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A New Concept on Intelligent Distribution Voltage Control for Dc Micro Grids Using Fuzzy Control and Gain-Scheduling Technique


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ABSTRACT:

Installation of many distributed generations (DGs) could be detrimental to the power quality of utility grids. Micro grids facilitate effortless installation of DGs in conventional power systems. In recent years, DC microgrid have gained popularity because DC output sources such as photovoltaic systems, fuel cells, and batteries can be interconnected without ac/dc conversion, which contributes to total system efficiency. Moreover, high-quality power can be supplied continuously when voltage sags or blackouts occur in utility grids. It is proposed a “low-voltage bipolar type DC microgrid” and described its configuration, operation, and control scheme, through simulations.

However, DC micro grids should have two or more energy storage units for system redundancy. Therefore, we modified the system by adding another energy storage unit in simulation model. Several kinds of droop controls have been proposed for parallel operations, some of which were applied for ac or dc micro grids. If a gain-scheduling control scheme is adopted to share the storage unit outputs, the storage energy would become unbalanced. This project therefore presents a new voltage control that combines fuzzy control with gain-scheduling techniques to accomplish both power sharing and energy management. The simulation results will be obtained for the DC distribution voltages were within 340 V ± 5%, and the ratios of the stored energy were approximately equal, which implies that dc voltage regulation and stored energy balancing control can be realized simultaneously in MATLAB Software.

I. INTRODUCTION:

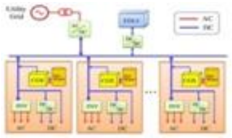
Increased in recent years because of the reduction in greenhouse gases and depletion of fossil fuels. After the 2011, Tohoku earthquake and tsunami, the trends have accelerated even more in Japan. As it is well known, installation of many DGs could be detrimental to the power quality of utility grids; therefore, microgrids have been studied as one of the candidates to support smooth installation of DGs . In particular, dc distribution microgrids have been studied for a few years. Apart from a reduction in ac/dc conversions losses, dc micro-grids can supply continuous high-quality power when voltage sags or blackouts occur in utility grids. For instance, dc power supplies are commonly used in telecommunication buildings and internet data centers where high-quality power is needed We previously proposed a “low-voltage bipolar-type dc micro-grids,” and described the configuration, operation, and control scheme, which were demonstrated through experimental result. In the experiment, we used one energy storage unit with a dc/dc converter to sustain dc-bus voltage when the system was in intentional islanding operation. A fuzzy control was applied to maximum power point tracking control of a photovoltaic system in an isolated micro-grid to improve the response against rapidly changing weather conditions.

In this paper, we focus on application of fuzzy control to gain-scheduling control and demonstrate the validity of the proposed control through experiments.

DC MICROGRID FOR A RESIDENTIAL COMPLEX

System Configuration

We proposed a dc microgrid for a residential complex, as shown in Fig. 1. There are around 50–100 houses in the system, each having a micro combined heat and power unit (micro-CHP unit) such as a gas engine or a fuel cell. The micro-CHP units are connected to a dc distribution line (three wire,±170 V), and the electric power is shared among the houses. Cogenerated hot water is either used by individual house or shared between adjacent houses. The utility grid is connected to the system by a rectifier. At the load side, various forms of electric power (such as ac 100 V and dc 48 V) can be obtained from the converters. EDLCs are used as the main energy storage unit because of their advantages such as fast response, safety (especially compared with Li-ion batteries), easy measurement of the stored energy, and no toxicity of the constituent materials. In a verification test of energy storage system using an EDLC unit, the voltage, and maximum energy were 500 V and 5 MJ, respectively. From this, EDLC is considered viable as an energy storage system in a small grid. The capital cost per kilo watt hour (kWh) for EDLC is 300–2000 dollars, while that for lead-acid and Li-ion batteries is 200–400 and 600–2500 dollars, respectively. In addition, EDLCs can handle many charge–discharge cycles, and therefore has a low-cost per cycle considering its long life. The capital cost per kWh-per cycle for EDLC is 2–4 cents, while that for lead-acid and Li-ion batteries is 20–100 and 15–100 cents, respectively. The disadvantage of EDLC is its low-energy density. If a large energy capacity is needed for a microgrid, a relatively large EDLC is required. However, a large-energy capacity is not necessary for the proposed dc microgrid because the micro-CHP units are operated to prevent over charge/discharge of the EDLCs as described in the following section.



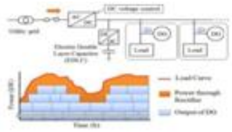


Fig. 2.4 System configuration of the dc microgrid for a residential complex. Fig. 2.5 Interconnected operation.

PURPOSE AND ARCHITECTURE OF THE DC MICRO GRID SYSTEM

Following three terms are briefly summarized purposes of the DC micro grid system.

(1) Increase the introduction of distributed PV units.

(2) Reduce energy dissipation and facility costs resulting from AC/DC conversion by integrating the junction between a commercial grid and DC bus which connects PV units and accumulators.

(3) Supply power to loads via regular distribution lines (not exclusive lines for emergency) even during the blackout of commercial grids.

II. DC MICRO GRID SYSTEM Converters.

These converters always track the maximum power point of the DC power sources which fluctuates depending on the intensity of solar radiation. Conventional appliances can be used as they are if an inverter is installed in each house to change the DC power into 200 V / 100 V AC power, but DC power feeding will spread widely because of its high efficiency, once safe and compact gears, such as breakers and outlets, are standardized in the future. Storage batteries of the community are also linked to the DC bus. The DC-based distribution system reduces facility costs and energy dissipation associated with AC/DC conversion because the PV units and battery are DC connected and most of the current energy-saving appliances operate on DC due to the progress of inverter technology. This is why we should push ahead with the DC system. The system doesn't require long transmission lines to convey solar power from remote areas because the PV units have been distributed in the demand area. Power sources and loads are closely located to each other in a community.

The excess and deficiency of power are variable factors which should be compensated for a good balance between supply and demand. The compensation system, which consists of storage batteries and a bidirectional power converter, keeps a good power balance in the community by absorbing short term power fluctuations. Since long term fluctuations, such as those between day and night, are also smoothed by the battery system, the micro grid system seems to be a small source or load for the outer wide-area grid. Consequently, this scheme reduces the cost for the stabilization of commercial grids. The state of charge (SOC) of the storage battery always indicates the time integral of difference between supply and demand in the DC micro grid system. The SOC be- comes full with excess power, whereas it reaches the lower limit in deficiency. The amount and direction of the power flow from a commercial grid is controlled according to the SOC, and power supply is maintained in the micro grid. However, power supply to the micro grid might be regulated to stabilize the power flow of the commercial grid.

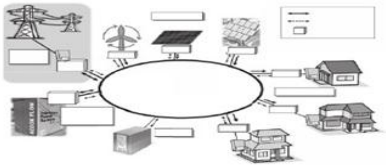


Fig. 2.6. Schematic diagram of a DC micro grid system

The above mentioned DC micro grid requires storage batteries and control units as its key components. To respond to short term power surplus or deficiency, the storage batteries have to repeat charge and discharge operation frequently under the condition where the current varies rap- idly. The DC micro grid requires batteries that quickly respond to changes in the current and ensures high durability in such demanding operation. Large capacity (from several hundred kWh to a few MWh) should be available for a community that consists of several dozens or hundreds of households. Furthermore, precise detection of the SOC during the frequent change in operation is also indispensable to manage the power load and control the amount of power purchased from or sold to the commercial grid. A redox flow battery (RF battery) satisfies the above mentioned four conditions: quick response, high durability, large capacity, and precise SOC detection. Figure 2 shows the basic concept of the RF battery. The battery works by a reduction-oxidation reaction in the electrolytic solution which circulates between cells and tanks. The cells, where ions exchange electrons, are separated from the tanks, where the solution is stored. While most batteries are named after their active materials, the RF battery is so called because of its special architecture. “Redox” is an abbreviated word of reduction and oxidation. “Flow” phrases the circulation of an electrolytic solution. The active materials of both the positive and the negative electrodes are vanadium ions. Battery reaction proceeds as the ions change their valence in the solution without any solid de- posit on electrodes. Therefore, the cell reaction is very fast. There is no degradation by the charge-discharge cycle, too. A large scale battery is also easily built due to its simple architecture. In fact, a 6 MWh RF battery system used to be utilized for smoothing the output fluctuation of a wind farm where many aero-generators were installed(2). Another significant advantage of the RF is the precise and simultaneous detection of the SOC while current flows in cells. The above mentioned features of the RF battery are best suited for DC micro grid systems, but the energy density of the RF battery is lower than that of other secondary batteries, and consequently, it requires large footprint.

4. Supply-Demand Balance Test for RF Battery

An experimental facility was constructed to demonstrate balanced operation between supply and demand in the DC micro grid., Fig. 2.6 the specification of the experimental facility, composition, and appearances of main devices, respectively. Since the purpose of this experiment is to demonstrate the balanced operation between supply and demand, the facility was disconnected from outer power sources.

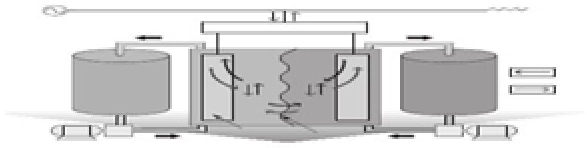


Fig. 2.7 Conceptual diagram of redox flow battery

In comparison with actual cases, the experimental facility uses the same length of lines but deals with 1% to 10% of electric power. In the DC bus, the target voltage is 350 V, and the total length is 1 km. The exclusive RF battery has been developed for this experiment, and it has 4 kW of maximum output and 10 kWh of accumulating capacity. The battery was connected at the center of the DC bus through a bidirectional DC-DC converter. The PV units and an aero generator were distributed on the DC bus. The total output of these generators is about 8 kW. The PV system consists of three different types of modules: polycrystalline silicon modules and CIGS compound modules, both of which are commonly used, and concentrator photovoltaic (CPV) modules that we have developed. The CPV module collects strong sunlight with lenses by precisely tracking the sun and generates electric power with multi-junction cells with extremely high conversion efficiency, thereby yielding about twice the power generated by a general polycrystalline silicon module on a sunny day.

CO-OPERATIVE VOLTAGE CONTROL SCHEME IN A DC MICROGRID

Voltage Drop Problem in a Radial DC Microgrid System

In a typical DC microgrid with a radial topology, power flows from its point of common coupling(PCC) to the end bus in one direction. Therefore, a voltage drop problem can occur with a line voltage drop and the lowest bus voltage is formed at the receiving end in the system. The value of the line voltage drop increases in proportion to the load current magnitude and the line length in the microgrid. Figure 1shows a typical voltage profile in a DC microgrid. In this instance, some bus voltages, normally at theend of a system, are out of the admitted voltage range as the distribution line becomes longer. Moreover, certain sensitive loads without a voltage compensator could malfunction and the voltage stability might deteriorate further as the bus voltages become seriously diminished. Therefore, a voltage control method is needed to maintain the system bus voltage within an appropriate range.

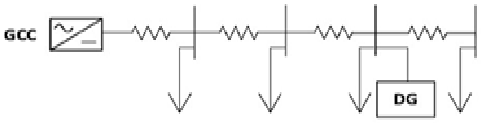


Fig 5.3. The proposed voltage control topology in a radial DC microgrid

In an AC power system, a variety of devices, such as shunt capacitors, shunt reactors, transformers, static VAR compensators (SVC), STATCOMs, are used to control system voltages because the voltages are influenced considerably by reactive power. However, there is no reactive power in a DC system, and system voltages are determined by active power-flow. Therefore, a different scheme from an AC system is needed to regulate system voltages in a DC system. In this paper, a grid-connected converter and a controllable distributed generator, which includes an energy storage device, are used for the cooperative voltage control in a DC microgrid as shown in Figure 2. Advantages of each device could be emphasized through the cooperative voltage control because the devices have opposite characteristics. A Grid-Connected Converter (GCC) acts as an on-load tap-changing transformer in an AC power system from a voltage control point of view, and it can efficiently control all system voltages at the secondary side of the converter by a PWM switching operation. The converter is located at the PCC in the proposed control scheme to control the voltages at all buses in a DC microgrid. Therefore, the GCC is used for voltage control at the PCC only, and an additional series converter is not considered in this paper.

Furthermore, the line voltage drop increases with load current, especially at a low bus voltage,which causes a large voltage difference between some buses in a radial DC microgrid. In the case where a large voltage difference exists between some buses and only the GCC controls the system voltages, maintaining all system voltages in the admitted range can be a problem. This problem cannot be solved with the GCC only, because voltage control of the GCC is performed either by increasing or decreasing system voltages.

OPTIMAL DG ALLOCATION ALGORITHM

Voltage control by a DG has a large dependency on its location in a power system. Moreover, voltage control in a DC microgrid necessitates power generation from a DG. Therefore, the more controlled the bus voltage is, the larger the amount of power needed from a DG. This involves increasing the capacity and thus, the installation cost of the DG. Therefore, an optimal DG allocation is essential for economical voltage control with minimum capacity and power generation from a DG.

III. SIMULATION RESULTS

SIMULATION MODEL:

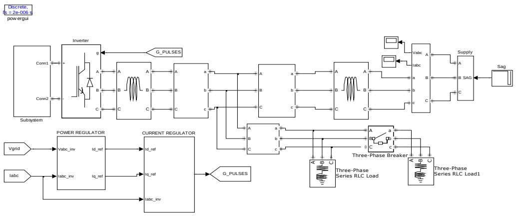


Fig 6.1: Simulation model

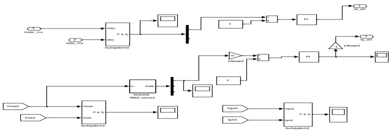


Fig 6.2:subsystem of power regulator

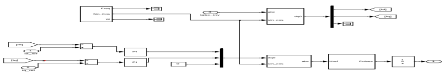


Fig 6.3:subsystem of current regulator

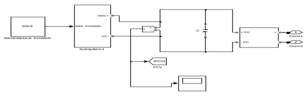


Fig 6.4: subsystem of battery energy storage

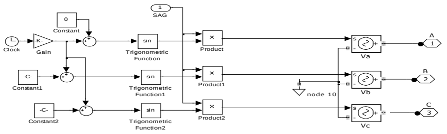


Fig 6.5:three phase sinwave generation

RESULTS:

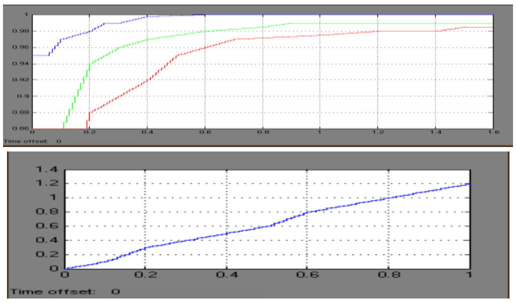


Fig. 6.6 Gain-dc/dc converter output power characteristics. (Voltage variation 2%).

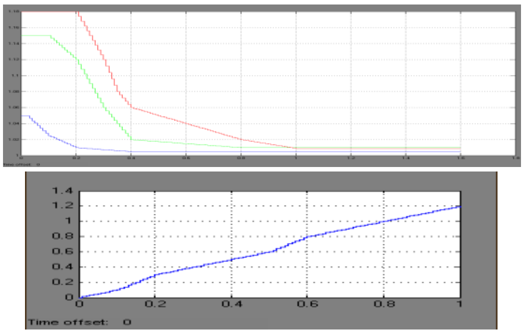
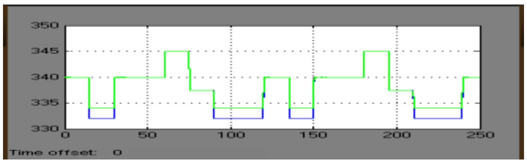
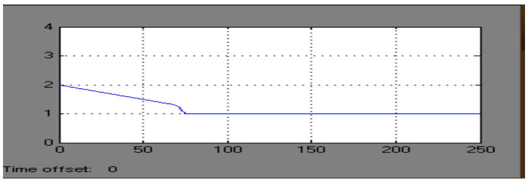


Fig. 6.7 Gain-dc/dc converter input power characteristics. (Voltage variation 2%).



Distribution Voltage



Ratio of EDLC change

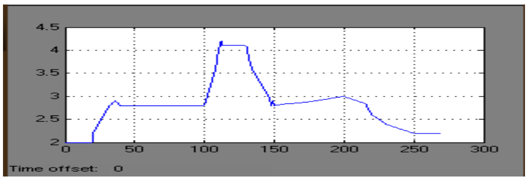
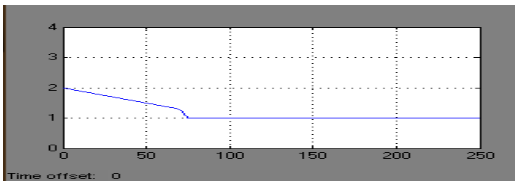
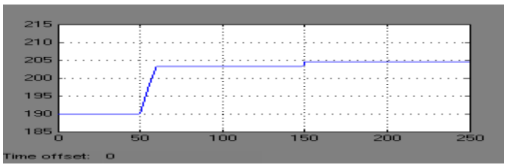


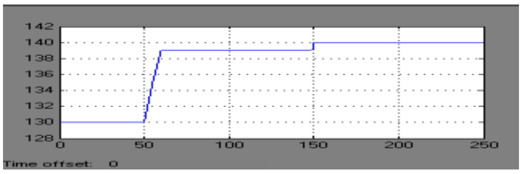
Fig. 6.8 Simulation results (gain-scheduling control and droop control, Kv = 10) (Initial condition W2 /W1 ≈ 2).



Ratio of EDLC ratio

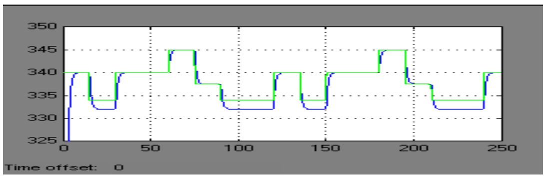


EDLC terminal Voltage (a)

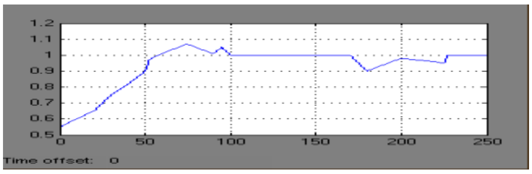


EDLC terminal Voltage (b)

Fig. 6.9 Simulation results (gain-scheduling control and droop control, Kv = 50) (Initial condition W2 /W1 ≈ 2).

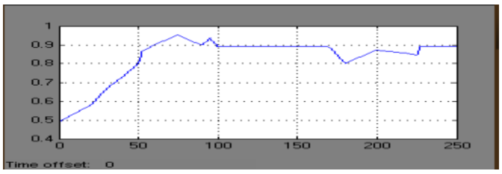


Distribution Voltage



Ratio of EDLC

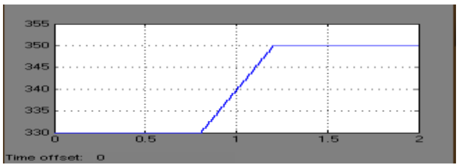
Fig. 6.10. Simulation results (gain-scheduling control and droop control, Kv = 50) (Initial condition W2 /W1 ≈ 0.5).



Ratio of EDLC

Fig. 6.11. Simulation results (gain-scheduling control and fuzzy control) (Initial condition W2 /W1 ≈ 0.5).

Droop control



Fuzzy control

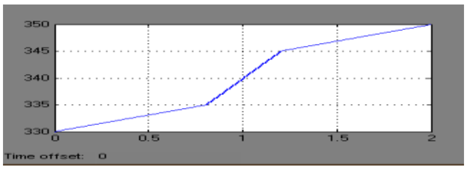
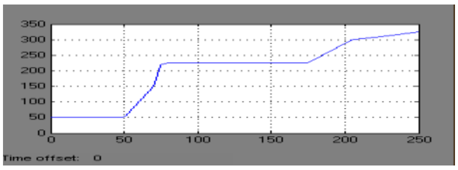
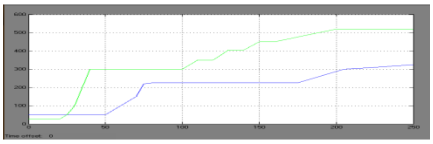


Fig. 6.12. Relations between input Xk and voltage reference Vdc.





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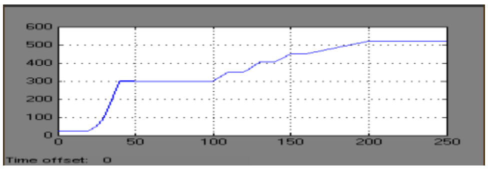


Fig. 6.13. Integral of the square of the current (IEDLC1 and IEDLC2).

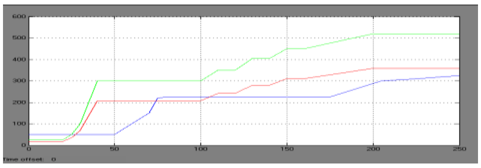


Fig 6.14: Integral of the square of the current with three controllers (Droop control, Fuzzy control and Model reference adaptive control)

RESULTS MODIFIED

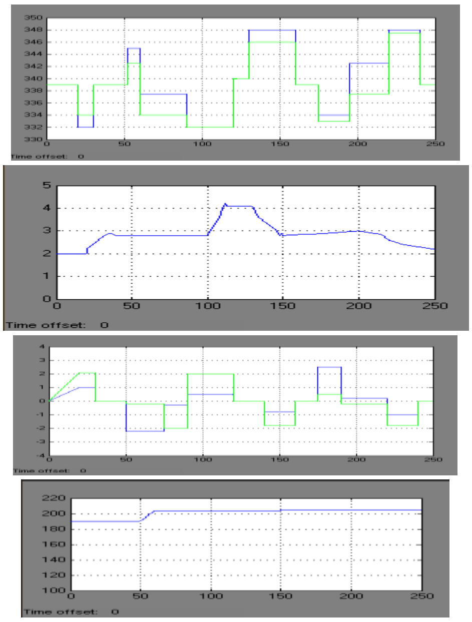
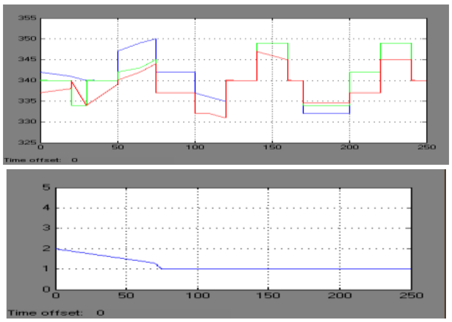


Fig. 6.15. Simulation results (gain-scheduling control only) (Initial condition W2 /W1 ≈ 2).



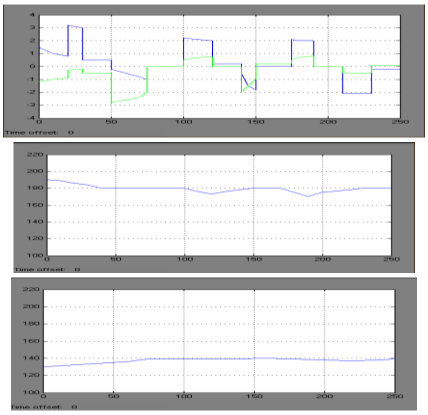


Fig. 6.16. Simulation results (gain-scheduling control and fuzzy control) (Initial condition W2 /W1 ≈ 2).

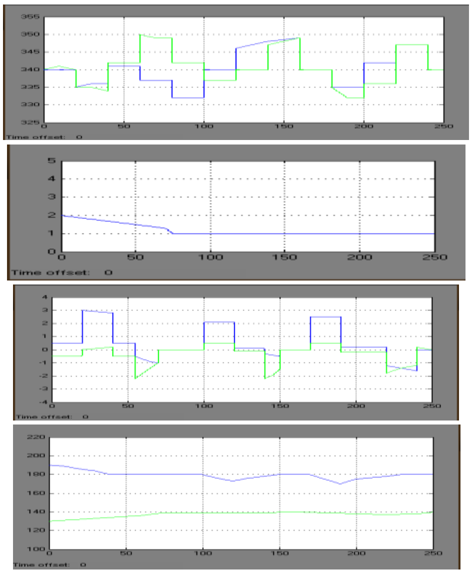
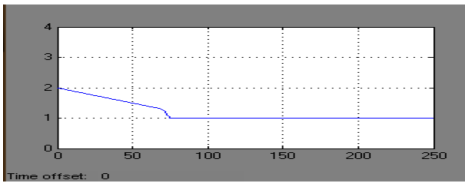
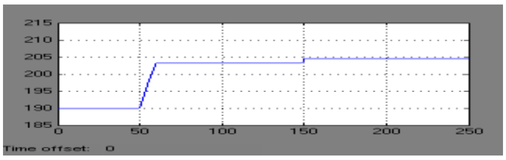


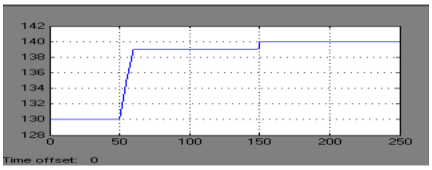
Fig. 6.17. Simulation results (gain-scheduling control and droop control,
Kv = 10) (Initial condition W2 /W1 ≈ 2).



Ratio of EDLC ratio

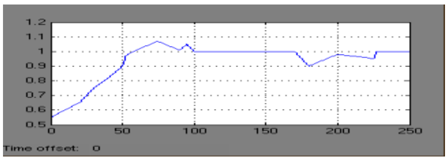


EDLC terminal Voltage (a)



EDLC terminal Voltage (b)

Fig. 6.18 Simulation results (gain-scheduling control and droop control, Kv = 50) (Initial condition W2 /W1 ≈ 2).



Ratio of EDLC

Fig. 6.19Simulation results (gain-scheduling control and droop control, Kv = 50) (Initial condition W2 /W1 ≈ 0.5).

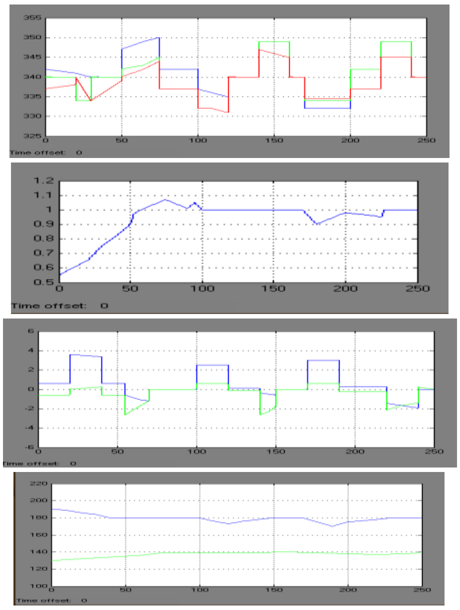
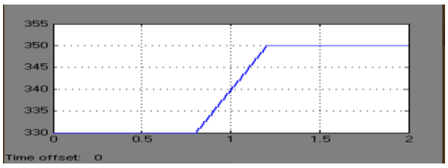


Fig. 6.20. Simulation results (gain-scheduling control and fuzzy control) (Initial condition W2 /W1 . 0.5).

Droop control



Fuzzy control

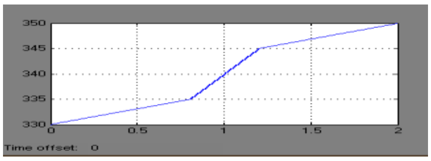


Fig. 6.21. Relations between input Xk and voltage reference Vdc .

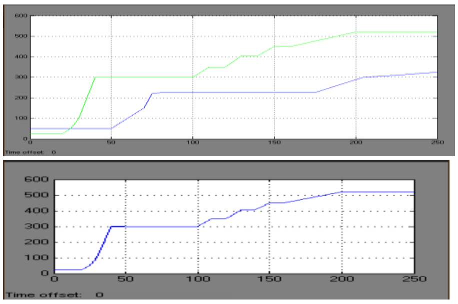


Fig. 6.22. Integral of the square of the current (IEDLC1 and IEDLC2).

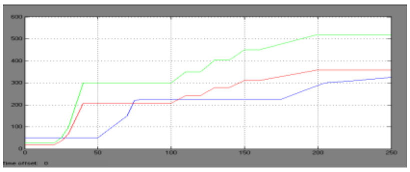


Fig 6.23 :Integral of the square of the current with three controllers (Droop control, Fuzzy control and Model reference adaptive control)

IV. CONCLUSION:

This project presented a new dc distribution voltage control for dc/dc converters with an energy storage unit. The proposed control combines a gain-scheduling technique with fuzzy control. The experimental results show that the dc distribution voltage was within 340 V ± 5%, and the ratios of the storage units were approximately equal. This indicates that dc voltage regulation and stored energy balancing control are realized simultaneously.

The main advantage of the proposed control is presented for the cases where the model is unknown or is mathematically complex. Therefore, the proposed control is relatively easy to introduce to real-life projects compared with the modern control theories that utilize the time-domain state space representation. However, for this purpose, trial and error methods might be adopted to adjust the membership functions in practice, which is a time consuming process. Our future study will attempt to establish the design procedure of the membership functions.

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