# Optimal Power Train Sizing for a Fuel Cell Electric Vehicle Using Two Intelligent Optimization Techniques

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***Abstract-*** This paper, will present a two optimization techniques (genetic algorithm (GA) and particle swarm optimization (PSO)). The two optimization techniques are adopted to optimize the sizing of a power train for a fuel cell electric vehicle (FCEV). The power train comprised of a fuel cell as the main energy source to supply the vehicle power demand during steady state, battery and supercapacitor as the auxiliary energy storage sources (ESS). It assists the FC during transient state and recovers the energy during braking or deceleration. The optimization objective is to achieve the minimum cost, volume, size and weight of the power train. Because of a hybrid powertrain, component sizing significantly affects vehicle performance, hence taking into account the constraints of vehicle performance, such as the energy characteristics, power limitations and a DC-link voltage. Optimal sizing of the power train components using GA and PSO algorithms will be presented. Moreover, the calculation and the analysis of the vehicle dynamics and detailed model of the power train is built in MATLAB /SIMULINK.

***Index Terms-*** Particle swarm optimization, Genetic algorithm, Fuel cell electric vehicle, Fuel cell, Battery, Supercapcitor.

## I. INTRODUCTION

Internal-combustion engine vehicles (ICEVs) consume oil at a rate equivalent to 3/4 of the world oil imports and accounts for 1/4 of the greenhouse gas emissions ($GHG_S$) and a significant fraction of the air pollutant Emissions. [1]. Hybrid Electric vehicles (HEVs), battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs) are the alternative vehicles to solve these problems. Although HEVs reduce emissions and possess the same travel range as ICEVs, they nevertheless discharge some emissions. BEVs have long held the promise of being zero-emission vehicles, but their long time to charge has been the main problem. FCEVs have the potential to become the vehicle's future, because FCEVs are more appealing than BEVs due to the shorter fuelling time and longer driving ranges, this due to that the fuel cell has a high efficiency, zero emission, high energy density and fast refuelling. However, the fuel cell has disadvantages of high price and not capable to cover rapid variations of vehicle power demand due to their slow inherit electrochemical and thermodynamic characteristics. So in automotive applications, fuel cell systems must be able to adapt to challenging operating conditions such as frequent start-up and stop and sudden change and widely varying power demand. These conditions are much easier to cope with if the fuel cell system is hybridized using batteries and/or supercapacitors. In addition to mitigating the stress on the fuel cell via load levelling, the energy storage permits the capture of regenerative braking energy, which will benefit vehicle fuel economy and can potentially permit downsizing the fuel cell system [2].

The high cost of fuel cell is one of the major obstacles for the commercialization of FCEVs. According to a report to DOE, the mass-produced fuel cell would cost more than $280/kW, which is higher when compared to the ICE [3]. There for optimal sizing of fuel cell needed to reduce its cost. In addition, using an auxiliary ESS to aid the fuel cell in the FCEV Powertrain to provide the required vehicle performance, this will reduce the power ratings of the fuel cell.. Therefore, in such a powertrain, it is not necessary to size the fuel cell for the maximum vehicle power demand, which enables a smaller fuel cell. In this research, ESS consists of a battery and supercapacitor. Because, during the cold start-up, the battery will provide the energy due to slow response of the fuel cell and also the fast self-discharge characteristic of the supercapacitor whoever, the supercapacitor has both strong charging and discharging capabilities. Hence, a supercapacitor can be used to capture the large braking power during deceleration.

The objective of this work is to present an optimal sizing of a fuel cell, battery and supercapacitor for a FCEV using GA and PSO. Also, a mathematical model of power train and comparison of the optimized power train using the two techniques are presented.

## II. FCEV CONFIGURATION

The proposed FCEV is shown in Figure 1, which consists of three parallel energy sources: the fuel cell is the main energy source, the battery and supercapacitor are the auxiliary ESS. Each one of these sources is connected to the DC-link via DC/DC converter, which regulates the DC-link voltage. The desired value of the DC-bus voltage is chosen to be 500 V, a DC/AC inverter converts the regulated DC voltage to an AC voltage to drive the AC motor. Three DC/DC converters are used, the first one is a boost converter used to regulate the fuel cell voltage with a DC-bus voltage, which in general the DC-bus voltage is higher than the fuel cell voltage to prevent the high degradation of platinum with high fuel cell voltages. The other two converters are a bidirectional converter to permit for the ESS (battery and supercapcitor) to operate in both directions as the next.

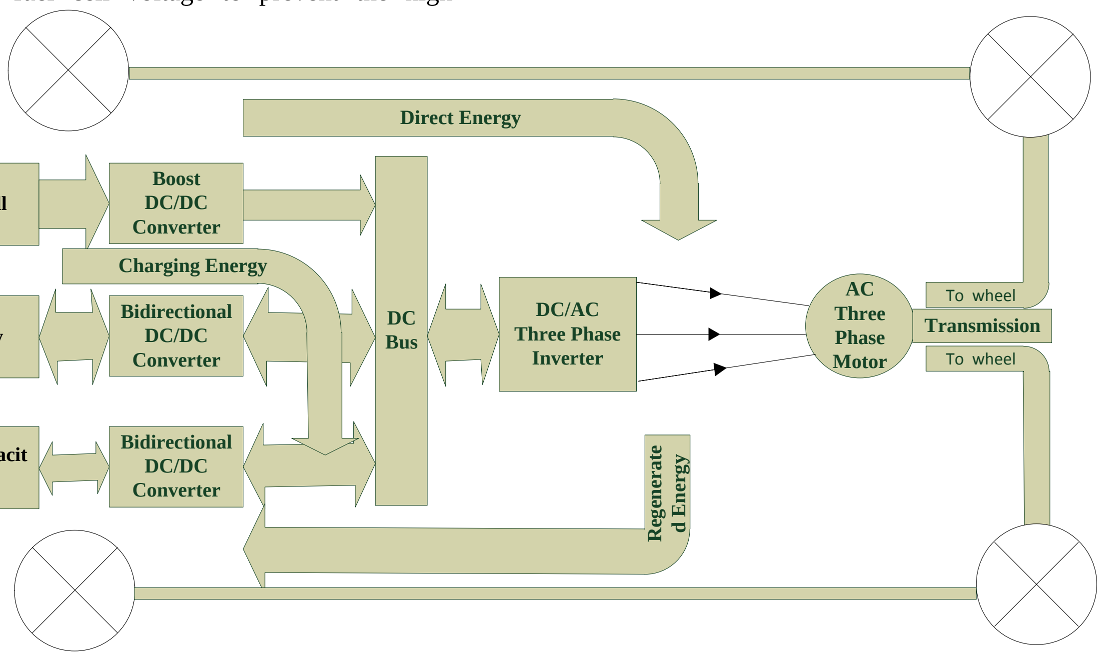


**Figure 1 Proposed block diagrams of the power train of FCEV**

1. ESS delivers power to the vehicle to compensate the drawback until the fuel cell reaches its rated power in the case of vehicle power demand larger than the fuel cell power, which reduce the fuel cell rated power and improve its transient response.
2. ESS charging power from the fuel cell in the case of the vehicle power demand is less than fuel cell power and capture the regenerative energy from the vehicle during braking or deceleration.

### 2.1. Vehicle Dynamic Load Model

The vehicle power demand is equal to the resistance power plus the dynamic power for acceleration of the vehicle as illustrated in Figure 2. The parameters of the proposed FCEV are illustrated in Table1. Vehicle power demand can be written as [4].

$$P_e = \frac{V}{\eta_t}\left(F_f + F_w + F_g + M_v \delta \frac{dV}{dt}\right) \quad (1)$$

$$F_f = M\, g\, f_r\, \cos(\alpha) \quad (2)$$

$$F_w = \frac{1}{2}\, \rho\, A_f C_D \left(V - V_w\right)^2 \quad (3)$$

$$F_g = M\, g\, \sin(\alpha) \quad (4)$$

$$f_r = 0.01\left(1 + \frac{V}{160}\right) \quad (5)$$

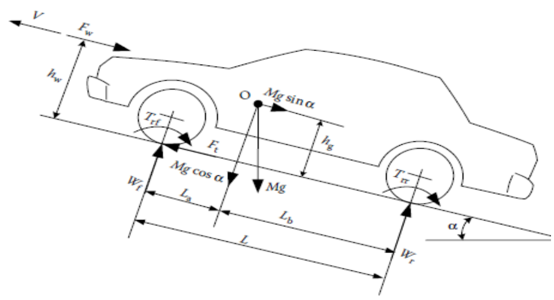

**Figure 2 Forces acting on a vehicle moving**

Where $P_e$ is the vehicle electric power demand, V is the vehicle speed, $V_W$ is the wind speed, $\eta_t$ is the total efficiency, $F_f$ and $F_g$ are the quadrature components of gravitational force, $F_w$ is the aerodynamic drag force, $M_v$ is the vehicle mass, $\delta$ is the rotational inertia factor, $\alpha$ is the slope angle, $\rho$ is the air density, $A_f$ is vehicle front area, $C_D$ is the aerodynamic drag coefficient, g is the acceleration of gravity, $f_r$ is the rolling resistance coefficient.

### 2.2. Fuel Cell Model

Toward transportation propulsion applications, the Polymer Electrolyte Membrane (PEM) Fuel Cell holds significant advantages over other fuel cell types. The PEMFC is light, compact, high power density and runs at a low temperature, which allows for relatively quick start-up. The dynamic model of the fuel cell is the electrochemical model with the component material balance equations. The total cell potential can be obtained as [5, 6].

**Table 1 Proposed FCEV Parameters**

| | | |
|---|---|---|
| $M_v$ | Vehicle mass (kg) | 1350 |
| $\delta$ | Rotational inertia factor | 1.013 |
| $C_D$ | Aerodynamic drag coefficient | 0.3 |
| $A_f$ | Vehicle front area ($m^2$) | 2 |
| r | Radius of the wheel (m) | 0.3 |
| $\rho$ | Air density ($kg/m^2$) | 1.202 |
| $\alpha$ | Slope angle | $0^o$ |
| $V_{max}$ | Maximum vehicle speed (km/h) | 180 |

$$V_{fc} = V_{ref} + \frac{RT}{nF}\ln\left(\frac{p_{H2}p_{O2}^{0.5}}{p_{H2O}}\right) - \frac{RT}{\alpha nF}\ln\left(\frac{I_{fc}}{I_o}\right) - R_{fc}I_{fc} - \frac{RT}{nF}\ln\left(1-\frac{I_{fc}}{I_L}\right) \quad (6)$$

$$p_{H_2} = 0.5\left(\frac{P_{H_2}}{\exp\left(1.653 I_{fc} / T^{1.334}\right)}\right) - P_{H_2O} \quad (7)$$

$$p_{O_2} = \left(\frac{P_{air}}{\exp\left(4.192 I_{fc} / T^{1.334}\right)}\right) - P_{H_2O} \quad (8)$$

$$q_{H2} = \frac{N_{fcs}.N_{fcp}.I_{fc}}{2FU} \quad (9)$$

Where $V_{ref}$ is the standard voltage of fuel cell, R is the Ideal gas constant, T is the cell temperature, n is the number of exchange protons per mole of reactant, F is the Faraday's constant, $P_{H2}$ is the partial pressure of hydrogen, $P_{O2}$ is the partial pressure of the oxygen, $P_{H2O}$ is the partial pressure of the water, $\alpha$ is the electron transfer coefficient, $I_{fc}$ is fuel cell current, $R_{fc}$ is the total cell resistance, T is the ambient temperature $I_L$ is limiting current density, U is the utilization factor, $q_{H2}$ is amount of hydrogen flow rate and $N_{fcs}$, $N_{fcp.}$ are the number of series cell, number of parallel cell respectively. The parameters of the fuel cell unit are illustrated in Table2.

**Table 2 Fuel cell Unit Specification [7]**

| | |
|---|---|
| Fuel cell type | PEM |
| Manufacturer | Relion |
| Weight | 16.28 g |
| Volume | 14.2 mL |
| Open circuit voltage | 1 V |
| Power | 3.78 W |
| Cost | 283 $/KW |

### 2.3. Battery Model

The model of the battery is based on state of charge (SOC) knowledge. In consequence, a battery model gives SOC and voltage level is sufficient. If the current is negative battery charge as in (11) and discharge if the current is positive as in (12). This model is taking in consideration the values of the charge and discharge resistance $R_{charge}$, and $R_{discharge}$ respectively of the batteries as shown in Figure 3 [8, 9].

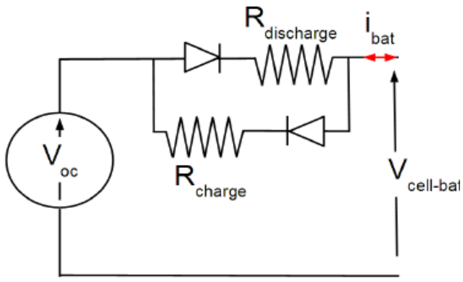


**Figure 3 Battery charge/discharge model**

$$SOC(t) = SOC(t0) + (1/3600)\ i_{bat}\ dt \quad (10)$$

$$i_{bat} \le 0 \rightarrow V_{cell-bat} = Voc + i_{bat}\ R_{charge} \quad (11)$$

$$i_{bat} \ge 0 \rightarrow V_{cell-bat} = Voc - i_{bat}\ R_{discharge} \quad (12)$$

Where Vcell-batt is the battery cell voltage, ibat is the current of the battery, Voc is the open source voltage. The parameters of the battery unit are illustrated in Table 3.

**Table 3 Battery Unit Specification [10, 11]**

| | |
|---|---|
| Manufacture | JC-Saft |
| Battery Type | lithium-ion |
| Nominal capacity | 1.2 Ah |
| Nominal voltage | 3.6 V |
| Battery volume | 0.02 L |
| Battery cell mass | 9 g |
| Battery price | 900 $/kWh |

### 2.4. Supercapacitor Model

Supercapacitor technology has been commercially available for over the past decade. They can store much more energy than conventional capacitors and are available in sizes up to 5000F with voltage ratings of up to 3V per cell. Supercapacitors cannot replace the batteries completely; however, they can be used to complement each other. The supercapacitors are modelled as a parallel connection of a capacitor C and a resistor RP, both of them series with a resistor Rs as shown in Figure 4. The supercapacitor dynamic model can be written as [12].

$$Req = \frac{V^2_{SC\_max}}{4P_{SC\_max}} \quad (13)$$

$$C_{SC} = \frac{2E_{SC\_max}36000}{V^2_{SC\_max}} \quad (14)$$

$$i_{SC} = \frac{-V_{SC}}{2Req} + \frac{\sqrt{V_{SC}^2 - 4Req.P_{SC}}}{2Req} \quad (15)$$

$$V_{SC} = V_{SC}(0) + \frac{1}{C_{SC}}\int i_{SC}dt \quad (16)$$

$$SOC_{SC} = \left(\frac{V_{SC}}{V_{SC\_max}}\right)^2 \quad (15)$$

Where Req is the supercapacitor equivalent resistance, Vsc is the supercapacitor voltage, Vsc(0) is initial supercapacitor voltage,Vsc_max is the maximum supercapacitor voltage, Psc_max is the maximum supercapacitor power, Psc is the supercapacitor power,Cscis the supercapacitor capacitance, isc is the supercapacitor current, and SOCscis the supercapacitor state of charge. The parameters of the supercapacitor unit are illustrated in Table 4.

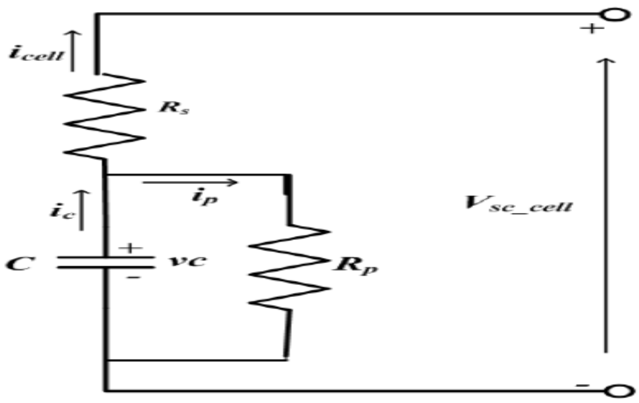


**Figure 4 Supercapacitor equivalent circuit.**

**Table 4 Supercapacitor Unit Specification [13]**

| | |
|---|---|
| Manufacturer | Maxwell 650 |
| Capacitance | 650F |
| Weight | 160 g |
| Volume | 0.13 L |
| Absolute Maximum Current | 680 A |
| Leakage Current at 25°C, maximum | 1.5 mA |
| Operating temperature | -40 C$^o$ to 60 C$^o$ |
| Specific Energy | 4.1 Wh/kg |
| Stored Energy | 0.66 Wh |
| Cycle Life at 25o C | 1,000,000 cycles |
| Cost | 3000 $ /kWh |

## III. Sizing Optimization Problem

The proposed FCEV powertrain is shown in Figure1. When the FCEV demands high power, the fuel cell, batteries and supercapcitor provide power to the vehicle's wheels through the DC/DC converter, the inverter, AC motor, and the transmission. In this case the power flow equation is shown in (16)

$$P_{load(t)} = P_{fc(t)} + P_{ess(t)} \quad (16)$$

On the other hand, when the FCEV demands low power, the fuel cell provides power to the wheels through the DC/DC converter, the inverter, the AC motor, and the transmission and charges the battery and Supercapcitor through bidirectional DC/DC converter. In this case, the power flow equation is shown in (17).

$$P_{fcs(t)} = P_{load(t)} + P_{ess(t)} \quad (17)$$

When the FCEV brakes, the AC motor converts the kinetic energy of the vehicle into electricity and charges the battery and supercapcitor through the inverter and the bidirectional DC/DC converter. In this case the power flow equation is shown in (18).

$$P_{ess(t)} = -P_{load(t)} \quad (18)$$

The optimization problem is formulated to compute the optimal cost of the FCEV power train components, the cost function is described in equation (19).

$$J = min\left(C1\,P_{fc} + C2\,P_{batt} + C3\,P_{sc}\right) \quad (19)$$

Where $J$ is the total cost of the fuel-cell, battery and supercapacitor given in U.S. dollars; $P_{fc}$ , $P_{batt}$ , $P_{sc}$ are the power of the fuel cell, battery, and supercapacitor respectively; C1, C2, and C2 are the power cost per one cell of FC, battery, and supercapacitor in U.S. dollars, respectively. Since the power of the fuel cell, battery and supercapacitor is a function of the number of series and parallel cells, the power equations are described in (20) through (22).

$$P_{fc} = N_{fc\_p} * N_{fc\_s} * P_{fc\_one\_cell} \quad (20)$$

$$P_{batt} = N_{batt\_p} * N_{batt\_s} * P_{batt\_one\_cell} \quad (21)$$

$$P_{sc} = N_{sc\_p} * N_{sc\_s} * P_{sc\_one\_cell} \quad (22)$$

From (19-22) we can obtain

$$J = min\begin{pmatrix} C1 * N_{fc\_p} * N_{fc\_s} * P_{fc\_one\_cell} + \\ C2 * N_{batt\_p} * N_{batt\_s} * P_{batt\_one\_cell} + \\ C3\,N_{sc\_p} * N_{sc\_s} * P_{sc\_one\_cell} \end{pmatrix} \quad (23)$$

From (23) it is clear that $N_{fc\_p}$, $N_{fc\_s}$, $N_{batt\_p}$, $N_{batt\_s}$, $N_{sc\_p}$, $N_{sc\_s}$ should be reduced to minimize the cost, mass, and volume of the FCEV power train. However, there are constraints on the reduction of all cost function coefficients.

### 3.1 Constraints

There are different constraints on the reduction of all cost function coefficients.

#### 3.1.1 Constraint of C1, C2, and C3

In this paper, the cost per one cell of the fuel cell, battery and supercapacitor is taken according to the cost per kW or kWh as presented in Table2, Table3, and Table4 respectively.

#### 3.1.2 Constraint of DC Bus voltage

The desired value of the DC-Bus voltage is chosen to to be 500V as Toyota Prius Hybrid Vehicle [15]. In general, DC-Bus voltage is higher than fuel cell voltage which, the degradation of platinum catalysts is higher with high cell voltages. Thus, we choose the DC- source voltage ($V_{SC}$, $V_{batt}$ and $V_{FC}$) to be 300 V with variations of ± 10% are permissible ($V_{min}$=270 and $V_{max}$=330V). From this constraint we can find the constraints of the $N_{fc\_s}$, $N_{batt\_s}$, $N_{sc\_s}$. These constraints are calculated by (24) and (25).

$$N_{min} = \frac{V_{min}}{Cell\_Voltage} \tag{24}$$

$$N_{\max} = \frac{V_{\max}}{Cell\_Voltage} \tag{25}$$

Where the $Cell\_Voltage$ is the voltage of fuel cell, battery and supercapcitor that are presented in Table2, Table3, and Table4 respectively. The computed constraints are presented in Table 5.

**Table 5 Constraints of $N_{fc\_s}$, $N_{batt\_s}$, $N_{sc\_s}$.**

| No. series cell | DC voltage | $N_{\min}$ | $N_{\max}$ |
|---|---|---|---|
| $N_{fc\_s}$ | $270 \le Vdc \le 330$ | 270 | 330 |
| $N_{batt\_s}$ | $270 \le Vdc \le 330$ | 75 | 92 |
| $N_{sc\_s}$ | $270 \le Vdc \le 330$ | 100 | 123 |

#### 3.1.3 Constraints of Power

The power train must be sufficient to deliver the vehicle power demand and recover all the available energy from regenerative braking to increase the vehicle performance. The auxiliary load in the proposed FCEV is assumed to be 1 kW and is provided only by the battery, this mean that the $P_{batt-\min}$ = 1 kW. The vehicle's driving performance is usually evaluated by its acceleration time, maximum cruising speed, and gradeability. The proposed FCEV performance parameters are presented in Table 6.

**Table 6. Proposed FCEV Performance Parameters.**

| Parameter | Value |
|---|---|
| Acceleration | (0-100 km/h) in 10 Sec |
| Gradeability | (at 90 km/h) 6.5% |
| Maximum speed | 180 km/h |

**A. Maximum speed**

At steady state only fuel cell or fuel cell and battery deliver the power to the vehicle according to the $SOC_{-batt}$. Using (1) and specifications of the vehicle presented in Table 1, the power demanded by the vehicle during maximum speed was calculated to be 74.2 kW.

**B. Gradeability**

The motor power rating is determined by gradeability performance. This means that the power rating designed to meet the gradeability In this paper, gradeability for the proposed FCEV is defined as the ability to grade a road of 6.5% inclination at a constant speed of 90 km/h. Using (27) and specifications of the vehicle presented in Table 1, the power demanded by the vehicle during grading was calculated to be 48.35 kW.

$$P_{grad} = \frac{V}{\eta_t}\begin{pmatrix} M\ g\ f_r\ cos(\alpha) + M\ g\ sin(\alpha) \\ +\frac{1}{2}\ \rho\ A_f C_D \left(V - V_w\right)^2 \end{pmatrix} \tag{27}$$

Where $P_{grad}$ is the vehicle power demand during grading.

**C. Acceleration**

The initial-acceleration performance for the proposed FCEV is defined as accelerating the vehicle from standstill to 100 km/h in 10 sec. Using (1) and specifications of the vehicle presented in Table 1, the power demanded by the vehicle during initial-acceleration speed is shown in Figure 5.

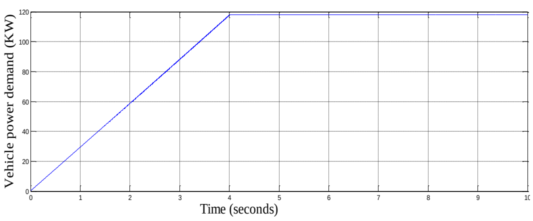


**Figure 5 Vehicle power demand during initial acceleration.**

When the vehicle cruises at the maximum vehicle speed (maximum fuel cell power) and during grading (minimum fuel cell power), the fuel cell alone provides power to FCEV.

$$P_{fc\min} \leq P_{fc} \leq P_{fc\max} \quad (28)$$

While during acceleration, both of the fuel cell and ESS in the FCEV powertrain have to supply a high power to the vehicle. The battery and supercapacitor is supposed to cover the power fluctuation above the fuel cell power. The magnitude of energy above $P_{fc}$ is calculated by:

$$E_{ESS} = \int_{t1}^{t2} \left(P_{inst} - P_{fc}\right) dt \quad (29)$$

### 3.1.4 State of Charge

The level of $SOC_{min}$ and $SOC_{max}$ of battery is chosen to be 75% and 90%, respectively.

$$SOC_{min} \leq SOC(t) \leq SOC_{max} \quad (30)$$

### 3.1.4 Constraint of Fuel cell and Battery Power Ramp Rate

The Power ramp rate constraints in (31) and (32) are applicable to the FC and the battery. The ramp rate limit is very important to prevent the oxygen starvation phenomenon of the fuel cell system, and increase the lifetime of the battery.

$$R_{min\_fc}\, f(t) \leq P_{fc}(t) - P_{fc}(t-1) \leq R_{max\_fc}\, f(t) \quad (31)$$

$$R_{min\_batt}\, f(t) \leq P_{batt}(t) - P_{batt}(t-1) \leq R_{max\_batt}\, f(t) \quad (32)$$

## IV. Optimization Techniques

In this paper, two optimization techniques, genetic algorithm and particle swarm optimization are used to obtain the optimal sizing of a fuel cell, battery and supercapacitor for a FCEV.

### 4.1. Genetic Algorithm

GA is a search algorithm that depends on a conjecture of natural selection and genetics. The general procedure of GA is to evaluate fitness (or objective function value) for a randomly generated initial population. Then, based on fitness, selection is done on the individuals for reproduction. Upon selecting individuals crossover and mutation is performed to create offspring which forms the population of the next generation. This process is repeated until the maximum number of generations or convergence is reached as shown in Figure 6 [16].

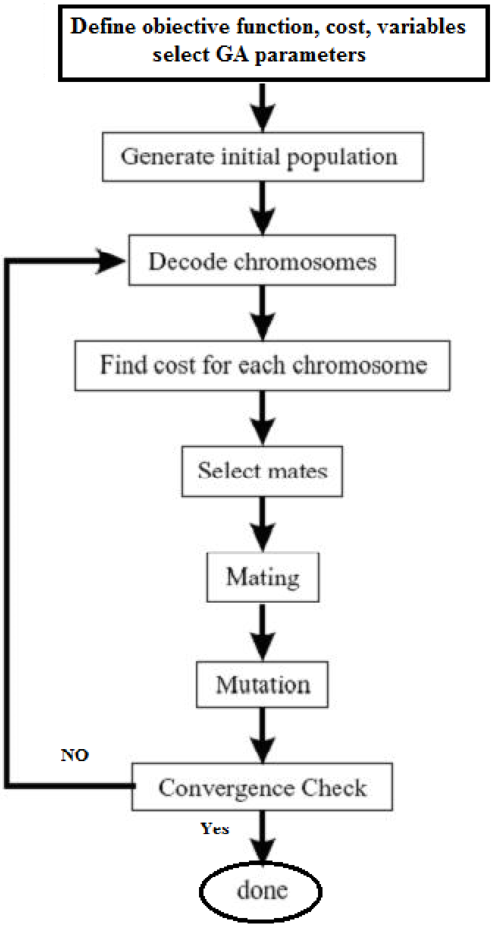


**Figure 6. Genetic algorithm optimization.**

### 4.2. Particle Swarm Optimization

PSO algorithm is based on the social behavior of birds. In this algorithm, initially a random population is created. Every individual known as particle is assigned a velocity and a small social network. For all particles, fitness or objective function values are evaluated. Based on fitness, unlike GA, PSO doesn't have the crossover / mutation, but the personal optimal for each individual, global optimization in the complete population and neighborhood optimal found by the neighbors of each individual are saved to update velocity and position for each individual. This process is repeated until either maximum generations or convergence is reached as shown in Figure 7 [17].

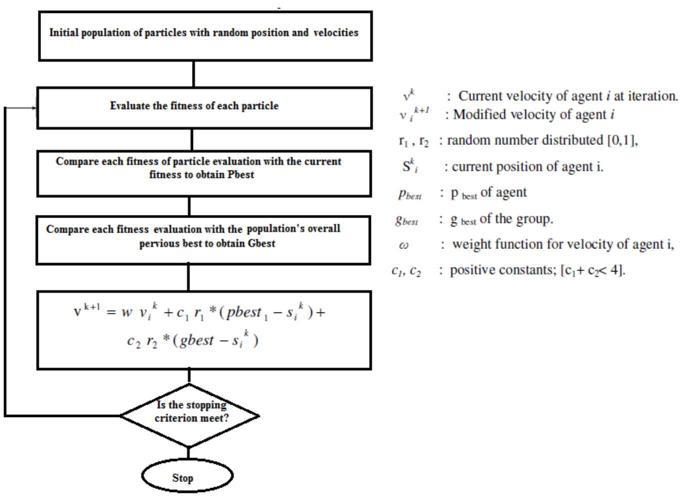


**Figure 7. Particle Swarm Optimization.**

## V. SIMULATION RESULTS

The optimal design of the FCEV power train satisfies the vehicle performance (DC bus voltage and required power during maximum speed, gradeability, and acceleration) is presented. The optimized $N_{fc\_p}$, $N_{fc\_s}$, $N_{batt\_p}$, $N_{batt\_s}$, $N_{sc\_p}$, $N_{sc\_s}$ were used to calculate the size, weight, cost, and volume of the fuel cell, battery and supercapacitor. In this section, there are two optimization methods (PSO and GA) have been designed to achieve the optimal sizing. The parameters of PSO and GA are shown in Tables 8 and 9 respectively. Figure 8 shows the optimized $N_{fc\_p}$, $N_{fc\_s}$, $N_{batt\_p}$, $N_{batt\_s}$, $N_{sc\_p}$, $N_{sc\_s}$ using PSO and GA optimization techniques. also, figures 9, 10, 11 show the corresponding optimized volume, mass, cost and power of the fuel cell, battery, supercapacitor and the total power train. Moreover, table 9 shows the size of the optimized fuel cell, battery, supercapacitors. It can be observed that the fuel cell has the large power, volume, mass, size and cost because, it is responsible for supplying the vehicle power demand during steady state. While, ESS assists the fuel cell during of the transient power required during FCEV acceleration. The comparison between these two optimization methods shows that the PSO is more efficient than GA to achieve the optimal powertrain for the FCEV.

**Table 8. GA Algorithm Parameters.**

| Parameters | Value |
|---|---|
| Population size | 50 |
| Number of Generations | 100 |
| Crossover Probability | 0.9 |
| Mutation Probability | 0.1 |

**Table 9. PSO Algorithm Parameters.**

| Parameters | Value |
|---|---|
| Population size | 50 |
| Max. iter | 150 |
| c1 | 0.5 |
| c2 | 0.5 |
| Max. weight | 1.2 |
| Min. weight | 0.1 |
| r1 | [ 0,1] |
| r2 | [ 0,1] |

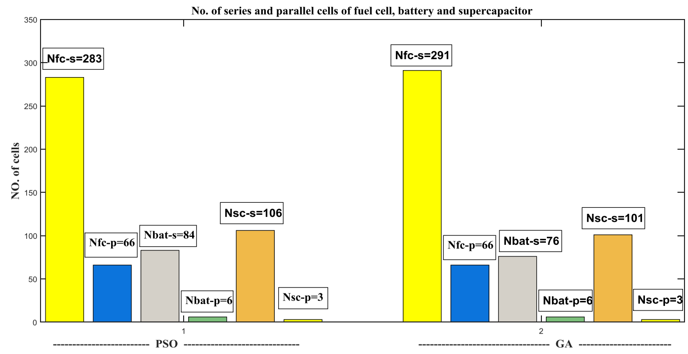


**Figure 8. Optimal No. of series and parallel cells of fuel cell, battery and supercapacitor.**

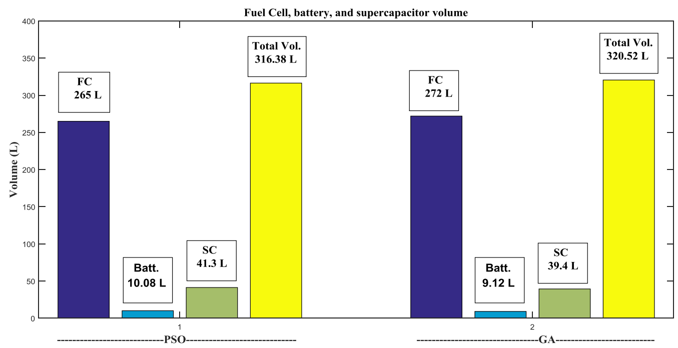


**Figure 9. Volume of Fuel Cell, battery, and supercapacitor.**

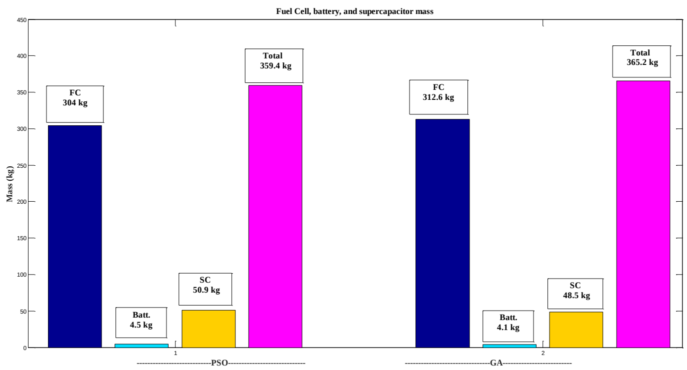


**Figure 10. Mass of fuel Cell, battery, and supercapacitor.**

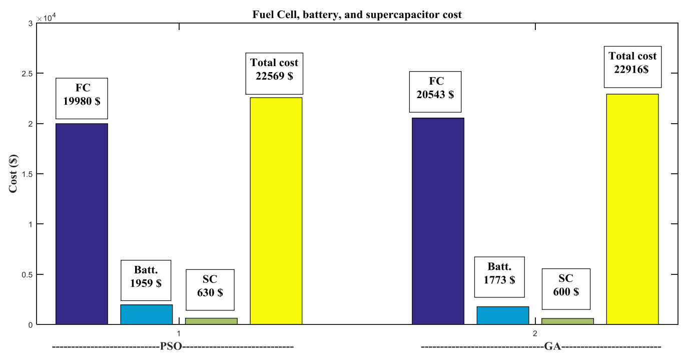


**Figure 11. Cost of fuel Cell, battery, and supercapacitor.**

**Table 9. Optimized fuel cell, battery, supercapacitors size**

| Source | Fuel cell | Battery | SC |
|---|---|---|---|
| Size (PSO) | 70.61 kW | 2.177 kW/h | 0.210 kW/h |
| Size (GA) | 72.59 kW | 1.970 kW/h | 0.199 kW/h |

## VI. Conclusions

In this work, the modelling of all components of the proposed power train for FCEV has been developed in order to investigate the dynamic behavior of each subsystem. The combined utilization of the battery and supercapacitor is the perfect ESS system because, it integrates the advantages of a high energy of the battery and a high power density of the supercapacitor. Fuel cell and battery power ramp rates have been used to stay away from the fast transition of the fuel cell and battery powers, and then reducing the fuel cell and battery stresses. In addition, hybrid power source will increase the lifetime of battery and fuel cell. Moreover, PSO and GA have been used for the optimization problem in order to minimize the total cost, volume, size and the mass of the fuel cell, battery, and supercapacitor. A wide range of constraints and targets were considered such as acceleration time, maximum cruising speed, gradeability, power limits, and battery state of charge. By analyzing and comparing the results, it is shown that PSO is more efficient than GA to achieve the optimal powertrain for FCHEV.

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