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Dual Mode Control of Motor Drive with Integrated Inverter/Converter Circuit for EV/HEV Application

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Abstract*— *The system configuration including green power generator, energy storage element, dc appliance and equipment, and energy management system (EMS) with fuzzy logic will be introduced. The proposed integrated circuit allows the machine to operate in motor mode or acts as boost inductors of the boost converter, and thereby boosting the output torque coupled to the same transmission system or dc-link voltage of the inverter connected to the output of the integrated circuit. In motor mode, the proposed integrated circuit acts as an inverter and it becomes a boost-type boost converter, while using the motor windings as the boost inductors to boost the converter output voltage. Enhancement of a renewable power management system with intelligence control techniques (Fuzzy) for a micro grid system. Modeling, analysis, and control of distributed power sources and energy storage devices with MATLAB/ Simulink are proposed, and the integrated monitoring EMS is implemented. To improve the life cycle of the battery, intelligence control techniques manage the desired state of charge. The controller is to optimize energy distribution and to set up battery state of charge SOC parameters. In the development of the green energy systems, a control method is required to optimize energy distribution of a micro grid system. The design concept of this study was to increase the useful life of lithium batteries and to include charge and over discharge protection mechanisms. The power generator includes PV panels, wind turbines, and fuel cells. The fuel cells provide base power for the emergency loads when the system is operated during a power failure. Maximum power point trackers are associated with PV panels and wind turbines to draw maximum power, which is fed into the dc grid. The loads are connected to the grid and supplied from the grid directly. If there is power shortage, the bidirectional inverter will take power from the ac grid and it is operated in rectification mode with power factor correction to regulate the dc grid voltage within a range of 380 ± 20 V.

Index Terms*— *Energy management system (EMS), Fuzzy Logic, State of charge (SOC), Micro grid, MATLAB/SIMULINK

I. INTRODUCTION

Renewable energy is converted into dc and buffered with energy storage elements, and then it is inverted to ac and fed into the utility grid. To use renewable energy more efficiently, dc electricity should be directly supplied to these loads. Such a supply scheme is far different from that of the conventional ac distribution and supply system. A configuration of the dc-distributed system with grid connection is in which a bidirectional inverter is introduced to regulate dc-grid voltage within a certain range [13].

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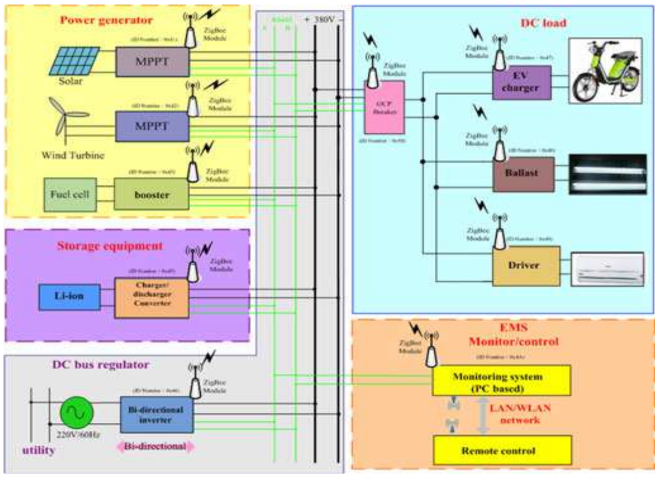
In this project, the system configuration including green power generator, energy storage element, dc appliance and equipment, and energy management system (EMS) with an intelligence control techniques will be introduced. In the development of the green energy systems, a control method is required to optimize energy distribution of a micro grid system.



Configuration of DC Micro Grid System with EMS.

Therefore, model construction is necessary for solar energy, wind power, and storage devices, such as lithium-ion batteries, to simulate dynamic changes of the renewable energy for optimal energy distribution [6]. The micro grid system in this study composed of solar power, wind power generation, lithium-ion battery, dc load, and ac/dc converter. The design concept of this study was to increase the useful life of lithium batteries and to include charge and over discharge protection mechanisms. The system configuration includes five major blocks: power generator, energy storage equipment, dc bus regulator, load, and EMS. The power generator typically includes PV panels, wind turbines, and fuel cells. The fuel cells provide base power for the emergency loads when the system is operated during a power failure [3]. Maximum power point trackers are associated with PV panels and wind turbines to draw maximum power, which is fed into the dc grid. The loads are connected to the grid and supplied from the grid directly. If there is power shortage, the bidirectional inverter will take power from the ac grid and it is operated in rectification mode with power factor correction to regulate the dc-grid voltage within a range of 380 ± 20 v. If there is a power failure, the Li-ion battery will be first discharged to supply power for a short-time interval and if the failure lasts longer, the fuel cell will start supplying power. Note that the battery discharger will be also responsible for dc-grid voltage regulation if the bidirectional inverter is not in operation. If the bidirectional inverter is in

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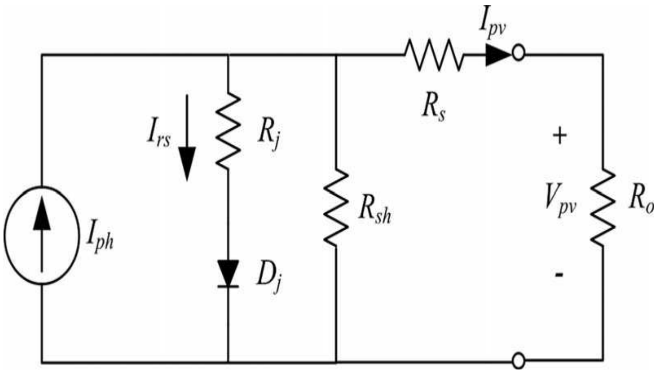
operation, the battery can be charged. If there is residual power on the dc grid, the battery can be charged depending on its status, and/or the bidirectional inverter can be operated in grid-connection mode to sell power and regulate dc-grid voltage to 380 ± 20 V.

II. MODELING OF GREEN ENERGY COMPONENTS

The modeling of dc micro grid distributed energy and an energy storage component was mainly built by MATLAB Simulink mathematical modules, based on equivalent circuits of the components. The following describes the model of each subsystem in detail.

A. MODELING OF PV PANEL

The output Characteristic of PV module depends on the cell temperature, solar irradiation, and output voltage of the module.



Solar Panel Equivalent Circuit.

Solar panel current equation can be expressed as

$$I_{PV}=n_P I_{Ph}-n_P I_{rs}[\exp(q/KTA*V_w/n_s)-1] \quad (1)$$

where V_{pv} is output voltage of solar panels, I_{pv} is output current of solar panels, n_s is number of solar panels in series, n_p is number of solar panels in parallel, k is the Boltzmann constant (1.38 × 10−23 J/K), q is electron charge (1.6 × 10−19C), A is ideality factor, T is surface temperature of the solar panels (K), and I_{rs} is reverse saturation current. The characteristic of reverse saturation current I_{rs} varies with temperature is expressed as

$$I_{rs}=I_{rr}[T/T_r]^3\exp(qE_R/KA(1/T_r-1/T)) \quad (2)$$

Where T_r is the reference temperature of the solar panels (K), Irr is reverse saturation current of the solar panels at temperature T_r (K), and E_g is energy band gap of the semiconductor material

$$I_{Ph}=[I_{scr}+\alpha(T-T_r)]S/100 \quad (3)$$

Where I_{scr} is the short-circuit current at reference temperature T_r and illumination intensity 1 KW/m^2, *α* is short-circuit current temperature coefficient of the solar panels, and S is the illumination intensity (KW/m^2).

B. WIND TURBINE MODELING [17],[18]

The power generated by wind turbine is expressed as

$$P_W=0.5\rho AV^3C_P(\lambda,\theta) \quad (4)$$

Where P_W is power generated by the wind turbine W, P is density of gas in the atmosphere (kg/m), A is cross-sectional area of a wind turbine blade m2, V is wind velocity (m/sec), and Cp is the wind turbine energy conversion coefficient.
The density of gas ρ and energy conversion coefficient CP in (4) is expressed by (5) and (6), respectively

$$\rho=(35305/T)\exp{-0.034(Z/T)} \quad (5)$$

$$Cp(\lambda,\theta)=(116//\lambda i-0.4*\theta-5).0.5\exp^{-163/\lambda}{}_i \quad (6)$$

Where Z is the altitude, T is the atmospheric temperature, λ_i is the tip speed ratio, and θ is the blade tilt angle. Expression of the tip speed ratio λ_i and initial tip speed ratio λ is expressed as

$$\lambda_i=1/1(\lambda+0.089\theta)-0.035(\theta^3+1) \quad (7)$$

$$\lambda=r(\omega/v) \quad (8)$$

The wind turbine used in this study was AWV-1500 of Gallant Precision Machining Company. Wind speed is the most critical factor in wind power generation.

C. FUEL CELL MODELING

Fuel cells provide a high efficiency clean alternative to today's power generation technologies. The polymer electrolyte membrane (PEM) fuel cell has gained some acceptance in medium power commercial applications such as creating backup power; grid tied distributed generation and electric vehicles [1]. The output voltage E of the PEM fuel cell is represented as

$$E=E_n-(-V_{act}+V_{ohm}+V_{co}) \quad (9)$$

Where E_n is Nernst voltage, V_{act} is the activation over potential, V_{ohm} is ohmic over potential and V_{con} is concentration over potential.

$$V_{act}=-[\xi_1+\xi_2\cdot T+\xi_3\cdot T\cdot 1n(Co_2)+\xi_4\cdot T\cdot 1n(i_f)] \quad (10)$$

$$V_{ohm}=i_f\cdot R_m \quad (11)$$

$$R_M=\frac{181.6[1+0.03(i_f/A_f)+0.062(T/303)^2(i_f/A_f)^{2.5}]}{[\lambda_1-0.634-3(i_f/A_f)]\exp[4.18((T-303)/T)]}\cdot\frac{l_1}{A_f} \quad (12)$$

$$V_{con}=-B_0\cdot 1n(1-\frac{J}{J_{\max}}) \quad (13)$$

Where T is operating absolute temperature, Co_2 is concentration of oxygen, if is output current of the fuel cell, $\xi_{1,2,3,4}$ are reference coefficients l_1 is effective thickness of membrane, λ_1 is adjustable coefficient, A_f is effective area, B_0 is operating constant, J is current density, and $J_{\max}$ is maximum current density.

D. LITHIUM ION BATTERY MODELING

Discharge equation (19) of lithium ion battery is

$$f_1(it\,i^*\,i)=E_O-K\cdot\frac{Q}{Q-it}\cdot i^*-K\cdot\frac{Q}{Q-it}\cdot it+A\cdot\exp(-B\cdot it) \quad (14)$$

Charge equation of lithium ion battery is

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$$f_2(it, i^*, i) = E_0 - K\cdot\frac{Q}{it+0.1Q}\cdot i^* - K\cdot\frac{Q}{Q-it} + A\cdot\exp(-B\cdot it) \qquad (15)$$

Where E_0 is initial voltage (V), K is polarization resistance (Ω), i^* is low-frequency dynamic current (A), i is battery current (A), (it) is the battery extraction capacity (Ah), Q is maximum battery capacity (Ah), A is exponential voltage (V),B is exponential capacity $(Ah)^{-1}$ SOC of the battery is an important factor, which is calculated by

$$SOC = 100\left(1 - \frac{\int_0^t i\,dt}{Q}\right) \qquad (16)$$

The battery voltage is easy to measure and implement in the circuit. From the simulated results, the nonlinearity between voltage and SOC of the Li-ion battery. Therefore, the SOC parameter of batteries has been selected as the design factor instead of battery voltage in this project.

III. INTELLIGENT ENERGY MANAGEMENT SYSTEM

Fuzzy control theory is designed and implemented in EMS for the dc micro grid system to achieve the optimization of the system (10). The design criterion requires that both the photovoltaic device and the wind turbine are supplied by a maximum power point tracker to maintain the maximum operating point. The difference between actual load and total generated power is taken into account for Li-ion battery in charge and discharge modes. The life cycle and SOC of the battery are in direct proportion. To improve the life of the Li-ion battery, we can control and maintain the SOC of battery with fuzzy control.

A) Fuzzy

The fuzzy controller is applied to the microgrid power supply system. To obtain the desired SOC value, the fuzzy controller is designed to be in charging mode or discharging mode for the proposed micro grid system. The input variables of the fuzzy control are ΔSOC and ΔP and output variable is ΔI. The definition of input and output variables are listed as

$$SOC = SCO_{command} - SOC_{now} \qquad (17)$$

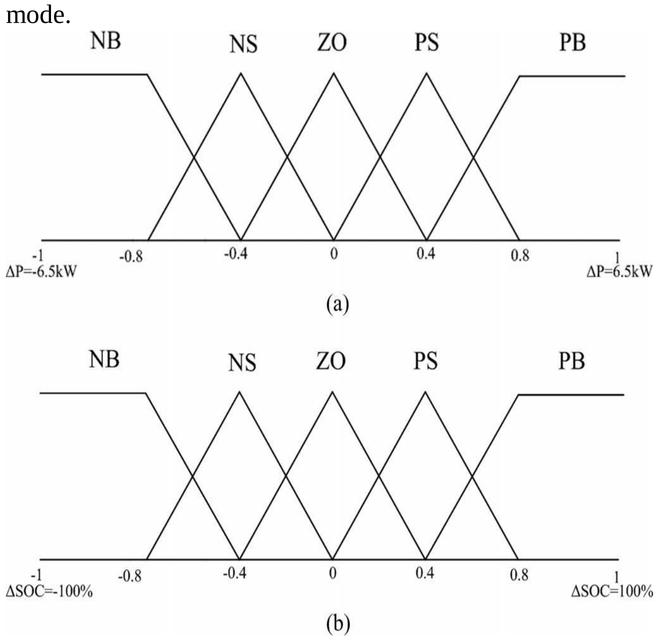
$$\Delta P = P_L - (P_{wind} + P_{PV}) \qquad (18)$$

The power difference ΔP is between required power for load and the total generated power of the micro grid. The fuel cells only provide base power for the emergency loads when the system fails. Therefore, the fuel cell is not considered as power source. The generated power comes from solar power P_{pv}, wind turbine P_{wind} and power load P_L for the proposed system.

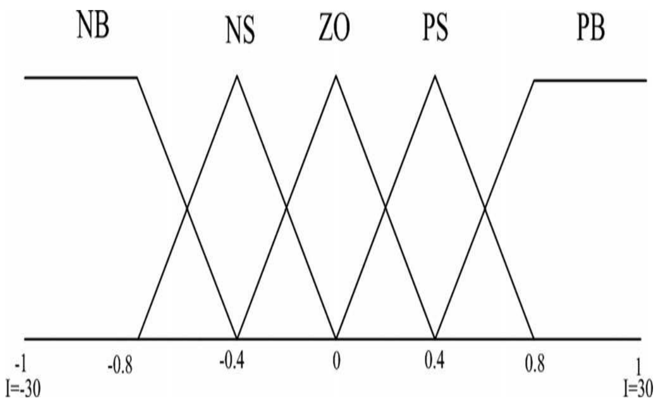
ΔI		ΔP				
		NB	NS	ZO	PS	PB
ΔSOC	NB	PB	PB	PB	PB	PB
	NS	PB	PB	PS	PS	PB
	ZO	ZO	ZO	ZO	PS	PB
	PS	NS	NS	NS	NS	PB
	PB	NB	NB	NB	NB	PB

Fuzzy Control Rules.

The input and output membership functions of fuzzy control contain five grades: NB (negative big), NS (negative small), ZO (zero), PS (positive small), and PB (positive big). By input scaling factors K_1 and K_2, we can determine the membership grade and substitute it into the fuzzy control rules to obtain the output current for charge and discharge variance ΔI of the Li-ion battery. If the ΔP is negative, it means that the renewable energy does not provide enough energy to the load. Thus, the battery must operate in charging mode; if the ΔSOC is negative, it means that the SOC of the battery is greater than the demand SOC. Thus, the battery must operate in discharge mode.



Input Membership Functions of Variables (a) ΔP and (ΔSOC).



Output Membership Function of Variable ΔI.

The control rules of this study prioritize selling additional electricity generated by the renewable energy in response to the present control strategy of micro grid development for selling electricity and increasing the life of Li-ion batteries. The fuzzy control table of the proposed dc micro grid system is not symmetrical. To extend the life of storage batteries in the design of fuzzy control, the fuzzy control rules are set to maintain battery SOC above 50%.

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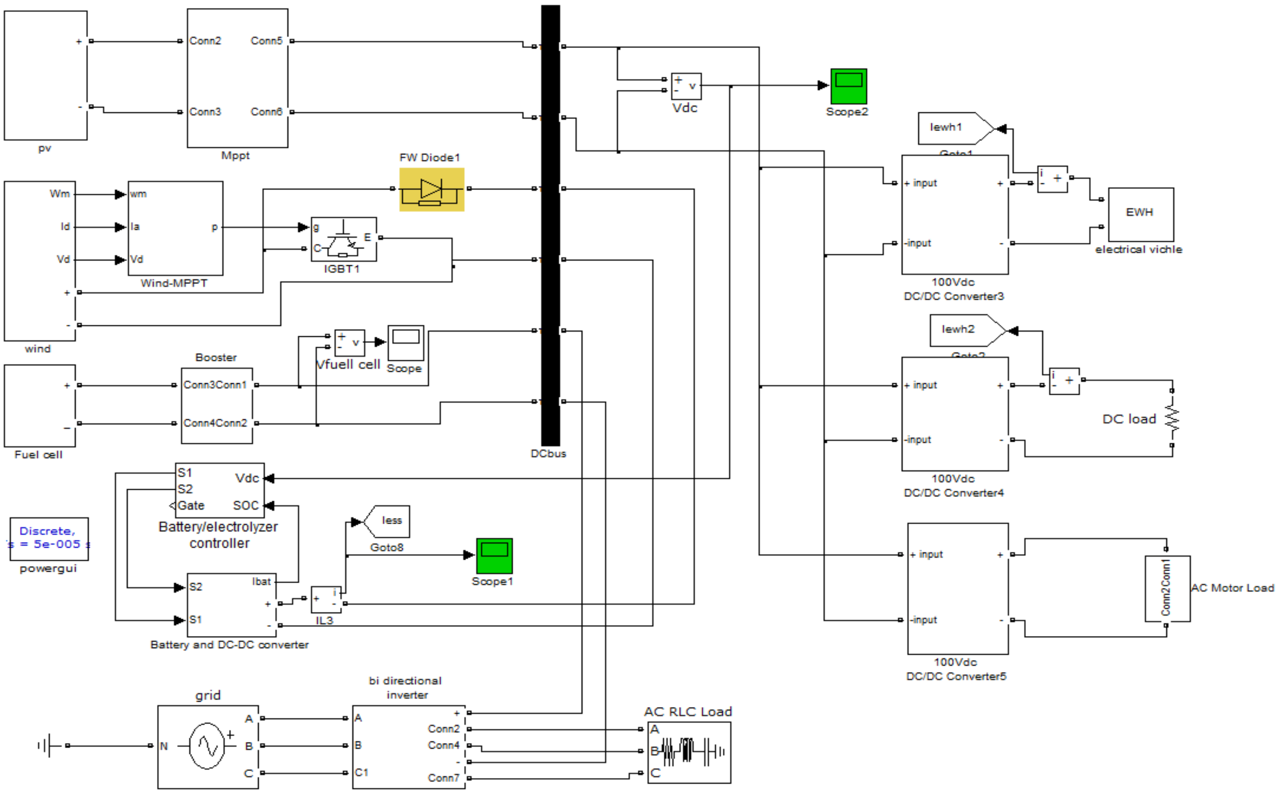
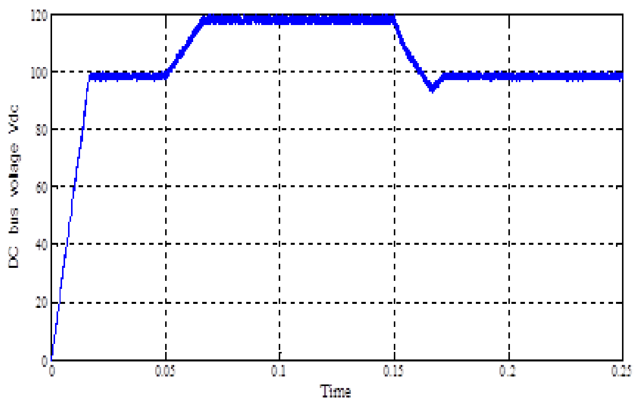
IV. SIMULATION MODULE

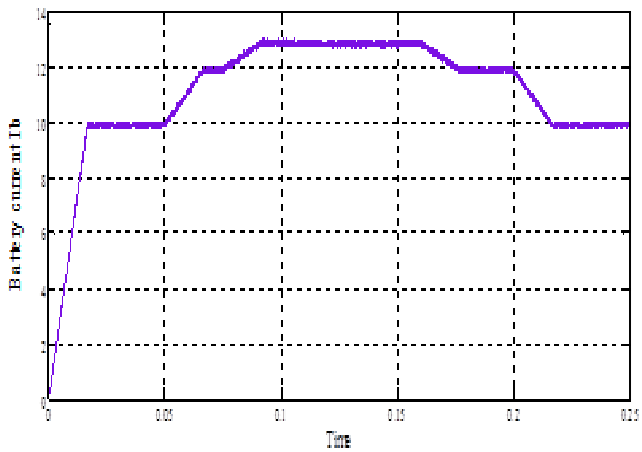


Block diagram of Dual Mode control of motor drives with Integrated Inverter/Converter circuit for EV/HEV applications

The above figure shows the block diagram of dual mode control of motor drives with integrated inverter/converter circuit for EV/HEV applications micro grid system composed of power generator, load, ac/dc converter, energy storage equipment, load, and EMS. The power generator includes PV panels, wind turbines, and fuel cells. The fuel cells provide base power for the emergency loads when the system is operated during a power failure. Maximum power point trackers are associated with PV panels and wind turbines to draw maximum power, which is fed into the grid. The loads are connected to the grid and supplied from the grid directly. The design concept of this study was to increase the useful life of lithium batteries and to include charge and over discharge protection mechanisms.



Fuzzy Control DC bus voltage of Micro Grid System.



Fuzzy Control Battery Current of Micro Grid System.

Simulation results shows the measured transient waveforms of dc-bus voltage V_{dc} and battery current I_b of the micro grid system with fuzzy control. From the measured results, we can see that the battery current is regulated by the fuzzy controller and the dc bus is regulated to 380 ± 20 V.

V. CONCLUSION

This project presents the modeling, analysis and design of intelligent control techniques to achieve optimization of a renewable energy management system for a micro grid system. The intelligent control techniques are to optimize energy distribution and to set up battery state of charge parameters. From simulation results the system achieves

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power equilibrium, and the battery SOC maintains the desired value for extension of battery life by using the intelligence control rules for a micro grid. Proposal of a dual mode control of motor drive with integrated inverter/ converter circuit for EV/HEV applications based on Renewable Energy Sources (RES) is proposed to significantly reduce the volume and weight, proposal of a new control method for the integrated inverter/converter circuit operating in boost converter mode to increase the efficiency, verification of the proposed integrated inverter/converter circuit. After all this discussion the above dual mode control of motor drive with integrated inverter/converter circuit represented in Simulink with the help of MATLAB 2010a .By using the Simulink library the connections are made

VI. FUTURE SCOPE

In future the project may be extended additionally; the optimization of control rules can be included in the intelligent micro grid management system. The system can be designed with more renewable energy and load can also be extended. And also the system can take the priority of selling electricity as the premise of energy distribution to allow remaining power generated by the renewable energy of the electrical grid sold through the connected mains grid.

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