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AC Chopper Application and Benefits of Auxiliary Windings for PSC Motors

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***Abstract*—In this work, a novel driver circuit is designed for permanent split capacitor motors (PSC). With this driver circuit, semi-conductive technology is used in place of cumulative winding for this type of motors that are particularly used in kitchen exhaust fans. Developed circuit is controlled via PWM method. IGBT transistors are used for the power circuit. An optocoupler driver is designed and used in order to drive and trigger these IGBT transistors. Due to this reason, this work includes an electronic AC/AC chopper application that provides energy conservation and noise reduction by removing cumulative winding in currently used asynchronous motors with cumulative auxiliary winding stators and shaded pole motors**

***Index Terms*—AC choppers, pulse width modulation, permanent split-capacitor.**

I. INTRODUCTION

Asynchronous motors are frequently used in industrial applications and residences, due to their user friendliness, simple design, being maintenance free and cheap. The fact that 70 % of the energy produced in the Earth is consumed by asynchronous motors shows the frequency of usage and importance of them [1]. Single-phase asynchronous motors are commonly used in household appliances. PSC motors, split phase motors, permanent magnet synchronous motors and shaded-pole motors are among the most frequently used ones. The direct AC-AC converters have applications in various fields, such as AC motor drives, electronic transformers, switching AC adjustable sources, output voltage waveform restorers, etc [2].

In this work, a novel driver circuit is designed, which removes cumulative winding from PSCs that are particularly used in kitchen exhaust fans. Semi-conductive material that is going to be used in speed control of asynchronous motors needs to be chosen properly. The aim here is to obtain the sinusoidal signal in the output correctly. In this study, a power circuit is designed by exploiting Isolated Gate Bipolar Transistor (IGBT) transistors. Signal that is applied to motor is used in Pulse Width Modulation (PWM) invertor form. This is achieved by changing the width of pulses applied to PWM. According to this, in order to select the most appropriate PWM method, both lower order harmonic currents must be limited and switching losses must be kept at minimum [3], [4]. By this study, inclusion of PWM controlled AC chopper usage method instead of stepping motors, in non-industrial small scale electric devices is characterized. An improvement to the notched waveform is to vary the on and off periods such that the on-periods are longest at the peak of the wave. This form of control is known as pulse-width modulation (PWM) [5].

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II. DESIGNED CIRCUIT

Block diagram for the designed circuit is given in Fig. 1. The motor shown in Fig. 1 that has been used in this study is a one-phase asynchronous motor with a permanent capacitance, which has a wide area of use in industrial applications. Especially in ventilator fan applications, stators of these types of motors are coiled in level fashion to enable easy speed tuning. In the present study, the stator winding has five levels. This motor has main and auxiliary winding, and its stator has 16 pitches and two poles. In unloaded operation, the speed can be tuned between 1800 rpm and 2800 rpm. The display given in Fig. 1 shows the speed level of the motor. A lamp is added to the ventilator for ambient lighting. Speed, light, time and On/off buttons are inputs for the user. “Speed” button is used for tuning the speed of the motor, “light” button is used to switch the ventilator lamp. The operation time of the motor is adjusted by the “Time” button. To open/close the motor, “On/off” button is used. The driver circuit and the control card used in the present study are elaborated in Chapter III and Chapter IV, respectively. In permanent capacitor motors, capacitor is connected to auxiliary winding in series. Value of the capacitor affects the value of motors rising and working torques. When low value capacitor is used, rising moment also stays in lower values. When high value capacitor is used, motor’s efficiency drops for low value loads, which can lead to saturation in auxiliary winding and cause magnetic vibrations. According to this, motor’s torque and direction are effected from voltage phase difference between main winding and auxiliary winding, and capacitor value. Motor rising torque and acceleration can be improved by 25 % via appropriate capacitor selection [6].

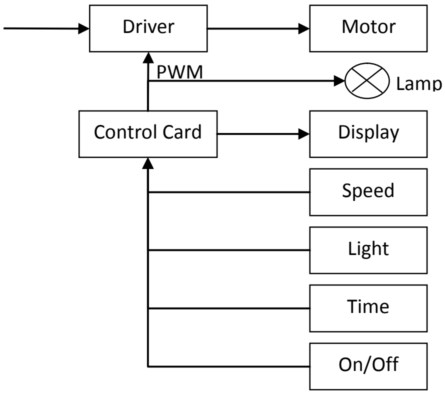

Fig. 1. The designed circuit block diagram.

Permanent capacitor single-phase asynchronous motor, which is used in this study, is frequently used in industrial applications. Mechanic switches with cumulative winding stators are used for speed control of these motors, which are especially used in fan applications such as kitchen aspirators. These are revolution controlled motors designed to be used in kitchen aspirators. They are designed to have three or five steps. These motors are permanent capacitor and have auxiliary winding and shaded pole.

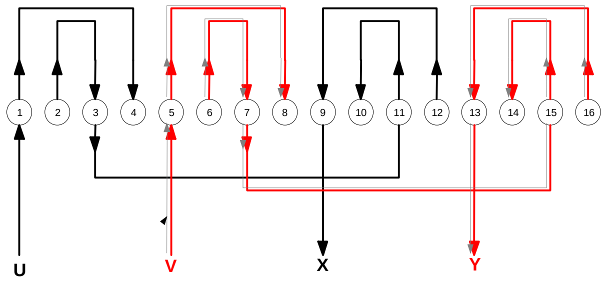

Fig. 2. The motor winding diagram.

Winding diagram of the auxiliary winding motor is given in Fig. 2.

III. Driver Circuit

Aim of PWM is to change main wave's basic components by changing width of pulses. Harmonic currents of motor inductance is limited by obtaining lots of gaps and increasing frequency of primary switching harmonics at each half wave. Motor begins to behave like a low-pass filter. So, high frequency harmonic currents are not effective on motor circuit. In turn, increase in switching frequency results in increase of switching losses. According to this, in order to select the most appropriate PWM method, both lower order harmonic currents must be limited and switching losses must be kept at minimum [7].

A simpler control method with parameters that can be easily tuned can be achieved with PWM method via use of microcontrollers. With this approach, adjustment of control structure due to a change of a parameter in an element can be achieved more easily. Biggest issues in control process are the translations caused by motor inductance and growing complexity of adjustment of transmission angles. Motor inductance is discharged through inductance switches on temporary times formed on positive and negative half-waves. Transmission times of switches are affected by this, and they cannot perform triggering in desired times [8].

Developed circuit is controlled by PWM method. PWM is obtained for the circuit. A PWM signal in 20 *kHz* frequency is generated for the circuit and this signal is used for triggering. IGBT transistors are used for power circuit. An optocoupler driver is designed and used in order to drive and trigger these IGBT transistors. This driver allows PWM signal that comes from the control circuit to drive IGBT transistors. Another reason is to operate the developed control circuit and power card, which supplies power to circuit, independent from each other. Independency of operation of control card and power card is accepted as an important factor to input a proper PWM signal to the motor. This factor aims to remove electrical noise in these types of motors caused by their work environments. To solve these issues, these two cards are made independent from each other and the effect of electrical noise generated in power circuit is eliminated in control circuit (Fig. 3).

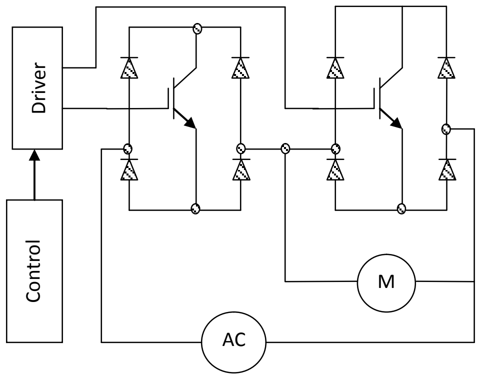

Fig. 3. Driver circuit block diagram.

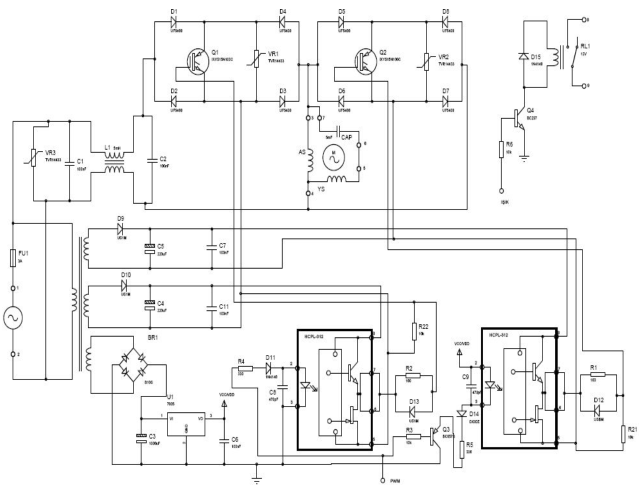

Fig. 4. Main electronic schematic circuit.

The circuit diagram of the main electronic driver is given in Fig. 4.

IV. Control Circuit

PIC16F628A type microcontroller is used for the required memory and I/O components in the control card. This microcontroller is preferred because it requires a small number of hardware components for programming, is easy to program and affordable. In the developed circuit, turning on/off, lighting, automatic operation time and speed adjustment is achieved via keys. Desired control has to be achieved via keys implemented on the system. Functional software of the used PIC 16F628A is done with Parsic software. A programming card is used to download codes to microcontrollers.

Microcontroller used in the circuit, which is displayed in Fig. 5, is selected for control and adjustment of functions of keys that generate PWM signal that controls the motor speed, control lighting system on the circuit and control motor speed via the user input. Gate switch on the control circuit is implemented to prevent need of opening doors or windows during operation. Reason for this is to create an area to gather air flowing from fan to funnel.

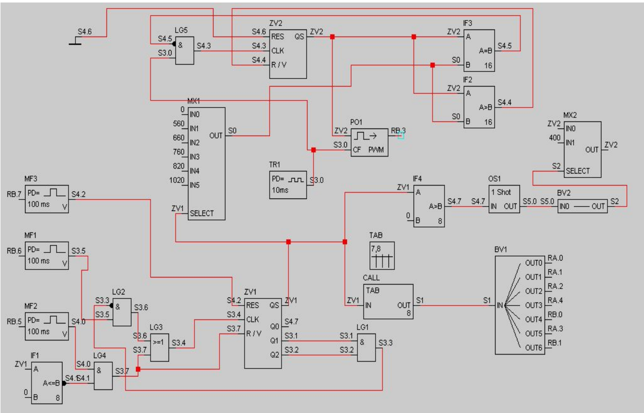

Fig. 5. Microcontroller's Parsic software diagram.

V. FILTERING CIRCUIT

In Fig. 6, to prevent loading of harmonic frequencies generated by AC chopper to network, a filter coil with toroidal winding known as power shock filter and capacitors are used.

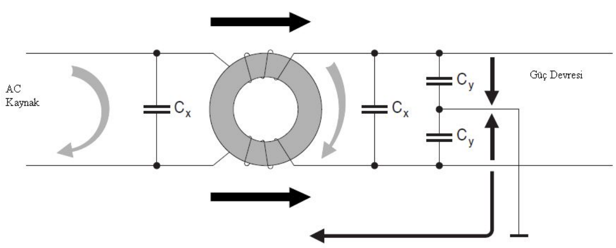

Fig. 6. Power card EMC filter circuit [9].

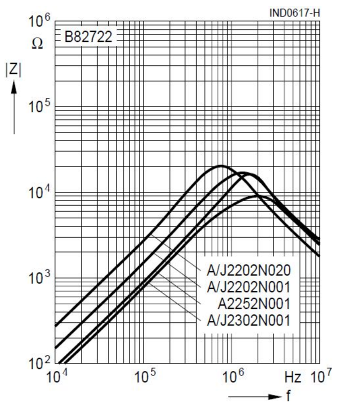

Fig. 7. EMC filter frequency as a function of resistance plot [7].

Coil used in the filter is EPCOS B82722J2202N001 model and its value is 2.2 *mH*, 2 *A*, 130 *m*Ω. Coils frequency vs. resistance plot is given in Fig. 7. Power card works on 20 *kHz* carrier frequency. Coils resistance in this frequency is 1.2 Ω (Fig. 7).

VI. EXPERIMENTAL RESULTS AND EVALUATION

Measurements associated with the developed circuit are obtained in two different ways. The first one is to measure by connecting five stages PSC motor and the other one is to measure by the developed card. By comparing these measurements, advantageous of the developed card is showed via experimental results. Measurements are based on comparison of power, current, voltage, phase angle, revolution and current parameters depending on the step. FLUKE 190 200 *MHZ* digital oscilloscope is used for phase angle and voltage measurements. FLUKE 117 digital multimeter is used for current and resistance measurement. An optic tachometer is used to measure revolution. FLUKE 922 flow-meter is used to measure air flow speed. Measurements obtained from connecting two stages PSC motor without connecting the card is displayed in Table I.

Measurements in Table I are obtained by engaging the motor steps gradually. Motor is operated in five steps. Second set of measurement are obtained with developed driver and control card. By using the fifth step of the same motor, a structure where step operation can be adjusted numerically is obtained. These numbers are adjusted to have the same speed with motor. Measurements obtained by this approach are displayed in Table II.

TABLE I. THE MEASURES OBTAINED FROM DIRECT CONNECTION OF MOTOR.

Steps	Rev.	Stepper, auxiliary winding, asynchronous motor to motor direct connection			Motor is directly connected (P=U*I*Cos Ø)	Air flow speed
	(*rpm*)	(*A*)	(*V*)	Cos Ø	P	*m/s*
1.	820	0.604	218	-18	125.23	6.3
2.	970	0.668	218	-17	139.26	7.5
3.	1090	0.757	218	-16	158.63	8.7
4.	1260	0.842	218	-11	180.18	9.5
5.	1603	1.084	218	2	236.17	11.9

TABLE II. MEASUREMENTS OBTAINED WITH DEVELOPED AC CHOPPER CARD.

Steps	Rev.	From card input with AC chopper			AC Chopper	Air flow speed
	(*rpm*)	Current (Ampere)	Voltage (*V*)	Cos Ø	P	*m/s*
1	820	0.395	218	1	86.11	6.3
2	970	0.515	218	1	112.27	7.5
3	1090	0.627	218	1	136.686	8.7
4	1260	0.745	218	1	162.41	9.5
5	1603-1571	1.072	218	0,999	233.696	11.9

Comparison plot based on Table III is given in Fig. 8.

Implemented card's efficiency is given in Table IV. Cards efficiency is measured based on the relation between motors input power and cards input power.

TABLE III. POWER COMPARISON BASED ON NUMBER OF SPEED.

Steps	Speed (*rpm*)	Direct Connection (*Watt*)	AC Chopper (*Watt*)	Speed (%)	Direct Connection Power (%)	AC Chopper Power (%)
0	0	0	0	0	0	0
1.	820	125.23	86.11	51	53	37
2.	970	139.26	112.27	61	59	48
3.	1090	158.63	136.686	68	67	58
4.	1260	180.18	162.41	79	76	69
5.	1603	236,17	233,696	100	100	100

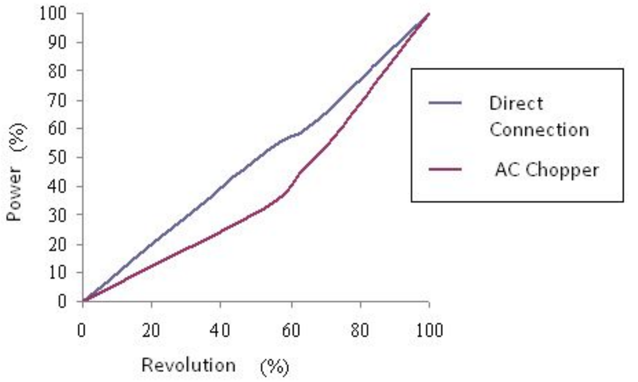

Fig. 8. Speed–Power comparison plot.

TABLE IV. EFFICIENCY OF AC CHOPPER CARD.

Highest Speed	AC Chopper Input			Motor Input			Power Loss (*W*)
	(*A*)	(*V*)	(*W*)	(*A*)	(*V*)	(*W*)	
	1.072	218	233.696	1.04	213	221.52	12.176

Developed cards efficiency is measured in maximum revolution. Based on this, efficiency of the card is

$$\eta = \frac{Pout}{Pin} \times 100 = \frac{221,52}{233,696} \times 100 = 94,7\%. \qquad (1)$$

TABLE V. SPEED STAGES AND POWER OF PSC MOTOR.

Speed Stages	Power (W)	Speed (rpm)
Stage 1	147,9	970
Stage 2	159,7	1135
Stage 3	177,8	1315
Stage 4	196,5	1490
Stage 5	248,8	1822

Technical data of the device are given in Table V.

A photograph of developed AC chopper application with PWM for PSC Motors is given in Fig. 9.

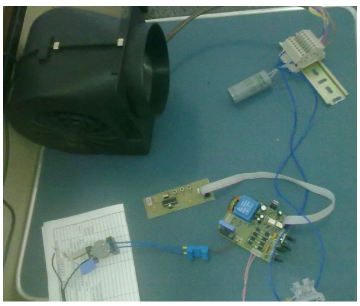

Fig. 9. Top view of schematic connection diagram for PSC motors.

Due to drop of current in motors lowest speed and making rising and stopping ramp 10 seconds, there is a hearable reduction on the electrical noise generated on the motor.AC motor input output signals are given blow. Current and voltage signals applied to the card based on this, is given in Fig. 10.

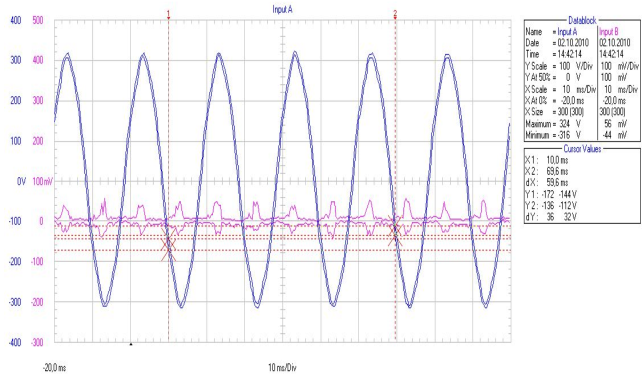

Fig. 10. Card input signals (Current and Voltage).

PWM signal at card output is given in Fig. 11.

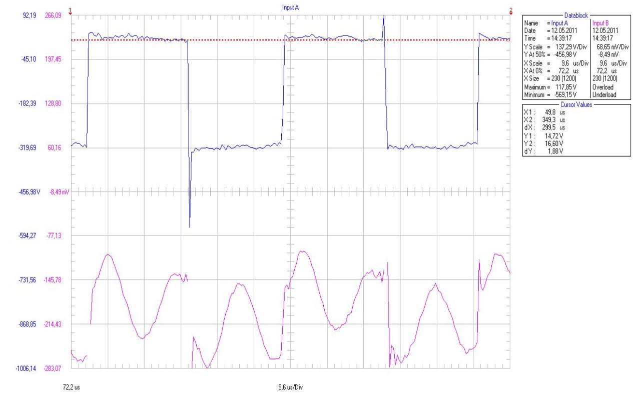

Fig. 11. PWM signals at motor output.

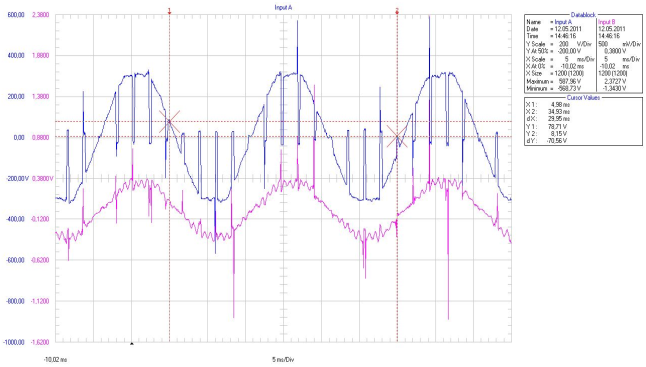

Fig. 12. Driver card output current and voltage signals.

Signal obtained from driver card output is given in Fig. 12. Signal shows current and voltage values.

VII. EVALUATION

The method which are subject to the study is in the way that the technical which is known for speed adjustment in aspirator and air curtains using places like home and office, coiling up a part of auxiliary winding stage and adjusting speed by connecting in series this winding to main winding, creating resistance and reducing the current drawn by main winding. There is no known AC/AC convertor application in referred electrical tools which are stepped winding capacitor motor and stepped shade pole motor.

Whereas current AC/AC chopper convertors have been a method used in industrial applications. AC voltage regulators which are the most basic AC/AC converters, provide the possibility of controlling output voltage at the same frequencies as input. AC voltage regulators are divided into different types with each other. Among them, type having the least harmonic activity is PWM controlled AC voltage regulators. It is characterized by containing PWM controlled AC chopper using method instead of step motors, in nonindustrial small electrical tools, with this study.

VIII. CONCLUSIONS

In this work, an AC chopper application is developed, for speed control of motors that are particularly used in kitchen aspirators and air curtains. State of the art motors used in aspirator structure are known to have technical issues in terms of both application and production. These issues can be given as; production difficulties associated with multistep winding, excessive heating, excessive current and pulsed acceleration problems between step transitions, sounds created by harmonics in lower revolutions and inefficient usage of energy.

In this work, results associated with an AC chopper application that allows usage of speed adjustment by circuit are obtained, which shows ease of production due to motor having single winding, decrease in motor heat loss, low volume operation and lower energy consumption at lower revolutions due to adjustment of acceleration ramp, decrease of volume of sound generated by harmonics and energy conversation up to 32 %.

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