Analysis of Opportunities for Increasing Energy Efficiency of Electric Vehicle with Hydrogen Cell

Blagoy Burdin[1], Borislav Traykov[2], Dimitar Bojchev[3]and Zhelyazko Kartunov[4]

Abstract - **One of the main problems of electric vehicle is the great value of start power. In current paper is made an analysis of opportunities for increasing energy efficiency by using PID regulator. It is made an expression of estimation start power energy efficiency, based on practical measurements.The results are confirmed with practical experiments and represented with graphics.**

Keywords– **Fuel cells, PID regulator.**

I. Introduction

Important technical limitation a fuel cell system is a current (or power) slope of fuel cell must be limited in order to prevent fuel starvation phenomenon [1] [2]. In addition, for vehicle applications power drive train consumed high power in a short time in vehicle acceleration process (around two times of average power during drive cycle [3].

This paper present method to decrease energy consumption in acceleration vehicle process. The experimental results are obtained with measurements of fuel cell car made for Shell Eco-Marathon 2011 competition.

II. Estimating Start Power (Energy)Consumption

The energy, required for electric vehicle starting can be estimating by consummated power vs. time The energy in starting process is given by Eq.1:

$$E_s = \int_{t_0}^{t_1} P(t)dt \quad (1)$$

E_s - Energy of starting process;

$P(t)$ -Consumed power.

In current paper consumedpoweris represented by power series expansionEq.2:

$$\int_{t_0}^{t_1} P(t) = a_0 + a_1 p + a_2 p^2 + ... + a_n p^n \quad (2)$$

In considering case it is made a computer simulation of dependence between start power in function of time. It is used a numerical method with inverse matrix division. Using practical measurement results, shown in table 1 it is made a matrix Eq.3

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & i & i^2 & i^3 \\ .. & ... & ... & ... \\ 1 & \sqrt{M} & M & M^{\frac{3}{2}} \end{bmatrix} . [a_k]^{'} = [P'_{di} + (i-1)]^{'} \quad (3)$$

Aftersolvingthe Eq.(3) becomes:

$$\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & i & i^2 & i^3 \\ .. & ... & ... & ... \\ 1 & \sqrt{M} & M & M^{\frac{3}{2}} \end{bmatrix} \backslash [K'_{di} + (i-1)]^{'} \quad (4)$$

The results are shown in Fig.1.It can be seen that for practical measurements in the purpose of current case the most appropriate polynomial order is 4-th.

Table 1: Power consumption, current of vehicle electric motor and battery voltage value.

t,s	0	0,5	1	1,5	2
I,A	80	45	36	34	32
U,V	22	23	24	24	24
P,W	1760	1035	864	816	768

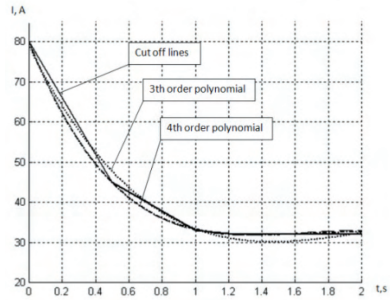

Fig.1 Computer simulation of dependence between start power in function of time

[1]Blagoy Burdin is PhD student with the Faculty of Transport at Technical university – Sofia, E-mail: b.burdin@abv.bg

[2]Borislav Traykov is associate professor with the Faculty of Transport at Technical university – Sofia, E-mail: btrykov@tu-sofia.bg

[3]Dimitar Bojchev – PhD at Technical university –Sofia

[4]Zhelyazko Kartunovis PhD student with the Faculty of Transport at Technical university – Sofia, E-mail: g_kartounov@tu-sofia.bg

Bearing in mind the above the start energy can be calculated by substitution of (2) in (1):

$$E_S = \int_{t_0}^{t_1} \left(a_0 + a_1 P\ (t) + a_2 P^2(t) + a_3 P^3(t) + a_4 P^4(t)\right) dt \quad (5)$$

Where $t_0 = 0$.

After calculation the expression becomes:

$$E_S = a_0 + \frac{a_1}{2} t_1^2 + \frac{a_2}{3} t_1^3 + \frac{a_3}{4} t_1^4 + \frac{a_4}{5} t_1^5 \quad (6)$$

A. Theoretical analysis of energy efficiency.

The relatively estimation achieves energy efficiency can be computing by the next Eq:

$$\rho = \frac{E_s - E_{s'}}{E_s}.100,\% \quad (7)$$

For increasing energy efficiency is applied Proportional integralderivative control regulator (PID). The regulation law can be express according Eq.8.

$$U(t) = k_p.\Delta(t) + k_I.\int \Delta(t)dt + k_d \frac{d\Delta(t)}{dt} \quad (8)$$

Where Kp- proportional coefficient;

Ki – international component;

Kd- derivative component.

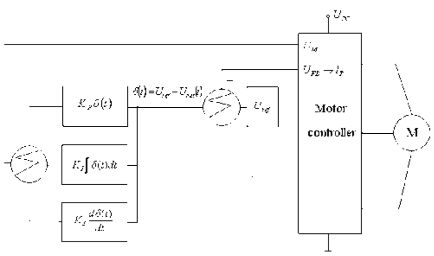

Fig.2 Functional scheme of used PID regulator

TABLE 2: THE REGULATOR COMPONENTS, ADJUSTED USING ZIEGLER- NICHOLS CLOSED LOOP TUNING METHOD.

Controller	K	T_i	T_d
P	$0{,}5.K_u$	-	-
PI	$0{,}4.K_u$	$0{,}8.T_u$	-
PID	$0{,}6.K_u$	$0{,}5.T_u$	$0{,}125.T_u$
20% over adjusting	$0{,}2.K_u$	$0{,}5.T_u$	$0{,}125.T_u$

where Tu – continues oscillations period;

Ku–ultimategain.

The functional scheme of regulator is shown in fig.2. The regulator components are adjusted using Ziegler- Nichols closed loop tuning method (table2).

B. Practical results.

It is made a practical experiment before and after applying the PID regulator. Using the numerical results it is made a 4-th order polynomial interpolation Fig.3.

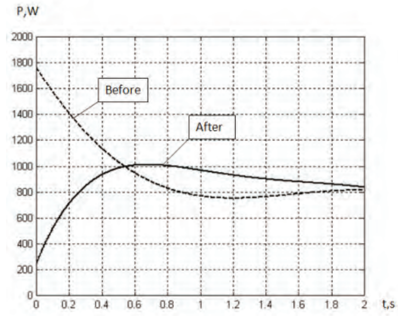

Fig. 3 Consumed power vs. time before and after using adjusted PID regulator

The real energy efficiency is calculated using (7)and represents anenergy savingsbetweenthe twointegrated areasofpower shown in Fig. 3.

The results of experiment shows that using the PID controller the start energy efficiency can be increased at least 8%.

Applying of PID controller is an real approach to increase energy efficiency of the fuel cell vehicle during the start mode. The same approach can be applied to increase energy efficiency in other driving modes of the vehicle.

III. CONCLUSION

Applying of PID controller is an real approach to increase energy efficiency of the fuel cell vehicle during the start mode. The same approach can be applied to increase energy efficiency in other driving modes of the vehicle.

ACKNOWLEDGEMENT

The results are obtained under a project funded by the grant for scientific research in TU - Sofia.

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