Cyclic Parameter Refinement of 4S-10 Hybrid Flux-Switching Motor for Lightweight Electric Vehicle.

J Abd Rani¹, E Sulaiman², R Kumar³
Research Centre for Applied Electromagnetics, University Tun Hussein Onn Malaysia, Johor 86400 Malaysia

Corresponding author: he150066@siswa.uthm.edu.my¹, erwan@uthm.edu.my², rajeshkumar@iiee.edu.pk³

Abstract. A great deal of attention has been given to the reduction of lighting the vehicle because the lighter the vehicle the energy consumption is comparatively low. Hence, the lightweight electric vehicle was introduced for lower carbon footprint and the sizing of the vehicle itself. One of the components to reduce the weight of the vehicle is the propulsion system which comprised of electric motor functioning as the source of torque to drive the propulsion system of the machine. This paper presents the refinement methodology for the optimized design of the 4S-10P E-Core hybrid excitation flux switching motor. The purpose of the refinement methodology is to improve the torque production of the optimized motor. The result of the successful improvement of the torque production is justifiable for a lightweight electric vehicle to drive the propulsion system.

1. Introduction
Lightweight electric vehicles (LWEV) have attracted considerably great attention among manufacturer for its inevitable options due to the size, energy storage, power consumption etc. [1]. A lightweight vehicle weighing lighter than other vehicles in its class consumes less energy to accelerate given the same distance due to the weight and dimension [2]. LWEV categorized as per the class of vehicles shown in Figure 1. Less power requires means smaller size energy storage device for limited power consumption or a bigger capacity of energy storage device given the same size of energy storage unit. The use of traditional heavy batteries increases the weight of electric vehicle [3]. This in turn opens a gap to be filled by LWEV. The electric vehicle provides smooth operation and stronger acceleration and LWEV provide additional value in terms of size and mileage. A vehicle can be called LWEV in terms of many characteristic as per depicted in Figure 2 but this paper will focus specifically on the contribution of the electric motor to LWEV as the electric machine is a fragment of the vehicle propulsion system.

The greatest restrictive factor in designing the electric motor for LWEV is the motor size and weight as the design restriction must be agreeable to the vehicle size, weight and passenger space to ensure low energy consumption without compromising the performance. Automakers are focusing primarily on reducing the car’s weight [4]. Research conducted by [5] showed vast shedding vehicle weight was the primary objective of achieving emission target and tackling the future economy. Reducing the vehicle weight comprising of reducing the body weight by changing the material and employing smaller propulsion system such as an electric machine with the same acceleration performance as internal combustion engine [6]. Nearly half respondent in a survey research conducted by WardAuto shows that
nearly half (49%) respondents identified technology in engine efficiency program as an instrument to meet 2025 Corporate Average Fuel Economy (CAFÉ) standard [7]. The overall weight reduction comprising a lighter body and propulsion system will boost the fuel economy ranging between 6 to 8 percent [8]. Therefore, propulsion drive with a characteristic such that lightweight and high performance with high efficiency are crucial for the automotive industry in the near future.

![Diagram of Class of Electric Vehicle](image)

**Figure 1. Class of Electric Vehicle** [9] [10] [11]

The greatest restrictive factor in designing the electric motor for LWEV is the motor size and weight as the design restriction must be agreeable to the vehicle size, weight and passenger space to ensure low energy consumption without compromising the performance. Automakers are focusing primarily on reducing the car’s weight [4]. Research conducted by [5] showed vast shedding vehicle weight was the primary objective of achieving emission target and tackling the future economy. Reducing the vehicle weight comprising of reducing the body weight by changing the material and employing smaller propulsion system such as an electric machine with the same acceleration performance as internal combustion engine [6]. Nearly half respondent in a survey research conducted by WardAuto shows that nearly half (49%) respondents identified technology in engine efficiency program as an instrument to meet 2025 Corporate Average Fuel Economy (CAFÉ) standard [7]. The overall weight reduction comprising a lighter body and propulsion system will boost the fuel economy ranging between 6 to 8 percent [8]. Therefore, propulsion drive with a character such that lightweight and high performance with high efficiency are crucial for the automotive industry in the near future.

At present, E-Core hybrid flux switching motor (HFSM) is an attractive type of motor for a lightweight electric vehicle due to the specific performances and constructions [12]. The revolutionize modular ‘U-shaped’ laminated stator of permanent magnet switched-flux machine (PMSFM) results in E-shaped stator positioned circumferential sandwiching alternate polarities of magnetized permanent magnet [13]. The circumferential magnetized permanent magnets sandwiched between rotors to avoid the aligned magnetic field short-circuited. The presence of the permanent magnets in the stator zone ship off the issue of temperature rise in the rotor employing a robust structure of E-Core [14]. The alternate winding configuration of DC current supply and AC current supply reduce copper loss, hence bringing in nominal total loss [15].

This paper studies the parameter refinement of 4S-10P E-Core hybrid flux switching motor (HFSM) utilizing salient rotor structure and non-overlap armature and field windings to deliver optimum performance. The performance analysis of 4S-10P was pivoted on flux linkage, flux distribution, cogging torque, induced voltage and average torque. The parameter refinement adopting the deterministic method was conducted in 3 cycles in order to get the best output. The whole parameter
refinement utilizes finite element method simulation conducted via J-MAG Designer 14.1 issued by the Japan Research Institute.

2. Refinement Methodology
The 4S-10P E-Core HFSM configurations and parameters are illustrated in Figure 2 and Figure 3, respectively. Figure 2 clearly depicted 4S-10P having 4 E-shape stator core and 10 rotor poles. The torque and power in initial design resulted at 182.02 Nm and 26kW which is far from predefined torque and power which are 101 Nm and 41 kW [15]. Then, the design undergoes 2 cycles of deterministic optimization resulting torque at 208.85 Nm with power at 49.2 kW [16]. The optimization is further taken with 3 cycles of optimization to refine the result for better torque performance.

![Figure 2. 4S-10P E-Core HFSM](image1)

![Figure 3. Design parameter](image2)

It can be understood that the basic principles of the motor that the fluxes sources from field winding, armature coil, and a permanent magnet. The field excitation windings and the permanent magnet are arranged in parallel to ensure nominal demagnetization and the permanent magnet magnetic circuit short-circuited. The interchanging flux in the stator and the rotor made up the operating principles of flux switching motor while the existence of 3 sources of flux makes the motor hybrid, hence, HFSM.

The motor design specifications of 4S-10P of E-Core HFSM from the initial design, the optimized design, and the refinement optimization design are listed in Table 1. Apart from that, the torque and power obtain in the initial design depicted in Table 2. Although 4S-10P E-Core HFSM had undergone rigorous optimization processes by updating each and every parameter as illustrated in Figure 2, hence, further enhance the torque and power output of the motor.
The parameter refinement is conducted to improve the motor performance by ameliorating the stator and rotor parameters while keeping the permanent magnet parameter variable subjected to the constant weight of 1.3kg. The design parameter and the refinement methodology are illustrated in Figure 4 and Figure 6 respectively. The design parameter describes the parameter assignment for each part of the motor such that rotor, stator, field winding, armature and a permanent magnet. The flowchart describes specifically the updating process of each parameter. Each parameter was updated mutually exclusive in the range of tenth to ensure the optimum result were obtained from the given range of dimension.

Since the refinement optimization is conducted in a manner to achieve a better output, the parameters are updated as per interpreted in Figure 3 with 3 cycles of refinement optimization. In general, the refinement process conducted by parts such that rotor, stator, armature, and field winding. The permanent magnet is excluded in the refinement process as the design restriction of making the weight constant throughout the process. As the weight is directly proportionate with a density that will affect the constant flux production of the magnet, thus keeping it constant means keeping the source of flux from permanent magnet constant as well. On top of that, as measurement such that weight translated

The parameter refinement is conducted to improve the motor performance by ameliorating the stator and rotor parameters while keeping the permanent magnet parameter variable subjected to the constant weight of 1.3kg. The design parameter and the refinement methodology are illustrated in Figure 4 and Figure 6 respectively. The design parameter describes the parameter assignment for each part of the motor such that rotor, stator, field winding, armature and a permanent magnet. The flowchart describes specifically the updating process of each parameter. Each parameter was updated mutually exclusive in the range of tenth to ensure the optimum result were obtained from the given range of dimension.

Since the refinement optimization is conducted in a manner to achieve a better output, the parameters are updated as per interpreted in Figure 3 with 3 cycles of refinement optimization. In general, the refinement process conducted by parts such that rotor, stator, armature, and field winding. The permanent magnet is excluded in the refinement process as the design restriction of making the weight constant throughout the process. As the weight is directly proportionate with a density that will affect the constant flux production of the magnet, thus keeping it constant means keeping the source of flux from permanent magnet constant as well. On top of that, as measurement such that weight translated

Table 1. Electrical design specification

| Electrical Specification          | Initial | Optimized | Refinement Optimization |
|----------------------------------|---------|-----------|-------------------------|
| Maximum DC voltage (V)           | 50      | 50        | 50                      |
| Maximum current (Arms)           | 500     | 500       | 500                     |
| Maximum $J_a$ (A/mm$^2$)         | 30      | 30        | 30                      |
| Maximum $J_e$ (A/mm$^2$)         | 30      | 30        | 30                      |
| PM volume (kg)                   | 1.3     | 1.3       | 1.3                     |
| Maximum speed (r/min)            | 12000   | 12000     | 12000                   |
| Maximum torque (Nm)              | 182.02  | 208.85    | > 208.85                |
| Maximum power (kW)               | 26      | 49.2      | > 49.2                  |

Table 2. Geometrical design specification

| Geometrical Specification                | Optimized | Cycle 1 | Cycle 2 | Cycle 3 |
|------------------------------------------|-----------|---------|---------|---------|
| Rotor poles                              | 10        | 10      | 10      | 10      |
| Air gap (mm)                             | 0.8       | 0.8     | 0.8     | 0.8     |
| Motor stack length (mm)                  | 70        | 70      | 70      | 70      |
| Field winding turn                       | 271       | 203     | 172     | 160     |
| Armature turn                            | 37        | 39      | 26      | 24      |
| Armature slot area (mm$^2$)              | 1743.5394 | 1304.7126 | 869.5116 | 815.0741 |
| Field winding slot area (mm$^2$)         | 1804.7922 | 1357.2713 | 1146.3553 | 1065.7664 |
| Rotor inner radius (mm)                  | 30        | 30      | 30      | 30      |
| Rotor pole radius (mm), $P_1$            | 86        | 91      | 95      | 97      |
| Rotor core radius (mm), $P_2$            | 61        | 62      | 66      | 68      |
| Rotor pole width (mm), $P_3$             | 15.8400   | 17      | 21      | 22      |
| PM height (mm), $P_4$                    | 6.6553    | 7.6486  | 8.4938  | 8.9904  |
| PM width (mm), $P_5$                     | 45.2      | 40.3    | 36.2    | 34.2    |
| Field winding slot width gradient(º), $P_6$ | 45     | 31      | 29      | 31      |
| Field winding slot radius (mm), $P_7$    | 119.5     | 119     | 119     | 119     |
| Armature slot width gradient(º), $P_8$   | 0        | 27.9    | 23.9    | 25.97   |
| Armature slot radius (mm), $P_9$         | 119.5     | 123     | 116     | 117     |
into volume gives out width, height, and length of the permanent magnet. In order to keep the weight of the permanent magnet constant at 1.3 kg, the length of the permanent magnet has been kept constant companionably with the stack length at 70 mm. Hence, the width and height of the permanent magnet are manipulative variables strictly to certain dimension reciprocally to parameter rotor pole radius, \( P_1 \), while detaining constant volume.

![Flowchart of refinement methodology](image)

**Figure 4. Flowchart of refinement methodology**

### 3. Cyclic Refinement Performance Development

The rotor part refinement output carrying torque intensification. Essentially, \( P_1 \) which represent the rotor pole radius is updated followed by \( P_2 \) which is rotor core radius and rotor pole width, \( P_3 \). The optimization range is kept within the 10\(^{th}\) unit with an interval of one or two unit of the dimension. Each parameter achieves maximum torque after updating process is conducted. In Cycle 1, the maximum torque sat at 91mm, 29mm, and 14mm for \( P_1 \), \( P_2 \) and \( P_3 \) respectively. The trend of the result is as per describe in Figure. 5 for Cycle 1. The trend clearly show the maximum torque achieved in each cycle for the said parameter \( P_1 \), \( P_2 \) and \( P_3 \) increase as the cycle executed. For parameter \( P_1 \) the torque achieved when both coils, armature coils and field excitation coils injected with 30 A/mm\(^2\) and 30 A/mm\(^2\) respectively is 200.67 Nm in Cycle 1. The maximum torque obtained in \( P_1 \), \( P_2 \) and \( P_3 \) fixtures the parameter for next update of \( P_6 \) and \( P_7 \). \( P_4 \) and \( P_5 \) are neglected as it represents permanent magnet parameter, as mentioned earlier those parameters are subjected to \( P_1 \) changes. The optimization is further carried out with the parameter dimension which had been fixed earlier in \( P_1 \), \( P_2 \), and \( P_3 \). \( P_6 \) and \( P_7 \) represent the field winding slot parameter for Cycle 1 in Figure 6, on which the parameter \( P_6 \) and \( P_7 \) maximum torque obtained at dimension 14mm and 119mm, respectively are 235.58 Nm and 230.59 Nm, respectively. The combination of maximum torque and power in the combination parameter \( P_6 \) and \( P_7 \) were brought to the last part of the cyclic refinement comprised of \( P_8 \) and \( P_9 \) shows in Figure 7 and Figure 8 shows further clarification of parameter \( P_9 \) trend of torque achieved as the parameter updated.
Figure 5. Parameter $P_1$, $P_2$ and $P_3$, Cycle 1

Figure 6. Parameter $P_6$ and $P_7$, Cycle 1

Figure 7. Parameter $P_8$ and $P_9$, Cycle 1

Figure 8. Refine Pattern Parameter $P_9$, Cycle 1

Figure 9. Parameter $P_1$, $P_2$ and $P_3$, Cycle 2

Figure 10. Parameter $P_6$ and $P_7$, Cycle 2
Figure 11. Parameter $P_8$ and $P_9$ Cycle 2

Figure 12. Refine Pattern Parameter $P_9$ Cycle 2

Figure 13. Parameter $P_1$, $P_2$ and $P_3$ Cycle 3

Figure 14. Parameter $P_6$ and $P_7$ Cycle 3

Figure 15. Parameter $P_8$ and $P_9$ Cycle 3

Figure 16. Refine Pattern Parameter $P_9$ Cycle 3
In the process updating field winding slot parameter as the dimension change, the slot area and the coil turn adjusted accordingly. In equation 1 shows the relationship between the slot area, number of turns and the injected current of the field winding.

\[ J_e = \frac{I_e N_e}{a_e S_e} \] (1)

where \( J_e \) is the field winding current density, \( I_e \) is the field winding current, \( N_e \) is the number of field the winding coil turn, \( a_e \) is the filling constant and \( S_e \) is the slot area of the field winding. The equation 1 shows that with constant field winding current density and field winding current, the slot area in directly proportional to the number of turn. As the slot area increase, the number of turn increase. The characteristic behavioural adjustment of the field winding slot parameter is the same as armature slot parameter because the armature slot parameter have the same relationship between the armature slot area, number of turn and the injected current of armature coil. The relationship is shown in equation 2.

\[ J_a = \frac{I_a N_a}{a_s S_a} \] (2)

where \( J_a \) is the field winding current density, \( I_a \) is the field winding current, \( N_a \) is the number of field the winding coil turn, \( a_s \) is the filling constant and \( S_a \) is the slot area of the field winding.

Hence, the parameter dimension of field winding slot radius at the maximum torque is brought forward for field winding parameter update of \( P_8 \) and \( P_9 \). In Cycle 1 the dimension of \( P_8 \) and \( P_9 \) are 28mm and 123mm, respectively on which the torque achieved for the optimised design at Cycle 1 sat at 227.3 Nm. The same process were repeated for Cycle 2. In Cycle 2 the highest torque achieved when parameter \( P_1 \), \( P_2 \) and \( P_3 \) are 95mm, 29mm and 21 mm, respectively as per illustrated in Figure 9. Moving forward to \( P_8 \) and \( P_9 \) depicted in Figure 10, the maximum torque obtained at dimension 16mm and 119mm, respectively. At parameter \( P_8 \) and \( P_9 \) the dimension is 24mm and 116mm, respectively illustrated in Figure 11 with the clearer representation of \( P_9 \) graph in Figure 12. Lastly, the cyclic refinement process reached Cycle 3, where parameter \( P_1 \), \( P_2 \) and \( P_3 \) portrayed in Figure 13 starts with maximum torque of \( P_1 \) at 258.9 Nm and increase to 258.6 Nm with dimension of \( P_2 \). The maximum torque obtained for the said parameter \( P_1 \), \( P_2 \) and \( P_3 \) characterized with dimension 97mm, 29mm and 22mm, respectively. In parameter \( P_8 \) and \( P_9 \) shown in Figure 14 the dimension are 14mm and 119mm, respectively. The final result of the cyclic refinement displayed in Figure 15 for parameter \( P_8 \) and \( P_9 \) is 26mm and 173mm, respectively and Figure 16 shows increasing torque of \( P_9 \). The completion of Cycle 3 bring to the conclusion of the parameter dimension development for the cyclic parameter performance generated 260.45 Nm.

4. Enhance Performance Analysis

The exploded view of refined 4S-10P is illustrated in Figure 17. The refined design had the same stator diameter at 264 mm but the rotor radius and permanent magnet have a small adjustment. The rotor radius change from 86 mm to 97 mm while the permanent magnet height and width also changes from 6.6553 mm to 8.9904 mm and 45.2mm to 34.2mm, respectively. The changes of wider permanent magnet improve the aspect ratio and susceptible for demagnetization. The air gap is maintained at 0.8 mm to fix the permeance effect to the motor from its predecessor.

The flux distribution of the motor and the flux line under maximum armature current density, \( J_a(max) \) and maximum field winding current density, \( J_e(max) \) are demonstrated as well in Figure 18 and Figure 19, respectively. Figure 18 clearly shows the flux generated are uniformly distributed throughout the stator and rotor pole because the green lines in Figure 18 and high concentration of lines in the stator pole and rotor pole shown in Figure 19 prove it. The small portion of white area on the stator in Figure 18 indicates low flux cancellation between the fluxes sourcing from field winding and the fluxes sourcing from the permanent magnet. The field winding area and the armature area are mostly covered with white colour and the flux lines in that area are few indicates there are very low flux leakage.
occurred. Small portion of flux saturation occurred at the stator tooth as indicated in circled in Figure 18 due to narrow stator tooth for the fluxes to pass between the stator and the rotor. Overall, the refined design of 4S-10P shows a promising results as it have few flux leakage, small flux saturation, nominal flux cancellation and the flux distribution is uniform.

The cogging torque for 4S-10P E-Core HFSM has two cycles as per-determined by [17] in correlation with equation 3 and equation 4. The cogging torque happened due to the torque interaction between permanent magnet and stator slot. The maximum magnitude of the cogging torque is 88.7854 Nm which is around 34% of the torque production at maximum load condition. The high percentage of cogging torque is due to high utilization of permanent magnet. On top of that, the cogging torque cause noise and vibration. However, the high speed of the motor moment inertia will filters out the effect of cogging torque, hence, less noise at high speed.

Figure 17. Exploded view of 4S10P refined design

Figure 18. Flux distribution

Figure 19. Flux line
Further examination of the motor profile is on the induced voltage or also known as back-EMF in no load condition with the motor running at 12000 rpm. The result is plotted in Figure 20. The refined design has high back-EMF with a maximum magnitude of 43.26 Wb. The high magnitude of induced voltage is illustrated in equation 5. According to the equation, the induced voltage is directly proportional to the motor speed and the flux linkage. The high magnitude of induced voltage is a favorable condition for regenerative braking system charging.

\[ E = k\phi\omega \]  

where \( E \) is the induced voltage, \( k \) is the geometrical motor contant, \( \phi \) is the flux linkage and \( \omega \) is the speed.

The torque output for the motor configuration is depicted in Figure 22. The graph increasing linearly from 27.4354 Nm at \( J_a = 5 \, \text{A/mm}^2 \) to 137.67288 Nm at \( J_a = 30 \, \text{A/mm}^2 \). In this condition, the torque is the output for flux interaction between the rotor and the stator sourcing from the permanent magnet and the armature coil itself only as there are zero fluxes coming from the field winding the coil. While in Figure 18, the graph is showing the average torque produced singularly by the armature coil with the presence of the fluxes sourcing from the field winding coil and the armature coil. At minimum injected current by the armature coil of \( J_a = 5 \, \text{A/mm}^2 \), the torque increase linearly as the injecting current to the field winding increase. When the field winding current injected at 5 A/mm², the torque decrease until 30 A/mm². The same trend is observed as the armature current density increase from 5 A/mm² to 30 A/mm². At \( J_a = 25 \, \text{A/mm}^2 \) and \( J_a = 30 \, \text{A/mm}^2 \) the graph for both torque increase linearly until field winding current density reached 30 A/mm² where the torque for both conditions is at 244.3948 Nm and 260.4651 Nm. The torque at maximum armature current density in Figure 18 is nearly doubled the maximum torque in Figure 19. The difference were explained by the origin of the flux. In Figure 17, the flux generated by the torque production is solely from the permanent magnet and the armature coil but in Figure 23, the flux generated by the torque production originated from the permanent magnet, field winding, and the armature coil.
5. Conclusion

In conclusion, this paper had presented the refinement optimization process of the then optimized 4S-10P E-Core hybrid flux switching motor. The refinement process has been clearly described to meet the objective of this paper. As a result, the refined design had better output torque production which increases from 208.85 Nm to 260.4651 Nm. The torque production at maximum load condition had maximized approximately to 124% with the same permanent magnet volume of 1.3kg, motor diameter, and stack length. This proved the refinement optimization process is a success as the methodology manage to improve the torque production of the motor for the application of the LWEV propulsion system.

Reference

[1] (VTO), Vehicle Technologies Office. 2016. VEHICLE TECHNOLOGIES OFFICE: 2016 ANNUAL MERIT REVIEW REPORT. Washington: U.S. Department of Energy (DOE), 2016.
[2] Eisler, M N. 2016. 2, February 2016, A Tesla in every garage?, IEEE Spectrum, Vol. 53, pp. 34-55.
[3] Auburn, Nissan of. 2016. 3 Advantages of Lightweight Vehicles. [Online] Rairdon's Nissan of Auburn, March 26, 2016. [Cited: February 26, 2017.] http://www.nissanofauburn.com/blogs/1180/3-advantages-lightweight-vehicles/.
[4] Carlson R. 2015. Tesla: Gigafactory Tipping Point. Seeking Alpha, March 2, 2015. [Cited: February 27, 27 February.] http://seekingalpha.com/article/2966026-tesla-gigafactory-tipping-point.
[5] Cheah L. W. 2010. Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the U.S. Massachusetts: MIT, 2010. Ph.D. Thesis.
[6] Daimler. 2013. Power to the truck – the history of electrically driven commercial vehicles. [Online] Daimler AG, March 4, 2013. [Cited: February 27, 27.] http://media.daimler.com/marsMediaSite/ko/en/13034029.
[7] Deng, Boer. 2015. Blended structure makes steel light yet sturdy. [Online] Nature, February 6, 2015. [Cited: February 2017, 27.] http://www.nature.com/news/blended-structure-makes-steel-light-yet-sturdy-1.16849.
[8] Sulaiman, E, et al., Design Optimization Studies on High Torque and High Power Density Hybrid Excitation Flux-Switching Motor for HEV. 2013. 1, 2013, Procedia Engineering, Vol. 53, pp. 313-322.
[9] Sulaiman E. and Zakaria, S. 2015 Magnetic flux analysis of a new e-core HEFS with various slot-pole combinations for HEV 2015. Beijing, 2015. 2015 IEEE Magnetics Conference (INTERMAG), pp. 1-1.

[10] Zakaria, S N U and Sulaiman E. 2014. Magnetic flux analysis of E-Core hybrid excitation flux switching motor with various topologies. Johor Bahru: s.n., 2014. 2014 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE).

[11] Mallick, P K. 2010. Materials, Design, and Manufacturing for Lightweight Vehicles. March: Woodhead Publishing, 2010.

[12] Sulaiman, E., Zakaria, S. N. U. and Kosaka, T. Parameter sensitivity study for optimization of single phase E-Core hybrid excitation flux-switching machine. 2015. Nagoya: s.n., 2015. 2015 IEEE International Conference on Mechatronics (ICM).

[13] Sulaiman, E. Zakaria S N U and Khan F, 2016. Performance Analysis of a New E-Core HESFM for Future HEV. Kuala Lumpur: s.n., 2016. 4th IET International Conference on Clean Energy and Technology 2016.

[14] Zakaria, S. N. U. and Sulaiman, E. 2014. Performance analysis of E-Core hybrid excitation flux switching motor for the hybrid electric vehicle. Langkawi: s.n., 2014. 2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014).

[15] Swain D. 2016. Lightweight Remains Top Focus for Automakers to Meet CAFE Standards. [Online] DuPont, March 8, 2016. [Cited: February 27, 2017.] http://www.dupont.com/industries/automotive/press-release/WardsAuto-survey-2016.html.

[16] Thomas, A. 2011. About the Hybrid Electric Bus. [Online] Brighthub.com, May 8, 2011. [Cited: February 27, 2017.] http://www.brighthub.com/environment/green-living/articles/91494.aspx.

[17] Winter, D. 2014. Automakers Focus on Lightweight to Meet CAFE Standards. [Online] Wards Auto, August 14, 2014. [Cited: February 27, 2017.] http://wardsauto.com/technology/automakers-focus-lightweighting-meet-cafe-standards.

[18] Zulu, A. 2010. Flux-switching machine using a segmental rotor. Newcastle: Newcastle University, 2010.