An Intelligent Energy Management System for Ship Hybrid Power System Based on Renewable Energy Resources

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ABSTRACT

A hybrid ship power system with fuel cell and storage system batteries/supercapacitors can be developed by adding renewable energy sources. Adding PV to the hybrid system enhances the system's reliability and dependability. A high-level control strategy is needed to manage the generated power between the fuel cell and the photovoltaic array and determine the suitable time to charge or discharge the stored energy according to the load demand. The perfect solution using an intelligent neural network technique to control the ship's hybrid power system because of the system's nonlinearity and the existence of pulsing and high-density load demand. This paper introduces an intelligent artificial neural network (ANN) technique that depends on previous experience. ANN is flexible and easy to modify adding/removing power system components and can be scaled to any ship power system rating. Simulation results using MATLAB software prove that the robust, intelligent power management system can control and identify which energy source will be exploited according to the daylight. Moreover, calculate the amount of generating power depending on the shipload demand. In addition to that, it ensures the system dependability considering the other source as standby while the storage system is the power source in the transient period in case of switching between the two systems and maintain the storage system in a high state of charge as possible. This will reduce fuel consumption during the ship's cursing mission.

Keywords

Renewable energy, fuel cell, solar energy, intelligent control, all-electric ship, ship power system, daylight, storage system neural network.

1. INTRODUCTION

After the Paris agreement under the United Nations Framework shipbuilders had gone vastly toward reducing the emission gases from ships, International Marine Organization (IMO) initial Green Houses Gas (GHG) strategy to accelerate the decarburization efforts in the shipbuilding industry[1]. The electric ship was a perfect solution to reduce GHG starts by trying to electrification ship equipment's[2]. Navy ship has been developed all-electric ships (AES) techniques, that allowing all ships' loads propulsion system and service loads to be powered from the same power supply[3]. All-Electric Ships allows reducing greenhouse emissions and shifting toward a wide increase in utilizing renewable and sustainable energy in naval ships[4]. The naval ship takes the opportunity to develop in this field. The naval ship has several types of loads not only the propulsion system loads but also the weapon, sensors load. The electrification for all ship systems needs an integrated power system (IPS) to integrate. An artificial intelligent control technique is proposed to manage and control the ship electric power system with nonhomogeneous power sources. [5, 6].

Early to mid-1980s, artificial intelligence (AI) provides solutions to complex problems in power system engineering was tough and tedious[7]. The Hybrid renewable energy system is bright up as the wide using renewable energy due to the existing of several non-homogeneous energy sources in the system and the power sources like fuel cell, solar energy, and sometimes diesel engine and storage energy like the battery or supercapacitor.

Hybrid systems use to overcome the drawback of the slow response of some sources like a fuel cell or the absence of the resources like solar energy during blackness and the physical characteristic of storing systems like heavy and increase the cost. All these factors lead to the use of a hybrid power system to get the most benefit of each system and overcome its drawback.

These ship's hybrid power systems can be considered as traction systems needed control and management strategy [8]. These strategies according to the vehicle applications [9, 10]. A new trend is present as Autonomous Vehicles[11]. Fuzzy logic is used to controller real-time design of a power management strategy for a hybrid electric traction system to protect the storage battery from overcharging during the repetitive braking energy accumulation[12]. Artificial neural networks (ANN) and machine learning are used to protect the fault in shipboard on a shipboard power system[13, 14]. Adaptive neuro-fuzzy technique ANFIS used to control the strategy to manage the hybrid system consists of the fuel cell, PV, and wind energy[15, 16].

2. SHIP MICROGRID MANAGEMENT AND CONTROL.

During overseas cruising, the ship's electrical power system is considered an island microgrid. At berth when connected to shore power, the same power system acts as a grid-connected microgrid or an extension of the grid [17]. Nowadays these conventional tenets obligatory for replacement by clean energy sources such as wind, solar, and fuel cells [18, 19]. The U.S. Navy has changed its priority from installing systems with high capabilities to systems that are more affordable but enable them to integrate with each other's to get the best performance.

The new generation of commercial and warships is characterized by an integrated power system (IPS). This system incorporates all power sources to provide the provide power and feed shipboard electric loads. This is the All-Electric Ship technique. Renewable energy, power generation, power electronics, and energy storage systems with good communication protocol controlled with intelligent control systems necessitate real-time power management and power system reconfiguration, especially in situations of equipment failure and battle damage. This is the new revolution in marine and naval ship microgrids [17]. The integrated power architecture provides the framework for partitioning the equipment and software of IPS into modules [18, 19].

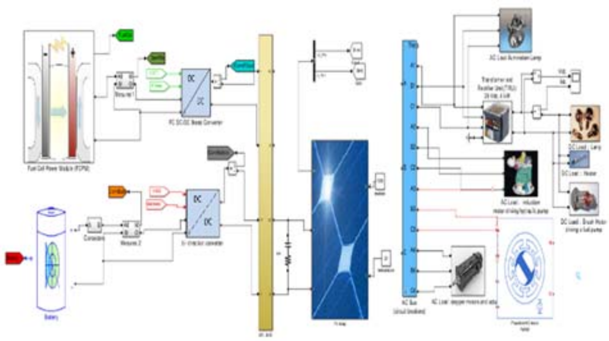

Figure 1. Proposed Hybrid System Architecture.

3. HYBRID SYSTEM ARCHITECTURE.

The hybrid power system allows the system to combine two or more energy sources into a hybrid energy system. The drawbacks of any source will be accomplished by the other sources. The system is designed based on the power and energy required for a typical special naval ship's mission. That submarine seeking mission required low acoustic and noise signature. The fuel cell has been identified as the most promising technology for ships, promising in future marine because of its dependability in all marine environmental conditions and ability to work in both low and high temperatures. The disadvantage of the fuel cell is its slow dynamic response. Any renewable energy should be coupled with an energy storage system to overcome the fluctuation from renewable energy resources due to environmental conditions or sudden outages and to ensure system stability.

3.1 Fuel cell /PV hybrid energy system.

A typical fuel cell/battery hybrid system is the famous pre-designed and tested system used in many applications such as an emergency landing cycle, provided by Bombardier Aerospace under the technique of more electric aircraft (MEA) [20]. And in naval ship systems under the technique all-electric ships (AES) [4].

The proposed hybrid electric power system is shown in Figure 2. consists of the fuel cell system as a DC power supply to meet the average demand load (10 kW), a photovoltaic array is introduced to enhancement the system response with clean, pollution-free energy, no fuel cost, etc., the common problem with these sources is their dependence on the climatic conditions due to which the power produced is unpredictable. The batteries and supercapacitors are designed to assist fluctuation during continuous, transient peak demand, and improve the power quality of the system. The fuel cell system is a proton exchange membrane (PEM) with 30-60 V 12.5-kW max. Valence battery modules four batteries (12.8 V, 40 Ah) are used along with six NESSCAP supercapacitor modules (48.6 V, 88 F)[20]. The highest level of control should be used as shown in fig. 2 to divide the system into three subsystems as follows: -

- A DC bus bar system which feeder from the fuel cell, the PVs, and the battery, Two DC/DC converters for discharging (4 KW boost converter) and charging (1.2 KW buck converter) for the battery system and DC/DC for controlling the fuel cell's output. These converters have an output voltage regulated with current limitation. The PV output module controls the voltage level and enabling the PV system according to the light intensity.
- AC systems consist of the inverter system and load profile and monitoring and protection systems. The inverter system consists of (160–320 V) input dc and converts to3X440 V/60-Hz 10-kVA dc/ac output.

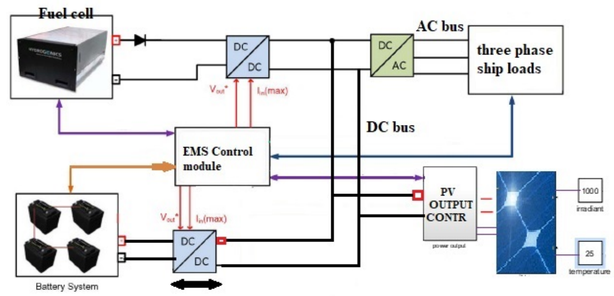

Figure 2. The schematic diagram for the proposed system.

- The load consists of variable loads to emulate the ship's loads. For each converter input/output voltage and current sensor and temperature measurement are equipped to control and monitoring the inverter. Figure.3, shows the schematic power and control for the overall proposed system. Signal conditioning is achieved through NI data acquisition cards.

3.2 Photovoltaic control modules.

Connecting the photovoltaic array to ship microgrid need some preparations because the photovoltaic output power not always intermittent. The variety of the environmental conditions during the day and the location in which the ship is sailing and the variation of the load demand causes shortage or excess in photovoltaic power. Hence, the photovoltaic module is designed with a high level of the control system to identify the best time to operate the photovoltaic module, control the output power, synchronize with the grid (AC or DC) grid according to the load type, and also to connect with the storage system to compensate the photovoltaic output power or to charge storage system in case of excessive power [21].

Photovoltaic module design considers the environmental conditions are constant values of irradiation (1000 W/m^2) & temperature (25^o C) however, those values not always constants with these values. In addition to the excellent atmospheric condition, it is necessary to have an effective maximum power point tracking (MPPT) for the PV system. The Maximum Power devices have several techniques such as perturbation and observation technique, voltage feedback technique, actual measurement technique, linear approximation technique, incremental conductance technique, and fuzzy logic control technique [22].

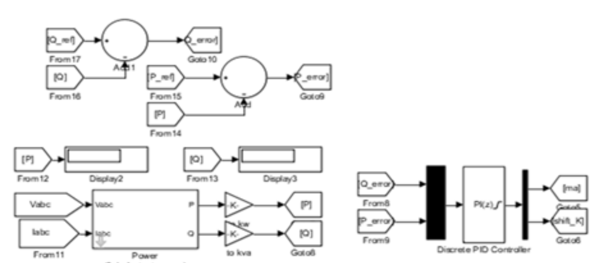

Figure 3 active and reactive power control for the PV module.

Photovoltaic control differs according to the grid-connected type in case of DC grid only voltage level and power is needed to ensure connected the to the busbar with the same DC voltage. For the AC grid additional controller to keep synchronized with the three-phase grid (voltage, frequency, phase sequence), PID controller adds as in Figure. 4 to control active and reactive power produced from the photovoltaic module.

4. ENERGY MANAGEMENT STRATEGY.

The energy management strategy is aimed to ensure the following:

- Reducing the system's energy fluctuations, which is the major problem in renewable energy systems.
- Increasing the battery's lifetime by maintaining its state of charge (SoC) in acceptable mode.
- Reduce fuel consumption (hydrogen).
- Produce a maximum amount of solar energy.
- Reduce the amount of energy production by the fuel cell.

This will achieve by using the "artificial neural network" (ANN) technique which is one of the artificial intelligence techniques based on training the system to solve the problem depending on the user expert with minimum error.

The system as shown in figure 4 consists of three input the battery state of charge and the load power and the light intensity to identify which source will produce power and the two output is the fuel cell power and photovoltaic power.

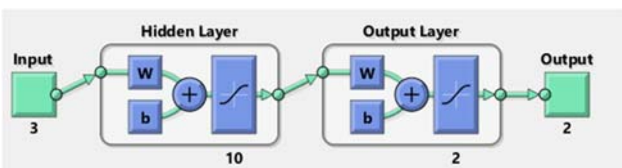

Figure 4. ANN control structure.

The ANN control system use (3x1568) input and (2x1568) output data as training data to train the system.

As the light intensity is enabled all power is produced from the photovoltaic module and when the light intensity is disabling the power is produced from the fuel cell. The energy management design parameters are shown in the table.1

Table 1. Energy management designed parameters.

parameter	Min	Max
Fuel Cell power	1 KW	10KW
Photovoltaic power	0 KW	10 kW
Battery power	-1.2 KW (charging)	4 KW (discharging)
Battery SoC (high)	90%	100%
Battery SoC (normal)	60%	90%
Battery SoC (low)	60%	40%
DC bus voltage	250 V	280V

5. SYSTEM OPTIMIZATION PROBLEM.

Hybrid systems that use at least two energy sources for providing the load with its needed power. that system is usually combined with one or more renewable energy sources, energy-storing system, or fuel system that may be the engine with fossil fuel or hydrogen. Hybrid systems are expected to have an optimization technique working with the (EMS) which identifies which source provides the load with its necessary power or how much power should provide for each source to reduce the fuel consumption and ensure the system stability[23],[24],[25].

For achieving this goal, the optimal minimization and control strategy is applied to the hybrid system component fuel cell, supercapacitor, and battery to produce the reference power determined by the EMS based on the load demand[20]. The electric power produced from the fuel cell and the energy storing system battery and supercapacitor should be converted to equivalent hydrogen consumption.

The calculation of the equivalent of the hydrogen consumption for load C that is the sum of fuel cell hydrogen consumption C_{fc} and battery hydrogen consumption $C_{bat}$and solar power from PV C_{pv}.

The equivalent mathematical problem for minimizing fuel consumption is the following:

$$P_{fc} = \min(C_{fc} + k_1 C_{bat} + k_2 C_{pv} + k_3 C_{SC}) \quad (1)$$

Where P_{fc} fuel cell output power
k_1, k_2 and k_3 penalty coefficients converter to hydrogen consumption.

The supercapacitor power is neglected in the optimization problem because the battery converter controls the DC-bus voltage, and the solar power is independent of the hydrogen consumption. And the discharging or charging of the supercapacitors within the same energy from the battery system so the load power is divided between the fuel cell and the battery in each cycle. The optimization problem can be written as:

$$x = [p_{fc} + k_1 P_{batt}] \quad (2)$$

To minimize the equation

$$F = [p_{fc} + k_1 P_{batt}].\Delta T \quad (3)$$

The battery equivalent hydrogen consumption C_{bat} can be calculated from the battery power P_{bat} and the battery SoC Under the equality constraints.

$$P_{load} = P_{fc} + P_{batt} \quad (4)$$

$$\mathrm{k}_1 = 1 - 2\mu \frac{(\mathrm{SoC} - 0.5(\mathrm{SoC}_{\max} - \mathrm{SoC}_{\min}))}{\mathrm{SoC}_{\max} - \mathrm{Soc}_{\min}} \quad (5)$$

With the boundary constrains

$$P_{fcmin} \le P_{fc} \le P_{fcmax}$$

$$P_{batt\,min} \le P_{batt} \le P_{batt\,max}$$

$$0 \le k_1 \le 100$$

The above is the system cost function which is a generic problem for any hybrid system consists of fuel cell energy storing devices and this multi-objective optimization problem was solved for this system in several papers which is not interested in this issue [24], [26], [27].

6. ANN CONTROL PROCEDURE.

ANN procedure will be carried out according to the learning result that pre-obtained from the old trial or human experience. This is the benefit of using ANN especially at the non-linear systems and the systems need a quick decision in real-time.

Three inputs are entered into the EMS's. The first input is the battery SoC that indicates the amount of power that the battery has, the optimal state is the normal state of charge between 65%to 85%.

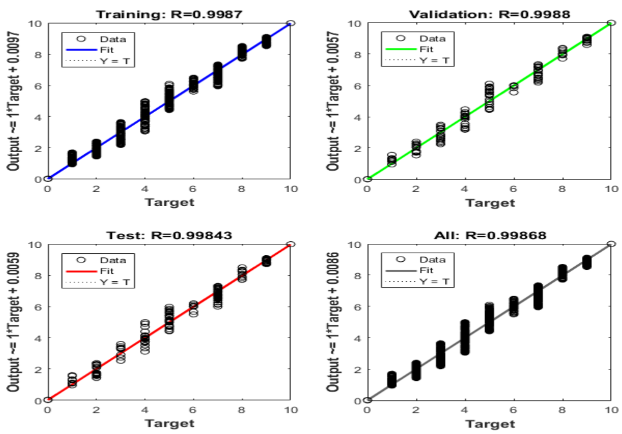

Figure 5 ANN training regression.

Another objective is to maintain the battery state of charge (SoC) within the acceptable limits so that the lifetime of the batteries can be increased.

The second EMS input is the ship load demand. The permissible load between 1-10 kW indicates the amount of power needed to stabilize the system. The third input to EMS's is the environmental condition that indicates if it is suitable for the photovoltaic to work or generate the power from the fuel cell.

The system trained with (5x1568) expert data to obtain the best validation performance with a minimum error of less than 0.0013 as shown in figure 5.

The system best validation system performance occurs at 443 epochs less than 0.1 % error as shown in Figure 6.

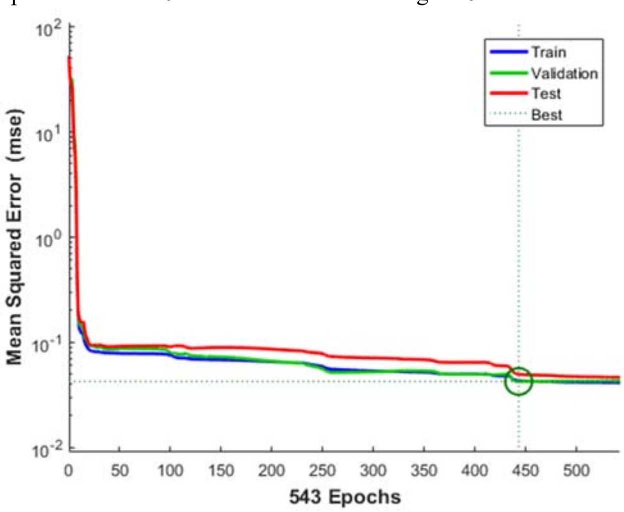

Figure 6 Best validation system performance.

7. ANN SIMULATION AND RESULTS.

The MATLAB simulation results obtained from the energy management system based on the ANN are shown in Table2. For one day sailing during two-period according to the light intensity.

Table.2 Simulation result obtained from EMS based on ANN

Time clock	EMS input			EMS output	
	SoC	Load power	Light intensity	FC power	PV power
0	90	5	0	4.2	0
1	80	5	0	4.8	0
2	80	7	0	6.8	0
3	70	6	0	6.3	0
4	60	8	0	8.3	0
5	60	8	0	8.3	0
6	50	8	1	0	8.5
7	60	7	1	0	7.6
8	60	7	1	0	7.6
9	70	9	1	0	9.8
10	80	10	1	0	9.8
11	80	10	1	0	9.8
12	70	11	1	0	10
13	60	10	1	0	10
14	60	8	1	0	8.4
15	70	8	1	0	8.1
16	80	5	1	0	4.8
17	90	5	1	0	4.4
18	80	7	0	8.6	0
19	80	9	0	8.6	0
20	70	9	0	8.8	0
21	80	8	0	7.7	0
22	90	6	0	5.4	0
23	90	5	0	4.2	0

The first column indicates the time during the full day. The second, third, and fourth columns are the system inputs (battery source, load demand, and the light intensity) the next two columns indicate the predictive power determine by the EMS, and which energy source is enabling.

The first period from sunrise at 6 am till dawn at 5 pm in which the solar energy has enabled, and all ship's demand load is provided from the photovoltaic module and safe hydrogen consumed in the fuel cell and the battery.

In the second period from 6 pm till the sunrise the light intensity is low so the energy source is generated from the fuel cell and battery according to the demand load and such.

In case of low light intensity, the fuel cell will provide the load with sufficient power depending on the source, and this increases the system's reliability.

8. CONCLUSION.

The artificial neural network is one of the promising intelligent energy management systems in the ship power system.

These intelligent techniques add flexibility and power to the control and management system when adding/removing any power source or equipment.

Using renewable energy sources in the ship power system has many advantages that are reducing the greenhouse emissions from ships, reduce the crushing cost by reducing fuel consumption, and increase the system dependability by using more than an energy source in the same power system.

This work is a ring of the chain work that design a hybrid power system for the ship, then enhance its performance by adding a renewable energy source, implement this intelligent management system in real-time by using Embedded system raspberry Pi to reduce the system cost.

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