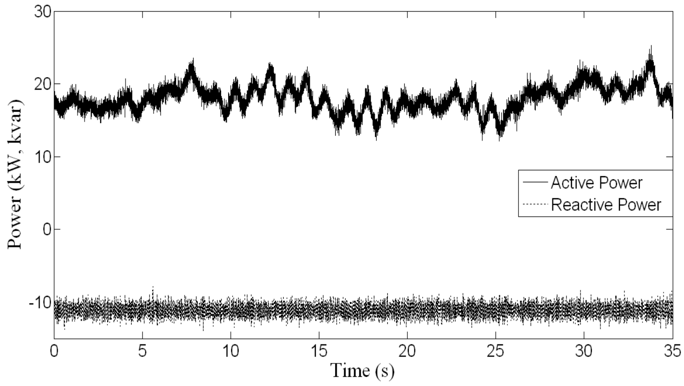


Figure 11. The generated power of the wind farm

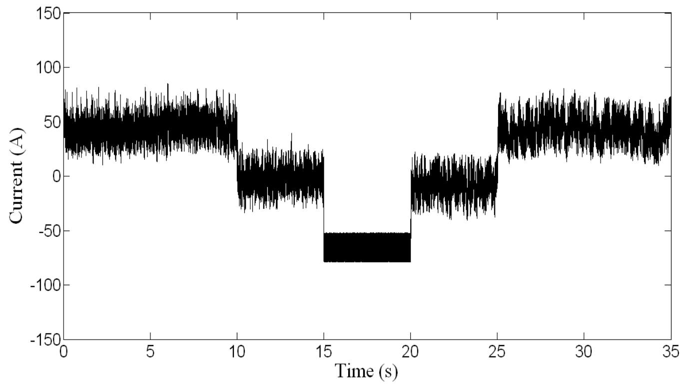


Figure 12. The current waveform of the battery storage

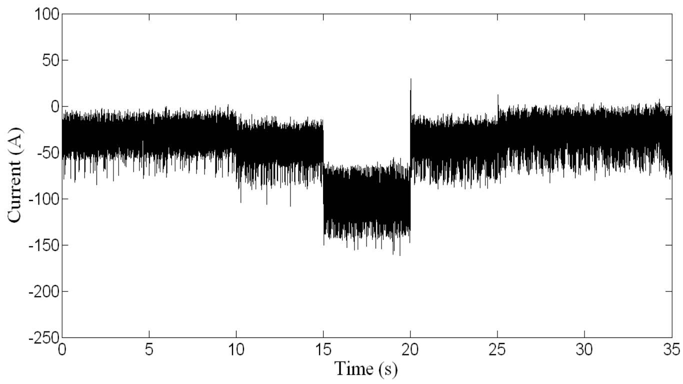


Figure 13. The current waveform of the super-capacitor storage

## V. CONCLUSION

In this paper, the controllers among the all converters are designed to improve the dynamic voltage stability of the dc part of microgrid operating in grid-connected mode. Also, PV panel and DFIG existed in ac and dc parts, respectively, are designed to tack MPPT. dc voltage control is studied under the small and large uncertainty of generators and loads. The achieved results verify the controllers robustness and efficiency to restore and stabilize quickly the voltage of the dc grid.

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