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BLDC motor driver design for use in new generation water coolers with FOC and constant torque control system

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Abstract
Water coolers are one of the household appliances that have remained in their original form since they became popular, and few changes have been made. This high consumption device, which is widely used in Iran due to weather conditions, needs changes to improve its performance and efficiency, which has received little attention in recent years. Among its changes, we can mention the replacement of its high-consumption single phase induction motor with a low-consumption high efficiency brushless DC (BLDC) type. This engine has a high efficiency, but it needs a driver to work, which has its own complications and of course adds many benefits. In this article, the problems in the old coolers and their improvement in the new models under the title of new generation water coolers, and then the driver made to drive the brushless motors have been discussed. In addition to using the sensorless FOC control method, this driver is controlled by constant torque to solve the problem of air flow loss in old generation coolers.

Keywords: Driver, constant torque, BLDC motor, FOC, water cooler

Introduction

Nowadays, due to the advancement of technology and the increase in the demand and use of electricity, the need to use electric devices has become more apparent. In many cases, reliability and cost are the primary needs of electricity consumers. Due to the simple structure of induction motors and their durability and long life and low cost, they are used in many industrial and domestic applications, such as: pumps and large and small fans [1].

The biggest consumers of electricity in the domestic and industrial sectors are electric motors; So that more than 65% of the total electricity consumption is consumed by all types of engines in these sectors. These motors in the household sector include refrigerator compressors and air conditioning motors, which consume the most electricity per day. In Iran, due to the hot and dry climate of this region, more than half of the household consumers use cooling devices such as water coolers. The motor of water coolers is single-phase induction type, in Iran, about 17 million single-phase motors are used in these coolers, which, considering that they are used more than 50% of the whole year, it can be said that they use about 6.8 GW of electricity produced in country, which due to the efficiency lower than 50% and the high energy losses that exist in a large number of these engines, increasing the efficiency and improving the performance in water coolers can result in significant savings in energy consumption [2 and 3].

Due to the characteristics and good performance of brushless DC motors (BLDC), the use of this type of motors in the industry is increasing. BLDC motors have high efficiency. These motors have a lower starting current. In recent research, this engine type has been suggested as an alternative to single-phase engines of water coolers [4].

A water cooler is one of the household appliances whose overall structure has not changed over the years and different companies produce it in the same old way and system. The different parts of the cooler can be divided as follows: 1- The body of the cooler: it consists of four columns, one floor, three doors and the roof of the cooler, which is usually made of metal. 2- Centrifugal fan: the propeller inside the housing rotates and creates wind. 3- The main motor: rotates the fan. 4- Belt and pulley: It couples the engine to the propeller. 5- Pump and water supply system: The pump located on the bottom of the cooler directs the water in the bottom through pipes to the cooling pads. 6- Cooling pads: cooling pads are usually made of short and long strings of wood and are located on the three doors of the cooler and reduce the air temperature by absorbing water and evaporating it. Although companies have made innovations in the field of water coolers in recent years, the general public still uses old generation water coolers. Among the works that have been done to improve the performance and efficiency of this type of cooler, we can refer to the article [5], which deals with two basic problems of the old generation coolers: low efficiency and the inability to compensate for air flow in different conditions. The low efficiency is due to the use of single-phase induction motors, which has been almost resolved by replacing it with BLDC motors. Due to the lack of a control system, old generation water coolers do not have the ability to compensate for air flow in different conditions, and the amount of air flow mentioned for them is for normal conditions and open outlet. But in practice, due to long ducting or inappropriate vents or insufficient air exit from inside the house, the static pressure rises and air flow falls according to the fan curve. But in the new generation water coolers, due to the use of the driver, there is more control over the motor and the loss of air flow can be compensated. In this article, by improving the work done in [5] and designing an updated driver, the performance

and efficiency of water coolers have been improved as much as possible.

The arrangement of the contents in this article is as follows: in section 2, the new generation water cooler system is discussed, in section 3, the designed driver is discussed, in section 4, the studied system is shown, and in section 5, the results have been analyzed.

2. New generation water cooler system

In the introduction section, a brief reference was made to the different parts of the old water cooler. In this section, some parts of it have been improved and it is introduced as a new generation water cooler:

1- The body of the cooler: The body of the new generation water cooler is made of polymer and is resistant to corrosion, and its color is not lost by the sun's rays and does not rot.

2- Centrifugal fan: The propeller of new generation coolers is made of polymer and due to its modified curve, it can produce higher static pressure.

3- Main motor: The main motor of the new generation water cooler is of BLDC type and as mentioned in the introduction, it has high efficiency. The power of this motor is 750 watts and it is an outrunner type. Single-phase induction motors, which are usually used in old water coolers, have very low efficiency at low loads, which is about 48%, but BLDC motors reach 76%, which is a significant amount [4]. Of course, this technology change is not so easy and it has to pay for it, because it has to use an inverter to drive the BLDC motor. The driver required for this motor is also designed and has the following features: 1- Input power factor of about 1. 2- Support for motor up to 1500 watts. 3- Fan torque control with vector control method. 4- High carrier frequency and without any audible noise. 5- Ability to communicate with a smart thermostat.

4- Belt and pulley: One of the disadvantages of old coolers is the belt, because this belt has a specific and relatively short life and must be replaced periodically. In addition, its efficiency is about 94% in the ideal state, which can drop up to 84% due to the irregular maintenance of belt [6]. In the new generation water cooler, the belt and pulley are completely removed, and since the BLDC motor used is outrunner, the motor is directly coupled to the propeller. As a result, belt and pulley losses are completely eliminated. This prevents 10% of losses.

5- Pump and water supply system: this part has not changed much and only changes were made for better distribution of water, which is not the subject of this article.

6- Cooling pad: In old coolers, they used wood chips to evaporate water and lower the temperature, which does not have a long life and loses its efficiency over time. In the new generation water cooler, a cellulose pad is used, which has a much longer life and a larger contact surface to increase water evaporation.

3. Driver system

The BLDC motor is one of the brushless motors that requires electrical commutation and for this purpose it requires driving circuits. The driver designed for this BLDC motor uses the FOC control method and constant torque reference so that the cooler air flow does not change in different ducting and outlet conditions. One sample of the built driver can be seen in the following figure:

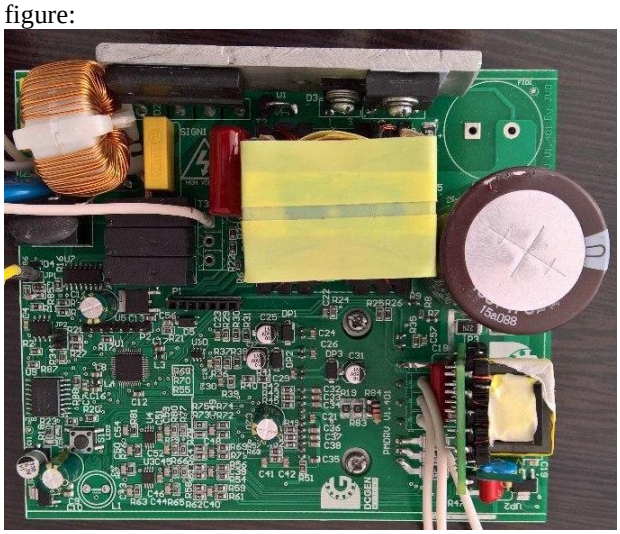

Figure 1: The built driver

The block diagram of the driver can also be seen in the figure below:

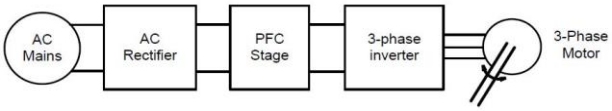

Figure 2: The general block diagram of the built driver

AC Rectifier: It consists of a simple diode bridge and only rectifies the input voltage. The DC link capacitor is also located after the PFC circuit.

PFC Stage: Due to the use of a diode bridge at the input of the circuit and the DC link capacitor, the input current became a needle shape, which has very high harmonics and causes many problems in the network. To overcome this problem, an active power factor correction is used. This part has the task of correcting the input power factor and keeps the power factor around 1. Current harmonics are also largely eliminated. The boost topology used here and its general schematic can be seen in the figure below:

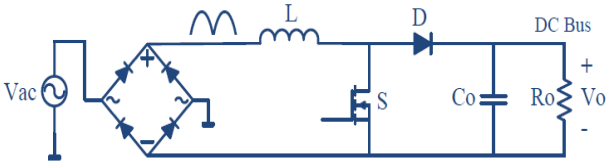

Figure 3: General schematic of the boost topology

The reason for using this topology is the simplicity of the circuit and its low cost while being efficient for home applications.

Inverter: The inverter used in this circuit is a two-level voltage source type inverter. An IGBT module with an internal gate driver was used as the inverter switches. The maximum current of this IGBT module is 15 amps and it normally supports the motor up to 1500 watts. PWM pulses are generated by a microcontroller. This microcontroller is manufactured by Texas Instruments and belongs to the C2000 family. The control algorithm

implemented by the microcontroller is Sensorless FOC, whose control block diagram can be seen in the figure below:

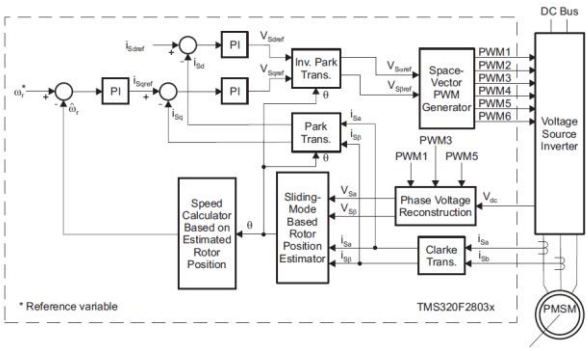

Figure 4: Block diagram of Sensorless FOC control method

The FOC control method is one of the conventional and practical methods to control BLDC motors. In this method, by using the rotating frame conversions, the existing AC variables are converted to DC variables and the BLDC motor is seen as a Brushed DC motor. This simplifies the control of the BLDC motor and makes it possible to easily control the torque and speed of the motor separately. One of the challenges in the FOC method is obtaining the exact position of the rotor to perform park conversion, which is done in two ways, with and without position sensors. Due to the high cost of position and angle sensors, the method without sensor is used. In this method, an angle estimator is used to obtain the position of the rotor based on the feedbacks of voltage and current and the internal model of the motor. There are different types of estimators, here the PLL estimator is used, which is suitable for applications such as fans because it does not require a lot of torque at the starting point.

Among the advantages of the FOC method compared to simpler methods such as the six-sector method, it can be mentioned that the motor movement is smooth and silent due to the use of PWM modulation with high carrier frequency, which is very important due to the direct coupling of the motor to the propeller. The smallest sound in the motor (due to being located in the center of the centrifugal fan) reaches the consumer's ears and annoys them. So the only suitable method here is the FOC method.

4. The studied system

A fan with air flow of 6000 m^3/h has been used to test and verify the performance of the new generation water cooler system.

Figure 5: Centrifugal fan under test

As mentioned in section 2, this propeller is made of polymer and is directly coupled to the BLDC motor. The propeller and motor used belong to Tehran Electric Company and are tested with the driver made in Figure 1. Tests related to air flow have been carried out in the laboratory of Mashhad-Davam Company. These tests have been carried out according to Iran's national standard number 4911 [7] and based on that, the energy efficiency ratio (EER) of the cooler is obtained. This number has no dimension and is obtained by dividing the cooling power by the total input power. In the next section, this number is used to compare the efficiency of different coolers.

As mentioned in the previous section, the driver works in constant torque mode. This driver is controlled by a smart thermostat made for this application.

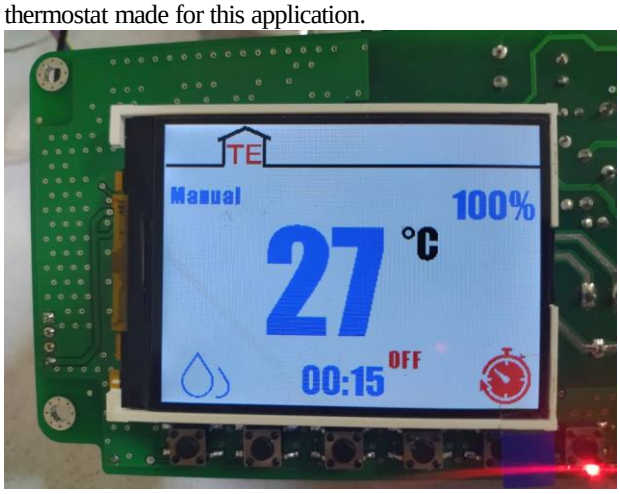

Figure 6: Smart thermostat built for inverter

In addition to the thermostat, the inverter can be controlled by a computer and more parameters can be measured and controlled. In order not to exceed the speed limits of the fan, a maximum RPM limit is considers in the driver so that the propeller does not damage while the efficiency of the fan was maintained.

The driver input voltage and current waveforms are obtained with a RIGOL DS1102D oscilloscope.

Power Factor and Total Harmonic Distortion (THD) have been used to check the input power quality. The THD formula is as follows:

$$THD = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2}}{I_1} \times 100 \quad (1)$$

These parameters have been measured by a Siemens SENTRON PAC4200 meter.

Graphs related to rotor angle, voltage and current of BLDC motor are obtained through computer software.

5. Results and Discussion

To check the laboratory results, we first look at the diagram of voltage and current input to the driver. Figure 7 shows the diagram of voltage and current input to the driver when PFC is disabled.

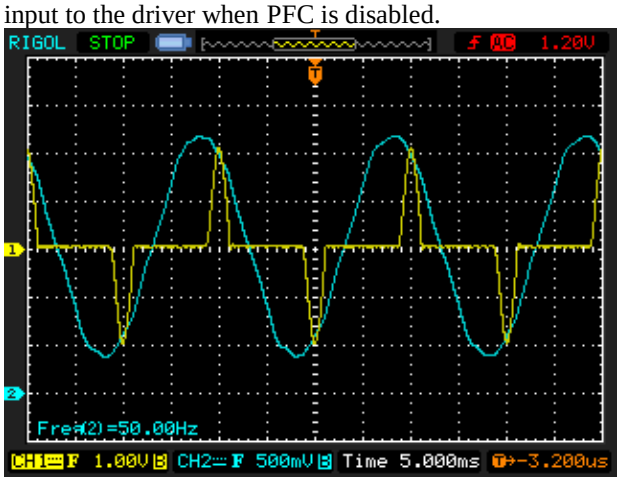

Figure 7: Input current and voltage to driver without PFC

As can be seen, the waveform of the current is needle-like and completely non-linear.

By activating the PFC part in Figure 8, it can be seen that the current is completely sinusoidal and is in phase with the voltage, and the PFC part works well.

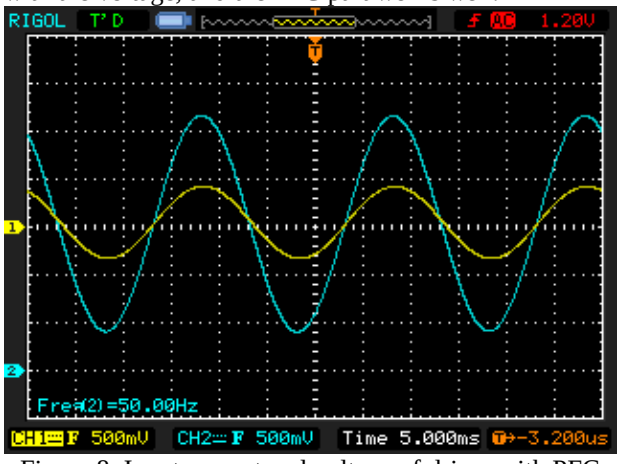

Figure 8: Input current and voltage of driver with PFC

Now, to check the correct operation of the driver's internal feedback and the correct operation of the rotor angle estimator, the voltage, current and rotor angle waveforms are shown in Figures 9 and 10.

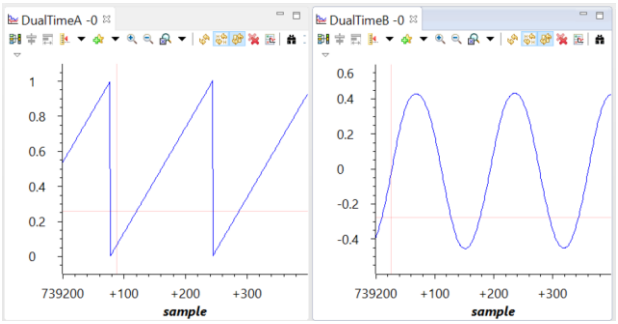

Figure 9: Waveform of rotor angle and motor current from left to right

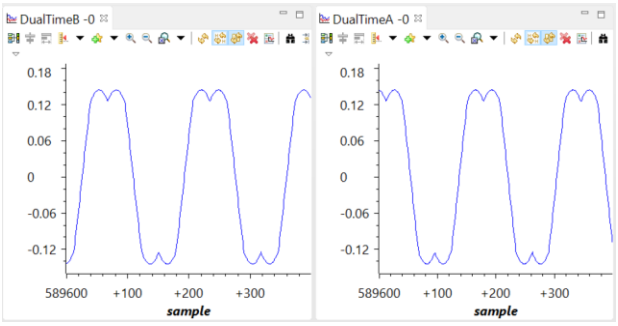

Figure 10: Waveform of motor phase voltages

As you can see, feedbacks and angle estimator work well.

Now it's time to check the tests done in the standard laboratory, where two water cooler models of the new generation and the old generation are compared in terms of performance, and the results can be seen in Table 1.

The new generation water cooler belongs to Tehran Electric Company and is of low consumption BLDC type. The old generation cooler is also a common cooler in the market with a single-phase induction motor.

Table 1: Standard test results of new and old generation water coolers

Quantity	New generation water cooler	Old generation water cooler
RPM	400	1425
Input power (W)	440	720
Input power factor	0.99	0.72
THD (%)	5	-
EER	55	36
Airflow rate (m^3/h)	6870	6000

As can be seen in the table, the efficiency of the new generation water cooler is much higher than the old generation, and the energy consumption in the new generation coolers is reduced by half. Of course, this consumption savings is much higher at low speeds, for example at 300 RPM, which is about as slow as normal coolers, the power consumption of this cooler is 160 watts, which is less than half of the power consumption of normal coolers at the same speed, and the air flow is also higher.

Conclusions

This article examines the need to change the system of old generation coolers as well as the driver designed for use in new generation water coolers. This driver controls BLDC motor by FOC method and works based on constant torque reference. The advantages of using this driver are smooth and noiseless control of the motor, reducing the additional costs of using the position sensor, improving the quality of the input power to the optimum level, and the ability to control air flow and keep the amount of output air constant based on the constant torque control method. Which solves the problem of old generation coolers. The use of this driver along with the smart thermostat allows the user to have more control over the cooler and by connecting it to the smart home system, the maximum efficiency of the water cooler is achievable. In addition, the results of the standard test of the new generation water cooler and comparing it with the old generation show that the energy consumption of the new generation water cooler has been reduced by half and even less at low speeds.

The only drawback of the new generation water cooler is the increase in initial cost, which can be fully compensated in the long term due to the low consumption of this cooler and low maintenance cost, and returns to the customer's pocket.

References

[1] Y. L. Zh. Zhao, S. Wang, D. G.Dorrell, W. Xu, “Design and analysis of star-delta hybrid windings for high voltage induction motors” IEEE Trans. Ind. Electron., vol. 58, no. 9, 2011

[۲] م. نظامی وطن دوست، ا. دارابی، ا. مددی، "طراحی بهینه موتور شار محوری مغناطیس دائم برای کولرهای آبی" سی‌امین کنفرانس بین‌المللی برق، تهران، ایران، آبان ۹۴

[3] K.S. Rathikrindi, S.Paramasivam, L. Sandeep, “Energy saving opportunities through Variable Frequency Drive for Commercial Air Conditioners”, 4th International Conference on Electrical Energy Systems (ICEES), pp. 338-340, 2018

[4] Sandun S. Kuruppu, John K. Rote “Replacing single-phase ACIMs with three-phase BLDC motors saves energy" Available online: https://www.ti.com/lit/pdf/slyy083 (accessed on 12/27/2022).

[5] A. H. Niasar and H. NikKhah, "Performance Enhancement of Evaporative Water Cooler Equipped With Permanent Magnet Brushless Motor Drive Based on Power Control Strategy," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 8, no. 2, pp. 1268-1275, June 2020, doi: 10.1109/JESTPE.2019.2909030.

[6] URL: https://www.tyma.eu/technical-information/belt-efficiency/ Acseced at 1/6/2023

[۷] استاندارد ملی، کولر آبی خانگی – مشخصات فنی و روش آزمون تعیین معیار مصرف انرژی و دستور العمل مصرف انرژی، شماره ۴۹۱۰-۲، تجدید نظر اول و اصلاحیه شماره ۱