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The architecture of an information system for the power management system on ship

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ABSTRACT: The object of this paper is to present the design of an information system for the management of power system on a ship using software agents. In shipboard power system a large number of electric components are tightly coupled in a small space and when a fault happens in one part of the system may affect other parts of the shipboard power system.

The Power Management System is a critical part of the control equipment in the ship. It is usually distributed on various control stations that can operate together and share information between each other or independently in case of special emergency situations in which ship have to operate. The system becomes more complex by applying renewable energy system due to special rules implemented by International Maritime Organization (IMO).

Safe, secure and efficient shipping on clean ocean, suggested by IMO, require the development of appropriate design, operational knowledge and assessment tools for energy efficient design and operation of ships.

Based on an analysis of the information flow of the data processing for making appropriate decisions, a control architecture for power distribution, which has to be hierarchical, is proposed. This control architecture is implemented as multi-agent system. It is modelled by Colored Petri Net.

1 INTRODUCTION

Marine power system represents a more complex management challenge. Compared to onshore power system, intercom system has a wider range of frequencies and cable lengths are much shorter, which contributes to reduced electricity losses and significantly lower voltage drops. Such a system has some specificity, the design of management solutions are not confined to download ready-made solutions from the mainland. The system of Power Management System (PMS) aims to optimally manage all energy resources on board as well as consumption of electricity and other energy. The aim of the system is also reducing operating costs, which is achieved by minimizing failures (Häkkinen, 2003.). Production management system and distribution of electricity is a critical part of the managerial level on board. Usually the distribution is done at various sampling stations which can work together by sharing information or independently in the event of emergencies in which the ship must carry out their functions. The system becomes more complex use of renewable energy sources, because of special rules adopted by the International Maritime Organization (IMO).

The aim of this paper is to present the design guidelines and requirements which are subject to the design of the system in general. The specific aim is to introduce a new management system using Coloured Petri nets (CPT). In addition to the technical requirements, recently strengthened and other requirements that affect the design of PMS. On one side are the economic requirements for increasing efficiency set by shipping companies and ship owners. On the other hand daily strengthen regulatory pressures aimed at reduced environmental pollution and limit global warming. The regulatory influences come primarily through changes to the IMO MARPOL Convention development or her with Annex VI. Last changes relating to ships that were built after 1 July 2015 and do not have a hybrid or diesel-electric drive including a new chapter four. This chapter introduces guidelines for improving the energy efficiency of design and operational measures. These new requirements affect the need to introduce new management solutions as well as new sources of energy to the ship.

Due to the complexity of management problems that arise by increasing the share of renewable energy sources, which relate primarily to the stability of the system, this paper proposes a model of PMS for managing the electric power system with low share of renewable energy sources. Renewable part of the system consists of solar panels and batteries.

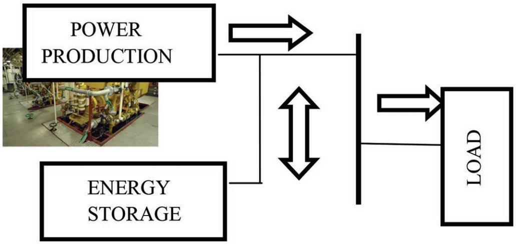

Figure 1. Hybrid power system.

2 MULTI-AGENT BASED SYSTEM FOR ENERGY MANAGEMENT

2.1 *Multi-Agent System*

A Multi-Agent System (MAS) is a distributed system consisting of multiple software agents, which work together to achieve a global goal. [1]. MAS has a great potential for modeling of autonomous decision making entities, which can be used to model and operate a power plant system. Agents have their own control over their behavior and internal states in any possible environment. They exhibit the following characteristics [2]:

- The agent must represent a physical entity so as to control its interactions with the rest of the environment.
- The agent must sense changes in the environment and take action accordingly.
- The agent must communicate with other agents in the power system via some kind of agent communication language with minimal data exchange and computational demands.
- The agent must exhibit a certain level of autonomy over the actions that it takes.
- The agent has minimally partial representation of the environment.

2.2 *Agent model of the proposed hybrid energy system*

Following the power plant modelling discussion found in Section 1, the platform consists of physical agents that are assigned to each type of physical entity found in a ship power plant. The essential data associated to agents are collected, organized, and stored in a database. Figure 2 shows a Unified Modelling Language (UML) class diagram of following types of agents: Photovoltaic array Agent (PVA), Battery Agent (BA), AC Generator Agent (GA) and Load Agent (LA).

Agent LA: The load agent LA is responsible for monitoring the evolution of the load. It manages these load to make it a controllable energy resource.

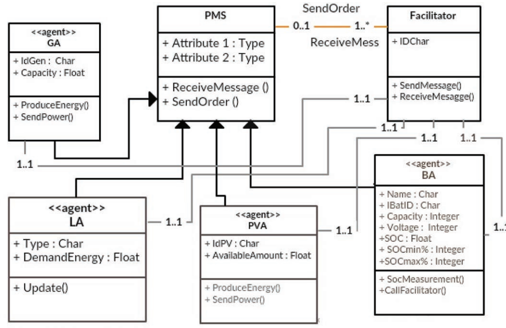

Figure 2. System infrastructure.

Agent PVA: This agent is dedicated to control the energy generated by the solar source. The agent PVA contains a DC/DC converter with MPPT which enables the PV sources to work at the maximum power point in a highly fluctuated environment. Indeed, the PVA agent normally uses a Maximum Power Point Tracking (MPPT) technique to continuously deliver the highest power through the converter to the load when there are variations in irradiation and temperature (Raju et al. 2015).

Agent BA: The agent BA, installed at each battery unit, can monitor the State of Charge (SOC) of the battery and manage the charge and discharge of the batteries. Obviously, the battery bank has two statuses (charging and discharging corresponding to the renewable energy source and the load, respectively). In fact, when the power, sent from the PV sources is insufficient to supply the load, the battery bank is discharged to meet the load demand as an energy supplier. In the opposite case, when the supply from the solar sources exceeds the load demand, the battery bank is charged and viewed as the load. BA has attributes such as State of Charge (SOC), SOCmax, SOCmin the capacity and the status (charge/discharge).

AC *Generator Agent* (*GA*): This agent, installed at each diesel generator, has attributes such as the generator minimum/maximum output value.

The information stored in the database includes:

- available renewable energy generator power production capacity
- hourly solar insolation
- hourly demand load profile of the ship
- diesel generator capacity
- battery bank capacity
- hourly scheduling of different renewable energy generators
- unit cost of generation of different energy sources
- minimum and maximum SOC of battery bank.

The main objective is to fulfill the load at a particular time by minimizing the use of diesel generators. To accomplish this, the agents are required to cooperate and coordinate so that they make efficient use of the power supplied by other sources at the time of power shedding.

The Power Management System (PMS) controller is informed about the demand and producer availability in one negotiation cycle. At the timestamp of power shedding, if the electrical power from renewable resources is insufficient, demand is fulfilled by the diesel generators. PMS sends a message of announcement of tender to all agents in the ship's grid.

All agents reply a message of purchase of electrical power. The message includes the amount of electrical power i.e. load demand. All power producer agents in the grid reply a message of electrical power. The message includes the generator available power and states of charges for the battery storage.

In the next step, controller makes a decision on operation of different producers based on generated load demand. The demand is checked with the power available with the producer. If the demand is not fulfilled by first PV resources, PMS sends operation command to next producers (batteries and AC generators) until the demand is fulfilled. Finally, generation load pattern is displayed for a given time period and next negotiation cycle begins.

2.3 *Concept of operations for modeled scenario*

The concept of operations for modeled scenario uses four kinds of agents: Battery Agents, AC Agents and PV Agents. The most important work is done by the PMS controller. It uses the control algorithm, called the dispatch strategy for a hybrid energy system, for calculating the energy flows from the various sources like diesel generator and different types of renewable generators, towards the loads, including the charging and discharging of the battery system, on a time scale of minutes to hours, in such a way as to optimize system performance in terms of operating cost.

The solar power, load, state of charge (SOC) of the batteries and loads are monitored hourly. Based on these data, the agent takes best possible actions for energy management of the hybrid energy system on the ship. Considering all the possible options available for the solar resources, a flow chart is drawn as shown on Fig. 3.

By observing hourly operation of proposed hybrid energy system (see Fig. 1), there are four possible dispatch strategies to meet the load (Gupta et al. 2011).

1. *Battery charging strategy*: The use of only the battery to absorb the surplus power. The absorption of energy continues until:
   - Maximum battery SOC is reached.
   - The renewable power is not sufficient to meet the load.
2. *Battery discharging strategy*: Battery energy may be used to meet the load in a timestamp. The battery discharging continues until:

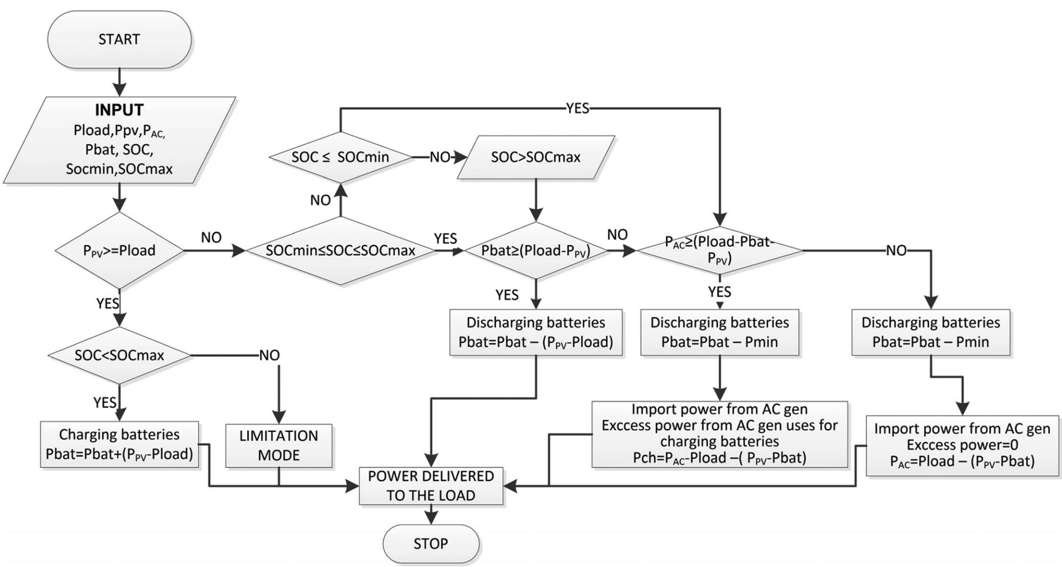

Figure 3. Flow chart of power management on the ship.

- Minimum battery SOC for discharge is reached.
- The renewable power is sufficient to meet the load.
- The renewable power is sufficient to meet the load as well as continue to charge the batteries.

3. *Load following strategy:* The diesel generator is running to follow the load, no charge to the battery and no discharge from the battery.
4. *Cycle charging strategy*: The diesel generator is running to cover the load demand and charge the battery. The diesel continues running for its prescribed minimum run time; after that, the diesel continues running until one of the conditions is met:

- The prescribed SOC set point has been met, or
- The renewable power is sufficient to meet the load.
- The renewable power is sufficient to meet the load as well as continue to charge the batteries.

Considered system has three operation modes to supply the load, which are given below:

Mode 1 (Stand Alone Mode): In this mode there is no sufficient solar power needed by the load and the state of charge (SOC) of the battery is also very low. All renewable sources are disconnected from the grid and the whole load will be supplied by the AC generator. In this mode the charging strategy is generally used in combination with the load following strategy. The PV power is not useful for the grid and is stored in battery storage units.

Mode 2 (normal mode): The total electrical power from renewable energy source is less than the power needed by the load, the energy deficit is covered by the battery source and the PMS controller puts the battery in the discharge condition (discharging strategy). If the storage cannot supply the whole, the rest will be supplied by the AC generator. If the generate power greater than the cycle charging strategy can be selected, else the load following strategy can be selected.

Mode 3: For this mode the photovoltaic panels produce the electric power more or equal than power references of the grid and the batteries are available. All sources are connected to the grid and the inverter delivers the electric power to meet grid power references. If the total power generated by the renewable energy is greater than the power needed by the load, the energy surplus is stored in the batteries (charging strategy). If the produced electric power from PV panels is less than power references of the grid, the batteries can be used to compensate this difference (discharging strategy). In the case of lack of energy during 1 hour the energy is obtained either from the batteries or from the AC generator.

3 THE USE CPN MODEL OF THE INFORMATION SYSTEM

3.1 *Colored Petri Net*

Colored Petri Net (CPN) is a language for the modelling and validation of systems in which concurrency, communication, and synchronization play a major role. CPN is a discrete-event modelling language combining Petri nets with the functional programming language Standard ML. A CPN model of a system is an executable model representing the states of the system and the events (transitions) that can cause the system to change state. The CPN language makes it possible to organize a model as a set of modules, and it includes a time concept for representing the time taken to execute events in the modelled system.

Since PN simulates all of the system states and all transition judgments by token passing in a quite straightforward manner, the graphical representation for a moderate system shows very complex configuration. In CPN a place node owns several colors to represent different states and base on the colors the judgment functions in a transition node checks the states of the incoming place nodes. These characteristics dramatically simplify the graphical representation of the traditional PN and improve the execution efficiency too.

3.2 *Agent modeling with CPN approach*

By combining the MAS framework, algorithms and rules in CPNs, the CPNs model for the switching process of PMS operating mode is depicted in Fig. 4. The model is designed as the CPN tools (Version 4.0.1). In contrast to low-level Petri nets (such as Place/Transition Nets), each of these tokens carries a data value, which belongs to a given type. As an example, place BA has one token in the initial state. The token value belongs to the type *SOC* and represents state of charge for batteries. The detail declaration of all colors and variables is shown on the Fig. 5. The descriptions of all the places are illustrated in Table 1. Hourly intervals are considered for the design control strategy, where all the involved variables are assumed to be constant throughout these intervals. Accordingly, the place Next_hour represents daily hour and it has one token. Initially this value is 0, and it is updated for one hour.

The place BA is used to model the battery agent which controls states of the batteries. Three states for the batteries are considered and they

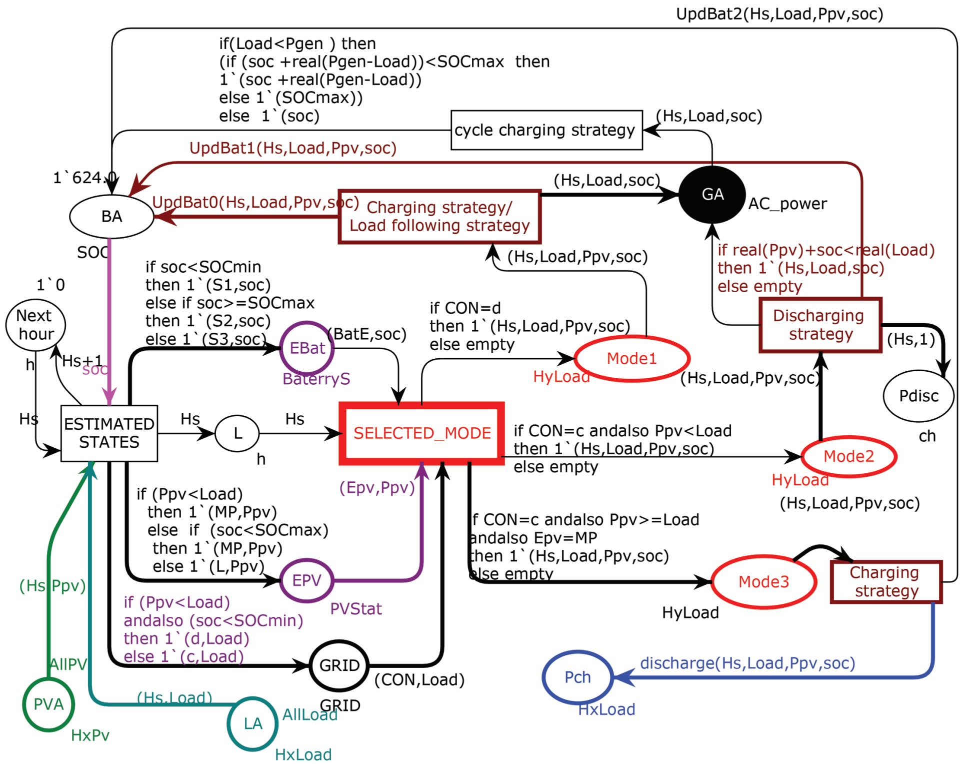

Figure 4. The CPN model for the cooperation process of the MAS.

Figure 5. The color settings and variable declarations.

are represented on the CPN model by three token colors (P1, P2, P3) of colors set *batType* with following declaration:

$$colst\ batType = with\ P1\ |\ P2\ |\ P3. \qquad (1)$$

It means that places having this colors set will have the value P1 or P2 or P3 as their token color. For the first color (P1), the battery is empty and this state is reached when its SOC (State of Charge) becomes equal or inferior to a minimum value (SOCmin). This condition is expressed as:

Table 1. The meaning of places in CPN.

Places	Description
BA	Battery Agent
PVA	PV Agent
LA	Load Agent
GA	AC Agent
GRID	Grid connection
Ebat	Estimated states for batteries
EPV	This place represent in which mode PV is working
Mode1 Mode2 Mode3	Selecting mode of the power station
Pch, Pdis	Values of the surplus power (Pch), or the value of the load that has not been met (Pdis)
NextHour	This place is daily hours

$$SOC <= SOCmin, \qquad (2)$$

where SOC is the estimated value of the state of charge.

For the second color (P2), the battery is fully charged and this state is reached when its SOC becomes equal or higher to a maximum value:

$$SOC >= SOCmax. \tag{3}$$

For the third color (P3), the battery is in an intermediate state if remaining conditions are satisfied:

$$SOCmax. < SOC < SOCmax. \tag{4}$$

The place PVA on Fig. 4 is used to model PV agents. Photovoltaic panels can work in the well-known MPPT mode (token color ML in color se PVstates) or in a power limitation mode (color L) when more power are available than required by the loads (Lu et al. 2010). In CPN model it is defined as color set PVstates.

To describe the connection with the ship's grid the place GRID is modelled. Two states have been defined. The first state (color d on Fig. 4 and 5) corresponds to the disconnection of the renewable sources from the grid. When the PV production is smaller than the required grid power and the storage units are fully discharged, the priority is given to charge the storage units in order to make available as soon as possible the power station in a safety operation. The second state (color c) corresponds to the grid connection.

The transition SELECTED MODE is the switcher and its aim is to switch from one mode to another according to the climate condition, the state of charge of the battery and the load. When this layer receives the information from the application layer in places Ebat, EPV and GRID, this layer selects the next node as aforementioned mode. Each mode is represented by a single place: Mode1, Mode2 and Mode3.

The transition SELECTED_MODE is enabled for all modes, but it can only occur for one mode at a. This situation is called a conflict (because the binding elements are individually enabled, but not concurrently enabled). This transition is in conflict with itself. The switching between the modes is determined by evaluating the corresponding arc expression given according to the rules of dispatching strategies described in Section 2. In presented CPN these rules are defined as arc functions to places Mode1, Mode2, Mode3.

4 CONCLUSION

The defining property of a shipboard power system is a large number of electric components that are tightly coupled in a small space and when a fault happens in one part of the system, it may affect other parts of the system. Safe, secure and efficient shipping on clean oceans, suggested by IMO requires the development of appropriate designs, operational knowledge and assessment tools for energy efficient design and operation of ships. The design of a future ship will require the development of new and increasingly sophisticated methods for modelling and simulation of complex systems that must be integrated in order to produce the total energy consumption of a ship. Control architecture for power distribution systems has to be hierarchical, distributed and easy to adapt. A complete logistic chain of this control architecture will be modelled by Colored Petri Net (CPN), which connects effective agents for autonomous control of complex distributed systems with agents for the control of power management systems.

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