



## INTEGRATION OF WIND AND SOLAR DC MICROGRID USING MATLAB

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**Abstract**—To support the integration of wind and solar power within microgrids operational controls are designed. To support the quantification of the operational reserve for day-ahead and real-time scheduling an aggregated model of renewable wind and solar power generation forecast is proposed. Then, a droop control for power electronic converters connected to battery storage is developed and tested. Compared with the existing droop controls, it is distinguished in that the droop curves are set as a function of the storage state-of-charge (SOC) and can become asymmetric. The adaptation of the slopes ensures that the power output supports the terminal voltage while at the same keeping the SOC within a target range of desired operational reserve. This is shown to maintain the equilibrium of the microgrid's real-time supply and demand. The controls are implemented for the special case of a dc microgrid that is vertically integrated within a high-rise host building of an urban area. Previously untapped wind and solar power are harvested on the roof and sides of a tower, there by supporting delivery to electric vehicles on the ground. Without creating a large footprint the microgrid vertically integrates with the host building.

**Keywords**- Distributed energy resources, droop control, electric vehicle (EV), emission constraint, fast charging, microgrid, multilevel energy storage, optimal scheduling, power electronic conversion, solar power, wind power

### I. INTRODUCTION

In the year 2012, 44.8 GW of new wind energy conversion systems were installed worldwide. The trend has been toward increasingly larger turbine sizes, culminating in the installation of off-shore wind parks that are located far from the load centers. This can lead to rather large distances between generation and load in the electricity sector. The transportation sector reveals an even larger disconnect between the locations of fuel production and consumption. The energy system proposed in this project seeks to address both issues related to electricity and transportation sectors. One potential solution is a microgrid that can be vertically integrated with a high-rise building as frequently encountered in urban areas. The harvesting of renewable wind and solar energy occurs at the top of the building. The rooftop generation connects to the ground level via a microgrid where electric vehicle (EV) charging stations are supplied, and a battery supports maintaining the balance of supply and demand. The potential value of an urban integration within buildings as considered here comes from the usage of rooftop energy resources, the storage of the latter for offering EV fast charging at the ground level, the contribution to emission-free EV transportation in urban areas, the co-location and integration of generation and load in urban areas, and the grid-friendly integration of the microgrid with the rest of the power system main grid. The combination of wind and solar energy resources on a rooftop was also investigated in. It was verified that the combination of wind and solar energy leads to reduced local storage requirements.

The combination of diverse but complementary storage technologies in turn can form a multilevel energy storage, where a supercapacitor or flywheel provides cache control to compensate for fast power fluctuations and to smoothen the transients encountered by a battery with higher energy capacity. Microgrids or hybrid energy systems have been shown to be an effective structure for local interconnection of distributed renewable generation, loads, and storage. Recent research has considered the optimization of the operation on one hand and the usage of dc to link the resources on the other. The dc link voltage was shown to be maintained by a droop control that relates the dc link voltage to the power output of controllable resources. In this project, it is proposed to set the droop as a function of the expected state of charge (SOC) of the battery according to its operational optimization set point versus the actual real time SOC. The proposed operational optimization is further distinguished in that it quantifies the uncertainty associated with renewable generation forecast, emission constraints, and EV fast charging. Following this introduction, an outline of the principle of a dc microgrid is given in outline of dc microgrid. In renewable energy integration section, a method is developed for quantifying the aggregated wind and solar power forecast uncertainty, the resulting required SOC of the battery, and the operational optimization. The optimization-guided droop control is dealt with in adaptive droop control of BESS Section.

#### 1.1 Outline of dc microgrid

A schematic of the dc microgrid with the conventions employed for power is given in Fig. 1 The dc bus connects wind energy conversion system (WECS), PV panels, multilevel energy storage comprising battery energy storage system (BESS) and supercapacitor, EV smart charging points, EV fast charging station, and grid interface. The WECS is

connected to the dc bus via an ac–dc converter. PV panels are connected to the dc bus via a dc–dc converter. The BESS can be realized through flow battery technology connected to the dc bus via a dc–dc converter.

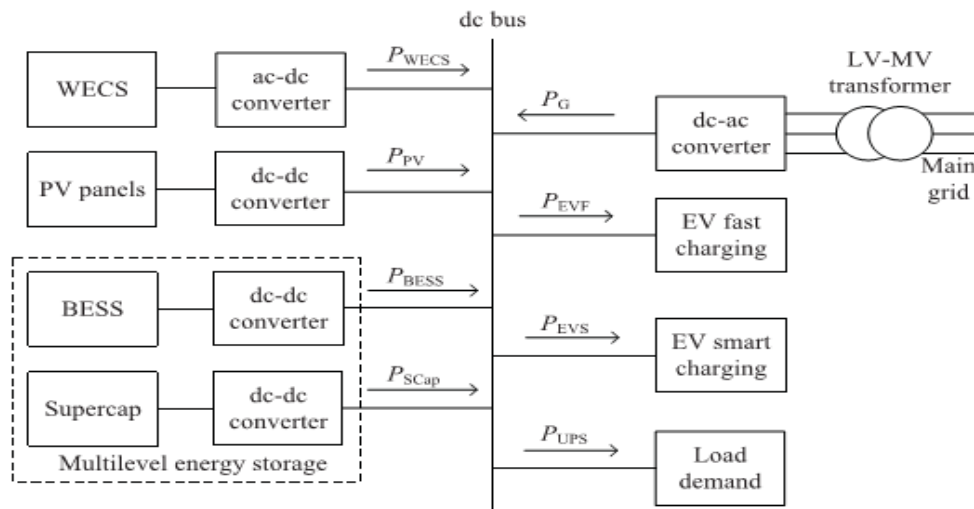


Fig. 1. Layout of dc microgrid

The supercapacitor has much less energy capacity than the BESS. Rather, it is aimed at compensating for fast fluctuations of power and so provides cache control. Thanks to the multilevel energy storage, the intermittent and volatile renewable power outputs can be managed and a deterministic controlled power to the main grid is obtained by optimization. Providing uninterruptible power supply (UPS) service to loads when needed is a core duty of the urban microgrid. EV fast charging introduces a stochastic load to the microgrid. The multilevel energy storage mitigates potential impacts on the main grid. In building integration, a vertical axis wind turbine may be installed on the rooftop as shown in Fig. 1. PV panels can be co-located on the rooftop and the facade of the building. Such or similar configurations benefit from a local availability of abundant wind and solar energy. The fast charging station is realized for public

## II. LITERATURE REVIEW

Asger B. Abrahamsen, Kais Atallah and Richard A. McMahon in Sep. 2013 [1], presented reviews of trends in wind turbine generator systems. After discussing some important requirements and basic relations, it describes the currently used systems: the constant speed system with squirrel-cage induction generator, and the three variable speed systems with doubly fed induction generator (DFIG), with gearbox and fully rated converter, and direct drive (DD). Then, possible future generator systems are reviewed. Hydraulic transmissions are significantly lighter than gearboxes and enable continuously variable transmission, but their efficiency is lower. A brushless DFIG is a medium speed generator without brushes and with improved low-voltage ride through characteristics compared with the DFIG. Magnetic pseudo DDs are smaller and lighter than DD generators, but need a sufficiently low and stable magnet price to be successful. In addition, superconducting generators can be smaller and lighter than normal DD generators, but both cost and reliability need experimental demonstration. In power electronics, there is a trend toward reliable modular multilevel topologies.

Francois Giraud and Ziyad M. Salameh presented this paper in March 2001 [2], the performance of a 4-kW grid connected residential Wind-Photovoltaic system (WPS) with battery storage located in Lowell, MA. The system was originally designed to meet a typical New-England (TNE) load demand with a loss of power supply probability (LPSP) of one day in ten years as recommended by the Utility Company. The data used in the calculation was wind speed and irradiance of Logan Airport Boston (LAB) obtained from the National Climate Center in North Carolina. The present performance study is based on two-year operation. (May1996–Apr 1998) of the WPS. Unlike conventional generation, the wind and the sunrays are available at no cost and generate electricity pollution-free. Around noontime the WPS satisfies its load and provides additional energy to the storage or to the grid. On-site energy production is undoubtedly accompanied with minimization of environmental pollution, reduction of losses in power systems transmission and distribution equipment, and supports the utility in Demand Side Management (DSM). This paper includes discussion on system reliability, power quality, loss of supply, and effects of the randomness of the wind and the solar radiation on system design.

M. H. Nehrir, C. Wang, K. Strunz, H. Aki, R. Ramakumar, J. Bing, Z. Miao, and Z. Salameh presented this paper in Oct. 2011 [5], prepared by a special task force of the IEEE PES Renewable Technologies Subcommittee, is a review of hybrid renewable/alternative energy (RE/AE) power generation systems focusing on energy sustainability. It highlights some

important issues and challenges in the design and energy management of hybrid RE/AE systems. System configurations, generation unit sizing, storage needs, and energy management and control are addressed. Statistics on the current status and future trend of renewable power generation, as well as some critical challenges facing the widespread deployment of RE/AE power generation technologies and vision for future research in this area are also presented. The comprehensive list of references given at the end of the paper should be helpful to researchers working in this area

### III. PROPOSED WORK

A simulation model of proposed topology is presented in this chapter. The detailed information of each simulation model used in the layout of dc microgrid is described as following.

#### 3.1 Wind turbine model

Wind turbines work by turning the kinetic energy of the wind into torque (a force) that causes the wind turbine to turn and drives an electrical generator. The wind is made up of real matter with mass, when mass is moving it has kinetic energy. Wind turbine in this microgrid simulation study is modeled by an aerodynamic input torque which drives a wind generator. The wind generator considered here is a squirrel cage induction generator.

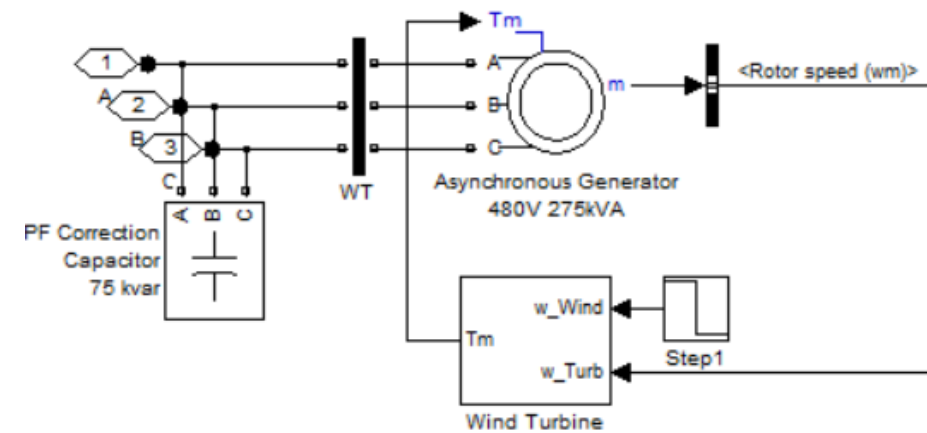


Fig. 2. Simulation model of wind energy conversion system

The above Fig.2 shows the simulation model of wind energy conversion system. In wind turbine system, turbine must rotate with constant speed mentioned by step which is the first input of wind turbine subsystem. Second input comes from rotor speed. The rotation speed must equal to speed mentioned by step. Both inputs are applied to wind turbine which generate differential error in turn give feedback to torque control of generator. Hence generator matches the speed with desired speed.

#### 3.2 Solar model

Photovoltaics is the method of converting solar energy into direct current electricity using semiconductor materials which exhibit photovoltaic effect. PV model represent solar irradiance and temperature changes which may happen during the day. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material.

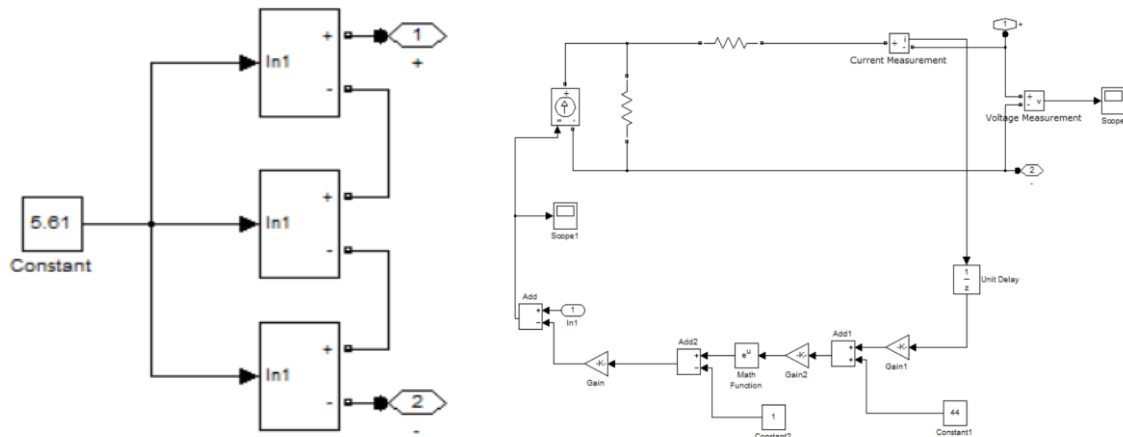


Fig. 3. Simulation model of solar

The materials used for photovoltaics include mono crystalline silicon, amorphous silicon. Photo voltaic power capacity is measured as maximum power output under standardized test conditions (STC) in Wp (Watts peak). The above Fig. 3 shows the simulation model solar system and this solar system based on the mathematical equation described as following.

$$I_{pm,ref} = I_{ph,ref} - I_{o,ref} \left[ \exp \left( \frac{V_{pm,ref} + I_{pm,ref} R_s}{a_{ref}} \right) - 1 \right]$$

$$I_{pm,ref} = 5.61 - 1e^{-7} \left[ \exp \left( \frac{44 + I_o * 0.221}{257e^{-3}} \right) - 1 \right]$$

$$I = I_{ph} - I_d$$

$$I_d = I_o \left[ \exp \left( \frac{V}{A.N_s.V_T} \right) - 1 \right]$$

$$V_T = k . T_c / q$$

$I_o$  is reverse saturation or leakage current of diode (A).  $V_T = 26$  mv at 300K for silisium cell.  $T_c$  is actual cell temp. (K).  $k$  is Boltzman const.  $1.381 * 10^{-23}$  J/K,  $q$  – electron charge ( $1.602 * 10^{-19}$  C).

$$V_T = 1.381 * 10^{-23} * \frac{300}{1.602 * 10^{-19}} = 0.02536$$

$N_s$  = No. of PV cell connected in series  
 $A$  = Ideality factor

$$a = \frac{N_s.A.k.T_c}{q} = N_s.A.V_T$$

In reality, it is impossible to neglect the series resistance  $R_s$  and parallel resistance  $R_p$ , because of their impact on the efficiency of the PV cell and PV module.

$$I_d = I_o \left[ \exp \left( \frac{V + I.R_s}{a} \right) - 1 \right]$$

In our model,

$$I_o = 1e^{-7}, R_s = 0.221 \text{ and } V = 44.$$

### 3.3 Battery energy storage system

An important concept in battery selection is that the amp-hour rating of a battery is discharge-rate specific. The greater the discharge rate, the less energy can be withdrawn from a specific battery. In this project lithium-ion type of battery is used. A lithium-ion battery is a member of family of rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. The battery parameters in matlab model is as following.

Table.1.Parameters of battery

|                         |                               |
|-------------------------|-------------------------------|
| Battery type            | Lithium-Ion                   |
| Nominal voltage         | 500 V                         |
| Rated capacity          | 1000 kAh                      |
| Initial state-of-charge | 80 % (Case A) & 40 % (Case B) |

### 3.4 Supercapacitor

Supercapacitors is that they have a long lifetime, about 1000000 charging cycles compared to some battery types that last for about 1000 cycles. The number of cycles for batteries is valid for variations of SOC of about 80 %. The supercapacitor is that the number of charging cycles is not greatly affected by the variation of SOC compared to batteries. Batteries have a significantly shorter lifetime when they are used in cycles with large SOC variation compared with low SOC variation cycles. Today the differences in energy and power density between these components can be used as an advantage by combining them in a power system, where they can complement each other. Simulation model of

supercapacitor which used for making of dc microgrid model is as below, which having resistance 0.5 ohms and capacitance 200 F.

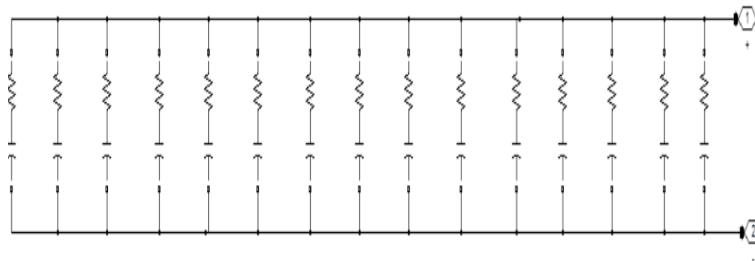


Fig. 4. Simulation model of supercapacitor.

### 3.5 Ac dc converter

To convert ac power to dc power, rectifier is used, which is thyristor based. To control dc power of rectifier, its firing angle must be controlled. To get amount of required dc power, for that controlling circuit is used. To which one input is feedback current of the rectifier, which is compared with reference input current and depending on which, controlled the firing angle of rectifier. The pulse required to controlled the firing angle of rectifier is also depend on voltage generated by wind. Hence this is also considered to controlled firing angle of rectifier. This converter is used after the wind block in simulation model to convert wind generated ac power into dc power and further it will send to the dc bus.

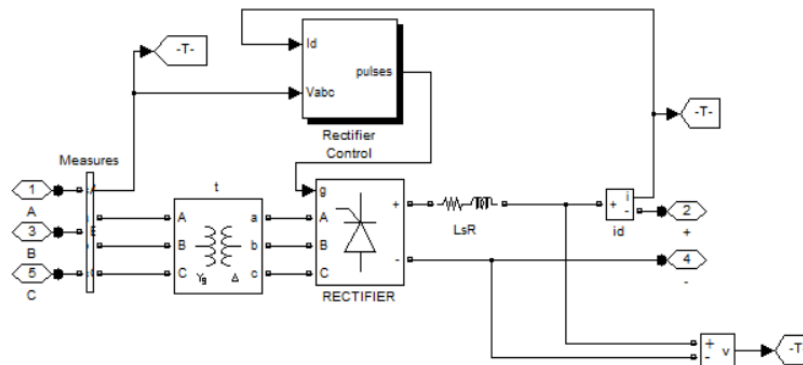


Fig. 5. Simulation model of ac dc converter.

As ac-dc converter is used after the WECS block in the simulink model, there is also another converter is used that is dc-ac converter. This converter is used after the dc bus to convert given dc power into the required ac power (that is inverter). That generated ac power we can given to the main grid via this dc-ac converter, which having same simulation model like ac-dc converter. Fig.5 shows the simulation model for both the converter, ac-dc / dc-ac.

### 3.6 Dc dc converter

The amount of energy generated by solar panel is not uniform to convert this energy at particular level dc-dc converter is used. The main block of boost converter is capacitor parallel switch across the capacitor and controlling circuit for the switch. The switch can be made on and off depending on charging and discharging of capacitor. The output developed by solar panel to keep amount of energy generated by solar panel upto certain limit. This dc-dc converter is used after solar system, battery and supercapacitor. After generated the required output it is fed to the dc bus. With the help of this converter we get the efficient dc power. The simulation model of dc-dc converter is as following.

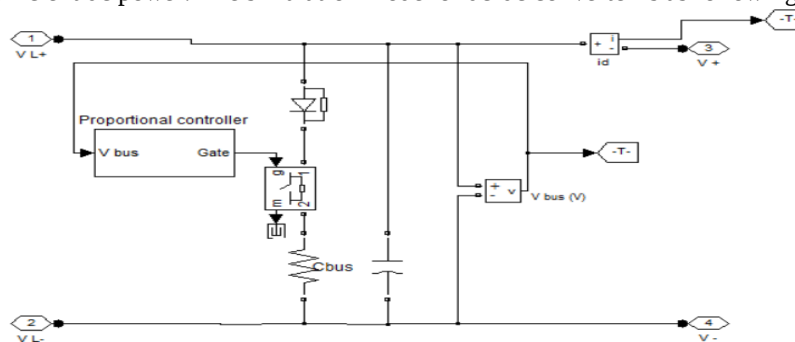


Fig.6. Simulation model of dc-dc converter

### 3.7 Model of dc microgrid

The following Fig.7 shows the overall simulation model of wind and solar power integrated dc microgrid. This model taken from MATLAB R2010a. The components used in this model is explained in the above sections. MATLAB program must respond to each event if the program is to perform its function. There must be callback to implement the function of each graphical component on the GUI. A complete model built of Microgrid including the power sources, their power electronics, and a load and mains model in MATLAB/Simulink is presented.

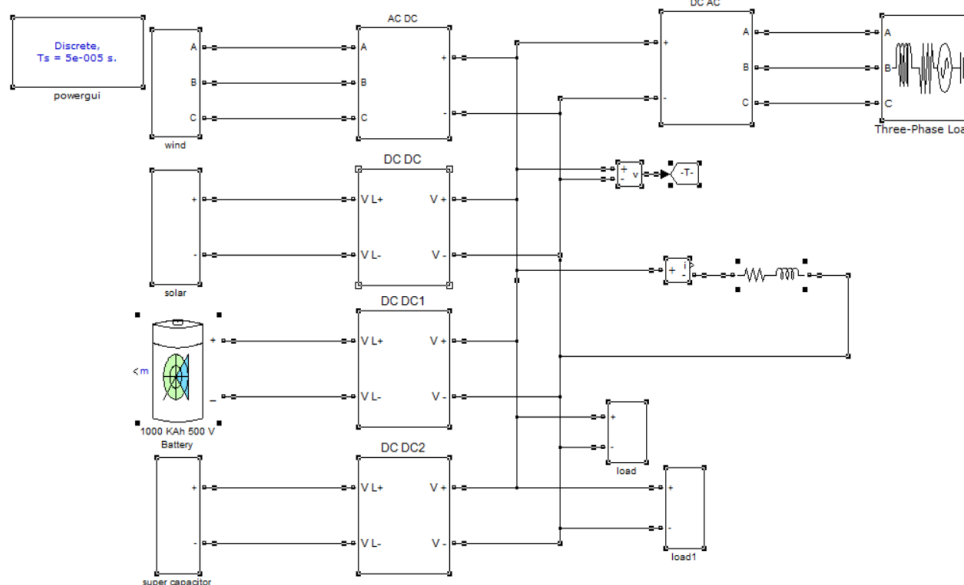


Fig. 7. Overall simulation model of wind and solar power integrated dc microgrid

## IV. RESULT

The layout of dc micrgrid as shown in fig.1, having following results. The obtained simulation results are based on the adaptive dc voltage droop control. The voltage power droop control is described in the adaptive droop control of BESS.

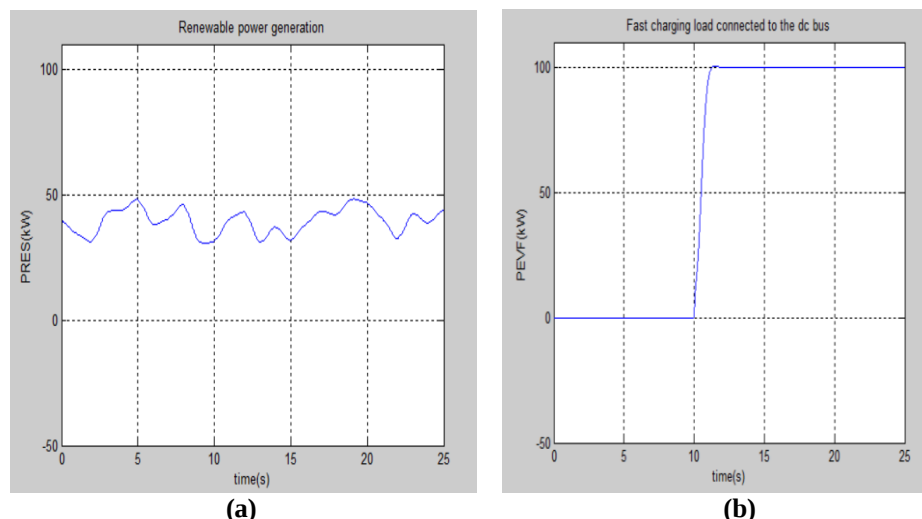


Fig. 8. Case study: Assumptions of the simulation. (a) Renewable power generation. (b) Fast charging load connected to the dc bus.

Renewable power generation is simulated for 25 s as shown in Fig. 8(a). The fast charging load is connected to the dc bus at time equal to 10 s at 100 kW as shown in Fig. 8(b). In this section there are two cases of results, that is case A & case B. Results for both cases are as followings.

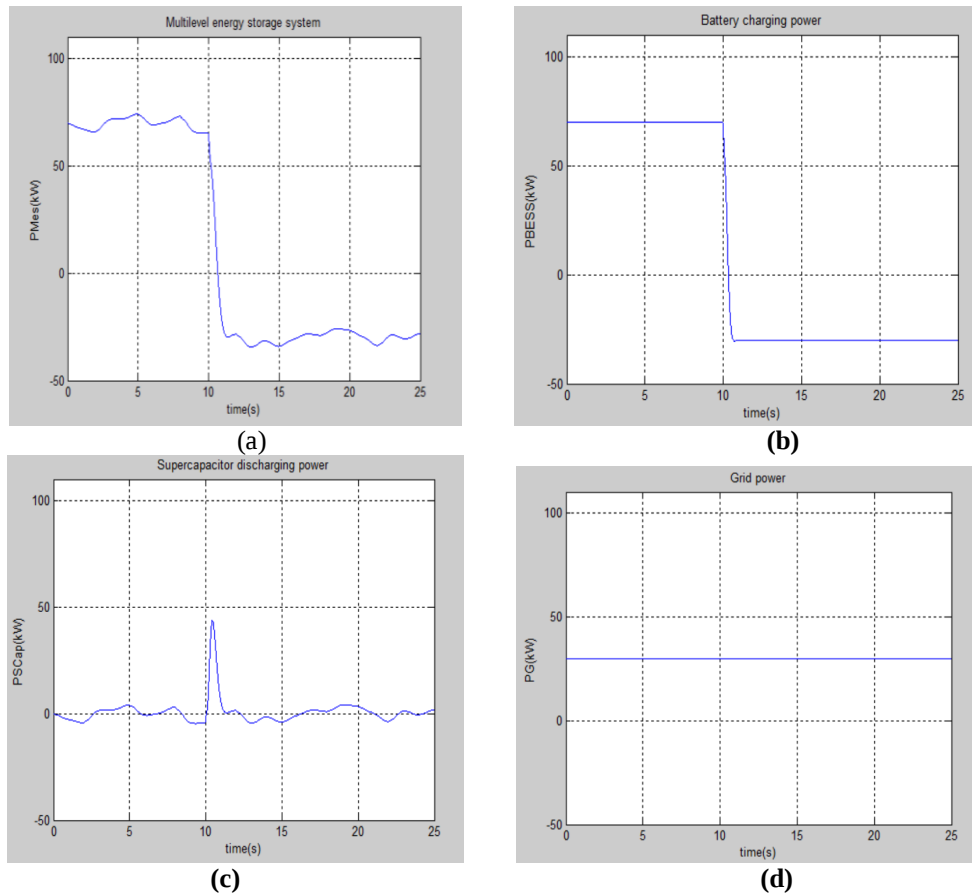


Fig. 9. Case A : Droop –control – based response to wind fluctuation and fast charging when SOC of battery is as scheduled. (a) Multilevel energy storage system (MES) charging power from dc bus. (b) Battery charging power from the dc bus. (c) Supercapacitor discharging power to the dc bus. (d) Grid power to the dc bus.

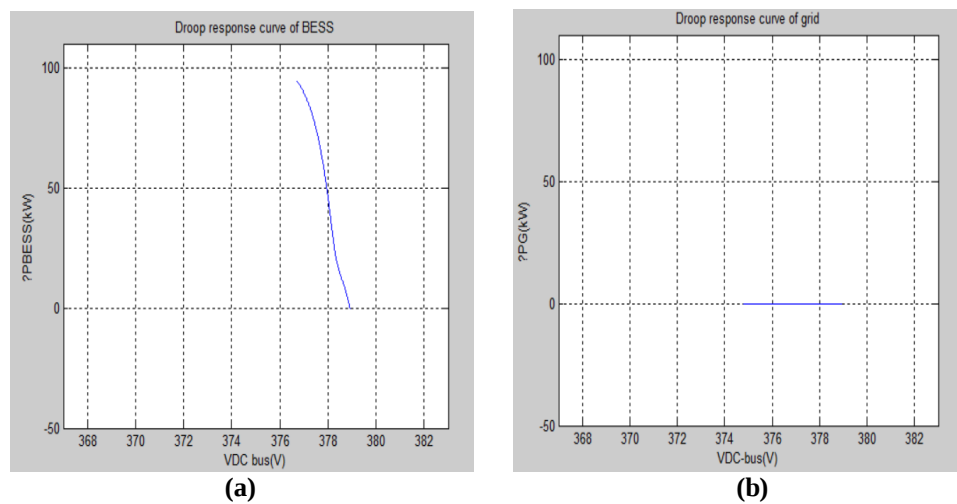


Fig.10. Case A : BESS and grid droop response curves. (a) Droop response curve of BESS. (b) Droop response curve of grid.

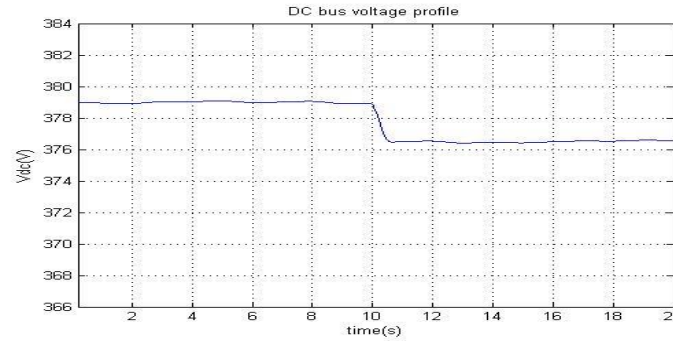


Fig.11. Case A : DC bus voltage profile.

In case A, it is assumed that the SOC of the battery is within close range of the scheduled SOC resulting from the day-ahead optimization. Therefore, the droop control in normal SOC of the battery as depicted. The simulation results are shown in Figs. 9-11.

The power PMES delivered by the multilevel energy storage combination of BESS and supercapacitor compensates both fast changes of renewable fluctuations and load. The rapid decrease of  $-PMES$  at 10 s shows that power is made readily available for fast charging. Thanks to the supercapacitor as cache energy storage, the power fluctuations do not propagate to the main grid. The grid power to the dc bus is unchanged. The droop control of the main grid converter is not active and thus the grid power remains the same as scheduled. The functionality of the BESS droop control can be recognized from Fig. 10. The dc bus voltage dropped approximately by 2.6 V and stabilized around 376.4 V as seen in Fig. 11.

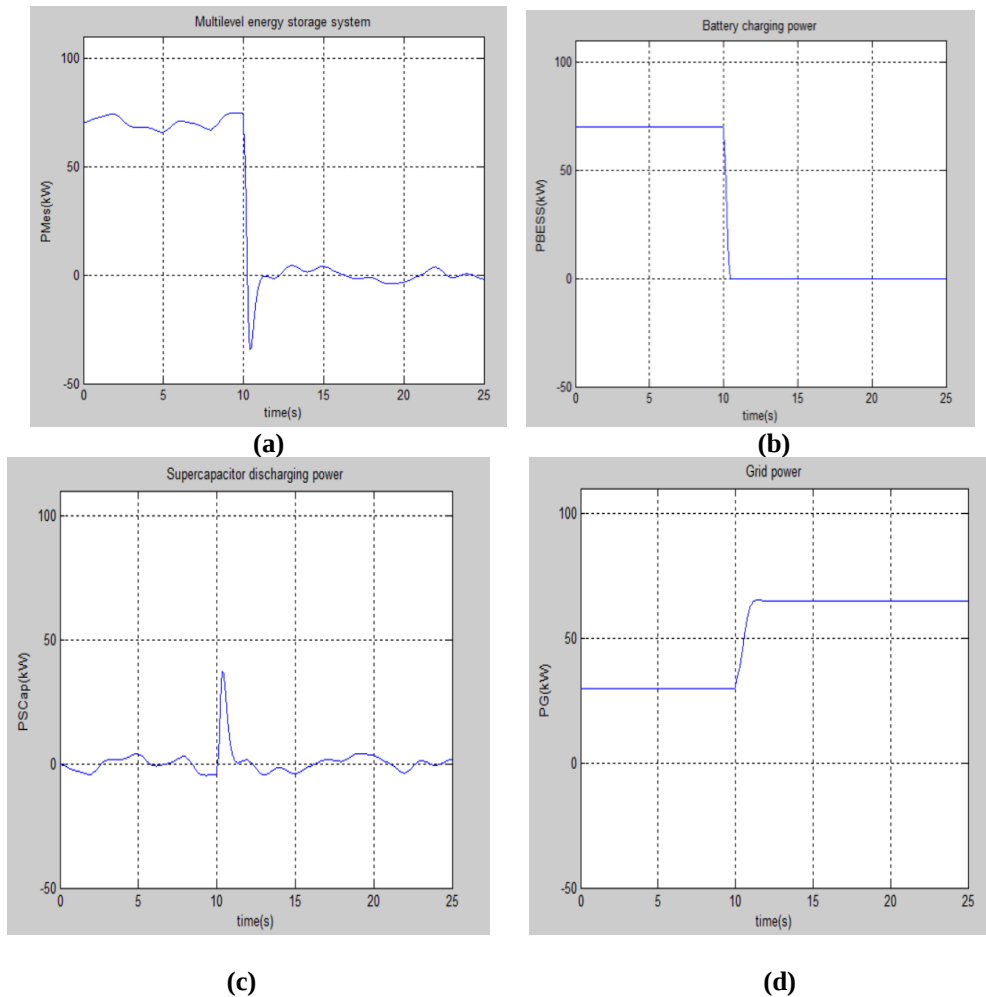


Fig. 12. Case B: Droop-control-based responses to wind fluctuation and fast charging when SOC of battery is lower than scheduled. (a) Multilevel energy storage system (MES) charging power from the dc bus. (b) Battery charging power from the dc bus. (c) Supercapacitor discharging power to the dc bus. (d) Grid power to the dc bus.

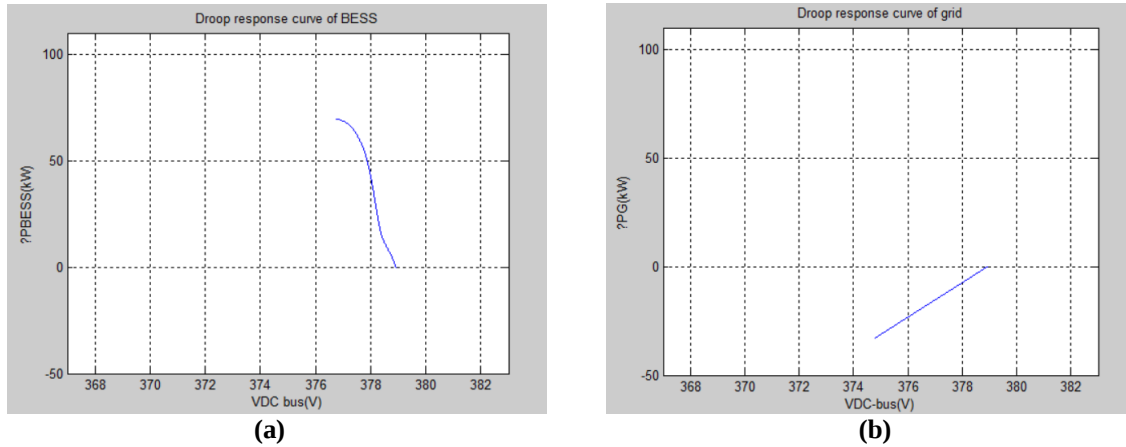


Fig. 13. Case B: BESS and grid droop response curves. (a) Droop response curve of BESS. (b) Droop response curve of grid.

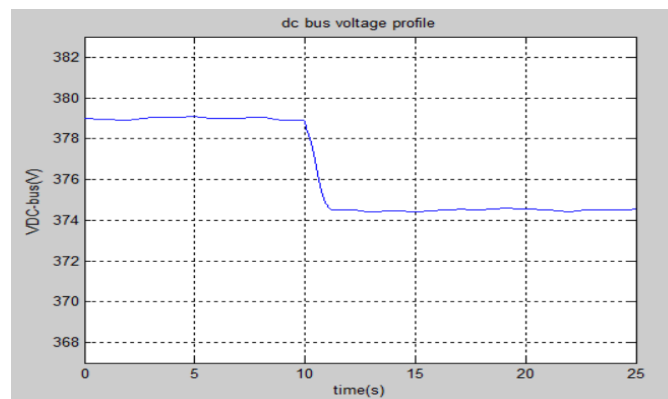


Fig. 14. Case B: dc bus voltage profile.

In case B, it is assumed that the BESS has lower than expected SOC compared with the SOC scheduled in the optimization. As a result, the BESS droop control as depicted is selected. In the new droop control,  $\gamma$  is 0.40. All other assumptions are the same as in case A where the fast charging load is connected to the dc bus at time 10 s. The simulation results are depicted in Figs. 12–14.

#### IV. CONCLUSION

A dc microgrid for renewable power integration has been proposed. It has greater efficiency. It can provide to remote places where government is unable to reach. So that the power can be utilize where it generated so that it will reduce the transmission losses and cost. Cost reduction can be done by increasing the production of the equipment. People should motivate to use the non conventional energy resources. It is highly safe for the environment as it doesn't produce any emission and harmful waste product like conventional energy resources. It is cost effective solution for generation. It only need initial investment. It has also long life span. Overall it good, reliable and affordable solution for electricity generation. The renewable power which can be produced from the renewable resources can be integrated by the accumulated model. By this accumulated model the power for the individual time can be calculated. At particular time, the load will be connected to the dc bus. The renewable power will be served to the load through dc bus. If there is any uncertainty affiliated with the forecast of aggregated wind and pv based power generation was created and used to quantify the energy reserve of the battery energy storage system. The battery is parallel connected with the super capacitor to form multi level energy storage. The battery plays critical role for compensating the power fluctuations. The control proposed is here adaptive droop control in that the voltage-power droop curves are modified depending on the outcome of operational optimization. These voltage-power droop curves satisfy the load forecast uncertainties. The resulting energy system serves local stationary and ev based mobile consumers, and it is a good citizen within the main gird as it reduces emission by local usage of wind and solar energy. In this way, simulation for integration of two renewable energy sources that is wind and solar for dc microgrid is done.

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