Abstract—Energy management in Electric Vehicle (EV) technology is very important as the energy source of all its system operations are solely relying on the battery. The unique characteristic of Electric Power Assist Steering (EPAS) system provides a way in realizing minimum energy consumption in EV subsystem. The controller in the EPAS system need to be tuned with the optimal performance setting so that less current is needed for its optimum operation. In this paper, Particle Swarm Optimization (PSO) algorithm is implemented as tuning mechanism for PID controller. The aim of this hybrid controller is to minimize energy consumption of the EPAS system in EV by minimizing the assist current supplied to the assist motor. The PSO searching method will search for the best gain parameters of the PID controller and providing the fast tuning feature that distinguish it from the conventional trial and error method. Simulation results shows the performance and effectiveness of using PSO algorithm for PID tuning.

Index Terms—Electric power assist steering (EPAS), C-type EPAS, PID, particle swarm optimization (PSO), electric vehicle (EV).

I. INTRODUCTION

Electric vehicle (EV) is not a new technology because the history of EV had started since 1834 after the discovery of electricity and the knowledge of electromechanical energy conversion. During that time, a non-rechargeable battery-powered electric car was used and it only for a short distance travel. EV then becomes outnumbered by the Internal Combustion Engine (ICE) vehicle as it can overcome distance travel issues faces by the EV. Then in 20th century, the scenario turned in favor to EV due to energy crisis faces by all around the world. In EV, an electric motor or a few electric motors are used to drive wheels of a vehicle.

Battery in EV system served as energy source and provides electric power to electric motor drives and other electrical equipment in the system. The whole system of electric vehicle can be divided into three major subsystem which are electric propulsion subsystem, energy source subsystem and auxiliary subsystem. The electric propulsion subsystem is dealing with the drive vehicle and vehicle’s propulsion. As for auxiliary subsystem, it comprises of the power steering unit, temperature control unit and auxiliary supply. And since all operations in EV is supported by the energy source subsystem, it has been a major concern in EV technology in terms of battery energy capacity to support the long-range operation [1].

Energy consumption is very vital in electric vehicle technology as the energy source of all its system operations are solely relying on the battery. Efforts are being made to reduce the energy consumed as much as possible in EV system. As one of the auxiliary elements of the system, EPAS system can be controlled or manipulated in such a way that minimum energy from the battery source is being draws during its operation. The controller in the EPAS system needs to be tuned with the optimal performance setting so that less current is needed for its optimum operation. With the dynamic changes of vehicle speed and external disturbance resulted from road condition, the controller need to be able to deliver a sufficient and best possible assist torque to the driver with minimum power consumed. For that reason, significant improvement should be made to the controller of EPAS system to ensure optimum performance with lowest possible current draws from the battery.

Mechanical steering system or hydraulic power assist steering (HPAS) draws a constant energy supply from battery to maintain the pressure in hydraulic pump [2]. Whereas the EPAS system improves the energy efficiency due to its on-demand system feature which is only operating when the steering wheel is turned [3]. It offers an additional advantages than hydraulic power steering as it can reduce the steering torque, provide various steering feel and improve return-to-center performance of a steering wheel when it is steered [4]. The EPAS system becomes an alternative to the automotive manufacturer in providing the convenience of steering assist without adding value to the engine cost and fuel consumption. Only approximately one-twentieth of energy is consumed by the EPAS system compared to the conventional HPAS system and this feature make EPAS a very suitable candidate in EV steering system [5].

Fig. 1 shows a model arrangement of column-type EPAS. Electric motor is attached to the steering rack or column via gear mechanism and sensors are located on the input shaft in EPAS system. It uses electromechanical actuation where the sensors determine the driver’s torque, steering angle and speed and direction of the steering wheel. The sensors together with the vehicle velocity are fed into the ECU. The resulting demand from the ECU process is used to excite the circuitry of the motor and finally giving an output to the rack [6].

In the research on EPAS system, some of the goals are to reduce the steering torque exerted by the driver and also to improve the steering performance. In line with these goals, many control strategies have been applied and implemented in the EPAS system such as a reference model, fuzzy logic, PID, H2 and H∞ [7]-[10]. Parmar and Hung in [11] discussed a simplified model and optimal controller structure of an EPAS by employing LQR and Kalman filter technique. In Marouf [12] a simplified model of the sensorless control of EPAS system with the permanent magnet synchronous motor (PMSM) using sliding mode techniques was introduced.
While Hassan in [2] integrated the genetic algorithm (GA) with the PID controller to provide optimized controller parameters. Many studies on EPAS system has been done however only limited number of study on EPAS concerning on the energy consumption of the EPAS system and involving evolutionary algorithm such as Particle Swarm Optimization (PSO). Therefore, this paper aims to study the potential of hybrid PSO to the PID controller in the EPAS system to reduce the energy consumption.

![Model diagram of the EPAS system](image)

**III. PARTICLE SWARM OPTIMIZATION (PSO)**

Particle Swarm Optimization (PSO) is a population based evolutionary algorithm which originally developed by J. Kennedy and R. C. Eberhart on 1995 [17]. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous nonlinear optimization problems [13]. Using this algorithm, the solution obtained is a high-quality solution which is generated within the shorter calculation time and can achieve stable convergence characteristic.

This method is developed from research on swarm such as bird flocking and fish schooling. It has features of easy implemented technique, stable characteristic convergence and good computational efficiency [18]. Instead of using evolutionary operators such as mutation and crossover to manipulate the particle, a flock of particles is put into the d-dimensional search space for a d-variable optimization problem. Each particle flies within the search space with velocities and positions which is dynamically adjusted according to its own flying experience and its neighbors' flying experience [13], [15].

The PSO technique combines the artificial-life methodology to bird flocking, fish schooling and swarming theory in its algorithm [19]. Stimulate by the animal social behavior such as fish schooling and bird flocking, PSO algorithm emulates the physical movement of individual member in the school or flock and also their cognitive and social behavior in its searching technique. This algorithm uses very straightforward mathematical concept and paradigm which can be realize within a few lines of computer code. Less codes needed couple together with small computer memory and speed requirement gives salient feature to PSO in terms of computational cost [20]. As one of the discipline in the CI, PSO shares similarities with other disciplines in terms of stochastic optimization method which based on population, random initial population generation, fitness concept application on the objective function and population update and search for optimum solution using random technique.

However, PSO does not apply the concept of survival of the fittest instead all individuals do not die, retain their memory and share their information with others [20]. A fitness function is used in determining the optimal solution. At each iteration, the fitness of each particle is evaluated. Each particle keeps track of its own best position and its best fitness in the problem space it has achieved so far. This is called particle best or pbest. The algorithm used for updating the particle velocity and position at each iteration is in equation (1) and (2) below:

\[
v_{id\_new} = (w \times v_{id}) + C_1 \left( rand_1 (p_{id} - x_{id}) \right) + C_2 \left( rand_2 (p_{gd} - x_{id}) \right) \quad (1)
\]

\[
x_{id\_new} = x_{id} + v_{id\_new} \quad (2)
\]

PSO also tracked another best value associated with the
Weight (LDIW) and Time-Variant acceleration coefficients linearly. This method is known as Linear Decreasing Inertia (LDIW) and Time-Variant acceleration coefficients. It is important to note that each coefficient in the computation methods because it produces random initial values. PSO is faster in finding solutions than evolutionary algorithms; however, it needs some tuning to improve the performance of this model, clamping is used by Eberhart in [23] as described by equation (3) below, 

\[ w = (w_1 - w_2) \times \frac{\text{maxiter} - \text{iter}}{\text{maxiter}} + w_2 \]  

(3)

\[ C_1 = \left( C_{1f} - C_{1l} \right) \frac{\text{iter}}{\text{maxiter}} + C_{1l} \]  

(4)

\[ C_2 = \left( C_{2f} - C_{2l} \right) \frac{\text{iter}}{\text{maxiter}} + C_{2l} \]  

(5)

The model was only valid for certain problem because when it is applied on benchmark problem, the model failed to improve the performance of this model, clamping is used by Eberhart in [23] as described by equation (3) –(5) below, \( C_1 \) will decreases linearly over time while \( C_2 \) will increases linearly. This method is known as Linear Decreasing Inertia Weight (LDIW) and Time-Variant acceleration coefficients (TVAC).

\[ J_m \ddot{\theta}_m + B_m \dot{\theta}_m + K_m \theta_m = T_m + G K_m \left( \frac{\theta_s - \theta_m}{r_s} \right) \]  

(7)

\[ M_s \dot{x}_r + B_r \dot{x}_r + K_r x_r = \frac{K_d \theta_s}{r_s} + \frac{G K_m \theta_m}{r_s} - F_d \]  

(8)

where \( J_s \) is the steering column moment of inertia; \( B_s \) is the steering column viscous damping; \( K_s \) is the steering column stiffness; \( J_m \) is the motor moment of inertia; \( B_m \) is the motor viscous damping; \( K_m \) is the motor stiffness; \( G \) is the gear ratio; \( M_r \) is the mass of the rack; \( B_r \) is the rack viscous damping; \( K_r \) is the tire spring rate; \( F_d \) is the road normal force; \( x_r \) is the rack position; \( r_s \) is the pinion radius; \( T_s \) is the steering wheel torque from the driver and \( T_m \) is the electromagnetic torque provided by electric motor.

According to the mathematical model, a Simulink diagram is designed. PID controller is used in the system to help minimizing the current and hence reducing its power consumption. The PID is known for its satisfying impact to the system performance, however it needs some tuning optimization to ensure maximum performance. Hence, PSO is applied in the system to improve the tuning of the PID controller. The mechanism is illustrated in the Fig. 3.

![Fig. 3. PID controller with ACO tuning of the EPAS subsystem.](image)

### V. SIMULATION AND RESULT

A Simulink model was built according to the mathematical model obtained for simulation. The simulation was performed using Matlab/Simulink on a Core i7-4770 CPU at 3.40GHz computer with 16.00GB RAM. Simulink model of EPAS system was given sinusoidal input to represent the steering wheel input torque with the range of 0 to 6.4N.m and the vehicle speed was set to 60km/h. Table I shows the initialization value for PSO parameters with maximum number of 100 iterations and population of swarm is set to 60.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of iterations</td>
<td>100</td>
</tr>
<tr>
<td>Number of variables</td>
<td>3 (Kp, Ki, Kd)</td>
</tr>
<tr>
<td>Swarm</td>
<td>60</td>
</tr>
<tr>
<td>Inertia weight, w</td>
<td>Wmax = 0.9, Wmin = 0.4</td>
</tr>
<tr>
<td>Acceleration coefficient, C1 &amp; C2</td>
<td>C1max = 2.0, C2max = 2.0, C1min = 0.05, C2min = 0.05</td>
</tr>
</tbody>
</table>

![TABLE I: PSO PARAMETERS](image)

![Fig. 4. shows the convergence of the objective function with final MSE value is 0.00040005. The parameters value of k_p, k_i, k_d obtained are k_p = 125.4541, k_i = 2.0909 and k_d = 4.1818 and the convergence profile of each parameters are presented as in Fig. 5, Fig. 6 and Fig. 7. From Fig. 4, it illustrates that the fitness function reach stable MSE value at 55 iterations. Before 55 iterations, as demonstrated in Fig. 5, Fig. 6 and Fig. 7, values of k_p, k_i, k_d changing before each](image)
finally reach their final stable value. The changes of these parameters which make the changes in of the MSE value.

![Mean-squared error](image)

**Fig. 4.** MSE convergence profile.

![kp convergence](image)

**Fig. 5.** Convergence profile of $k_p$.

![kd convergence](image)

**Fig. 6.** Convergence profile of $k_d$.

![ki convergence](image)

**Fig. 7.** Convergence profile of $k_i$.

To show the reduction in power consumption, the assist current of the assist motor is first being compared between manual tuned PID (labeled as PID) and PSO tuned PID (labeled as PSO-PID) as illustrated in Fig. 8. From Fig. 8, it shows that less current consumed by the PSO-PID as compared to PID. Power consumption analysis of the assist motor is then shown in Fig. 9. It is observed from Fig. 9 that PSO-PID consumed less power than PID with reduction of 33.1W. Maximum power of PID is 490.4W and maximum power achieved using PSO-PID is 457.2. These shows that significant power reduction obtained using PSO-PID because the tuning has been optimized for better performance using PSO algorithm. Table II summarized the parameters value of PID using manual tune and ACO algorithm.

From the results obtained, the PSO algorithm is able to tune properly the PID and effective to use as PID optimization technique. However, the solution of obtained is not the universal solution and this is an offline tuning technique.

![Power of Motor](image)

**Fig. 8.** Assist current to motor.

**TABLE II: PARAMETERS VALUE FOR $k_p$, $k_i$ AND $k_d$.**

<table>
<thead>
<tr>
<th>PID tune using:</th>
<th>$k_p$</th>
<th>$k_i$</th>
<th>$k_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Try and error (manual tune)</td>
<td>200</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>PSO tuning mechanism</td>
<td>125.4541</td>
<td>2.0909</td>
<td>4.1818</td>
</tr>
</tbody>
</table>

![Power of Motor](image)

**Fig. 9.** Assist motor power.

VI. CONCLUSION

An EPAS system Simulink model has been developed using PSO as the tuning mechanism for PID controller. The simulation done shows the feasibility of using PSO for tuning purpose in controlling assist current of the assist motor. The result shows that PSO-PID controller able to reduce the power consumed by the assist motor as an effort to minimize energy consumption for EV application. In future work, further improvement need to be carried out in the case of dynamic vehicle velocity. The PSO-PID based controller
shows a potential in optimizing energy efficiency of EPAS system.

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