Vol. 05, No. 1 (2023) 133-146, doi: 10.24874/PES05.01.013

Proceedings on Engineering Sciences

www.pesjournal.net

ALTERNATIVE ELECTRIC PROPULSION SYSTEM FOR HEV MANIPULATING PREDICAMENT VIA POWER PREPOTENCY

Reshma. S. [1]

Received 21.11.2022.
Accepted 27.01.2023.
UDC – [629.331:621.33]:004.942

Keywords:

Hybrid Electric Vehicle, Fuel Cell, Ignition Delay, Hydrogen Depletion, Energy Demand, Multiple Agent Modelling.

ABSTRACT

Hybrid Electric Vehicle (HEV) is considered as the evolution of Electric vehicle in which hydrogen is taken as a fuel. In this paper, a novel Alternative Electric Propulsion System has been proposed to tackle the major issues in HEV such as, the long auto ignition delay, hydrogen gas fuel depletion and power energy demand. Initially, Perpetual extent cauldron has been introduced to tackle the long auto ignition delay via considering pressure levels, lean, quasi-stoichiometric and rich conditions for estimation of delay time which handled through simulation. Consequently, Canny predicament approach is adopted to handle the hydrogen depletion in emergency cases by introducing predicament manipulate algorithm where fuel reserved in house as well as boost converter will contributed in this algorithm to fulfill the hydrogen demand. In addition, Astute power prepotency is proposed to manage the power energy demand with the cooperation of manifold proxy system, which can be achieved via communication between multiple agents via supervising agent as well as predicament manipulate algorithm can subordinate for such power energy demand. Thus it provides, an efficient electric propulsion system for hybrid electric vehicle with power management. This proposed system has been implemented in MATLAB Simulink and compared with the recent researches.

Nomenclature list:

τ_{id}	- Ignition delay
φ	- Equivalence ratio
E_a	- Activation energy
R_g	- Gas constant
T_{cc}	- Cylinder charge temperature
α, k^*, n^*	- Empirical constants
T_u	- Unburned temperature
P_V	- Vehicle power (W)
P_R	- Rolling power (W)
P_{VD}	- Viscous drag power (W)
P_W	- Wheel power (W)
P_S	- Slope effect power (W)
P_{Br}	- Braking vehicle power (W)
η_{gr}	- Gear efficiency (%)
η_{inv}	- Vehicle inverter efficiency (%)
η_m	- Vehicle motor efficiency (%)
τ_{lack}	- System lacking rate
τ_{rec}	- System recovery rate
Q_i^{req}	- Required H2 amount from component i
Q_i	- Gathered H2 amount from component i
I_{CSC}	- Control SC operating current (A)
I_{SCHR}	- SC home reserve (A)
I_{SC}	- Super capacitor current (A)

---

[1] Corresponding author: Reshma. S.
Email: reshmasaroj@gmail.com

D_{BSC} - SC boost delay cycle
I_{rq} - Required current (A)
I_{rsc} - Required super capacitor current (A)
SOC_{vh} - Vehicle hydrogen fuel state (%)
SOC_{cs} - Charging station state of charge (%)
SOC_{sc} - Super capacitor state of charge (%)
SOC_{vhi} - Initial vehicle H2 state of charge (%)
SOC_{csi} - Initial charging station H2 state of charge (%)
SOC_{sci} - Initial super capacitor H2 state of charge (%)
SOC_{req} - Required H2 state of charge (%)
SOC_{rcs} - Required charge station H2 state of charge (%)
SOC_{rsc} - Required SC H2 state of charge (%)
Q_{vh} - Actual vehicle fuel reserve (mol)
Q_{cs} - Charging station hydrogen fuel amount (mol)
Q_{vh}^{max} - Maximum vehicle reserve amount (mol)
Q_{cs}^{max} - Maximum charge station reserve amount (mol)
I_{sc}^{max} - Maximum SC operating current (A)
Q_{rcs} - Required charge station hydrogen fuel amount (mol)
Q_{rsc} - Required super capacitor hydrogen fuel amount (mol)
D_{FC} - Decision making factor of fuel cell (‘1’ or ‘0’)
D_{CS} - Decision making factor of charge station (‘1’ or ‘0’)
D_{SC} - Decision making factor of super capacitor (‘1’ or ‘0’)

1. INTRODUCTION

Currently, conventional energy sources generate most electricity in many countries which are based on fossil-fuel. These generating resources are continuously polluting the air and emitting greenhouse gases. There is a strong commitment by the Governments of many countries to reduce greenhouse gas emissions and global warming through the use of renewable energy resources (Haidar, et al., 2020). In order to tackle this, significant researches are rapidly evolving because of its crucial role in endowing smartness and flexibility to multi-energy systems like smart grids (Imran, Adil, et al., 2020), microgrids (Leonori, S., et al., 2020), Nano grids (Kalair et al., 2020), smart homes (Akbari-Dibavar et al., 2020) and Hybrid Electric Vehicles (HEVs) (Guo et al., 2019).

Microgrid is an emerging paradigm of localized electrical clusters comprising of distributed energy resources (DERs) including intermittent renewables and controllable local generators (Jia et al., 2020). Even though the current technologies of power electronics have enabled easy integration of renewable energy sources (RES) into microgrid, its reliable and economic operation still necessitates specific energy management regimes that can effectively coordinate the internal schedulable and non-schedulable sources (Tooryan et al., 2020). The characteristic of microgrid with flexible and efficient of DG units makes renewable energy which mainly includes Photovoltaic generation (PV) and Wind Turbine (WT) accessible on a large scale (Rajamand, 2020). At the same time, because of the flexible composition of the microgrids, the energy trading in microgrids has become an emerging power market in the presence of multiple nodes with different owners in the microgrid (Zhao et al., 2020). In microgrid, the electric vehicles (EV) enable full consumption of energy and produce almost zero emission. Hybrid power system is conceived to give back for underperformance in the battery. A HEV consists of I.C engine vehicle with battery and electric motor (Patassa, 2020). The benefits of HEVs comprise good fuel economy and less emission. The natural flexibility of HEVs will permit them to be utilized in wide range of applications. A HEV provides increased fuel efficiency and emissions are decreased thus can minimize dependence on fossil fuels (Baskar et al., 2020).

Hybrid electric vehicles (HEVs) currently represent a profitable technology to potentially comply with worldwide tightening CO_2 emission regulations and simultaneously accomplishing customers’ needs. Moreover, HEVs constitute an important stage in the global paradigm shift of the transportation sector towards electrification (Anselma, P.G., et al.). A typical HEV has two energy sources, namely the battery and the fossil fuel, and two energy conversion devices, namely the engine and the electric motor. Both the engine and electric motor can provide the power to the wheels. However, there is much possible power or torque split ratios between the engine and the electric machine.

In order to achieve optimal fuel economy, the energy management strategy (EMS) should be carefully devised to control the power or torque split ratio. Currently, various EMSs have been reported and can be classified into three categories: rule-based, optimization-based, and data-driven (Du et al., 2020). However, due to the use of internal combustion engines (ICE), the traditional HEVs still lead to the consumption of fossil fuels and the emission of greenhouse gases (Tooryan et al., 2020). Considering the higher system efficiency and zero-emission property of the Proton Exchange Membrane Fuel Cell (PEMFC), fuel cell hybrid electric vehicles (FCHEVs) are becoming the competitive substitution to traditional HEVs in automotive industries.

Currently, several technical challenges, such as the hydrogen storage, the durability of the fuel cell system (FCS) and the early stage of the hydrogen refueling infrastructures, still remain the major obstacles in the commercialization process of FCHEVs (Zhou et al., 2020). Hydrogen is the most abundant element in the world and produces only water vapor as a result of chemical reaction that occurred in fuel cells. Therefore, fuel cell electric vehicles, which use hydrogen as fuel, continue its growing trend in the sector. Hydrogen (H_2) and its derivatives have been used in automotive sector as a fuel since last century. (Xu et al., 2020) In road transportation, generally, H_2 fueled conventional internal combustion engines (ICE) in gaseous form is utilized.

H_2 effected positively to engine performance in terms of torque and power due to its heating value. In the way of entrance to engine, gas form of H_2 which enriched the air in intake manifold, increases the air/fuel ratio that it is end with lesser fuel consumption. Additionally, H_2 reduced the emissions (except NOx) because of carbon absence of its nature (Tanç et al., 2020). However, the transition from ICEVs to battery EVs (BEVs) has not been smooth because the battery technology development is still in its early stages. Hybrid electric vehicles (HEVs) have proven to be a necessary bridge into the eventual complete BEV (Tran et al., 2021).

The HEVs require an efficient system for the management of energy which is dealt by Energy Storage System (ESS). Regarding the ESS technology, the combined use of battery-and-hydrogen ESS is a promising solution, especially if hydrogen is produced in the microgrid itself and exclusively through renewable resources. This hybrid ESS can be used not only to meet the load demand, but it can also be managed with economic interests. Indeed, the ESSs can participate in the electrical market by purchasing the energy from the main power grid, storing it, and selling it later to the main power grid during the peak demand hours (Vivas et al., 2020). With all these advantages, hydrogen has been a significant desire for automotive manufacturers.

Nowadays, hydrogen can be applied for transport as a main fuel (or supplement fuel) for ICEs and for fuel cell. (Acar et al., 2020) H_2 ICEs have the potential for high power because of more energy per unit mass and high flame speed; high efficiency because of high flame speed that causes high rate of pressure rise in the cylinder and hence near constant-volume combustion and they also have near-zero emissions, because of the absence of carbon in the fuel molecular structure (Arat, 2019). The need for fuel-related properties has brought to the development of detailed chemical kinetics mechanism comprising hundreds of species and thousands of reactions. These mechanisms describe the main oxidation pathways of the main fuel constituents in high and low temperature regions. For this reason, in many preceding works chemical kinetics mechanisms were engineered or modified to better represent the reactivity and the oxidation pathways of the components of interest (Del Pecchia & Fontanesi, 2020).

The most accurate way to simulate the combustion process is including all possible species, reactions, corresponding thermodynamic and transport properties, which is frequently referred to as detailed kinetics model (DKM) (Yu et al., 2017). Such model often involves hundreds of species and thousands or even more reactions for complex multidimensional flows. And thus, the computational cost will be unaffordable for these types of system (Yu et al., 2019). Since hydrogen energy content on a mass basis is around 141 MJ/kg, which is 2.5 times higher than that of methane and 3 times higher than that of gasoline, hydrogen offers the highest specific energy of any fossil fuel (Lee et al., 2019).

Despite these advantages, hydrogen propulsion systems may exhibit long auto-ignition delay as well as unexpected H_2 depletion affecting the expeditious and potent response of the system. Moreover, it requires reconcile of power which may result in the variation of state of charge of the system. To confront the aforementioned issues, a novel alternative electric propulsion system has been proposed. Thus the main contribution of this paper is given below:

- Initially, the long auto ignition delays are estimated through considering different pressure levels, lean, quasi-stoichiometric and rich conditions with the assist of simulation.
- The unexpected hydrogen depletion in emergency cases are handled through house fuel reserve and boost converter as well as the power energy demand also managed by the multiple agent modelling.
- The implementation is done through the MATLAB Simulink as well as the comparisons are provided to ensure the better performance of our proposed system.

The paper is organized as follows: section 2 surveyed the recent related researches; the proposed system has been explained in section 3; section 4 covers the implementation results and comparison; section 5 concludes this paper.

2. LITERATURE SURVEY

Terao et al (Terao et al., 2020), designed fully superconducting generators and motors for future electrified propulsion systems via analytical equations and Finite Element Method (FEM) analysis. The results showed that the high output and high-speed fully super-conducting machines (FSCM) have numerous potential to achieve nearly 50 kW/kg. On the other hand, the high rotation speed machine of 10000 rpm alone generated nearly 200 kW losses. Even other design cases have a lot of possibilities to exceed 16 kW/kg; the results showed that there are many variations of electrified aircraft propulsion systems using the FSCMs. But it did not discuss the transient state of the propulsion systems, such as short circuit problems via system analysis.

Selmane et al (Selmane et al., 2020), proposed a thermodynamic model to analyze the influence of some usual engine parameters such as compression ratio, ambient temperature, turbocharger compressor pressure ratio, equivalence ratio, and engine speed on the performances of a diesel–hydrogen dual-fuel marine engine. The model considered the change in the composition of the working fluid resulting from the combustion cycle as well as the reactive mixture. The dependence of the working fluid specific heat on temperature was also taken into account. But it did not concentrate on detailed combustion models.

D'Ovidio et al. (2020), introduced a partitioning of the hydrogen fuel cell (FC) and novel optimal power control strategy, with the aim of limiting the capacity of the energy storage, still avoiding FC transient operation. The limited capacity of the resulted energy storage systems which, instead, has to answer higher power requests, made it possible to consider the utilization of a high-speed flywheel energy storage system (FESS) in place of high energy density Li-ion batteries. The proposed control strategy was validated by vehicle simulations based on a modular and parametric model; input data were acquired experimentally on an operating electric bus in real traffic conditions over an urban bus line. But the approach limited its attention to vehicles operating on predetermined paths and on some experimentally-measured vehicle missions.

Giap et al. (2020), investigated a hybrid electrical propulsion system of gas engines and a solid-oxide fuel cell (SOFC), quantifying the CO_2 emission and proposed a way to further reduce CO_2 emissions. The indirect-coupling and direct-coupling configurations are proposed and analyzed from the perspectives of energy. In the indirect-coupling configuration, the engine and fuel cell system are only integrated electrically without the transfer of any heat or material stream. In the direct-coupling configuration, the unused remaining fuel, which is released from the fuel cell, is transported to the gas engine, and the unused surplus steam, which is produced from the engine exhaust, is provided with the reforming section of the fuel cell system. But the system corresponded to a complex configuration.

Sadey et al (2020), proposed a hybrid electric propulsion architecture where most of the electric power is transmitted from the generator to the motors without conversion. Doubly-fed induction machines were chosen for generation and propulsion, due to their ability to operate over a range of speeds using reduced-size power converters. It allowed for the stable and independent operation of multiple motors using the power produced by a single generator. The control methodology included synchronization, soft-start, and closed-loop speed control of each motor as a means of controlling output thrust. But it failed to generate required voltage, frequency and current levels.
Terao et al. (2020) did not discuss the transient state of the propulsion systems and Selmane et al. (2020) failed to concentrate on detailed combustion models. D'Ovidio et al., 2020) limited its attention to vehicles operating on predetermined paths and on some experimentally-measured vehicle missions while Giap et al. (2020) exhibited a complex configuration. Sadey, et al. (2020) neglected the generation of required voltage, frequency and current levels. In order to meet the needs and improve the efficiency of hydrogen propulsion system in electric vehicles, a novel alternative electric propulsion system has been proposed.

3. ALTERNATIVE ELECTRIC PROPULSION SYSTEM

In recent years, researchers' attention has been drawn to the use of distributed energy resources and renewable energy sources to reduce the power generation cost and environmental pollution. It emerged in the use of new technologies in the energy systems, like electric vehicles. The energy system requires information interaction between the system operator and its consumers which is accomplished by a smart micro-grid (MG). The development of smart micro-grids makes the use of hybrid electric vehicles (HEV) more suitable and is tending to use hydrogen (H_2) as a valuable energy source. Hybrid electric vehicles become more environmentally friendly due to H_2 enhancement resulting in less pollution which is presented in fig.1. But utilization of H_2 in previous methods exhibited combustion anomalies provoking in long auto ignition delay which further leads to minimized capability of the hybrid electric system. In addition, hybrid electric system may suffer unexpected H_2 gas depletion which affects the expeditious and potent response of the system against any constraint. Hence the fuel consumption has to be controlled which requires the supply of instant power that guarantees normal operation. This instant power supply may result in the variation of the state of charge of the system which in turn requires the reconciliation of supplied power. Henceforth to accord the aforementioned issues like auto ignition delay, unexpected H_2 gas depletion and power management a novel strategy has to be proposed ensuring the design of turbo hydrogen fuel engine for hybrid electric vehicles.

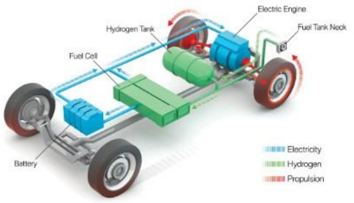

Figure 1. The systematic view of hydrogen fuel electric vehicle

The block diagram of the proposed system is illustrated in fig.2. Emissions from the transportation sector due to the consumption of fossil fuels by conventional vehicles have been a major cause of pollution. Hybrid electric vehicles (HEVs) are a cleaner solution to reduce the emissions caused by transportation, and well-designed HEVs can also outperform conventional vehicles by the utilization of H_2. However, exploiting H_2 resulted in long auto ignition delay which is tackled by Perpetual extent cauldron. It considers pressure levels, lean, quasi-stoichiometric and rich conditions. The ignition delay is estimated by adopting threshold condition which is used to infer auto-ignition occurrence and compares the reactivity with increasing pressure. Moreover, HEVs suffer unexpected H_2 gas depletion affecting the expeditious and potent response the system. To tackle this issue, Canny predicament approach is adopted to optimally manage all operating transitions. It adopts a Predicament manipulate algorithm to overcome the H_2 depletion by cooperation with the electrical reserve in house and the assist of boost converter to maintain its operation in desired conditions. The system is correlated with an intelligent supervision unit which further requires instant power supply. The supplied power should be reconciled and consequently astute power prepotency is proposed to act rapidly against abrupt circumstances due to instant power supply. It utilizes manifold proxy system to define the appropriate agent according to energy demand and power supply thus supervising the power fluctuations. In that, the power energy demand has been fulfilled through the communication between multiple agents via supervising agent. Eventually from the above novel strategy, issues like auto-ignition delay, effects of H_2 depletion and power reconciliation problems in hybrid electric vehicles are eradicated generating an efficient electric propulsion system with power management. The detailed description of each novel technique are explained in the upcoming sections.

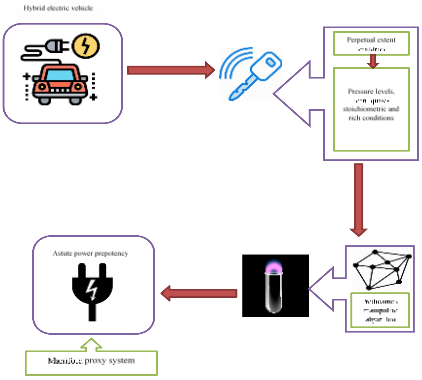

Figure 2. Block diagram of the proposed system

3.1 Perpetual Extent Cauldron

Hybrid electric vehicles become more environmentally friendly due to H_2 enhancement resulting in less pollution. But utilization of H_2 in previous methods exhibited combustion anomalies provoking in long auto ignition delay which further leads to minimized capability of the hybrid electric system. The ignition delay is measured from the moment the incident shock wave arrives (t=0) until the maximum slope of the CH* emission trace is extrapolated to the baseline.

At first, the ignition delay of hydrogen blend has been conducted from lean to rich condition as well as various pressure levels and quasi- quasi-stoichiometric condition also considered for regulating the long auto ignition delay. Here the perpetual extent cauldron has been utilized to regulate the ignition delay. The ignition delay data is used to check the capability of the available kinetic model and to classify any important reactions for dual-fuel ignition chemistry. The ignition delay has been measured through the formula given below:

$$\tau_{id} = \alpha\varphi^{-k^*}P^{-n^*}exp\left(\frac{E_a}{R_gT_{cc}}\right) \qquad (1)$$

Where,

τ_{id} - ignition delay
φ - equivalence ratio
E_a - activation energy
R_g - gas constant
T_{cc} - cylinder charge temperature
α, k^*, n^* - empirical constants

The air in this paper is a 21:79 molar ratio mixture of oxygen and argon. At the equivalence ratios of 0.45, 0.9, and 1.8, the ignition delay times of the argon-diluted (fixed dilution ratio of 80 percent) n-pentane/hydrogen/air blends were determined. The 0-D constant volume and adiabatic solver were used to simulate the ignition delay time in the shock tube.
A proper kinetic model of dual-fuel ignition can be able to accurately predict the ignition behavior of single components. Pentane Isomer model has been validated against the hydrogen ignition delay. From low to high pressures and lean to rich environments, the Pentane Isomer Model can capture the high temperature ignition delay time of hydrogen.

The ignition delay time estimation was handled through simulation. This considers three pressure levels, as well as equivalence ratio of lean ($\varphi = 0.45$), quasi-stoichiometric ($\varphi = 0.9$), and rich condition ($\varphi = 1.8$). In addition, unburned temperature $T_u + 400K$ is considered as a threshold condition. Then the estimated ignition delay is compared with the reactivity so that the readiness of the substance for chemical reaction can be achieved. The fuel-lean mixture had the highest reactivity, then the quasi-stoichiometric mixture had the higher reactivity, and the fuel-rich mixture had the lowest reactivity. In addition to the ignition delay, the hydrogen depletion is considered as one of the major issue in hybrid electric vehicle, which is explained in the following section.

3.2 Canny Predicament Approach

A hybrid electric vehicle combines a conventional internal combustion engine (ICE) system with an electric propulsion system, where hydrogen is used as one of the fuel. In an emergency case, the unexpected hydrogen (H_2) gas depletion and electric charge reserve depletion may occur, which affects the expeditious and potent response of the system against any constraint. To compensate this above situation, a super capacitor (SC) is embedded with the hybrid electric vehicle. Super capacitor is used as optimistic energy storage due to its fast charges, discharges and its capacity (20 to 200 times higher). Precisely, the regeneration acceleration and braking phases can be controlled and monitored by the SC. In addition, SC is recommended to manage the fluctuations power of the fuel cell during short and fast braking periods than batteries due to its high power. Due to its power density, high pressures, energy densities, and high capacity, SC is preferred in transportation applications to batteries.

The system becomes unable to survive in a serious hydrogen shortage, which could result in its imminent shutdown. To overcome this scenario, a predicament manipulate algorithm has been implemented in this work, which is explained in the next section.

3.2.1 Predicament Manipulate Algorithm

In hybrid electric vehicle, the depletion of hydrogen gas fuel is one of the serious issue. It affects the immediate response of the system against any hindrances. Super capacitor is used as an optimistic energy storage device. In some cases, such super capacitor also suffers to the hydrogen fuel depletion and the total electrical energy depletion. This can be done through the cooperation of home agent (hydrogen fuel reserve, house electric reserve), thus HEV can maintain its desired condition. Thus the predicament manipulate algorithm uses super capacitor power supply through house electric reserve with regulatory duty cycle related to SC which achieves the energy demand.

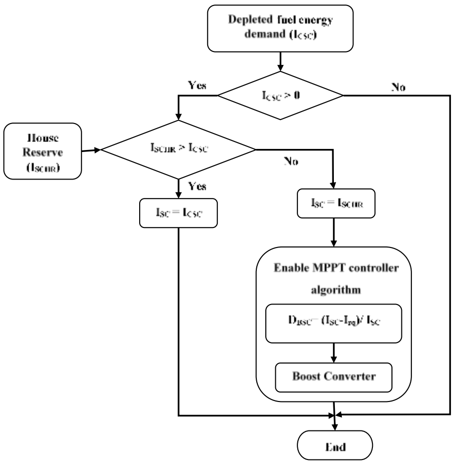

Figure 3. Predicament Manipulate Algorithm

The flowchart representation of predicament manipulate algorithm is shown in fig.3. This algorithm also uses the Maximum Power Point Tracking (MPPT) controller algorithm. MPPT is used in electric charge controller thus MPPT controller is an electronic DC to DC converter. As well as this uses boost converter, which is also a DC to DC converter. This boost converter can step up the voltage from its input to output. It is a class of switched-mode power supply which contains at least two semiconductors and one energy storage device. Thus in present work, it steps up the given home reserve energy to meet the required level. Also the boost control decisions are illustrated in table 1.

When the depleted fuel energy demand from super capacitor that is, control SC operating current (I_{CSC}) arrives, the given algorithm starts to overcome such energy demand. The steps of the algorithm have been explained below,

Step 1: Initially it checks, whether there is any energy demand.
Step 2: If yes, it offers its energy from the home reserve, that is the energy is taken from the home reserve (I_{SCHR}).
Step 3: If no. directly go to step 9.
Step 4: After that, the algorithm checks that the available energy from the home reserve is sufficient for the received energy demand or not.
Step 5: If sufficient means, the required super capacitor energy demand is fulfilled (i.e. $I_{SC} = I_{CSC}$). Go to step 9.
Step 6: If I_{SCHR} is not meet the required energy demand, the whole home reserve energy is taken as super capacitor current.
Step 7: Then it enables the MPPT controller algorithm, where the duty cycle regulations are achieved for the requirement.
Step 8: Next the boost converter is used to step up the input energy to the required level.
Step 9: End.

Predicament Manipulate Algorithm

```
Input: Depleted energy demand ($I_{CSC}$)
if ($I_{CSC}>0$)
        $I_{SCHR}$ from House reserve
        if ($I_{SCHR}>I_{CSC}$)
                $I_{SC}=I_{CSC}$
        else
                $I_{SC}=I_{SCHR}$
$D_{BSC}= (I_{SC}-I_{rq})/ I_{SC}$          // Duty cycle regulation
Boost converter for step up the energy
        End if
End if
End process
```

Table 1. Boost control through Super capacitor

Condition	Update	Decision	Boost control
$I_{SCHR} < I_{CSC}$	$I_{SC} = I_{SCHR}$	Regulate duty cycle	$D_{BSC}= (I_{SC} - I_{rq})/ I_{SC}$
$I_{SCHR} > I_{CSC}$	$I_{SC} = I_{CSC}$	System duty cycle	

As a result of the above algorithm, the emergency energy demand can be easily met with the help of house fuel reserve. Thus the adopted algorithm highly solves the hydrogen fuel energy demand in an emergency situation.

3.3 Astute Power Prepotency

In hybrid electric vehicle, proton-exchange membrane (PEM) fuel cell has been used due to its wider advantages of high efficiency, lower operating temperature, fast start, etc. but, PEM can highly have affected by the sudden changes followed by the power fluctuations. Thus it cannot be respond to the sudden peak demand. To counteract such power fluctuations, super capacitor has been added. Though the hybridization of super capacitor with fuel cell can achieve the energy demand, which can reduce the hydrogen consumption. In this work, the super capacitor can supervise the state of charge to generate a reserve of instant power that ensures normal activity in the face of severe energy transients.

The proposed system embedded with an intelligent supervision unit, which can able to manage all operating transients optimally. In this the energy flow distribution control depends on the system requirements and the communication between its components. This utilizes manifold proxy system, which can be accomplished by using an agent-oriented modeling environment to create the communication mechanism and define the representative interaction as a feature of decision-making. So that, each agent is able to manage a variety of similar resources that it owns and utilizes. The available hydrogen reserve in a fuel cell vehicle or the electrical charge in a super capacitor are used to identify these resources. An autonomous agent is associated with each unique source of fuel reserve providing communication between various system components.

The intelligent supervision unit attentively controls the energy flows in the vehicle through an accurate evaluation of the hydrogen consumption rate and the variation of the state of charge of each system element. The intelligent supervision unit relies on the demand and the related solution to make a reliable and proper decision in order to keep the system running smoothly.

This work relies on manifold proxy system such that multiple agents are presented to maintain the effective operation and to handle the energy demand through communication between them via control agent or supervisor. Here three agents: hydrogen fuel cell, charging station and super capacitor are used.

Agent 1: Fuel cell
FC is made up of a generator that generates an electric current in the presence of hydrogen to help with stack demand accomplishment. This agent is present to manage and recognize component activity that differs from its current state of charge:

$$SoC_{vh} = \frac{Q_{vh}}{Q_{vh}^{max}} \quad \ldots. (2)$$

Agent 2: Charging station
The recharging station is comprised of an external charging station where the amount of H_2 fuel inlet and outlet is regulated by the state of charge as follows:

$$SoC_{cs} = \frac{Q_{cs}}{Q_{cs}^{max}} \quad \ldots. (3)$$

Agent 3: Super Capacitor
The super capacitor is an electrical device that can help one restore its strength by discharging it. The super capacitor is thus regulated by its state of charge variance in order to guarantee its security against the profound release:

$$SoC_{sc} = \left[\frac{I_{sc}}{I_{sc}^{max}}\right]^2 \quad \ldots. (4)$$

Other parameter:

$$P_V = P_R + P_{VD} + P_W + P_S \ldots. (5)$$

Where,

P_V - Vehicle power (W)
P_R - Rolling power (W)
P_{VD} - Viscous drag power (W)
P_W - Wheel power (W)
P_S - Slope effect power (W)

Required vehicle power is formulated as:

$$P_{VRQ} = \frac{P_V - P_{Br}}{\eta_{gr}.\eta_{inv}.\eta_m} \ldots. (6)$$

Where,

P_V - Vehicle power (W)
P_{Br} - Braking vehicle power (W)
η_{gr} - Gear efficiency (%)
η_{inv} - Vehicle inverter efficiency (%)
η_m - Vehicle motor efficiency (%)

The system lacking rate can be calculated using the formula below:

$$\tau_{lack} = \frac{Q_i^{req} - Q_i}{Q_i} \times 100 \quad \ldots. (7)$$

$$\tau_{rec} = 100 - \tau_{lack} \quad \ldots. (8)$$

Where,

τ_{rec} - System recovery rate
Q_i^{req} - Required H_2 amount from component *i*
Q_i - Gathered H_2 amount from component *i*

For the power requirement as well as to recover the system lacking, some amount hydrogen fuel is needed, which can be get from the multiple agents presented in this work. which can be explained below.

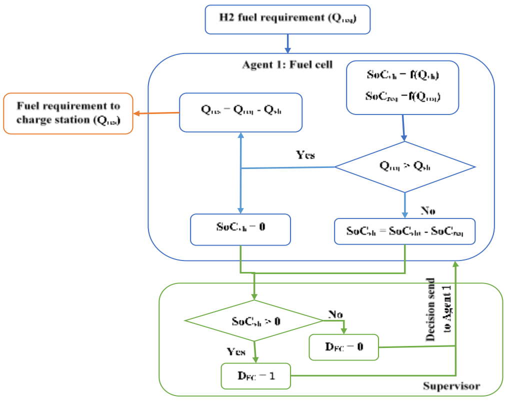

Figure 4. Fuel cell state checking and decision making

Initially, each agent regulates its state of charge in accordance with the vehicle's energy requirements and reports detailed data to the supervisor. The required hydrogen fuel can be estimated based on the activity of each agent. Here the agent-to-agent communication is controlled by the supervisor who works on receiving the status information and making the most appropriate operation decision.

When the system lacking hydrogen fuel requirement arrives to agent 1, the state of the fuel cell has been checked for whether the available fuel is sufficient for the received requirement or not. As well as the operation decision is taken by the supervisor and send back to the agent 1. If the available hydrogen fuel in fuel cell can sufficient for the requirement, the supervisor provides the decision making factor as 1 (D_{FC}=1) to fuel cell agent. If the available fuel is insufficient for the requirement, then it provides the available fuel and requesting to the agent 2 for remaining. As this scenario, the supervisor provides the decision making factor as 0 (D_{FC}=0) to fuel cell agent. The fuel cell state checking and decision making process are shown in fig.4.

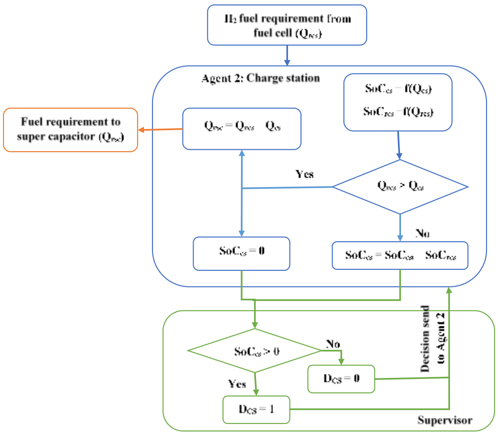

Figure 5. Charge station state checking and decision making

Similarly, when the hydrogen fuel requirement arrives from fuel cell to agent 2, the state of the charging station has been checked for whether the available fuel is sufficient for the received requirement or not. As well as the operation decision is taken by the supervisor and send back to the agent 2. If the available hydrogen fuel in charge station can sufficient for the requirement, the supervisor provides the decision making factor as 1 (D_{CS}=1) to charge station agent. If the available fuel is insufficient for the requirement, then it provides the available fuel and requesting to the agent 3 for deficit. As this scenario, the supervisor provides the decision making factor as 0 (D_{CS}=0) to charge station agent. The charge station state checking and decision making process are shown in fig.5.

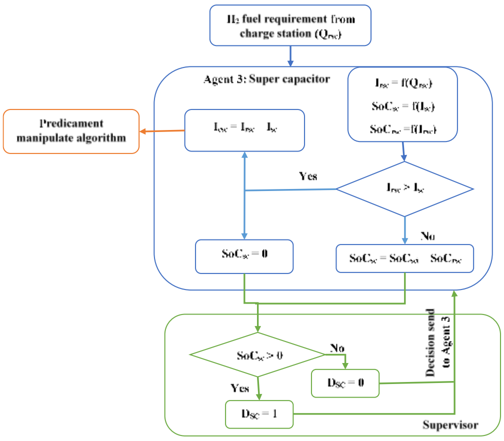

Figure 6. Super capacitor state checking and decision making

As same as, when the hydrogen fuel requirement arrives from charging station to super capacitor (agent 3), the state of the charging station has been checked for whether the available fuel is sufficient for the received requirement or not. As well as the operation decision is taken by the supervisor and send back to the agent 3. The super capacitor's energy capacity is too high; thus the requirement can be easily fulfilled through the super capacitor. In super capacitor, if the available hydrogen fuel is at most sufficient for the requirement, thus the supervisor provides the decision making factor as 1 (D_{SC}=1) to super capacitor agent. Rarely in some cases, the available energy in super capacitor is insufficient for the requirement, then it provides the available fuel. And the decision factor is provided as 0 (D_{SC}=0) by supervisor. Such insufficiency of energy from super capacitor scenario is considered as the emergency scenario, which also can be resolved through the predicament manipulate algorithm presented in section 3.2.1. The super capacitor state checking and decision making process are shown in fig.6.

As a result, through the multiple-agent modelling, the energy demand that is power lacking in system can be resolved hence the system can be recovered from the lacking of power.

4. RESULT AND DISCUSSION

This section provides a comprehensive description of the implementation results as well as the performance of our proposed system and the comparison section to ensure the enhanced performance of our proposed system.

4.1 Experimental Setup

This work has been implemented in SIMULINK in the working platform of MATLAB with the following system specification and the simulation results are discussed below,

Platform: MATLAB Simulink
OS: Windows 8
Processor: Intel Core i5
RAM: 8GB RAM

4.2 Evaluation Metrics and Simulation Output

This section presents the implemented Simulink model and the resulted outputs of implementations. As this fig.7 illustrates the Simulink model.

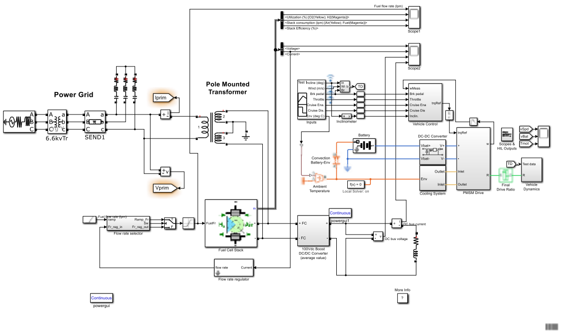

Figure 7. Implemented Simulink model

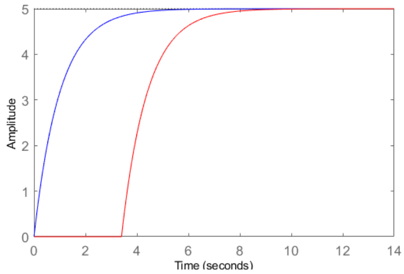

Figure 8. Delay free response and its shifted version

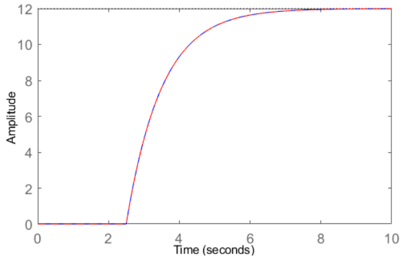

Figure 9. Ignition delayed step response

In fig.8, the delay free response and its shifted version is presented. In that, the shifted version of step response is considered as the delay of 3.4 seconds. Fig.9 shows the step response of the delayed signal, which establishes the delay of 2.5 seconds. As well as fig.10 shows the phase and magnitude of delayed response that is the frequency response of the ignition delay.

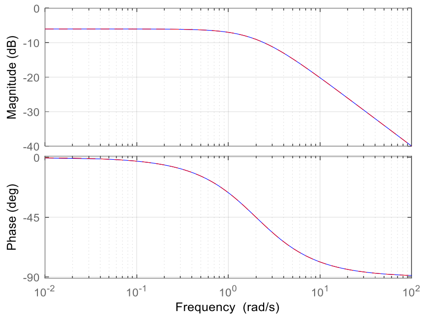

Figure 10. Frequency response

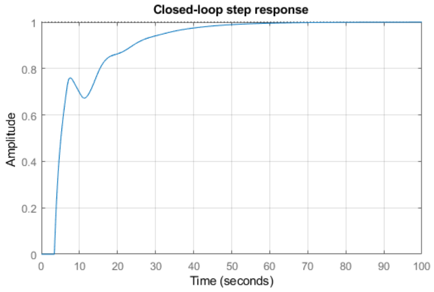

Figure 11. Closed loop step response

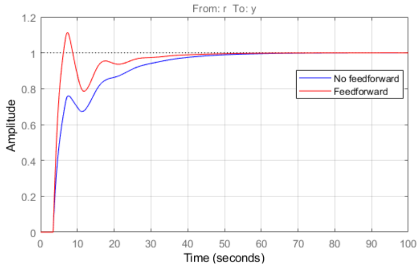

Figure 12. Step response comparison

In addition, the ignition delay response is checked in the closed loop format which is presented in fig.11. In that, some part of the output is send back to the input to make the closed loop. This will be more efficient that the series response such that the feed forward and no feed forward response are compared and presented in fig.12. this shows the feedforward has the highest amplitude of response than the no feedforward model.

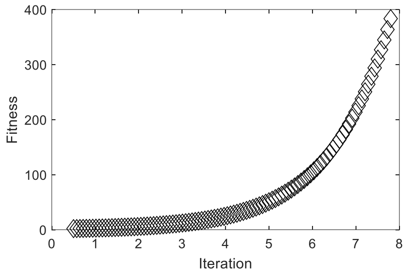

Figure 13. Ignition delay fitness decision

In this work, the ignition delay has been regulated after its estimation. This was done through number of iterations, which is presented in fig.13. Here, at the 8th iteration, it achieves the perfect fitness as 400.

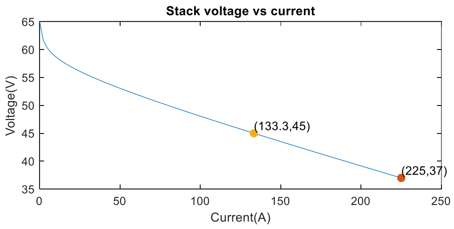

Figure 14. Fuel cell stack voltage vs Current

In this work, a fuel cell stack has been included in the Simulink model, which is used to obtain the power requirements. The power output of a fuel cell stack is a product of stack voltage and current, which is presented in fig.14. Where, 133.3A,45V is presents the linear drop due to activation losses as well as 225A,37V is the mass transport losses at high current densities.

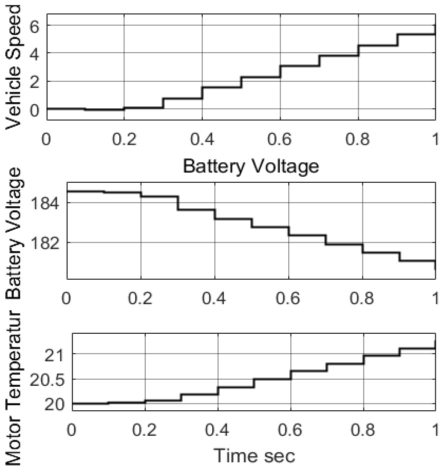

Figure 15. (a) Vehicle speed **(b)** Battery voltage **(c)** Motor temperature

As the output of the simulation, the measures vehicle speed, battery voltage and motor temperature are presented in fig.15. As the understanding from the graph, while the vehicle speed increases, the battery voltage has been reducing due to its usage as well as the motor temperature also increases on the increased speed of vehicle.

Fig.16(a) presents the fuel flow rate which is the input of the fuel cell stack. Fig.16(b) shows the hydrogen utilization (%) in that, oxygen (O_2) utilization is plotted in yellow color, such that the oxygen utilization is nearly 60%. As well as the hydrogen (H_2) utilization has been plotted in magenta color, where 100% of H_2 has been utilized in fuel cell stack. Fig.16(c) shows the stack consumption of fuel and air. Here the fuel consumption is indicated as magenta color as well as the air consumption is indicated as the blue color in graph plot. From the graph, it is shown that there is no fuel has been consumed by the fuel cell stack as well as $3x10^5$ lpm of air only consumed by the stack. Fig.16(d) presents the fuel cell stack efficiency (%), which achieves 77%.

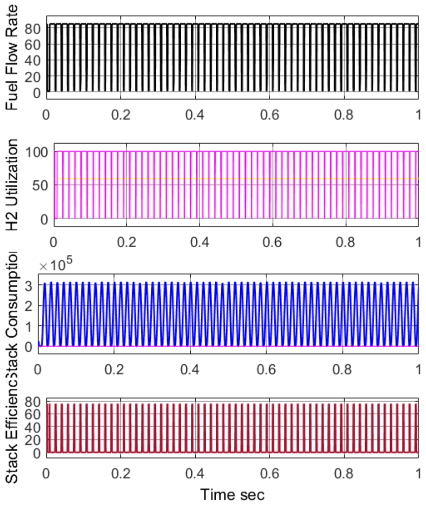

Figure 16. (a) Fuel flow rate **(b)** H_2 utilization **(c)** Stack consumption **(d)** Stack efficiency

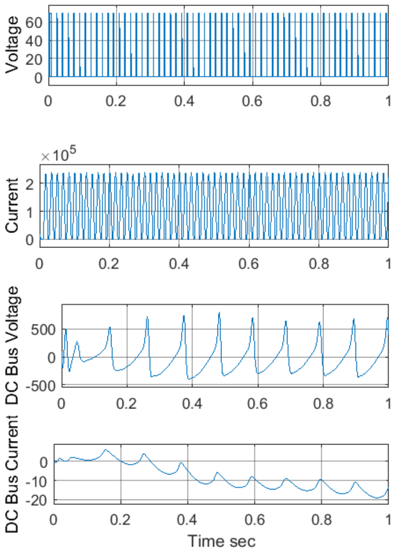

Figure 17. (a) Stack voltage **(b)** Stack current **(c)** DC bus voltage **(d)** DC bus current

The fuel cell engine stack voltage as well as stack current has been plotted in fig.17(a) and (b). Where, the stack current is fed to the flow rate regulator as a feedback loop. In addition, a boost converter has been used in this work for step up the input voltage, thus the outputs of boost converters are shown in fig.17(c) and (d). In that, the bus voltage has been increased as well as current falls to store the energy in converter.

4.3 Comparison Strategies

The results of the proposed alternative electric propulsion system have been compared with the existing approaches, which is presented in this section.

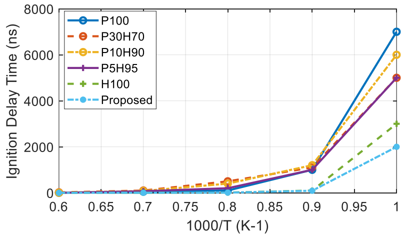

Figure 18. Comparison of ignition delay time

The ignition delay time has been compared with the different pentane/hydrogen mixtures. Pure pentane (P100), 30% of pentane with 70% of hydrogen (P30H70), 10% of pentane with 90% of hydrogen (P10H90), 5% of pentane with 95% of hydrogen (P5H95), and pure hydrogen (H100) mixtures are used for the comparison of ignition delay time. From the graph it is clear that the ignition time delay of the proposed one is lower than the others such that the ignition delay of the proposed is 2000ns only. And there is a difference of 1000ns between the pure hydrogen and the proposed one.

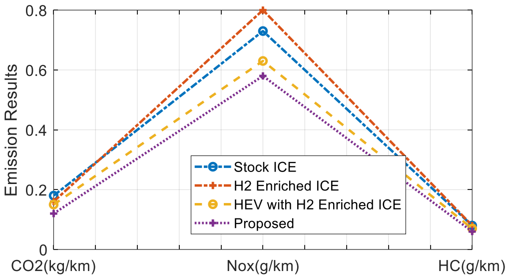

Figure 19 Emission result comparison

Stock modelled internal combustion engine (ICE), H2 enriched ICE, HEV with H2 enriched ICE are considered for comparing the CO_2, NO_x, HC emission of proposed work which is presented in fig.19. On the graph, reduced emission values have been shown to be better result. From the graph, the emission rate of the proposed work is lower than the existing engines.

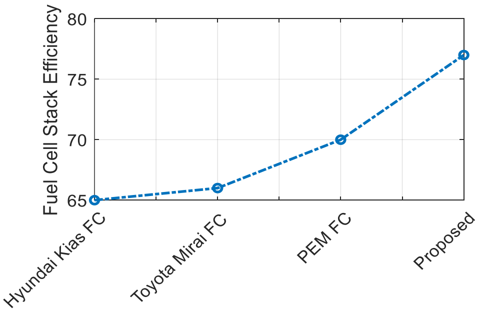

Figure 20. Fuel cell stack efficiency comparison

The stack efficiency of the Hyundai kia's fuel cell, Toyota mirai fuel cell, Proton exchange membrane fuel cell (PEMFC) are compared with the proposed stack efficiency of fuel cell, which is presented in fig.20. From the graph, it is clear that the stack efficiency of the proposed fuel cell achieves 77% which is 7% higher than the existing PEMFC.

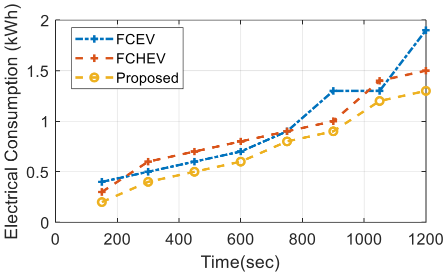

Figure 21. Comparison of electrical consumption

Fig.21 compares the electricity consumption of Fuel Cell Electric Vehicle (FCEV), Fuel Cell Hybrid Electric Vehicle (FCHEV) with the proposed system. From the graph, it is clear that, the electrical consumption of FCEV is higher than FCHEV, whereas the proposed system consumes less electricity than FCHEV as well.

5. CONCLUSION

Hybrid electric vehicles are indeed a promising technology that can help consumers to meet their needs even while coping with tightening CO2 emission regulations around the world. An alternative electric propulsion system has been developed in this paper with the aim of solving the issues such as long auto ignition delay, hydrogen gas fuel depletion and power energy demand in hybrid electric vehicle. In this, long auto ignition delay has been minimized via perpetual extent cauldron. Consequently, the unexpected hydrogen fuel depletion in emergency cases has been resolved through the predicament manipulate algorithm with the assist of house fuel reserve as well as boost converter. In addition, manifold proxy system is utilized to define the appropriate agent according to energy and power demand. In that, the proposed predicament manipulate algorithm also can subordinate such energy power demand. Thus the proposed work has been highly diminishing the ignition delay as 2000ns and effectively handles the unexpected hydrogen fuel depletion as well as power energy demand. As well as it achieves 77% of proposed fuel cell stack efficiency which, 7% higher than the PEM fuel cell.

REFERENCES

Acar, C., & Dincer, I. (2020). The potential role of hydrogen as a sustainable transportation fuel to combat global warming. *International Journal of Hydrogen Energy, 45*(5), 3396-3406.

Akbari-Dibavar, A., Nojavan, S., Mohammadi-Ivatloo, B., & Zare, K. (2020). Smart home energy management using hybrid robust-stochastic optimization. *Computers & Industrial Engineering, 143*, 106425.

Anselma, P.G., Biswas, A., Belingardi, G., & Emadi, A. Rapid assessment of the fuel economy capability of parallel and series-parallel hybrid electric vehicles. *Applied Energy, 275,* 115319.

Arat, H. T. (2019). Alternative fuelled hybrid electric vehicle (AF-HEV) with hydrogen enriched internal combustion engine. *International Journal of Hydrogen Energy. 44*(34): 19005-19016.

Baskar, S., Vijayan, V., Premkumar, I. I., Arunkumar, D., & Thamaran, D. (2020). Design and material characteristics of hybrid electric vehicle. *Materials Today: Proceedings.*

D'Ovidio, G., Ometto, A., & Villante, C. (2020). A Novel Optimal Power Control for a City Transit Hybrid Bus Equipped with a Partitioned Hydrogen Fuel Cell Stack. *Energies, 13*(11), 2682.

Del Pecchia, M., & Fontanesi, S. (2020). A methodology to formulate multicomponent fuel surrogates to model flame propagation and ignition delay. *Fuel, 279*, 118337.

Du, R., Hu, X., Xie, S., Hu, L., Zhang, Z., & Lin, X. (2020). Battery aging-and temperature-aware predictive energy management for hybrid electric vehicles. *Journal of Power Sources, 473*, 228568.

Giap, Van-Tien, et al. (2020). System simulation and exergetic evaluation of hybrid propulsion system for crude oil tanker: A hybrid of solid-oxide fuel cell and gas engine. *Energy Conversion and Management, 223*, 113265.

Guo, L., Chen, H., Gao, B., & Liu, Q. (2019). Energy management of HEVs based on velocity profile optimization. *Science China Information Sciences*, *62*(8), 1-3.

Haidar, A. M., Fakhar, A., & Helwig, A. (2020). Sustainable energy planning for cost minimization of autonomous hybrid microgrid using combined multi-objective optimization algorithm. *Sustainable Cities and Society*, *62*, 102391.

Imran, Adil, et al. (2020). Heuristic-based programable controller for efficient energy management under renewable energy sources and energy storage system in smart grid. *IEEE Access*, *8,* 139587-139608.

Jia, Y., Lyu, X., Xie, P., Xu, Z., & Chen, M. (2020). A novel retrospect-inspired regime for microgrid real-time energy scheduling with heterogeneous sources. *IEEE Transactions on Smart Grid, 11*(6), 4614-4625.

Kalair, A.R., Abas, N., Hasan, Q.U., Seyedmahmoudian, M., & Khan, N. (2020). Demand side management in hybrid rooftop photovoltaic integrated smart nano grid. *Journal of Cleaner Production, 258*, 120747.

Lee, H., Shao, Y., Lee, S., Roh, G., Chun, K., & Kang, H. (2019). Analysis and assessment of partial re-liquefaction system for liquefied hydrogen tankers using liquefied natural gas (LNG) and H2 hybrid propulsion. *International Journal of Hydrogen Energy, 44*(29), 15056-15071.

Leonori, S., Martino, A., Mascioli, F. M. F., & Rizzi, A. (2020). Microgrid energy management systems design by computational intelligence techniques. *Applied Energy*, *277*, 115524.

Patassa, S. (2020). Design, production and testing of innovative key components of HEV/BEV powertrains.

Rajamand, S. (2020). Effect of demand response program of loads in cost optimization of microgrid considering uncertain parameters in PV/WT, market price and load demand. *Energy, 194*, 116917.

Sadey, D. J., Bodson, M., Csank, J., Hunker, K., Theman, C., & Taylor, L. (2017). Control demonstration of multiple doubly-fed induction motors for hybrid electric propulsion. In *53rd AIAA/SAE/ASEE Joint Propulsion Conference* (p. 4954).

Selmane, F., Djermouni, M., & Ouadha, A. (2020). Thermodynamic Modeling of a Turbocharged Diesel–Hydrogen Dual-Fuel Marine Engine. *Journal of The Institution of Engineers (India): Series C*, 1-14.

Tanç, B., Arat, H. T., Conker, Ç., Baltacioğlu, E., & Aydin, K. (2020). Energy distribution analyses of an additional traction battery on hydrogen fuel cell hybrid electric vehicle. *International Journal of Hydrogen Energy, 45*(49), 26344-26356.

Terao, Y., Ishida, Y., Heideman, D.A., Ohsaki, H., Okai, K & Taguchi, H. (2020). Electromagnetic Analysis of Fully Superconducting Synchronous Machines for Future Turbo Electric Propulsion Systems. *In AIAA Propulsion and Energy 2020 Forum, 3550*.

Tooryan, F., Hassanzadeh Fard, H., Collins, E. R., Jin, S., & Ramezani, B. (2020). Smart integration of renewable energy resources, electrical, and thermal energy storage in microgrid applications. *Energy, 212*, 118716.

Tran, M.K., Akinsanya, M., Panchal, S., Fraser, R., & Fowler, M. (2021). Design of a Hybrid Electric Vehicle Powertrain for Performance Optimization Considering Various Powertrain Components and Configurations. *Vehicles, 3*(1), 20-32.

Vivas, F. J., Segura, F., Andújar, J. M., Palacio, A., Saenz, J. L., Isorna, F., & López, E. (2020). Multi-objective fuzzy logic-based energy management system for microgrids with battery and hydrogen energy storage system. *Electronics, 9*(7), 1074.

Xu, P., Ji, C., Wang, S., Cong, X., Ma, Z., Tang, C., ... & Shi, C. (2020). Effects of direct water injection on engine performance in a hydrogen (H2)-fueled engine at varied amounts of injected water and water injection timing. *International Journal of Hydrogen Energy, 45*(24), 13523-13534.

Yu, G., Hadi, F & Metghalchi. H. (2019). Rate-controlled constrained-equilibrium application in shock tube ignition delay time simulation. *Journal of Energy Resources Technology*, *141*(2).

Yu, G., Askari, O., Hadi, F., Wang, Z., Metghalchi, H., Kannaiyan, K., & Sadr, R. (2017). Theoretical prediction of laminar burning speed and ignition delay time of gas-to-liquid fuel. *Journal of Energy Resources Technology, 139*(2).

Zhao, Z., Guo, J., Luo, X., Xue, J., Lai, C. S., Xu, Z., & Lai, L. L. (2020). Energy transaction for multi-microgrids and internal microgrid based on blockchain. *IEEE Access, 8*, 144362-144372.

Zhou, Y., Ravey, A & Péra, M.C. (2020). Multi-mode predictive energy management for fuel cell hybrid electric vehicles using Markov driving pattern recognizer. *Applied Energy*, *258*, 114057.

Reshma S.
Department of Electrical &
Electronics Engineering
College of Engineering
Kidangoor, Kidangoor South,
Kottayam
reshmasaroj@gmail.com
ORCID 0000-0002-5352-9210