On the Optimum Powertrain Configuration of Fuel Cell Powered Vehicle for Minimum Hydrogen Consumption

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Abstract

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In the study, we investigated the hybrid systems to reduce the hydrogen consumption of fuel cell systems. We used super capacitors as auxiliary power source for hybridization. We set four different configurations using super capacitors and DC/DC converters. We performed the tests on İstanbul University hydrogen powered vehicle. We extracted the energy and hydrogen consumptions of fuel cell for each configuration and determined optimum configuration.

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1. Introduction

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The proton exchange membrane fuel cells (PEMFCs) are considered to be one of the promising energy sources for the fuel cell powered vehicle due to high efficiency and environment friendly. However, PEMFCs' poor dynamic response and environmental and operating conditions induced output fluctuations prevent its efficiency [1-3].

For more fuel-efficient vehicles, the combination of an auxiliary power source (energy storage device), such as battery or super capacitor, with a fuel cell gaining more attention and referred to as hybridization. It's expected that the hybridization, fulfill the transient power demand of the fuel cell [4-5].

Hybridization of fuel cell systems with super capacitors and batteries are investigated in laboratory and simulation environment [6-8]. In the studies [6-8], using super capacitors as auxiliary power source decreases the hydrogen consumption according to using batteries as auxiliary power source. In our study, we performed fuel cell- super capacitor hybridization tests on hydrogen powered vehicle.

In the study, we investigated the different powertrain configurations for minimum hydrogen consumption. We used super capacitors as auxiliary power source and DC/DC converters for suppressing the fuel cell output fluctuations. We performed configurations on the Istanbul University Hydrogen powered vehicle which is produced for TÜBİTAK Alternative Energy Vehicles Race. We investigated the below configurations:

i. The hydrogen fuel cell directly connected to electrical motor.
ii. The hydrogen fuel cell, super capacitors and electrical motor are directly connected in parallel with each other.
iii. The hydrogen fuel cell connected to super capacitors and electrical motor through a DC/DC converter.
iv. The hydrogen fuel cell and super capacitors are connected to electrical motor via DC/DC converter.

For each test we extracted the energy and hydrogen consumption of fuel cell and determined the optimum configuration.

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2. Material and Method

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We used 700W fuel cell system produced by ZBT. It has 40 cells and its maximum voltage/current rating are 37V/25A. The electrical motor is 500W, produced by Mitsuba. Its nominal voltage is 48 V. The super capacitors' ratings are 2,7V and 360 F. We serially connected 20 piece super capacitors and formed 54V and 18F super capacitor module. The fuel cell, super capacitors and electrical motor are shown in Fig. 1.

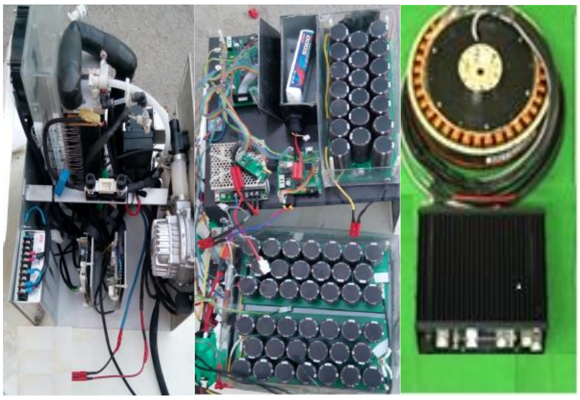


Fig. 1. The fuel cell system components

We performed our tests at the track shown in Fig. 2. The track is 400m.

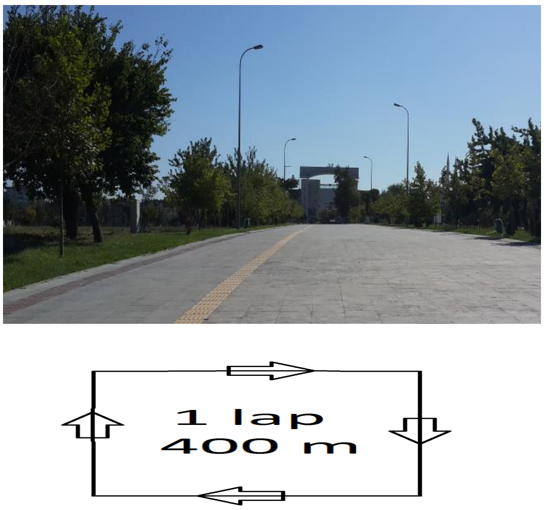
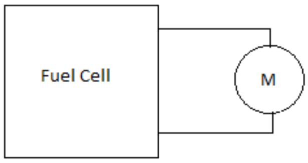


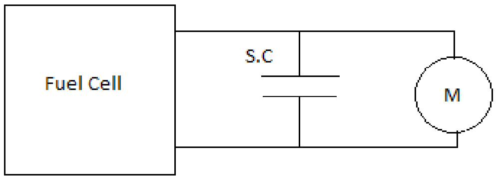
Fig. 2. The test track

We measured the hydrogen consumption using Red-y flow meter. We extracted the energy consumption using telemetry system.

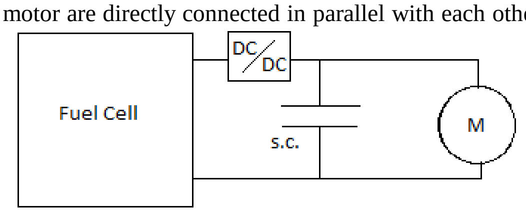
We presented the configurations performed in the tests are presented in Fig. 3. In Fig. 3. M stands for electrical motor, SC stands for super capacitors and DC/DC stands for DC/DC converters. We used two different DC/DC converters. One of the converters is 19-72 input voltage- 30V output voltage and the other DC/DC converter is 19-72 input voltage- 48V output voltage.



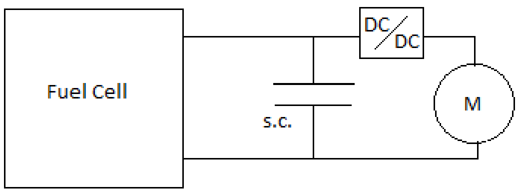
a) The hydrogen fuel cell directly connected to electrical motor.



b) The hydrogen fuel cell, super capacitors and electrical motor are directly connected in parallel with each other.



c) The hydrogen fuel cell connected to super capacitors and electrical motor through a DC/DC converter.



d) The hydrogen fuel cell and super capacitors are connected to electrical motor via DC/DC converter.

Fig. 3. The configurations performed in the tests

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3. Results

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In tests for each configuration we set our top speed 27km/h, same acceleration and lap time for comparing the results. We took 5 laps on track because it is approximately 1 lap in TÜBİTAK Alternative Energy Vehicles Race.

For the first configuration we extracted the energy and hydrogen consumptions and presented in Table 1.

Table 1. Test results for configuration (a)

Configuration (a) (Conf_a)	Energy Consumption (Wh)	Hydrogen Consumption (lt)
	24,5	14,25

In Table.1 wh stands for watt-hour and lt stands for liter.

For second configuration tests, we firstly set one super capacitor module and extracted the results. We saw that the super capacitor module reduced the energy and hydrogen consumption. After that, we added one more super capacitor module parallel to first module and repeated the test. The hydrogen consumption is reduced but energy consumption is increased according to one super capacitor module. We added one more super capacitor module for a new test parallel to other modules. The hydrogen consumption is reduced and energy consumption is decreased according to other tests in configuration (b). We presented the results in Table 2.

Table 2. Test results for configuration (b)

Configuration (b)	Energy Consumption (Wh)	Hydrogen Consumption (lt)
One Super Capacitor Module (18F 54V) (Conf_b1)	22,5	12,7
Two Super Capacitor Modules (36F 54V) (Conf_b2)	24	12,25
Three Super Capacitor Modules (54F 54V) (Conf_b3)	29,5	11,4

It is seen that adding new modules increase the energy consumption but decrease the hydrogen consumption.

We investigated the fuel cell current with and without the super capacitor module and presented the results in Fig. 4. The super capacitor module prevents the instantaneous increase in fuel cell current and thus decrease the hydrogen consumption.

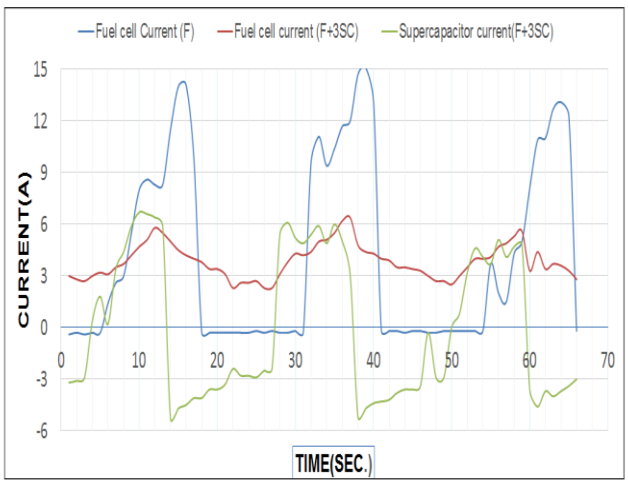

Fig. 4. The fuel cell current with and without the super capacitor

In configuration (c) we used DC/DC converter after the fuel cell. We aimed to suppress the environmental and operating conditions induced fluctuations at the output of the fuel cell and determine the effect on hydrogen consumption. We performed the test for 30V and 48V DC/DC converters separately. We performed 48V DC/DC converter because of the motor nominal voltage is 48V. We aimed the increase the motor efficiency and thus decrease the hydrogen consumption. We presented the results in Table 3.

Table 3. Test results for configuration (c)

Configuration (c)	Energy Consumption (Wh)	Hydrogen Consumption (lt)
30V DC/DC Converter (Conf_c1)	30,2	17,85
48V DC/DC Converter (Conf_c2)	32,8	17,85

In configuration (d) we connected the DC/DC converter after the fuel cell and super capacitor modules. We performed the test for 30V and 48V DC/DC converters separately as in configuration (c). We presented the results in Table 4.

Table 4. Test results for configuration (d)

Configuration (d)	Energy Consumption (Wh)	Hydrogen Consumption (lt)
30V DC/DC Converter (Conf_d1)	26	17,1
48V DC/DC Converter (Conf_d2)	29	15,7

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The both configurations with DC/DC converters increased the energy and hydrogen consumption. Major reason of the increase is efficiency of the converters. Such systems as this fuel cell system needs more efficient converters. As a result the configuration (d) is better than the configuration (c).

As seen in results there are fluctuations between energy and hydrogen consumption. We considered the hydrogen consumption as major parameter and determined the configuration (b) with three super capacitor module (Conf_b3) is best configuration for us. If one need to consider the energy and hydrogen consumption together, we prefer to consider the energy consumption/hydrogen consumption ratio. We presented the results considering this ratio in Fig. 5.

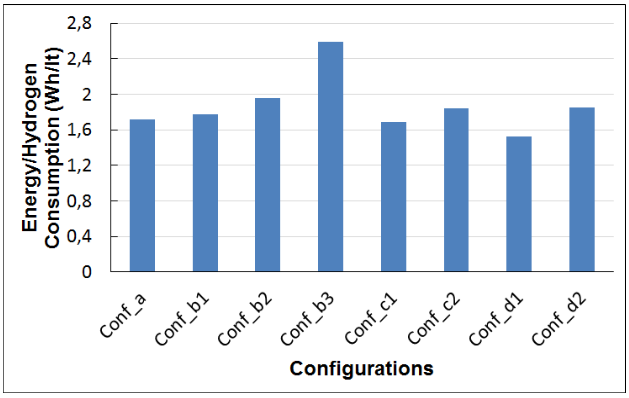

Fig. 5. Energy consumption/hydrogen consumption ratios according to configurations

As seen in Fig.5, configuration (b) with three super capacitor module (conf_b3) has the best ratio according to other configurations.

4. Conclusion

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In the study, we determined the optimum fuel cell/super capacitor configuration for minimum hydrogen consumption. We investigated four different configurations including super capacitors with and without DC/DC converters. We performed the super capacitor tests with different capacitances values and saw that energy consumption is increased while hydrogen consumption is decreasing. We determined that using DC/DC converters increased the energy and hydrogen consumption. We also proposed that, if one need to consider the energy and hydrogen consumption together, the energy consumption/hydrogen consumption ratio can be a key parameter to decide the optimum configuration.

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