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A PAPER ON POWER MANAGEMENT STRATEGY RESEARCH FOR DC MICROGRID WITH HYBRID STORAGE SYSTEM BY USING MPPT

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Abstract

Microgrid arises at the historic moment. At present, DC microgrid is an effective solution to integrate renewable energy sources which are DC power supply with DC loads. In allusion to the power unbalance intra-microgrid and the wide fluctuation of DC bus voltage due to unstable output of DC micro resources in DC microgrid, A DC microgrid structure consisting of photovoltaic generation system, hybrid energy storage systems and AC main grid, is researched in this paper. A novel power management strategy for this DC microgrid is proposed. The control strategy divides the DC bus voltage into seven ranges by six critical voltage values which are employed as the represents of power states, and according to the range which the bus voltage belongs to, the operation mode of the system can be automatically judged and switched freely. A hybrid energy storage system in this microgrid that contains two complementary type storage element battery and super-capacitor, can enhance the reliability and flexibility of the system based on their special supply logical. Experimental results show that above-mentioned control strategy is feasible through the MATLAB-SIMULINK simulation platform.

Key Words: Microgrid, storage system, DC bus, PV cell, MPPT.

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1. INTRODUCTION:

As electric distribution technology steps into the next century, many trends are becoming noticeable that will change the requirements of energy delivery [1]. These modifications are being driven from both the demand side where higher energy availability and efficiency are desired and from the supply side where the integration of distributed generation and peak shaving technologies must be accommodated.

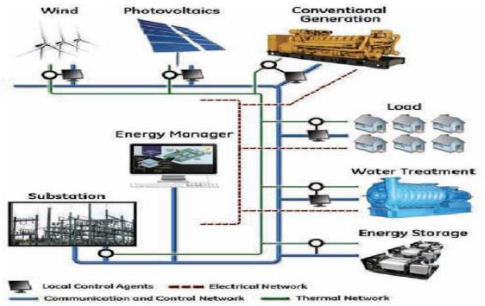


Fig.1.1. Micro grid power system

Power systems currently undergo considerable change in operating requirements mainly as a result of deregulation and due to an increasing amount of distributed energy resources (DER) [2]. In many cases DERs include different technologies that allow generation in small scale (micro sources) and some of them take advantage of renewable energy resources (RES)

WHAT IS MICROGRID: It is a small-scale power supply network that is designed to provide power for a small community. It enables local power generation for local loads. It comprises of various small power generating sources that makes it highly flexible and efficient. It is connected to both the local generating units and the utility grid thus preventing power outages. Excess power can be sold to the utility grid[3]. Size of the Micro grid may range from housing estate to municipal regions.

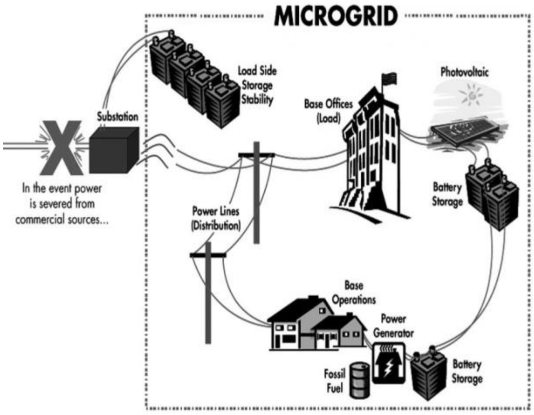


Fig 1.2 Typical Micro

Micro grid could be the answer to our energy crisis. Transmission losses get highly reduced. Micro grid results in substantial savings and cuts emissions without major changes to lifestyles. Provide high quality and reliable energy supply to critical loads.

Application of individual distributed energy resources, DER, can cause as many problems as it may solve. A better way to realize the emerging potential of distributed energy resources is to take a system approach viewing DER and associated loads as a grid resource or a "micro grid". The sources and loads can operate in parallel to the grid or as an island [4]. It can provide for the customer's critical needs while providing services to the distribution system. Micro grids can provide for

Local load grow and enhance the robustness of the distribution system. Facilitate greater use of renewable such as small wind and photovoltaic systems. Increase energy efficiency and the level of local reliability demanded by customers' loads.

Micro grid control is designed to facilitate an intelligent network of autonomous units. Micro grids have an interface switch, DER units and loads. The interface switch has the ability to autonomously island the micro grid from disturbances such as faults, events or power quality events. After islanding, the reconnection of the Micro grid is achieved autonomously after the tripping event is no longer present [5]. Each DER component can seamlessly control power and provide required energy to each load. The DER units in the islanded micro grid use a power vs. frequency droop controller to track the energy requirements of the loads.

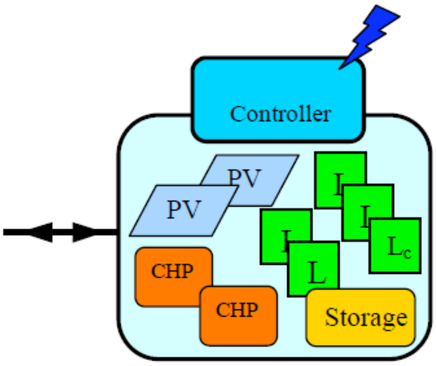


Fig.1.3 Grid Resource or Micro grid

Micro grid components must follow peer-to-peer and plug and- play concepts to insure high power quality and effective use of waste heat.

Each source is connected in a peer-to-peer fashion with a localized control scheme implemented for each component. This arrangement increases the reliability of the system in comparison to having a master-slave or centralized control scheme [6].

In the case of master-slave controller architecture the failure of the master controller could compromise the operation of the whole system. Plug and play concepts allow us to expand the micro grid to meet the requirements of the site without extensive re-engineering. This implies that the micro grid can continue operating with loss of any component or generator. With one additional source, (N+1), we can insure complete functionality with the loss of any source.

PV MICRO GRID: Currently the relatively low penetration levels of renewable systems cause few problems. As penetration becomes greater the availability of sun becomes a greater problem requiring central generation to provide the power backup.

Such systems are intermittent and can cause similar stability problems found with intermittent loads such as rolling mills and arc furnaces. Central generation or DER units are required to smooth out power fluctuations from these renewable sources. In any case there is a need for reserves when there is no sun. An obvious solution includes DER units on the distribution system. Without storage and/or local generation there is a technical limit to the amount of PV generation on the distribution system. Systems with high levels of PV penetration need to be supplemented with local “dispatch able” resources such as storage and local generation to fill-in for temporary loss of solar energy. PV micro grids can be designed for high export of PV energy without the short-term problems associated with intermittent power fluctuations. The DER units in a PV micro grid can have multi-roles such as control of real and reactive power flow between the micro grid and distribution system, power fill-in when intermittent generation is not available and local load support during islanding.

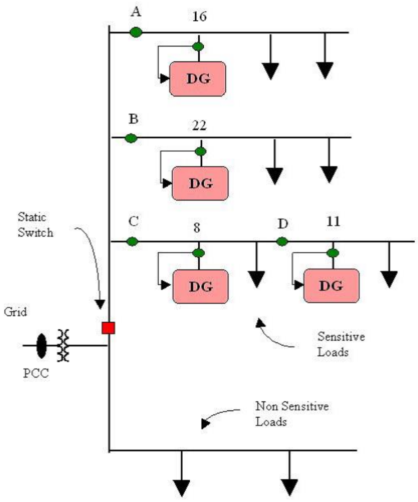


Fig.1.4 Micro grid Architecture Diagram

When there is a problem with the utility supply the static switch will open, isolating the sensitive loads from the power grid [7]. Non sensitive loads ride through the event. It is assumed that there is sufficient generation to meet the loads’ demand. When the micro grid is grid-connected power from the local generation can be directed to the non-sensitive loads. To achieve this we promote autonomous control in a peer-to-peer and plug-and-play operation model for each component of the micro grid. The peer-to-peer concept insures that there are no components, such as a master controller or central storage unit that is critical for operation of the micro grid.

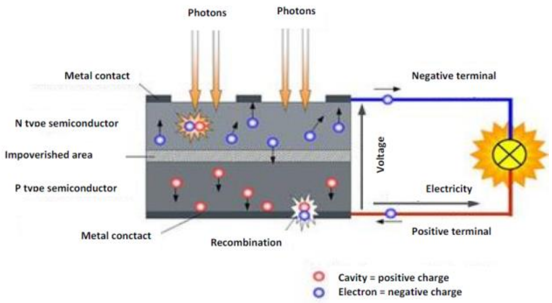


Fig.1.5 function of the photovoltaic cell

A single cell generates very low voltage (around 0.4), so more than one PV cells can be connected either in serial or in parallel or as a grid (both serial and parallel) to form a PV module. When we need higher voltage, we connect PV cell in series and if load demand is high current then we connect PV cell in parallel. Usually there are 36 or 76 cells in general PV modules. Module we are using having 54 cells. The front side of the module is transparent usually buildup of low-iron and transparent glass material, and the PV cell is encapsulated. The efficiency of a module is not as good as PV cell, because the glass cover and frame reflects some amount of the incoming radiation.

2. SYSTEM CONFIGURATION

Hydroelectric dams with reservoirs can be operated to provide peak generation at times of peak demand. Water is stored in the reservoir during periods of low demand and released when demand is high. The net effect is similar to pumped storage, but without the pumping loss.

While a hydroelectric dam does not directly store energy from other generating units, it behaves equivalently by lowering output in periods of excess electricity from other sources. In this mode, dams are one of the most efficient forms of energy storage, because only the timing of its generation changes. Hydroelectric turbines have a start-up time on the order of a few minutes.

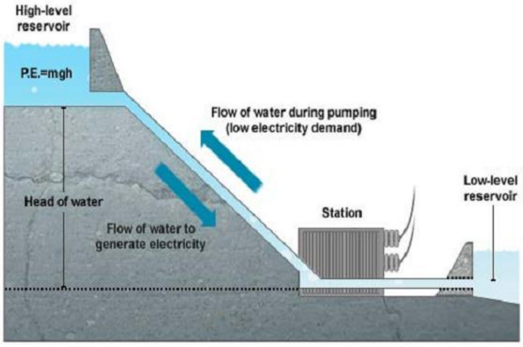


Fig.2.1 Pumped – Storage system

The Sir Adam Beck Generating Complex at Niagara Falls, Canada, which includes a large pumped storage hydroelectricity reservoir to provide an extra 174 MW of electricity during periods of peak demand [8].

Worldwide, pumped-storage hydroelectricity (PSH) is the largest-capacity form of active grid energy storage available, and, as of March 2012, the Electric Power Research Institute (EPRI) reports that PSH accounts for more than 99% of bulk storage capacity worldwide, representing around 127,000 MW.[2] PSH reported energy efficiency varies in practice between 70% and 80%,with claims of up to 87%.

At times of low electrical demand, excess generation capacity is used to pump water from a lower source into a higher reservoir. When demand grows, water is released back into a lower reservoir (or waterway or body of water) through a turbine, generating electricity. Reversible turbine-generator assemblies act as both a pump and turbine (usually a Francis turbine design). Nearly all facilities use the height difference between two water bodies. Pure pumped-storage plants shift the water between reservoirs, while the "pump-back" approach is a combination of pumped storage and conventional hydroelectric plants that use natural stream-flow.

A grid-connected DC micro grid investigated in this paper is shown in Fig.3.1. It consists of PV-panel, hybrid storage unit, utility grid, DC/DC converters, DC/AC converter and DC load. The PV panel is connected to the DC bus through a boost DC/DC converter which extracts the maximum power from PV panel using maximum power point tracking (MPPT) algorithm. The hybrid energy storage unit is composed of lead-acid batteries and super-capacitors. The batteries and the super-capacitors are connected with the DC bus through two bi-directional half-bridge DC/DC converters. The utility grid is connected to the DC bus through a three-phase bi-directional full-bridge AC/DC converter [9].

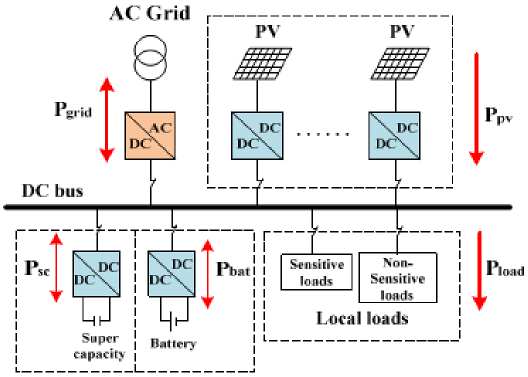


Fig.2.2. DC micro grid with hybrid storage system

MPPT CONTROL OF PV MODULE

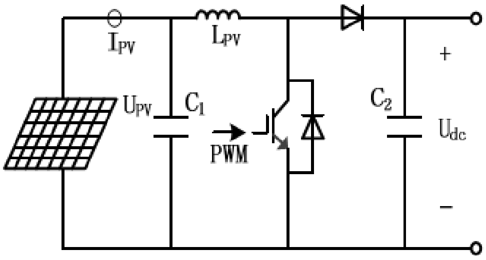


Fig.2.3 DC/DC converter of PV module with MPPT function

The photovoltaic (PV) cells are connected in series to form a module that gives a standard dc voltage. Modules are connected into an array to produce sufficient current and voltage to meet a demand for a grid-connected application. Normally, the PV modules are first connected in series into strings and then in parallel into an array. The PV model can be described by detailed equation [10].

The power produced by a PV array is dependent on the irradiance and temperature. There is a maximum power point (MPP) which should be tracked in the power-voltage (P-V) curve. It can be accomplished through DC/DC converter linking the PV array to the DC bus as shown in fig.3.2. Typical MPPT control strategies include open-circuit voltage method, short-current circuit current method, perturb and observe method (P&Q) and incremental conductance method (INC). In general, P&Q method and INC method are the widely used approaches for MPPT control. However, those conventional MPPT algorithms have disadvantages such as instability, poor adaptability to external environment. Sometimes they may fail to track the MPP when the atmospheric conditions change rapidly. To solve the tradeoff between the accuracy of the dynamic and steady state, a variable-step size INC method is utilized to realize MPPT of PV panel in this paper. The step size is automatically tuned according to the inherent PV array characteristics. If the operating point is far from MPP, it increases the step size which enables a fast tracking ability. If the operating point is near to the MPP, the step size becomes very small that the oscillation is well reduced contributing to a higher efficiency. The flow chart of the variable step size INC MPPT algorithm is shown in fig.2.3 and the variable step size &V is automatically tuned [11].

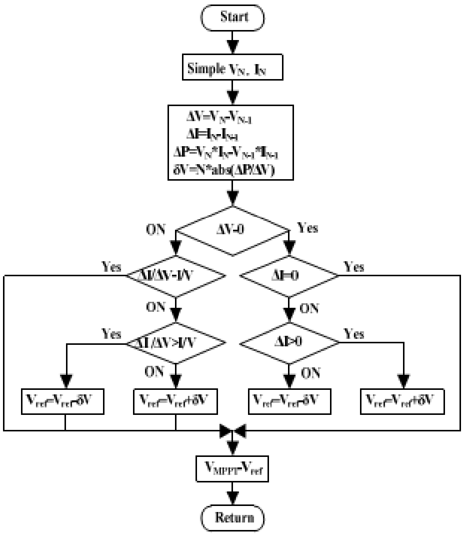


Fig.2.4 Flowchart of the variable step size INC MPPT algorithm

CONTROL OF BI-DIRECTIONAL DC/DC CONVERTER FOR HYBRID ENERGY-STORAGE: Battery has high energy density whereas it has relatively slow charging and discharging speed [12]. On the other hand, super-capacitor has high power density and fast response. The super-capacitor as a short-term energy storage device is utilized to compensate for fast changes in the output power, while the battery as a long-term energy storage device is applied to meet the energy demand. The battery is modeled using a simple controlled voltage source in series with a constant resistance. The SC is modeled as a regular capacitor in series with a constant resistance. The bi-directional buck/boost converter is used in the paper to link the SC or battery with the DC bus. The structure of the two converters is a parallel connection. This converter works as a boost converter during storage unit discharge mode and a buck converter during charge mode. The control method is a conventional double loop, including an inner current loop and an outer voltage loop, which is shown in Fig.2.4.

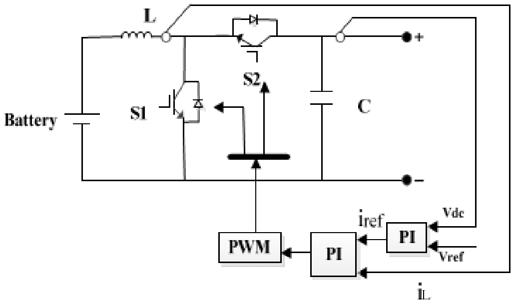


Fig.2.5 Control strategy of the bi-directional DC/DC converter

The utility grid is connected to the DC bus through a three-phase bi-directional full-bridge AC/DC converter. The control strategy is a direct-quadrature (DQ) current controller together with an outer voltage control loop as illustrated in fig.2.5. When utility grid works normally, the DC bus will be connected to utility grid through the bi-directional converter and the power will be transmitted mutually; otherwise it will be disconnected with utility grid to avoid faults [13].

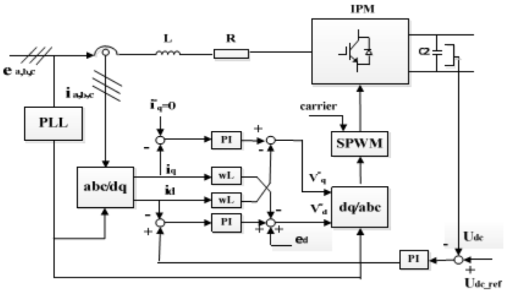


Fig.2.6 Control strategy of the bi-directional DC/AC converter

CONTROL STRATEGY

A novel power management strategy of DC micro grid is proposed in this paper. The key point of power management scheme in DC micro grid is to keep the power balance among PV module, storage systems, utility grid and loads all the time, which is manifested by DC bus voltage. The operations of the proposed DC micro grid include five main modes shown as fig.3.6: mode 1(regulation by PV), mode 2 (regulation by super-capacitor), mode 3 (regulation by utility grid), Mode 4 (regulation by battery in islanding mode).The operation modes in the proposed power management strategy are shown in fig.2.7. As shown in fig.3.6, every mode has its working range of voltage [14].

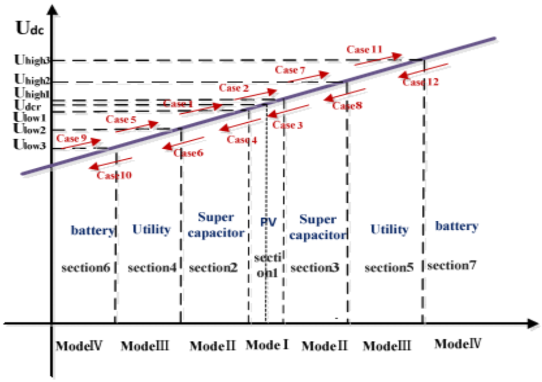


Fig.2.7 Operation modes in the proposed power management strategy

3. MATLAB/SIMULINK MODEL and SIMULATION RESULTS:

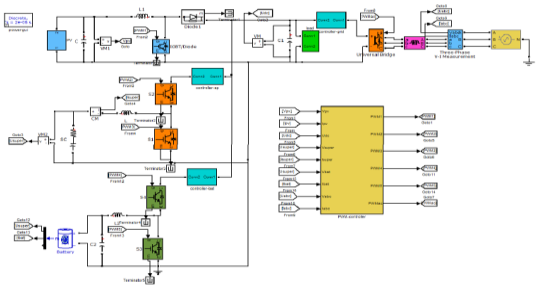


Fig 3.1 Block diagram

1 Transition between Mode 1 and Mode2:

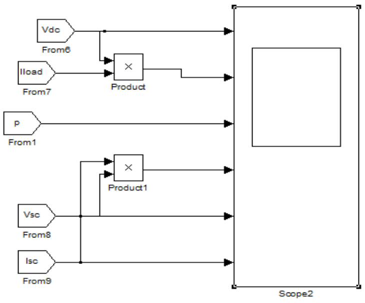
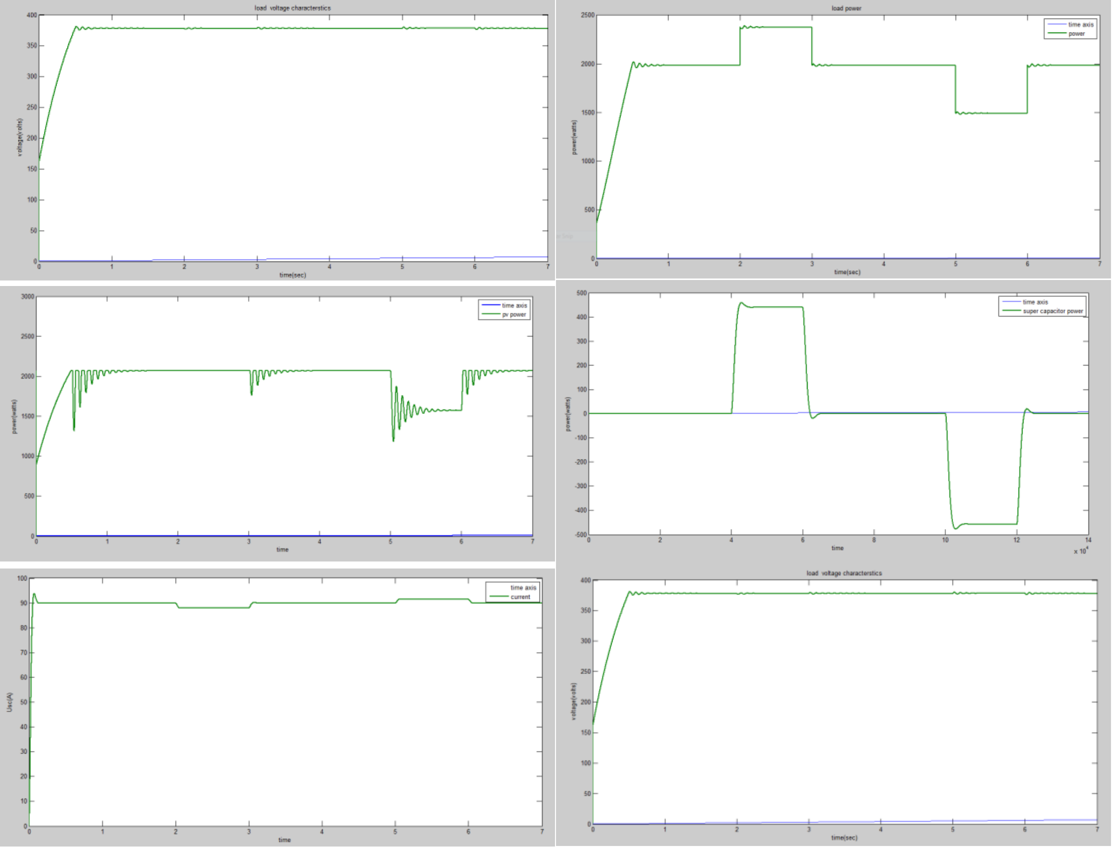


Fig 3.2 Sub diagram for Transition between Mode1 and Mode2

The DC micro grid experimental test has been carried out to validate the proposed operation strategy through MATLAB/Simulink simulation platform. The DC micro grid setup consists of PV generation units, grid-tied unit, battery and super-capacitor storage unit and local resistor load, which are connected through a DC bus. The PWM-controller includes voltage signals collect units, channels judging and selecting units. The DC bus reference voltages (Uhigh3, Uhigh2, Uhigh1, Udcr, Ulow1, Ulow2, Ulow3) are set at 365V, 370V, 377V, 380V, 383V, 390V, 395V, according to the seven operation modes. When the PV generation is working on MPPT mode, the maximum power is 2000W and the MPPT voltage is 180V (Temperature=25oC Irradiance S=1KW/m2). The rms value of the utility grid is 110V. The nominal voltage of the battery is 90V, while its rated capacity is 90Ah. The capacitance value of super-capacitor is 12.5F in series with a 0.01Ω resistance [15].



2. Transition between Mode1 and Mode3:

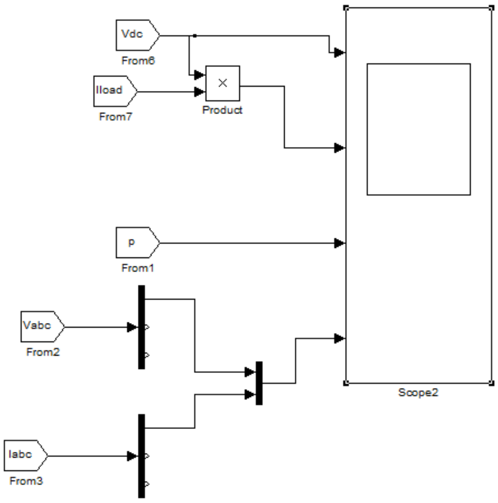
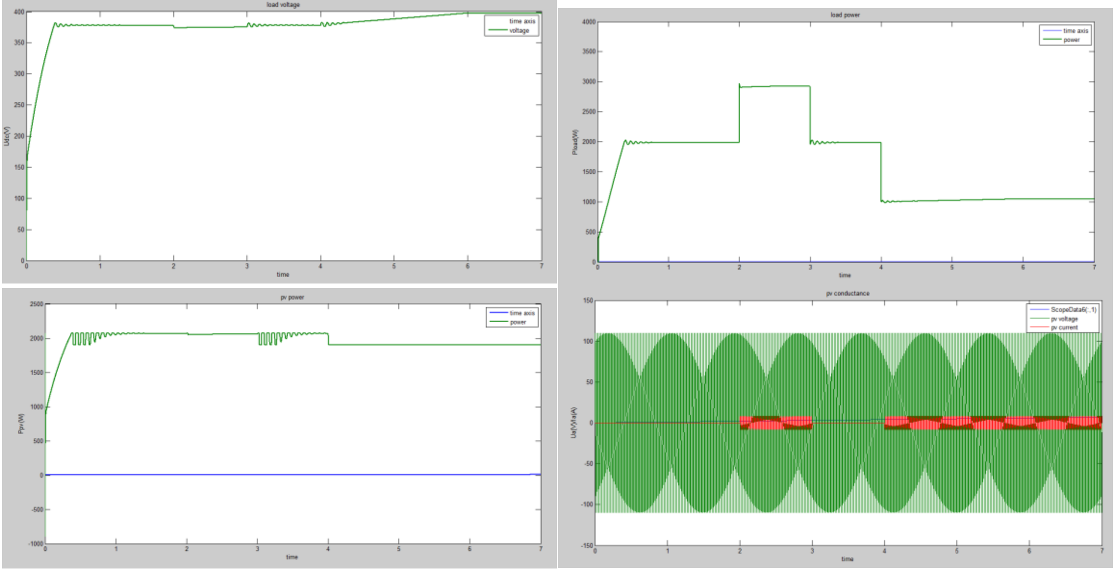


Fig 3.3 Sub diagram for transition between Mode 1 and Mode3

The simulation in the mutual transition from Mode1 and Mode3 is shown in Fig.3.3. It includes the case 19,the case 20 and the case 23.The transitions will happen in the situation that the super-capacitors' converter breaks down or the energy of super-capacitors is full or insufficient. In the initial state, the DC bus voltage is regulated by the PV converter at 380V. In the 2s, a 1000W load is connected with the system, then, the grid-connected AC/DC converter starts and works in rectification mode.The current and voltage of the AC grid is synchronous. The voltage is regulated by the gird converter at the 370V. In the 4s, the 2000W load is cut off from the system, and the DC bus voltage is up to 390V in 4.8s. The current and voltage is anti phase [16]. The results have proved that the transitions between the modes and the both modes are successful and stable.



3. Transition between Mode2 and Mode4:

The simulation shown in fig.3.4 includes the case 4, the case 5 and the case 6. These cases will happen in the situation that grid is power off or the grid-connected converter breaks down [17].

Firstly, the DC bus voltage is regulated by the PV converter at 380V. In the 2s, a 300W load is connected with the system, then, the bus voltage is regulated by the bi-directional DC/DC converter of the super-capacitor at 377V [18].

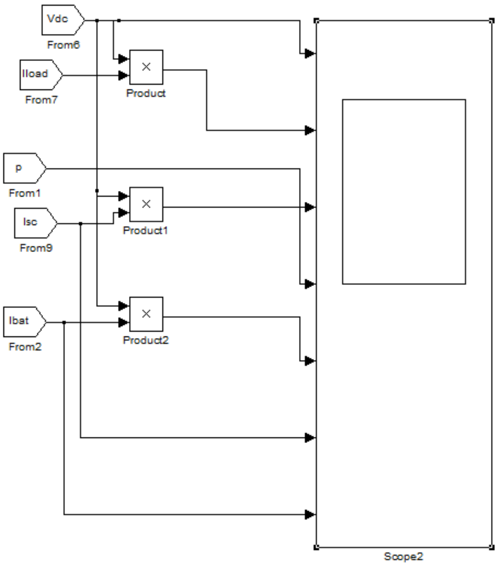
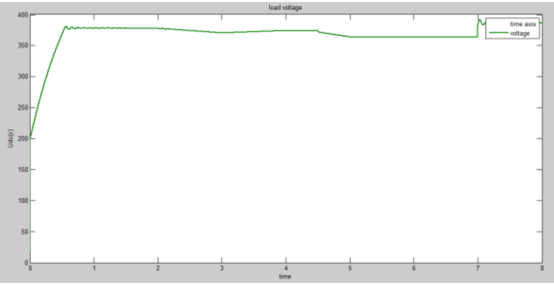
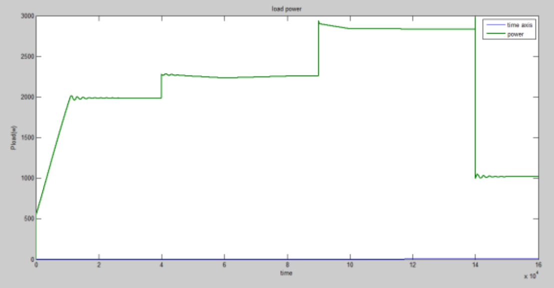
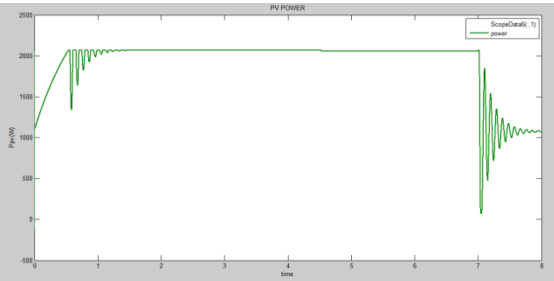


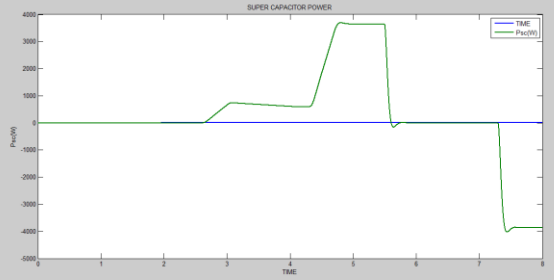
Fig 3.4 Sub diagram for transition between Mode 2 and Mode4

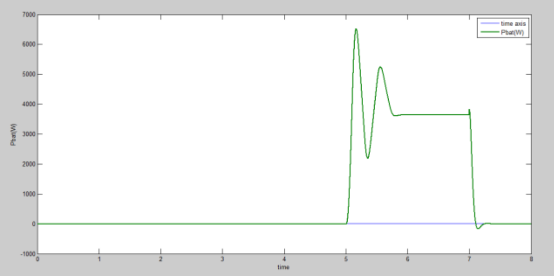
an 1100W load is connected with the system, and the DC bus voltage will drop to 365V which is controlled by the converter of the battery. In the 7s, a 1400W load is cut off from the system; the voltage is up to 383V. The results have shown the success of the transition of the mod1, mode2 and mode 4 [19,20].

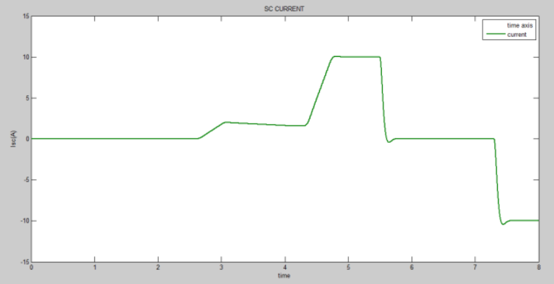


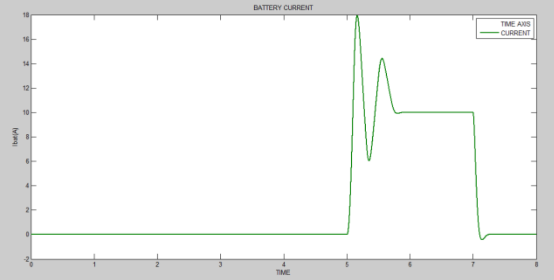












CONCLUSIONS

DC micro grid with hybrid storage system is investigated. A power management strategy for this DC micro grid is proposed, in which the bus voltage is employed as a carrier to represent different operation modes. The hybrid energy storage system in this micro grid that contains two complementary type storage elements---battery and super-capacitor, can enhance the reliability and flexibility of the system based on their special supply logical. Different from the previous studies, the ac grid has a new supply status in the system. The practical feasibility and the effectiveness of the proposed control strategies have been validated by the simulation of MATLAB model.

Thereby, it can be acknowledged that the main goals of this project have been entirely accomplished.

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