Reduction of Torque Ripple of Segmental Type Switched Reluctance Motor Controlled with dsPIC

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Abstract**—***In this study, in order to reduce torque ripple of 5 phase-10/8 segmental type switched reluctance motor (SRM) a controller was designed and then performed. The SRM was controlled as a bipolar by H-bridge topology with flexible controller circuit. To determine the effectiveness of the designed driver circuit, the motor was operated at various conditions and the torque ripple of the motor was recorded. The SRM was driven by the H-bridge converter topology which can operate at both constant frequency signal and signal obtained from the encoder. The obtained results showed that the torque ripple of the SRM is reduced by using the encoder signals rather than the constant frequency signal. This control technique demonstrated that the torque ripple of the SRM can be kept within acceptable limits.*

Keywords— dsPIC33, H-Bridge Converter, Segmental Type Switched Reluctance Motor, Torque Ripple.

I. INTRODUCTION

Switched Reluctance Motor (SRM) was first introduced by Davidson in 1838 in Scotland to propel an electric locomotive. Studies on this issue were not performed for many years because the control of switched reluctance motor (SRM) was difficult. However, the improvements in the motor and the driver circuit techniques have increased the interest of researchers again.

Today, easily controllable motors with low production cost and high performance have come into prominence. Due to SRM's features such as the simple and durable structure, low cost, low inertia, high speed and efficiency, SRMs are widely used electrical machines nowadays [1]. Although SRMs have many advantages, they haven't found many usage areas until quite recently. The necessity to have rotor position information or a position sensor, torque ripple and acoustic noise are important reasons [2]. From these disadvantages, one of the most significant is ripple occurring in their torques. In many studies, researchers proposed solutions methods on the physical structure of the motor, drive circuit and control circuit [2]. In the performed studies, a new SRM with 5 phase-U shape segmental rotor was designed and it was stated that this newly designed SRM produces more torque than the classical SRM [3]. Besides, Bal G. et al carried out a study to determine the ratio between the rotor and stator thread width for a high torque and proper output power [4]. A sudden torque control was fulfilled by using linear magnetic model. Torque control was done by determining commutation angle. In experimental and simulation results, it was seen that torque ripple was reduced [5]. Speed regulation was performed using model combination controller (AFCMAC) configurable fuzzy cerebrals [6]. They used ANN model to determine rotor position of SRM. Three methods that consisted of traditional ANN, developed ANN and developed and curve fitting were compared with each other [7]. A new troubleshooting was offered for the drivers of SRM. In normal operating conditions, troubleshooting was determined by comparing magnitudes of power source current and reference current. As a fault, open and short circuit mistakes were specified. Asymmetric bridge was used as converter structure [8]. Phase inductances were described as vector quantity and disintegration of orthogonal was used to determine rotor position [9]. The speed of SRM was checked by using fuzzy control method [10]. By using torque sharing function method, torque waves were minimized and in this way reference torque values were turned into reference analytical wave directly by means of analytical method [11]. Direct torque control was advised for SRM by means of Lyapunov function-based stability and the nonlinear magnetization characteristics of SRM (because of the complex structure of rotor position, torque and phase current). To minimize torque ripple a method was suggested in [12]. A new stable technique was developed for the speed control applications of SRMs and in the mathematical model of SRM that was used in this technique, second order sliding mod control and super twisting algorithm diagram were used [12]. A system where coil current and rotor position could be measured automatically was created to determine magnetization characteristics of SRM [13]. Using Adaptive ANN controller, the speed control of SRMs, which was connected to the system driven by variable speed wind turbine, was performed [14]. A 5 phase-segmental type SRM was designed to increase the torque of SRM. Also, bipolar application strategy was used to increase the torque even more. For this, traditional full bridge converter was used. As a result of bipolar application method, a higher torque output was obtained [15]. A new power converter circuit was created for SRMs [16]. A new SRM was designed by placing permanent magnet and auxiliary winding in the stator yoke of SRMs. By means of asymmetrical half bridge, traditional SRM and newly designed SRM were tested [17]. 50 kW SRM was designed for hybrid electrical vehicles (Toyota Prius 2003). In the study, new SRM and synchronous motor were compared. It was seen that the efficiency of newly designed SRM was %95 and it reached the targeted torque at the ratio of % 85 [18]. In the study, 5 phase-10/8 segmental type SRM was designed and it was seen that the ripple of the motor driven by the H- bridge was %56 [19]. The vibration and the noise of the motor could be reduced with the changes in the design and control system of the motor, and it was determined that trigger angles affect the torque ripple of the motor [20]. With the control of 8/6 SRM, a new approach was brought to determine the initial and final of trigger angles of power switches [21].

In this study, 5 phase-10/8 segmental type SRM was controlled by H-Bridge converter topology with help of a dsPIC33EP512MU810. SRM and H-Bridge with a flexible working structure were driven as bipolar. By using a dsPIC control card, SRM was controlled at a definite time determined by signals from both the Hall-Effect sensors and the encoder passing between phases. While the SRM is running, 5 phase currents, torque and speed are measured and the results are shown in the designed interface. As a result of the performed experiments, the effects of the trigger methods over motor torque were also determined.

introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

II. SEGMENTAL TYPE SWITCHED RELUCTANCE MOTOR

In this study 10/8 segmental type SRM with a different rotor structure from classical SRM was used. The rotor of the used SRM consists of the packages which made of silicon steel sheet and aluminum blocks. Aluminum block, which is used in the rotor structure, functions as flux barrier and this feature makes a different motor from classical SRM. The rotor structure of segmental type SRM is U-shape, so it is also called U-Shaped Segmental Type Motor. The cutaway view of segmental type SRM is shown in Fig. 1 [19]. Specifications of segmental type SRM are given in Table 1.

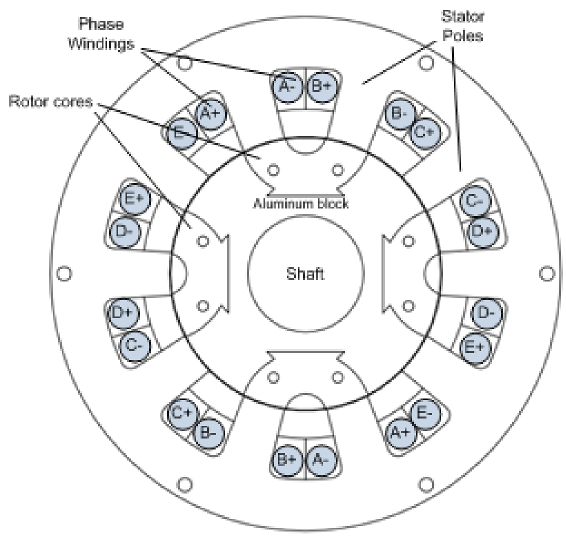

FIG. 1 THE VIEW OF 5-PHASE SEGMENTAL TYPE SRM

Equation (1) was used to determine the torque ripple of the SRM.

$$\%T_{ripple} = \frac{T_{max} - T_{min}}{T_{avg}}.100 \quad (1)$$

TABLE 1
SPECIFICATIONS OF SEGMENTAL TYPE SRM

No	Characteristics	Value
1	Maximum torque in 5 A	2.34 Nm
2	Maximum inductance	13 mH
3	Resistance per phase	0.86 Ω
4	Magnetic field energy at 5 A	0.848 Joule
5	Torque/weight ratio	0.22 Nm/kg
6	Phase number	5
7	Stator/Rotor Configuration	10/8
8	Stator phase angle	0.314 rad
9	Rotor phase angle	0.331 rad

III. H-BRIDGE BIPOLAR CONVERTER TOPOLOGY

The H-Bridge converter topology provides maximum flexibility to observe and produce running modes of the converter [20]. The most important feature of H-Bridge converter topology is that it allows changing the direction of phase. H-bridge driver is always in modular position and a fault that occurs in one of the phases is automatically isolated from the other phases. This fault tolerance topology has a feature that can be easily used in automotive applications. The bipolar converter topology uses more power switches than others.

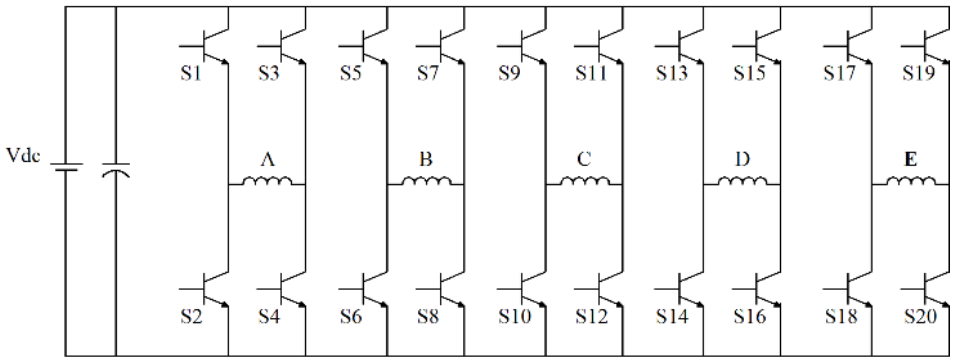

FIG. 2 H-BRIDGE BIPOLAR CONVERTER TOPOLOGY

IV. DRIVER CIRCUIT CARD

In order to control the H-bridge converter circuit in SRM driver a dsPIC33EP512MU was used. High performance dsPICs are preferred because they are highly efficient, more sensitive and long-lasting in sensitive motor control systems. In our study to control the SRM, a dsPIC was preferred because dsPIC33EP512MU card has 16 bit features, high–speed PWM feature and it has also USB 2.0 and 10 bit/ 24 channel analogue input. In this study, SnadPIC PIC Microchip development board SD card was used with dsPIC33EP512MU810. A card photo is shown in Fig. 3.

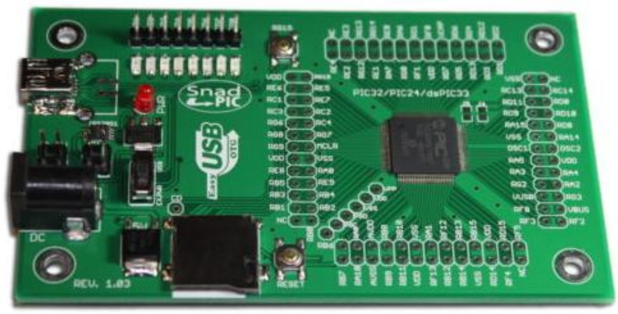

FIG. 3 SNADPIC PIC MICROCHIP DEVELOPMENT BOARD SD CARD

V. EXPERIMENTAL STUDY AND THE RESULTS

In this study, H-Bridge converter structure with the control of dsPIC33EP512MU810 was used for the segmental type SRM. The picture of dsPIC33EP512MU810 control card is given in Fig. 4.

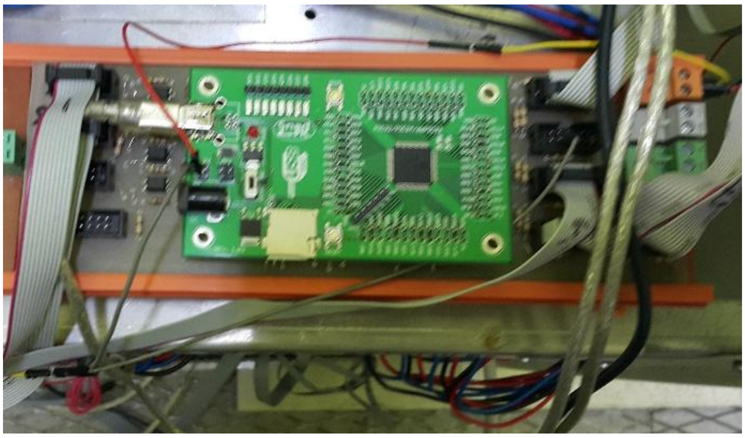

FIG. 4 CONTROL CIRCUIT DESIGNED WITH DSPIC33EP512MU810

A phase circuit of the H-Bridge that was designed in Proteus program is given in Fig. 5.

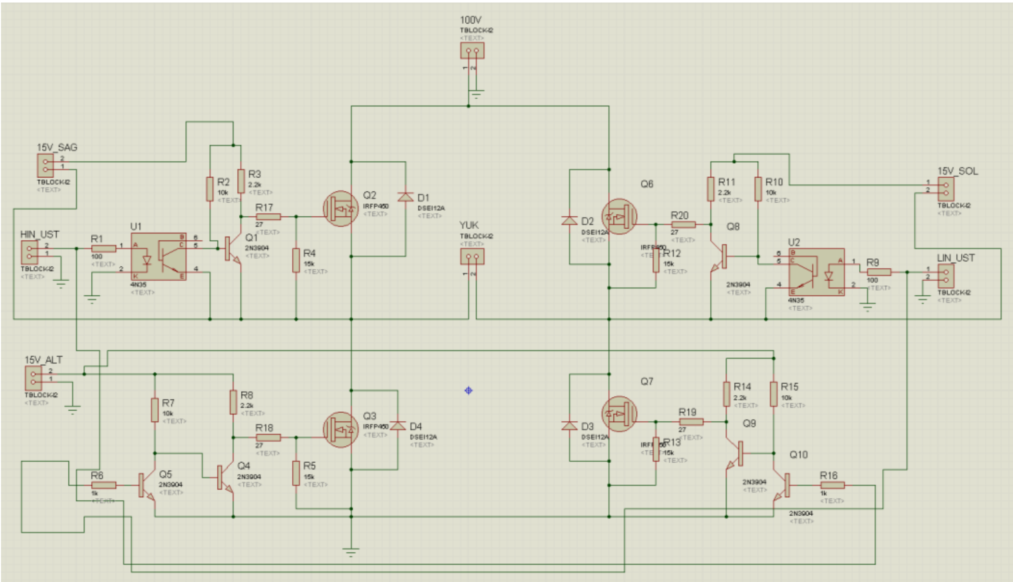

FIG. 5 A DRIVING CIRCUIT AND H-BRIDGE OF A PHASE

In this study, the motor was run as bipolar. The order of trigger signals of 5 phase segmental type SRM is given in Table 2 [20]. In the performed studies, the order of the triggering was performed as given in Table 2.

TABLE 2
POWER ORDER OF THE PHASES

	0-18	18-36	36-54	54-72	72-90
A Phase	0	+	0	-	0
B Phase	-	0	0	+	0
C Phase	+	0	-	0	0
D Phase	0	0	+	0	-
E Phase	0	-	0	0	+

The experiments were performed using the test set up as shown in Fig. 6. In this study RD300 with 0-10 Nm measuring range was used to measure motor torque. The signal received from the torque sensor was amplified to 0-5 V voltage level using CSG110 amplifier. The motor speed was measured by 3600 pulse encoder.

FIG. 6 THE PICTURE OF THE TEST SET UP

Motor current was measured using ACS712 current sensor. In the experimental study, the voltage produced by the torque sensor was measured by an oscilloscope. To observe and record the experimental results such as current, torque and speed an interface was designed. On the segmental SRM there are 5 Hall-Effect sensors placed with 18 degree angles, as shown in Fig. 7.

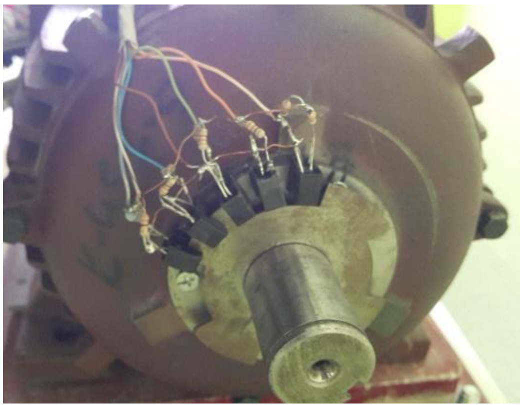

FIG. 7 THE PICTURE OF HALL-EFFECT SENSORS

In the experimental studies, motor was driven with definite time signals according to the data received from the Hall-Effect sensors and according to the signals received from the encoder. The experiments were performed applying 75 V to the SRM.

The transition from one phase to another was determined by the signals coming from the Hall-Effect sensors at definite time according to the order in Table 2. As seen in Fig. 8, one phase of the SRM is triggered at regular intervals, until the signal from the Hall-Effect comes.

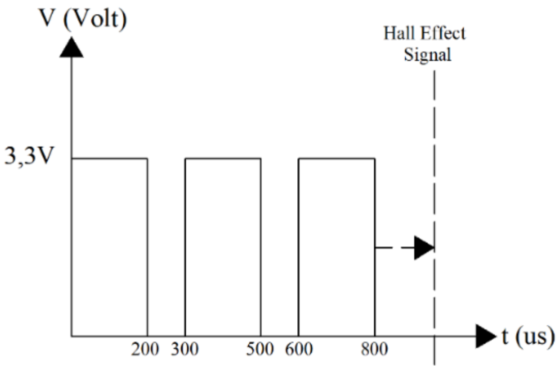

FIG. 8. TRIGGER INTERVALS: 200µs – 100µs – 200µs – 100µs

The data and the curves obtained when the signal in Fig. 8 is applied for one phase of segmental type SRM are shown in Fig. 9. The motor runs at 828 rpm with 0.83 Nm torque and % 50.8 on average.

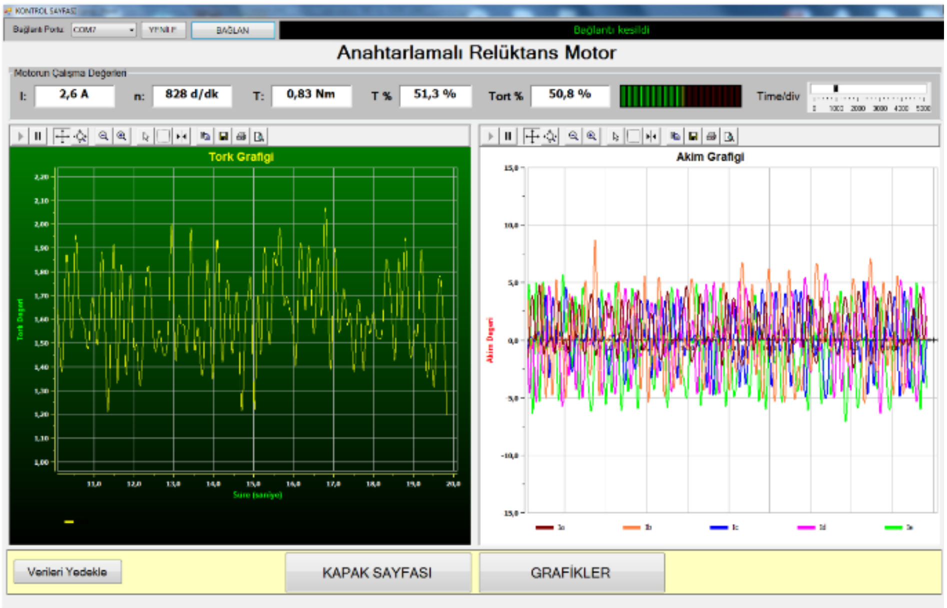

FIG. 9 THE RESULTS OF SEGMENTAL TYPE SRM TRIGGERED AT DEFINITE TIMES

In Fig. 10, the oscilloscope signal obtained from the torque of SRM that was controlled at definite time is shown. Measured torque values are Tmax= 1.02 Nm, Tmin=0.6 Nm and Tavg=0.81. If torque ripple is calculated from (1) using these measured values, it is seen that SRM has a ripple of 51.85 %.

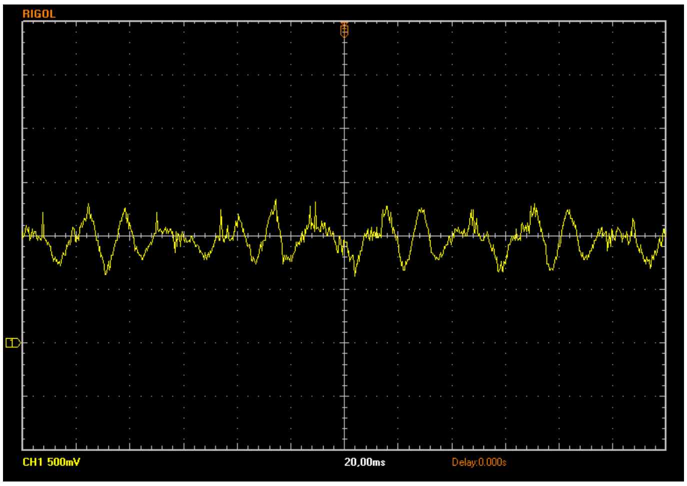

FIG. 10 THE RESULTS OF THE SEGMENTAL TYPE SRM TRIGGERED AT DEFINITE TIMES.

One phase of segmental SRM was triggered as in Fig. 11 according to the rotor position received from the encoder.

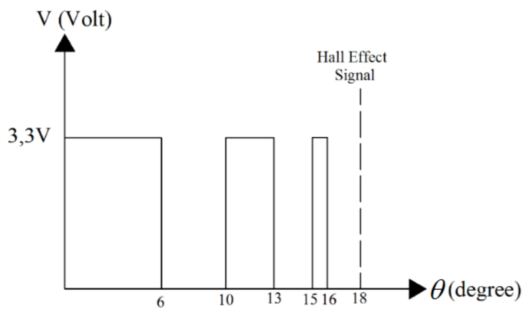

FIG. 11. 6-10-13-15-16 DEGREE SENT TRIGGERING

Data and curves acquired when the signal in Fig. 11 was applied to one phase of the SRM are shown in Fig. 13. The motor runs at 1285 rpm speed with 0.77 Nm torque.

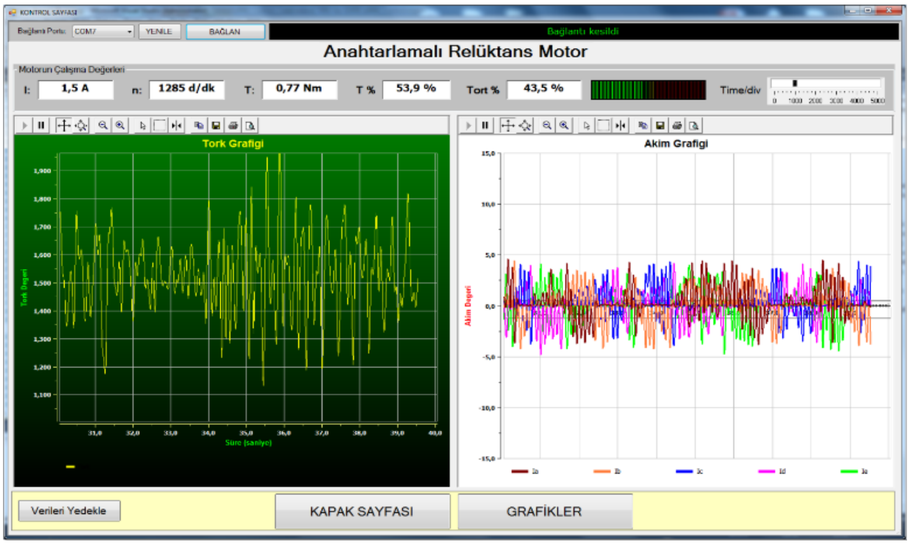

FIG. 12 THE RESULTS OF THE SEGMENTAL TYPE SRM TRIGGERED AT 6-10-13-15-16 DEGREE.

In Fig. 13, oscilloscope signal obtained from the torque sensor is seen. Where, Tmax=0.97Nm, Tmin=0.62 Nm and Tavg=0.8. If torque ripple is calculated from (1) using this measured values, it is seen that SRM has a ripple of 43.75 %.

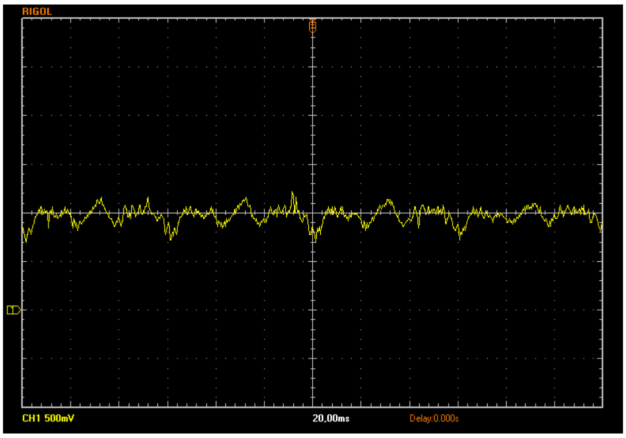

FIG. 13 THE RESULTS OF SEGMENTAL TYPE SRM TRIGGERED AT 6-10-13-15-16 DEGREE INTERVALS.

As a result of the experimental studies, it was seen that torque ripple of SRM that was controlled according to rotor position was lower than running with the signals at definite time. In the study, SRM motor was directly controlled by Hall-Effect sensors and it was seen that motor ripple was 56% [20]. For this reason, the proposed controller with dsPIC provided better results than the previous studies in both working conditions and has 7.5% better torque ripple.

VI. CONCLUSION

In this study, the control of 5 phase 10/8 segmental type SRM was performed by means of H-Bridge converter topology controlled by dsPIC33EP512MU810. The obtained results proved that the torque ripples were reduced 7.5 % in SRM which is controlled by the signals produced from rotor position, instead of the signals produced from Hall-Effect sensors.

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