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PI Controller for Energy Management System in Hybrid Electric Ship

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ABSTRACT—DC hybrid power systems are of interest for future low emission, fuel-efficient vessels. The hybrid electric ship is mainly dependent on electricity and so there is always a need for storage. PV panel, Batteries, Ultracapacitors (UCs), Fuel Cells (FC) are being used for the proposed HES as an electric power source or as a storage unit. The aim of paper is developing an energy management technique in which the hybrid electric ship utilizes the sources according to the requirements. This increases the efficiency of hybrid electric ship and reduces the fuel consumption and unwanted emission. The maximum power point tracking (MPPT) in fuel cells and PV panel is done using (P&O) algorithm. Diesel generator performs the energy management process when all the other sources are not in use.

INDEX TERMS— Photo Voltaic (PV) system, Hybrid Electric Ships (HESs), Batteries, Energy Management System (EMS), Maximum Power Point Tracking (MPPT).

I. INTRODUCTION

Increasing rapidly population and energy consumption in the world, increasing oil and natural gas prices, and the depletion of fossil fuels are justifiable reasons for using electrical hybrid ships (HESs) instead of fossil-fuel ships [1]. The interest in developing the HESs with clean and renewable energy sources as a replacement of fossil-fuel ships has therefore steadily increased. The HESs has been proposed as a potential and attractive solution for transportation applications to provide environment friendly operation with the usage of clean and renewable energy sources [2]. The solar panel is fitted at the rooftop of the ship. The PV panel is operated at rapidly changing environmental conditions. Since the PV panel performs a nonlinear voltage-current curve, its maximum power point (MPP) varies with irradiance and temperature. A major challenge in using photovoltaic system is to tackle its nonlinear characteristics. In order to utilize the PV power the term MPPT (Maximum Power Point Tracker) technique is employed. Since the power from a given PV module mainly depends on solar insolation and panel temperature. As these quantities vary with time, it is essential to develop a maximum power point tracking (MPPT) algorithm to extract maximum power from the PV module at real time. Over the past decades, many MPPT algorithm have been proposed such as, hill climbing method,[3],perturb and observe(P&O) method [4],incremental conduction method etc.,[5] in this paper proposed technique is P&O because it is easy to implement and is cost is less.

This paper is focused on simulation of hybrid electric ship power and propulsion systems. The different electrical and mechanical elements including the diesel generator–rectifier system, dc/dc converters, PV, fuel cell, battery and Ultracapacitor. Power electronic converters are modeled through nonlinear averaging techniques to give an effective solution with the accuracy and speed of simulation for large signal analysis. Thereafter, a simulation platform is developed in MATLAB/Simulink for system-level studies of hybrid electric ships. As a case study, a hybrid electric ship is simulated in different modes of operation. The simulation results of a power sharing control among PV, diesel generators, a fuel cell unit, and an energy storage system show practical utility of such a simulation tool in system studies associated with design, evaluation, power management, etc.

HESs have the advantage of storing the high energy efficiency. This energy is typically stored in batteries, the Fuel Cell (FC) stack, Ultracapacitors (UCs). Fig.1. shows the overview of five sources for the energy management system in hybrid electric ship.

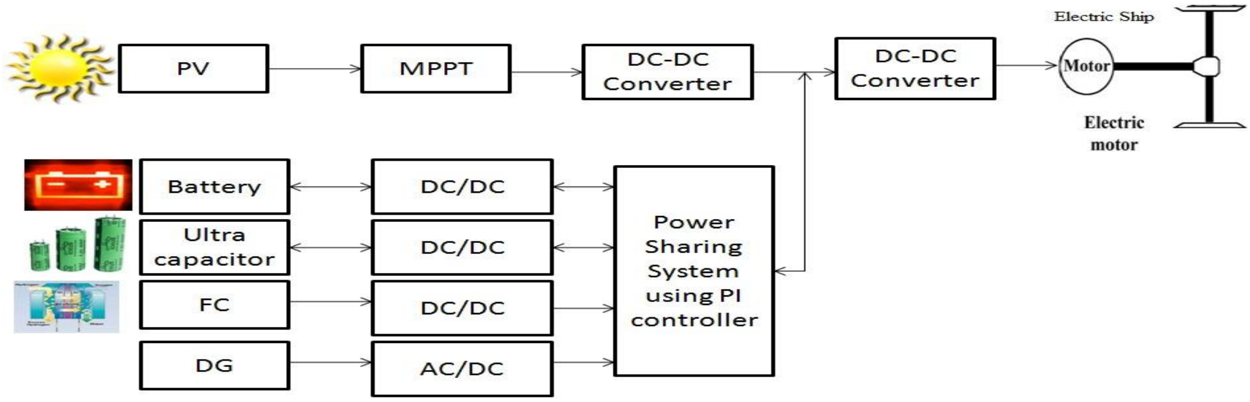

fig. 1. Proposed System of a hybrid electric ship.

II. MODEL OF HYBRID ELECTRIC SHIP

The sources of proposed HES are five sources. They are PV, Fuel cell, Battery, Ultracapacitor and Diesel generator.

A. PV Sources

The PV array characteristics profoundly influence the converter and control system. The array volt ampere curves at different light intensity λ but at constant temperature.

A solar panel is a p-n junction semiconductor which generates a DC current when it is exposed to direct sunlight. With varying value of the irradiance the generated DC current also varies [15]. Equivalent circuit of the solar cell is shown in figure1. Where, solar cell is considered as a current source.

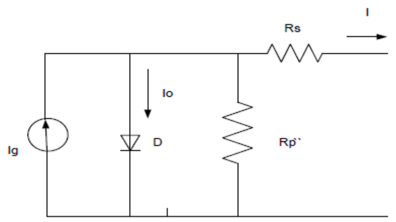

Fig 2. Equivalent circuit of PV array

From the equivalent circuit the I-V characteristics of a solar cell are given by following equations. The diode current is given as:

$$I_D = I\,[\exp(q\,(V+IR_s)/KT)) - 1] \quad (1)$$

$$I = I_L - I_D - I_{sh} \quad (2)$$

$$I = I_L - I\,[\exp(q\,(V+IR_s)/KT)) - 1] - (V+IR_s)/R_{sh} \quad (3)$$

Where:
I: Solar cell current (A)
I_L: Short circuit value assuming no series/shunt resistance
I_D: Diode saturation current (A)
q: charge of an electron
K: Boltzmann constant
T: Temperature of cell in Kelvin (K)
R_S: Series resistance of solar cell (Ω)
R_{sh}: Shunt resistance of solar cell (Ω)

Using the simulated Matlab model the effect of varying temperature is simulated and shown in fig 2.It is observed that the open circuit voltage varies linearly with varying the temperature value while ,short circuit current varies slightly with the cell temperature. The short circuit current at any temperature can be calculated by:

$$I_{scIT} = I_{scIT0}\,[1 + \alpha\,(T - T_0)] \quad (4)$$

B. Battery and UC Modeling

The batteries and UCs represent an SOC dependent voltage. The power constraints, available energy, volume and cost are directly scaled to the mass [6]. The internal resistance calculation is dependent on the energy and voltage.

$$R_{factor} = (R_{int}\,.E_{max}) / V^2_{max} \quad (5)$$

The R_{int} for a known amount of battery or UC is determined by

$$R_{int} = (R_{factor}\,.V^2_{max}) / E_{max} \quad (6)$$

The R_{int} is responsible for voltage fluctuations away from the open-circuit voltage during charging and discharging. The voltage fluctuations allow UCs to handle large amount of energy in passively connected system, which can result in extended battery life.

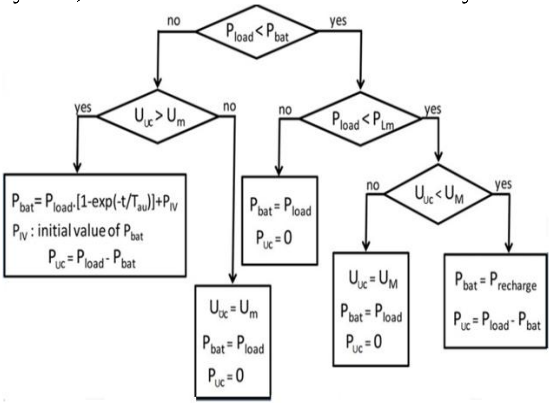

Fig. 3. Control strategy for battery and UCs .

A battery unit could be short circuit without damaging itself, it would take a certain amount of time to fully discharge all of the stored energy, which depends on energy capacity of the battery.

C. Control Strategies for Battery and UC

The control strategy is designed to benefit the fast charge and discharge capability of UCs in order to reduce the battery stress due to instantaneous power demands.

The flowchart in fig.3. shows the principle of power distribution between the battery and UCs [7]. The HES is follows this condition during variable speed operation in propulsion of the ship. The battery is subjected to rising power request by load. A low pass filter is applied to the load current diverting sudden power variation to the UCs.

D. DC motor modeling

The modeling of the permanent magnet DC motor has been carried out with torque and rotor angle consideration. The steady state motor torque T is related to armature current I and a torque constant K.

$$T_m = KI_a \quad (7)$$

The back emf is related to angular velocity by

$$E_b = K\omega_m = K\, d\Theta/dt \quad (8)$$

E. Diesel Generator

The diesel generator is also called as static synchronous generator for hybrid electric ship. The rectifier was modeled by algebraic equations to relate the ac variables to rectifier dc variables assuming as a voltage behind a constant reactance [8]. The accuracy of this approach in steady state, due to neglecting the stator dynamics, it is in fast transient.

The fuel consumption of the DG, $Cons_G$, in terms its output power is expressed as follows

$$Cons_G = B_G . P_{N\_G} + A_G . P_G \quad (9)$$

where A_G & B_G are fuel consumption curve coefficient provided for the output power P_G and nominal power P_{N_G} of the generator.

F. Fuel Cell

The fuel cell used in hybrid electric ship is PEMFC a traditionally uses hydrogen. FC could be capable alternative for the power generation in environment free ship applications. The electric power as output in steady state conditions. The FC output electric power is expressed by the following equation [9].

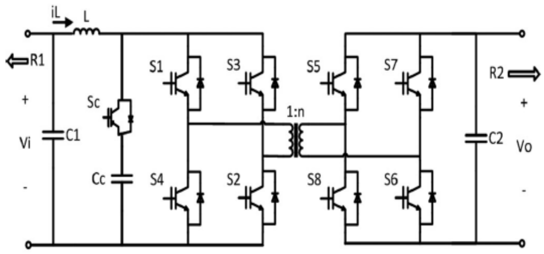

Fig. 4. A full bridge bidirectional converter.

$$Cons_{FC} = B_{FC} . P_{N\_FC} \cdot \quad (10)$$

where P_{FC} is the output power of FC, P_{N_FC} is the nominal output power, A_{FC} and B_{FC} are the coefficients of the consumption.

G. Bidirectional DC to DC Converter

The circuits of a full bridge bidirectional converter are shown fig.4. High frequency transformer should be necessary in this application where the voltage ratio between LV and HV is high that devices. There is also additional degree of freedom [10]. The direction of power flow the converter is operated in three modes: boost mode, capacitor power mode and capacitor recharge mode. When the DC bus charges the battery or UCs, the power flow direction is reversed which means the energy transferred from HV side to LV side under capacitor recharge mode.

H. PI Controller

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. The conventional PI controller used Hybrid Electric Ship for controlling purpose in energy management system.

The proportional plus integral is a device that produces an output signals, u(t)consisting of two terms- one proportional to input signal, e(t) and the other proportional to the integral of input, e(t).
In PI controller, u(t) α [e(t) + ∫ e(t)dt]

$$G_c(s) = U(s)/E(s) = K_p + \quad (11)$$

The PI controller reduce the steady state error, increase the order and type number of the system by one.

I. Perturb and observe

The P&O algorithm is also called “hill-climbing”, but both names refer to the same algorithm depending on how it is implemented. Hill climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and Fuel Cell.

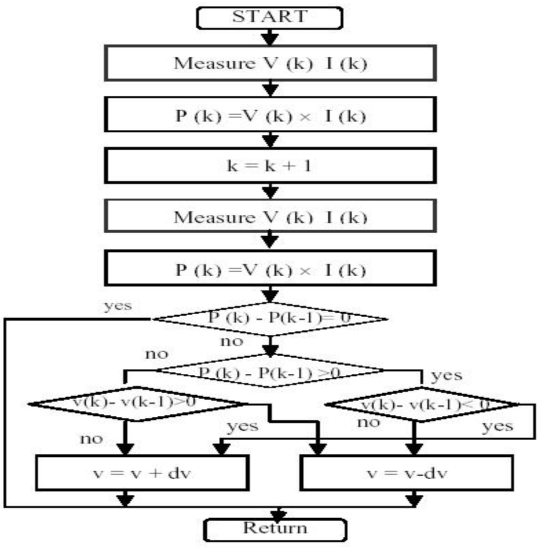

Fig. 5. A flowchart for P&O MPPT Technique.

Fig.5. shows operating point is near to the MPP, the perturbation size is reduced and if the points far, then it is increased. This technique improves the convergence speed and reduces the oscillation around the MPP. The HES having the environmental change condition so P&O is flexible to operate.

III. SIMULATION MODEL

A. Photovoltaic Cell

The solar cell was modeled in the single diode format. This consists of a 0.1 ohm series resistance and an 8 ohm parallel resistance. This was modeled using the Sim Power System blocks in the MATLAB library. The Simulink model fig.6. controlled current source is utilized to drive the solar cell. The control signal is provided by the I_{lg} generator unit. The I_{lg} generator takes into account the number of series connected, number of parallel connected solar cells and the temperature to determine the input signal from the solar cell. The MPPT unit for this method utilizes the power and the voltage values instead of the current and voltage values as in P&O method. Rest every unit is similar to the previous model units. The repeating sequence being utilized in the model has an operating frequency of 10 KHz. This is also the frequency of the gating signal.

B. Model of EMS in HES

The proposed HES system is having energy management system. The control strategy is given for both battery and UCs. The output power of the buck convertor is makes the compare with reference power. If the power is varies below or above of the zero then the PI controller will generate the gate pulse to bidirectional converter.

The PV, FC, DG, battery and UCs are connected in a dc bus. So the HES will operate in every environmental condition. The speed and current of the 5HP dc motor is sensed and according to that the pulse is generate for the buck converter.

The PV and FC is used the P&O MPPT technique. The output of PV and FC is around 24V it is boosted to 130V using boost converter. The MPPT technique is used to generate pulse for the boost converter for both PV panel and fuel cell. The diesel generator is considered as a static synchronous generator. The output of the generator is ac voltage. It was converter to dc using uncontrolled rectifier.

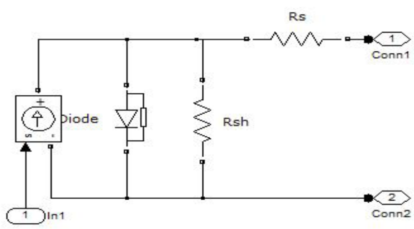

Fig. 6. Solar cell modeled in single diode format

The output of the rectifier is 130V is capable for the dc bus voltage. The components of the simulink model are tabulated below:

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TABLE I COMPONENTS OF HES

S.No	Components	Rating
1.	Photo Voltaic Panel	24V
2.	Fuel Cell	PEMFC, 24V
3.	Battery	Li-ion , 24V
4.	Ultra Capacitor	12F
5.	Diesel generator	SSG, 6350MVA
6.	DC motor	5HP, 240V

C. Model For Bidirectional boost converter

The dc/dc bidirectional converter topologies and their controller are designed and investigated by using MATLAB/Simulink. Fig.7. shows the bidirectional boost converter.

The bidirectional boost converter is used for both battery and ultracapacitor. The control strategy is used to generate the gate pulse according to the condition.

IV. SIMULATION RESULT

A. DC Bus Power, Speed, Buck output Power

Fig.8 and Fig .9 shows the output power of a dc bus across the dc link capacitor. The speed is maintained as a constant for 100 rad/sec because of that the speed is maintained as constant. The buck output power is used for make the speed to constant. The power is sensed from the buck converter is used for battery and UCs charging and discharging.

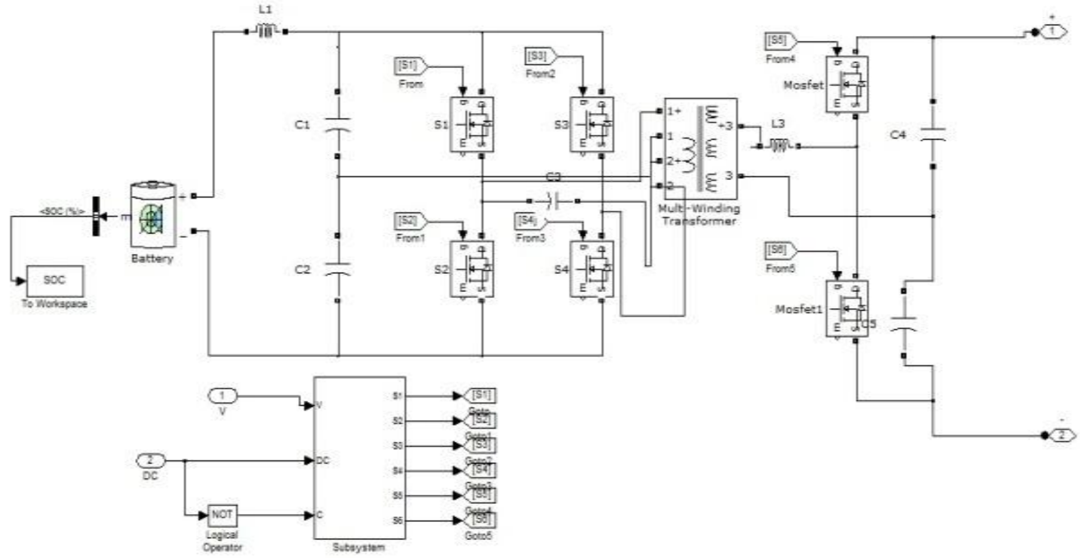

Fig. 7. Model of bidirectional boost converter

B. Battery and Ultracapacitors

The charging and discharging of battery and UCs is shown in fig.10, and fig.11. The battery is linearly discharge the energy for the HES using bidirectional boost converter. So normal speed operation the battery is used mainly. When the ship goes beyond the speed limit the battery cannot able to withstand for discharging energy. During the high speed operation of the ship the ultracapacitor is under the process. The ultracapacitor is having sudden charging and discharge in nature within 30s. The energy is from PV, Fuel cell and diesel generator. So under the condition of the environmental purpose the sources will charge the battery and ultracapacitor from dc bus of the hybrid electric ship. The battery voltage using bidirectional boost converter waveforms are shown fig.12.

C. Priority of the Sources

The hybrid electric vehicle used the multiple sources for propulsion of the vehicle using motor. The electric power is stored using two storage element such as battery and ultra capacitor. The renewable sources are Photo Voltaic (PV) and are generate electric power according to the environmental conditions. The diesel generator is used generate the electric power and it is used to store energy in battery. Each source is acting at different conditions to make the motor of the HEV in constant speed operations.

a) Case 1:

The Photo Voltaic is the major source for the hybrid electric vehicle using maximum power point tracking and boost converter. The generate electric power from PV is stored in the battery. If the irradiance of the solar is good means the generation of electric power is more efficient to run the vehicle. If the irradiance is low means the stored energy in battery is used for propel the vehicle.

b) Case 2:

The second case in the stored energy of the battery is become low it also want to charge the energy during rainy days, cloudy conditions etc., The PV cannot able to generate the power according to the load condition of the vehicle and battery charging conditions. So the second battery source is will be generate the electric power for the vehicle. The generate power is used to charge the battery. The charges of the battery are also used for the propulsion of the vehicle.

c) Case 3:

If PV are not present to charge the battery and run the vehicle means the diesel generator will generate the power. The diesel generator is used to charge the battery. The discharge of the battery energy is used to propel the vehicle.

d) Case 4:

The battery is linear discharge device for propel the hybrid electric vehicle. During sudden high speed operation of the motor in the vehicle the battery cannot able to withstand that condition. In that case the Ultra Capacitors (UCs) is used to run the vehicle for sudden high speed conditions. The UCs has high charging and discharging conditions. Due to these conditions the battery lifetime is extended and also continuous operation of motor in vehicle will get obtained.

D. Pulse Generate

The PWM signal is generated based on the speed and current characteristic of the dc motor. The speed of motor is compare with the reference speed signal in speed controller and it generate reference current signal. The current from the motor is compared with the reference current signal in current controller. The gate pulse is generating for the buck converter of the HES.

The output power of the buck converter is compared with the reference power then by using the PI controller the gate pulse generate for bidirectional converter of battery and ultracapacitors . According to the gate pulse the battery and ultracapacitor will get charging or discharging for the speed condition of the ship.

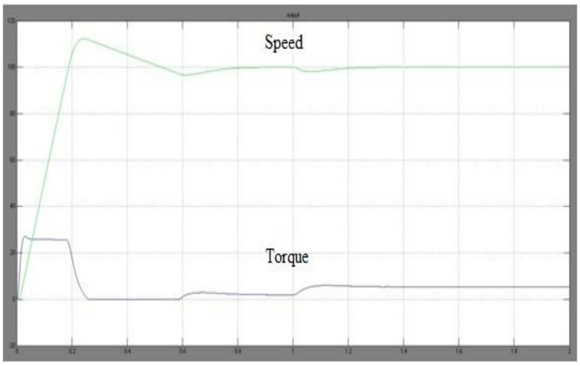

Fig. 8. Speed and Torque waveform

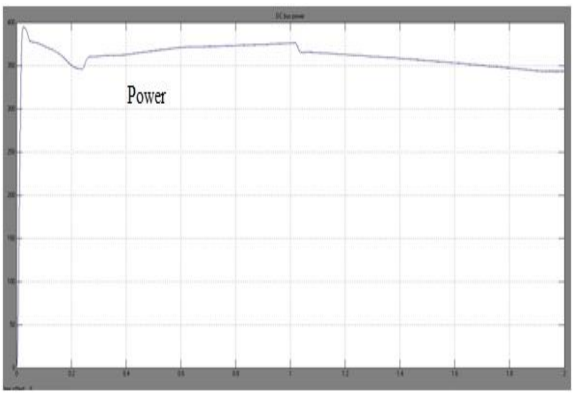

Fig. 9. Power waveform of DC bus.

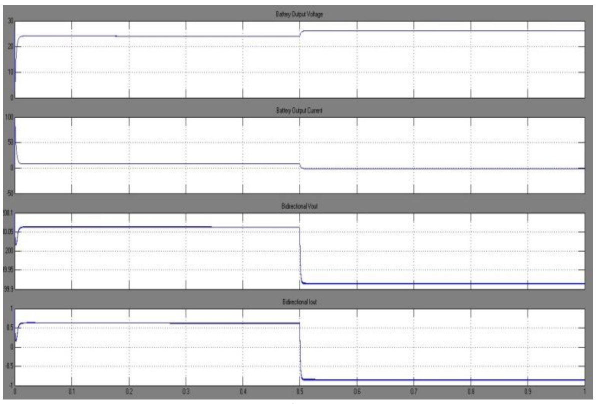

Fig. 10. Bidirectional boost waveforms.

V. CONCULSION AND FUTURE WORK

In this paper, the power flows of several energy source of the HES, has been presented. A hybrid arrangement, with a parallel combination of PV, FC, DG, battery and UCs, can be observed and studied using MATLAB/Simulink program. It is found that the P&O technique is straight forward, accurate, and easy to implement for both PV and FC. Furthermore, battery life can be improved due to decrease in the output current. A hybrid energy storage arrangement enhances the overall energy management system and a bidirectional dc/dc converter was simulated.

Future work in this area of research will aim at addressing different combinations of system to reduce the size and cost, and also reduce the switching of the converters and instead of using P&O technique can use other techniques.

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