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Implementation of a Power Management System on Combat Robots based on a Hybrid Energy Storage System

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ABSTRACT

This paper presents a power management (PMS)-based resource regulation system for combat robots equipped with batteries, supercapacitor banks, and solar cells. Hybrid energy storage source arrangements are needed to increase operational duration and increase the range of combat robots. Integration of multiple devices with different characteristics requires the implementation of a PMS. Distribution of the load of a combat robot by solving a power management problem, formulated as a finite quadratic program (CQP). Optimization of parameters is carried out, such as speed, drag coefficient and operating point of robot components, which are then regulated by the PMS controller. Data information during robot maneuvering by the PMS is measured and takes into account power management issues during the control period. In this research simulation, variations in weight factor parameters are given to determine various difficulties, namely regenerative power management. The simulation results show that the combat robot power management control system is capable of optimally generating electrical power loads for all components. In another study, a comparison of CQP performance in power management is comparable to benchmark performance after being analyzed based on nonlinear model predictive control.

Keywords: combat robot, hybrid energy, PMS, and CQP.

INTRODUCTION

An unmanned vehicle is a vehicle system that can be controlled autonomously and manually remotely by an operator (Mohamed et al., 2023; Peng et al., 2023). Electrically powered combat robots are part of the technological products that have been used by several countries to assist in combat tasks, but the technology currently applied still depends on the use of batteries which do not yet use a power source other than batteries, so if you only use battery power then the operational duration will not be long (Gorre et al., 2020; Impram et al., 2020). Combat robots have also been developed using fuel engine power but the noise produced can be heard by the enemy, this will be shot by the enemy. Hybrid technology is needed to accommodate this problem, namely by controlling the combat robot's power system using batteries but can also be supplied from solar cells, so that the power consumption required by the components is regulated according to the load received. The efficiency value is achieved by using the PMS method, so the duration of use can be longer and the robot control distance can be maneuvered further when using autonomous mode (Dewi, 2022).

In electric vehicle power systems to increase mileage, using ICE technology results in less power loss when combined with batteries and SC (Jiménez-Espadafor et al., 2015). Electric vehicle systems save more energy in cold climates by circulating waste heat from the range extender for cabin heating (Di Cairano et al., 2021; Gissing et al., 2015; Zhang, Lu, Kadam, et al., 2023; Zhang, Lu, Ouderji, et al., 2023). The average total cost of use, maintenance, and repair costs of electric vehicles with hybrid energy storage systems (HESS) are cheaper than pure electric vehicles by 11.5% and 9%, respectively (Propfe et al., 2012). Although the use of HESS in electric vehicles can extend the driving range, a power management system (PMS) is required to coordinate multiple energy storage devices. Rule-based energy management strategies are widely realized in electric vehicles built with HESS (Astina et al., 2012; da Silva et al., 2022; Hoen et al., 2023; Mohammed et al., 2023; Yang et al., 2022). This approach is considered more efficient in using parameters and settings that can be applied. Some governing control systems can be easily extracted using optimization techniques such as dynamic programming and artificial neural network algorithm-based optimization (Y. Chen et al., 2023).

However, the extracted control system still depends on the terrain pattern. If you use a fuzzy logic control system, it can also regulate the energy use of long-range hybrid vehicles and EVs (Li et al., 2012). Fuzzy logic control systems are able to work well for electrical management on ships (B.-C. Chen et al., 2014; Z. Chen et al., 2017). The fuzzy logic control system is able to make rational decisions quickly, but the energy optimality value is not good. As the control system parameters depend on the operator's experience, it becomes very dominant for the fuzzy controller membership function. Various adaptive methods are also applied to solve online power management problems, such as stochastic DP and line search method (Thirunavukkarasu et al., 2022). As it turns out, this algorithm requires complete knowledge of the journey. The use of convex optimization can be used for many purposes in EV applications, and energy management (Cha et al., 2023; Tran et al., 2020). Meanwhile, the convex optimization algorithm can be combined with the DP formula to solve discrete decision optimization problems. Quadratic programming mathematical algorithms integrated with other decision-making programs improve the energy efficiency of plug-in hybrid electric vehicles (Z. Chen et al., 2015). The application of convex optimization algorithms is still limited to getting global solutions that are not specific to component needs. The use of predictive control models can be applied through optimal control to optimize the system in the future (Viljoen et al., 2020). The power supply capability is balanced between the battery and supercapacitor using linear model predictive control.

This system can adapt DP to solve discretized optimization problems. Xiang et al (Xiang et al., 2017). Meanwhile, the implementation of energy management for dual-mode power sharing hybrid EVs uses a nonlinear model predictive control (NMPC) algorithm based on forward DP. Prediction methods that provide fast and accurate information are an important element in creating a good predictive control method model. NMPC is considered computationally inefficient when solving optimal control problems with large and unbalanced loads. The PMS method used in this research is considered suitable for use on electric combat robots using HESS technology. Hess technology is able to avoid large computing loads and can be applied in real-time. PMS is implemented from the optimization and component levels. In previous levels it only functions as the main controller. This requires setting several settings points that will be optimized, executed by the controller at the component level. Outcome, combat robots are able to maneuver at optimal speeds and have longer operational duration.

RESEARCH METHODS

As shown in Figure 1, it shows the experimental method where the combat robot was tested on a road with a slope of 0^0, 5^0, 10^0, 15^0, 20^0, 25^0, 30^0. Comparison of trials of 3 methods for combat robots, first methods using a power control system without PMS; second methods using a power control system with PMS and SC; third methods using a power control system with PMS, SC and Solar cells. The test results show the efficient values of motor speed variables, component power consumption, and operational duration resulting from the three methods. The combat robot is made like a tank with a small size, namely 100cm long, 90cm wide, 60cm high. The drive wheels are attached to a chain that is used to tread the ground for maneuvering. The width of the chain tread is 10cm, the length of the chain wheel is 2 meters, the number of chain wheels is 2 units, namely 1 on the left and 1 on the right which are installed symmetrically. The robot body drive system uses two 5A 24V dc motors to drive the robot body. At the top of the body, there is a weapon system platform using 2 DC 4A 24V motors, consisting of 1 motor for azimuth movement and 1 motor for elevation movement. The total weight of the combat robot is 100 kg, the weight of the weapon and the azimuth platform is 4 kg, the weight of the weapon and the elevation platform is 6 kg. The trigger weighs 300 grams, uses a solenoid with a trigger pull capacity of 10 kg/cm. The power source for driving combat robot maneuvers is 80AH x 24 Volt = 1920 VAH. The power source for moving weapons and shooting is 40AH x 24 Volts = 960 VAH. Another source of power is solar cells with a total size of 50cm x 100cm placed on the robot body and 2 solar cells measuring 10 x 80 cm placed on the right and left above the rocket launcher. The solar cell power supply for the robot body is 50AH x 12 V = 600VAH, and the solar cell power for the weapons is 10AH x 12V = 120VAH.

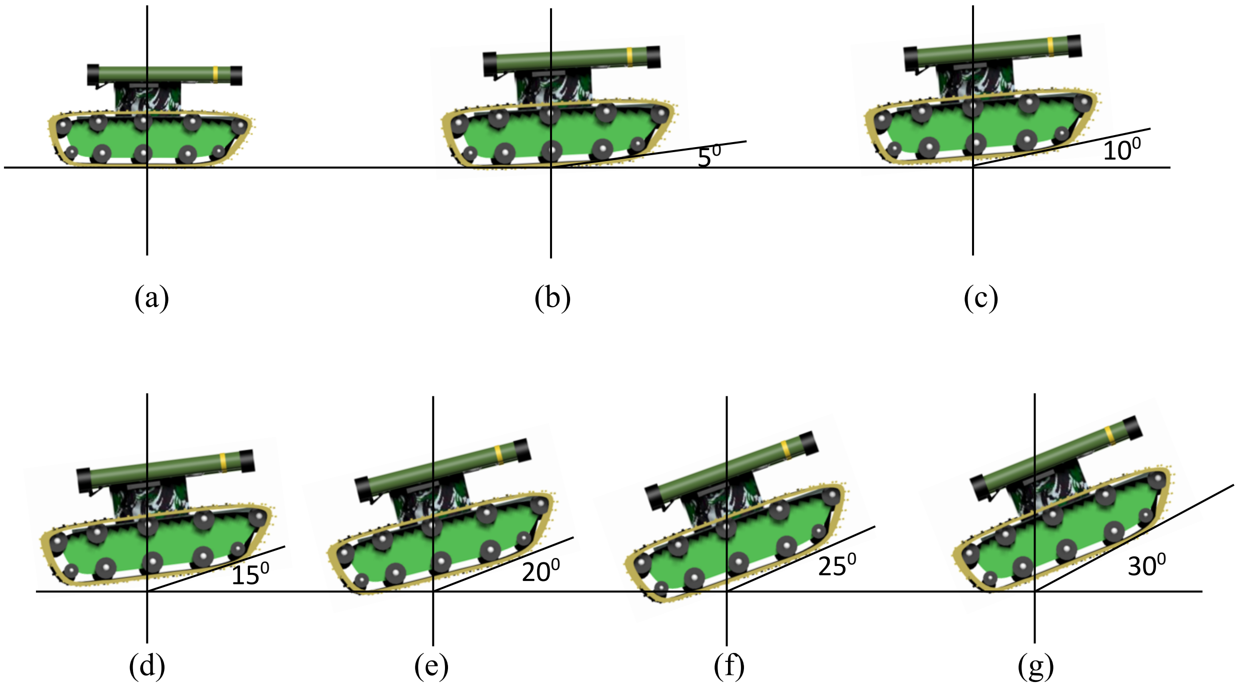

Figure 1. experiemental of battle robot on road slope
(a)0^0 (b) 5^0 (c) 10^0 (d) 15^0 (e) 20^0 (f) 25^0 (g) 30^0

From Figure 2, the power management (PMS) as power controllers of the major components. Then, the single-ratio gearbox transmits driving torque to the rear wheels. Mechanical brakes cooperate with the motor to decelerate the car. A supercapacitor (SC) bank helps provide high power for the car. A range extender charges up the battery pack while driving. Each subsystem is controlled by its control system to follow the optimised set-points.

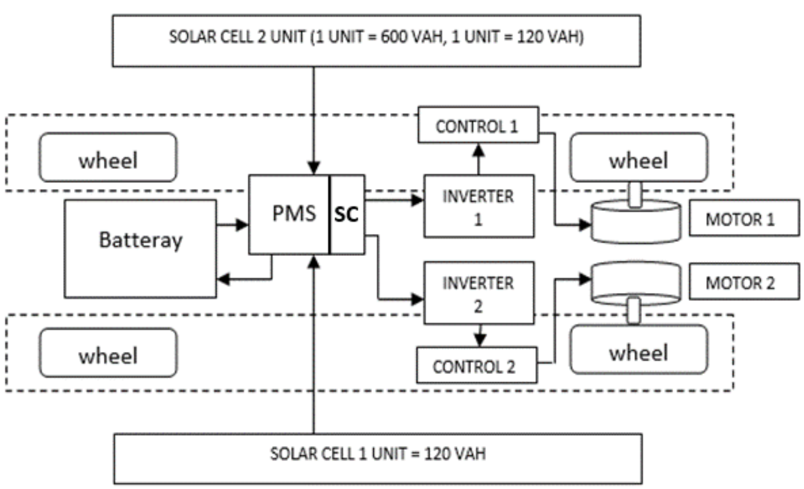

Figure 2. A diagram of PMS and SC.

Measurements are carried out using power measuring instruments (watt meters), time measuring instruments, motor speed measuring instruments (rad/s). Measurements on components are adjusted to the conditions of the combat robot on flat terrain or 0 degrees, incline angles of 5 degrees, 10 degrees, 15 degrees, 20 degrees, 25 degrees, 30 degrees. Comparing the power control system for combat robots without PMC, the power control system using PMC and Supercapacitor (SC), and the power control system using PMC, SC adding solar cells for energy supplement. The variables measured are motor speed performance, component power consumption, resource supply, operational duration of the combat robot system.

Table 1. Component power consumption without PMS

degree angle ramp							
	0	5	10	15	20	25	30
Speed (rad/m)	315	257	212	186	151	112	89
Power Consumption (VAH)	1940	1942	1944	1949	1950	1953	1955
Power Source (VAH)	2880	2780	2580	2430	2180	2029	1872
Operating Duration (s)	3300	2692	2201	1948	1582	1173	932

Table 2. Components power consumption using PMS and SC

	degree angle ramp						
	0	5	10	15	20	25	30
Speed (rad/m)	320	309	298	287	276	261	249
Power Consumption (VAH)	1940	1940	1940	1941	1941	1941	1942
Power Source (VAH)	2880	2820	2750	2683	2616	2587	2449
Operating Duration (s)	3500	3406	3390	3275	3139	3003	2887

As shown in table 1, the power consumption of components that do not use PMS, the motor speed decreases significantly with respect to the incline angle, every 5 degrees it rises, it decreases between 50 rad/m to 60 rad/m. This is due to poor component power distribution, which causes power losses. due to the effects of inaccurate component power usage.

Table 3. Components power consumption using PMS, SC and Solar cell

	degree angle ramp						
	0	5	10	15	20	25	30
Speed (rad/m)	328	319	309	301	291	283	275
Power Consumption (VAH)	1943	1943	1943	1943	1943	1944	1944
Power Source (VAH)	3440	3322	3251	3184	3117	3089	2953
Operating Duration (s)	4500	4438	4390	4305	4289	4124	3979

Meanwhile in table 2. Power consumption of components using PMS and SC. The use of power sources is more stable and efficient than if the system was without PMC. This has an impact on the duration of the combat robot if using PMC and SC is 61.1% longer than without PMC. Energy waste can occur because the distribution control system does not match the load effects on the components. The role of supercapacitors also plays a role in making the power source supply more stable and reducing power losses by up to 39.7%. As shown in table 3, the PMC control system, SC adding supply from a solar cell (600 VAH + 120 VAH) or 720 VAH can actually increase the efficiency value by 81.8%. This has an impact on faster and more stable motor speed performance, more efficient power supply, longer operational duration of the combat robot.

RESULTS AND DISCUSSION

Figure 3 shows a comparison graph of the speed of a control system without PMS, a control system using PMS and SC, a control system using PMS, SC and solar cells. The comparison results in Figure 2 show that the power control system that uses PMS, SC and solar cells produces the fastest robot motor speed and is still able to maintain stability even when given an incline angle of 5, 10, 15, 20, 25, 30. Meanwhile the system control using PMS and SC produces the same stable speed as the PMS, SC and solar cell control systems, but the robot motor speed is lower than the PMS, SC and solar cell control systems. A different thing is shown by the power control system which without using PMS, on average produces the lowest robot motor speed which tends to be unstable if given a load at an angle of 5, 10, 15, 20, 25, 30. The most prominent thing is that at an angle of 30 it experiences 81.3% reduction in efficiency due to load effects and causing power losses.

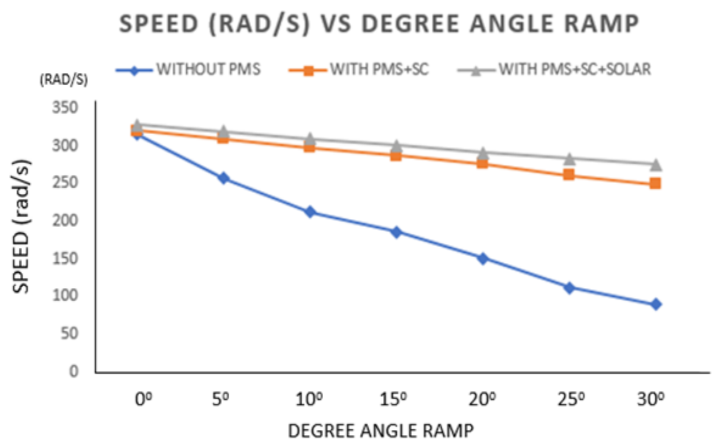

Figure 3. Comparison Speed (rad/s) vs Degree Angle Ramp

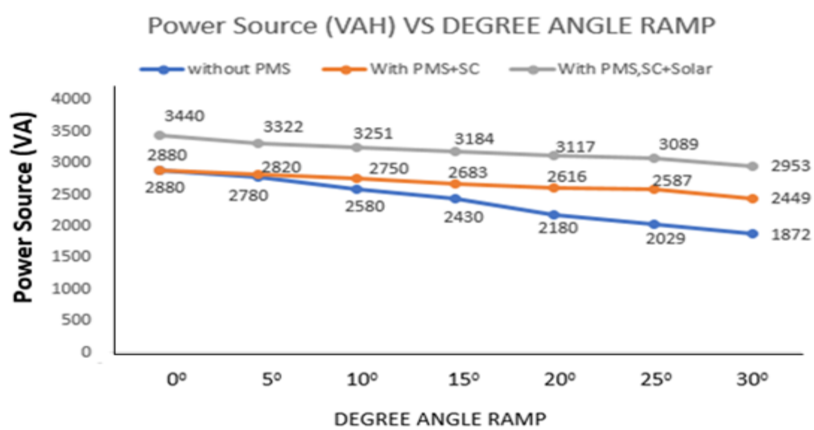

Figure 4. Power Souce (rad/s) vs Degree Angle Ramp

As shown in figure 4. Power Source (rad/s) vs Ramp Angle Degrees, the comparison results show that the power control system that uses PMS, SC and solar cells produces the highest power value and is able to maintain a decrease in power value as the combat robot's power requirements are adjusted with incline angles of 5, 10, 15, 20, 25, 30. Control systems using PMS and SC produce 94.5% lower efficiency compared to PMS, SC and solar cell control systems, this occurs because the influence of the presence of solar cells can increase source by 19.4% and increase power efficiency by 1.5%. However, if the combat robot's power source is without PMS, there will be a 36.6% decrease in efficiency compared to if it uses PMS, SC and solar cells, and a 23.6% decrease in efficiency. Based on the analysis of the use of resource settings, the one that is efficient and has the greatest power value is the combat robot power control system that uses PMS, SC and solar cells.

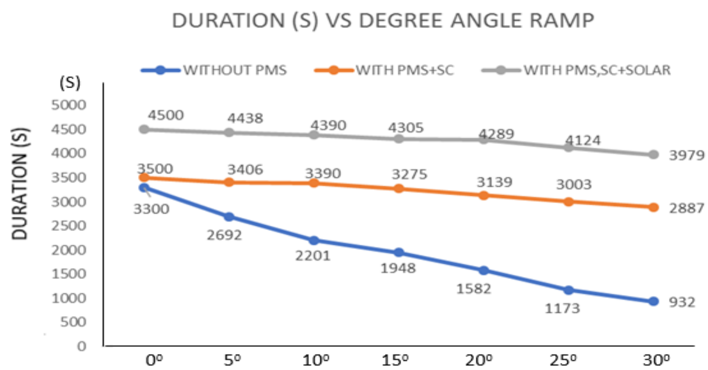

Figure 5. Duration (s) vs Degree Angle Ramp

As shown in Figure 5. Operational duration (s) vs Degree Angle Ramp. The comparison results show that the power control system that uses PMS, SC and solar cells produces a longer operational duration and is able to maintain a decrease in operational duration as the combat robot moves through incline angles of 5, 10, 15, 20, 25, 30 with an efficiency value of 98. 6% higher than the PMS and SC control system with a duration efficiency value of 96.1%, this occurs because the solar cell can increase the operational duration by 2.5% longer, whereas if the combat robot resource without PMS decreases up to power 31.6% remaining power compared to using PMS, SC and solar cells, and a 67% reduction in operational duration. Based on the analysis of the use of resource settings, the one that is efficient and has the greatest power value is the combat robot power control system that uses PMS, SC and solar cells.

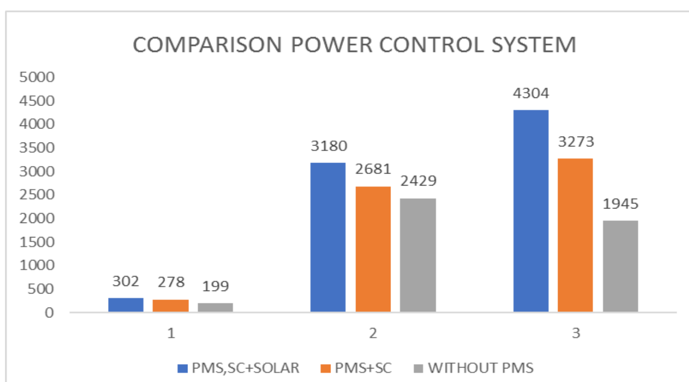

Figure 6. Comparison of Power Control System

In figure 6. comparison speed (rad/s) vs degree angle ramp, in figure 4. power source (rad/s) vs degree angle ramp, and figure 5. duration (s) vs degree angle ramp, shows that the power control system for combat robots, the most optimal is a combat robot control system using PMS, SC and solar cells which produces the highest average speed, namely 302 (rad/s), the highest average power source (VA), namely 3180 (VA), the average operational duration is 4296 (s).

CONCLUSION

The power control system that uses PMS, SC and solar cells produces the fastest robot motor speed and is still able to maintain stability even when given an incline angle of 5, 10, 15, 20, 25, 30. The power control system that uses PMS, SC and solar cells produces the highest power value and is able to maintain a decrease in power value as the combat robot's power requirements are adjusted with incline angles of 5, 10, 15, 20, 25, 30. The power control system that uses PMS, SC and solar cells produces a longer operational duration and is able to maintain a decrease in operational duration as the combat robot moves through incline angles of 5, 10, 15, 20, 25, 30 with an efficiency value of 98. 6%. The power control system for combat robots, the most optimal is a combat robot control system using PMS, SC and solar cells which produces the highest average speed, namely 302 (rad/s), the highest average power source (VA), namely 3180 (VA), the average operational duration is 4296 (s).

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