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Starting of three phase permanent magnet synchronous motor using BLDC motor driven

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ABSTRACT

Three phase permanent magnet motor has many advantages including simple construction that makes it easy to maintain, has dynamic performance, high power density, reliability and durability. Permanent magnet motors can be operated as stepper motors, brushless direct current motor (BLDCM) and synchronous motor without having to change the three-phase driver motor circuit. The BLDCM are supplied with square or trapezoidal voltages, while the synchronous motor are supplied with sinusoidal voltages. The synchronous motor have advantages in terms of torque and power efficiency but cannot operate from a stationary condition, so it requires starting techniques to run it. The starting technique in this paper is the motor initially operated as the BLDCM until it approaches the desired synchronous frequency then moves into the synchronous generator for a while and then becomes the synchronous motor. The frequency of the motor and the phase difference between the stator field and the rotor field are critical points for this operating displacement. When the stator field precedes the rotor field, the displacement is smooth and the displacement time is very short, that is 1 second. Whereas when the stator field is left behind from the rotor field, the motor experiences a moment of jerking during its displacement and takes 3 seconds.

Keywords: PMSM, BLDCM, starting method, synchronous motor, brushless direct current motor

ABSTRAK

Motor magnet permanen tiga fasa memiliki banyak keunggulan antara lain konstruksinya sederhana sehingga mudah dirawat, memiliki kinerja yang dinamis, kepadatan daya yang tinggi, keandalan dan daya tahan. Motor magnet permanen dapat dioperasikan sebagai motor stepper, motor arus searah tanpa sikat (BLDCM) dan motor sinkron tanpa harus mengubah rangkaian motor penggerak tiga fasa. BLDCM disuplai dengan tegangan persegi atau trapesium, sedangkan motor sinkron disuplai dengan tegangan sinusoidal. Motor sinkron memiliki keunggulan dalam hal torsi dan efisiensi daya tetapi tidak dapat beroperasi dari kondisi stasioner, sehingga memerlukan teknik pengasutan untuk menjalankannya. Teknik pengasutan dalam makalah ini adalah motor awalnya dioperasikan sebagai BLDCM hingga mendekati frekuensi sinkron yang diinginkan kemudian bergerak ke generator sinkron untuk sementara waktu dan kemudian menjadi motor sinkron. Frekuensi motor dan perbedaan fasa antara medan stator dan medan rotor merupakan titik kritis untuk perpindahan operasi ini. Ketika medan stator mendahului medan rotor, perpindahannya halus dan waktu perpindahannya sangat singkat, yaitu 1 detik. Sedangkan pada saat medan stator tertinggal dari medan rotor, motor mengalami momen sentakan pada saat perpindahannya dan membutuhkan waktu 3 detik.

***Kata kunci:** PMSM, BLDCM, metode starting, motor sinkron, motor arus searah tanpa sikat*

1. INTRODUCTION

Electric vehicles have attracted new attention in the vehicle market as well as in the global market. By 2030, electric vehicle users are expected to triple the number recorded in 2011 [1]. Three-phase permanent magnet motors are suitable for use as electric vehicle drivers because they have superior characteristics than induction motors and DC motors in terms of losses, efficiency, thermal performance, dynamic response and long life motors. This motor also has a high ability to overcome overload because its thermal performance is good, even the best when compared to induction motors and DC motors, and has advantages when viewed from the character of environmental pollution compared to induction motors and DC motors. Permanent magnet motors, especially as BLDC motors (Brushless DC Motors),

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are cleaner than induction motors and DC motors, more economical in terms of materials, and also have a smaller size. This motor reduces electromagnetic interference (EMI), is lower in terms of RFI (radio frequency interference), and there is no noise because it does not use brushes [2] [3].Three phase permanent magnet motor has many advantages including simple construction that makes it easy to maintain, has dynamic performance, high power density, reliability and durability [4]. All permanent magnet motors are categorized as synchronous machines. This type of motor can be operated as a stepper motor, brushless direct current motor (BLDCM) and synchronous motor [5] [6] [7].The BLDCM are supplied with square or trapezoidal voltages, while synchronous motors are supplied with sinusoidal voltages [8] [9]. The BLDCM has a trapezoidal or square back electromotive force (BEMF) shape while the synchronous motor is sinusoidal BEMF shape. In terms of ease of control, the BLDCM is easier to control, while synchronous motors require more complicated control [10] [11]. The BLDCM also has non-constant torque, so it requires certain control techniques to control it. Conversely, synchronous motors have a constant torque [12]. The next difference from permanent magnet motors that are operated as BLDCM and synchronous motors can be seen from the distribution of flux density and the form of current excitation. The BLDCM has a magnetic flux whose distribution is rectangular inside the air gap, has a rectangular current waveform and a centralized stator winding. While synchronous motors have a magnetic flux whose distribution is sinusoidal in the air gap, they have sinusoidal current waveforms and they have sinusoidal distributed stator conductors [13] [11] [14]. The difference between the BLDCM and synchronous motor can be seen from Figure 1.

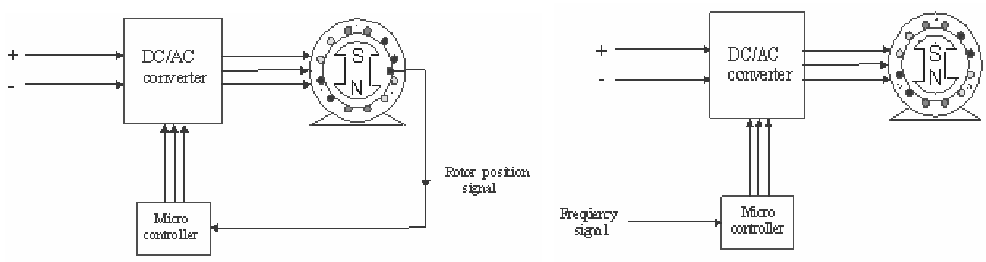

Figure 1. A schematic of the BLDCM (left) and synchronous motor (right) [15]

We can see from Figure 1 (left) that to operate the BLDCM, it requires the exact position of the rotor from the hall sensor to run the motor. The inverter circuit will change the power supply voltage poles supplied to the stator, according to the rotor state detected by the hall sensor, so that the stator magnetic field pulls the rotor magnet to move towards a new equilibrium point. Each stator winding switching condition will produce the direction of the magnetic field of the winding at different angles so that the electrically equal angles are also different. The three-phase motor has three terminals on its stator winding, so that the switching combination that can be applied is three terminals connected to the power supply, or only two switches connected and the last one is combination of three and two switches connected to the power supply. Maximum power flow occurs at the input of three connected switches, intermediate power flow occurs at the input of two connected switches.

Meanwhile, we can see from Figure 1 (right) that to control synchronous motors, we only need frequency signal information. A synchronous motor is not a motor that can start itself as an induction motor that can be directly supplied with an AC source. If the synchronous motor stator windings are directly connected to the AC source when starting process, the motor will begin to experience vibrations upon [16]. Starting the motor can be done in three ways namely first by using an additional motor, for example an induction motor. The induction motor is turned on simultaneously with the synchronous motor until its speed approaches synchronous speed, then the induction motor is removed and only the synchronous motor is turned on. This method has the disadvantage that starting can not be done when the condition of the motor is loaded. In addition, this method requires expensive fees for installation. The second way, namely starting with asynchronous way first [17] [18] [19]. This method is only used for synchronous motor types that have cage windings inside the rotor. The use of this method for permanent magnet motors certainly can not be done. The third way is to change the frequency at the start of running the motor. The frequency of the power supply voltage is given slowly from a value close to zero until the desired synchronous frequency. The motor will work synchronously from the start. To run this method, we need an inverter that has a variable frequency and a variable voltage. This method is most often used because it can be done when the condition of the motor is loaded and the cost required is not too expensive [5].

The starting technique in this paper is in a different way. The motor is operated as a BLDCM before approaching the desired synchronous frequency. After the frequency is appropriate, the motor switches operations into a synchronous generator for a while and then becomes a synchronous motor. The purpose is to optimize all the potential possessed by three phase permanent magnet motors, especially operations as BLDCM and synchronous motors. The combination of BLDCM operations with synchronous motors can be applied to electric cars. Electric cars are used on roads that have contours up and down and straight roads. When the roads go up and down, the electric car motor can be operated as BLDCM mode, while on a straight road that is not much of an obstacle, the motor can be operated as synchronous motor mode.

2. RESEARCH METHOD

The problem when starting a synchronous motor by running it first as a BLDCM is the regulation of its displacement and sinusoidal signal generator. This sinusoidal signal can be obtained analogously or digitally using the PWM technique. The characteristic of sinusoidal PWM technique is the constant amplitude pulse with a different duty cycle each period. The pulse width is modulated to determine the inverter output voltage control. Three sine waves and triangular carrier waves that have high frequencies are used to generate three phase PWM signals. The three sine waves are referred to as the reference signal, where all three have a phase difference of 120^0. The frequency of the sine wave is chosen based on the needs of the inverter output frequency. While the frequency of triangular waves is usually higher than the frequency of sine waves. Switching signals are generated by comparing sinusoidal waves with triangular waves. The comparator issues a pulse when the sine voltage is greater than the triangle voltage. These pulses are used as triggers for each inverter switching. To avoid undefined switching conditions and unwanted AC output voltage, the switching of each inverter cannot be switched off simultaneously. To generate SPWM in analog, several circuits are needed, as shown in the Figure 2.

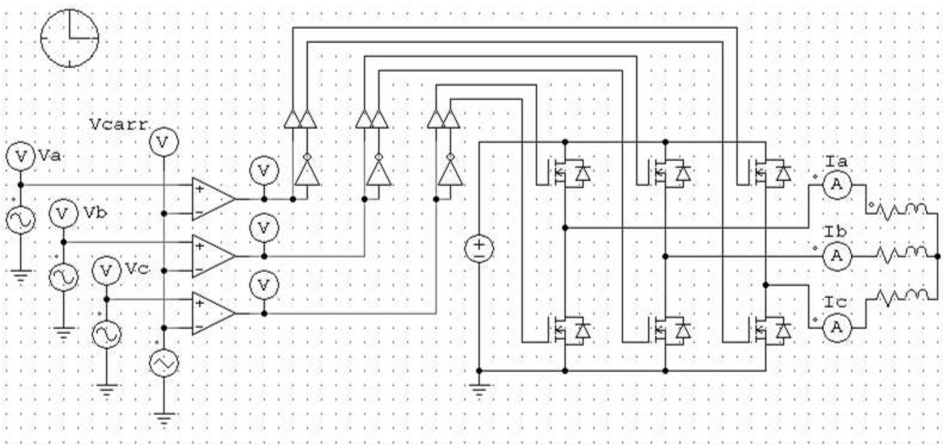

Figure 2. A schematic of three phase SPWM generator

The sine wave and the triangular wave are generated from two function generators. The sine wave is first connected to a phase shifter circuit to produce the three-phase sine wave. The phase shifter circuit is shown in Figure 3.

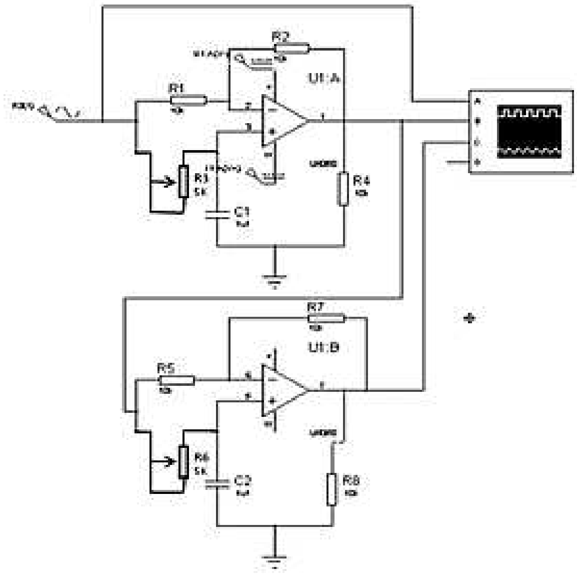

Figure 3. A phase shifter circuit [20]

The sine wave from the function generator is connected to the input of the first phase shifter to produce phase B which is 120^0 different from phase A. The output of the first phase shifting circuit is connected to the input of the second phase shifting circuit to produce phase C. The most important components in determining the 120^0 phase difference are resistors and capacitors (pairs R_3 and C_1 and pairs R_6 and C_2). The value of the capacitor is kept constant while the value of the resistor is made variable, so when we want to change the frequency of the input sine wave, we don't need to replace the component anymore, just simply adjust the value of the potentiometer used.

The motor frequency and phase difference between the stator field and the rotor field are the requirements for the operation shift from BLDCM to synchronous motor. Frequency information is obtained from the hall sensor. A frequency to voltage converter circuit is needed to speed up the reading of information by the microcontroller ADC. Phases A, B and C are then compared to the triangular signal through three comparators. These three comparator outputs are called sinusoidal PWMs. The comparator output is connected to the inverter. The inverter section connected to the positive power supply is connected directly to the comparator output. As for the inverter part which is connected to the power supply, the negative part is connected to the comparator output which has been connected first with the note gate. The frequency of the motor and the phase difference between the stator field and the rotor field are conditions for the changing operations from BLDCM to synchronous motors. Frequency information is obtained from the hall sensor. A frequency to voltage converter circuit is needed to speed up the reading of information by the ADC microcontroller.

The other information needed is phase accuracy when the motor is run as the BLDCM and sinusoidal frequencies for the synchronous motor. This information is obtained from the phase detection circuit which will compare the frequency information from the hall sensor with the sine wave frequency of the function generator. Because the hall sensor output is a periodic square signal, the frequency information from the generator must first be connected to the comparator. The comparator output is compared by the XOR gate with the hall sensor output. If the square signals from the comparator and the hall sensor are the same, the phase difference between the motor and the sine signal is 0^0. When the phase difference is 0^0, no torque is generated. The motor can rotate it must be designed the torque angle is not equal to zero, and try to approach 90^0 so that the maximum torque. The output signal from the XOR gate is connected to the rectifier circuit so that the average voltage can be read by the ADC microcontroller. A completely phase differences detector circuit is shown in Figure 4.

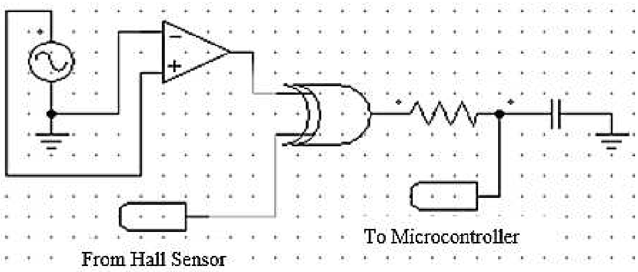

Figure 4. A phase differences detector circuit

One of important aspect in controlling operations from BLDCM to synchronous motors is the controlling part. The controller functions to provide input to the switching circuit / inverter based on input from the sensor and the command signal so that the motor rotates according to what has been planned. It has been explained previously that the conditions for displacement are the frequency and phase differences specified have been met. The frequency is set at 30 Hz and the phase difference between the stator and rotor fields is set in the range of 77^0-84^0. When the motor operates as a BLDCM, the switching program is provided by the microcontroller and the switching technique used is a combination of three and two terminals connected to the power supply. Whereas during synchronous motor operation, switching is obtained from the analog SPWM generator circuit. To smooth the input signal displacement, before entering the synchronous motor program, the switching is stopped for 5 µs (motor become a generator for a while).

3. RESULTS AND DISCUSSION

The implementation of three phase permanent magnet motor starting when the operation changes from BLDCM to synchronous motor in general can be said to have been successful, both in terms of hardware and software. At first the motor operates as BLDCM, as shown in the Figure 5.

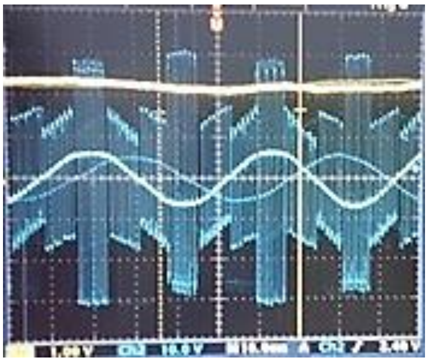

Figure 5. Phase to phase voltage when used as a BLDCM

When the motor frequency with the sine wave frequency generated by the SPWM circuit is synchronized, and the phase difference is also fulfilled and the stator field is leading, the BLDCM operation is stopped for a moment so the motor turns into a synchronous generator for 5 µs before finally entering the synchronous motor operation. The Figure 6 shows the motor turns momentarily into a synchronous generator before switching operations to a synchronous motor.

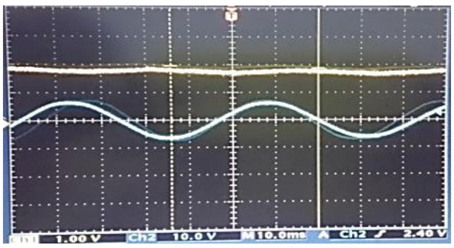

Figure 6. Phase to phase voltage when motor is changing to a synchronous generator

After 5 μs the motor then switches from synchronous generator to synchronous motor. And the changes that occur are very smooth. This can be seen from the Figure 7 and Figure 8.

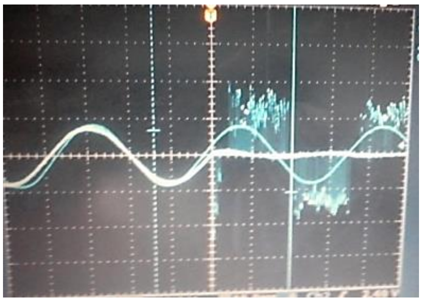

Figure 7. Phase to phase voltage when switching from a synchronous generator to a synchronous motor

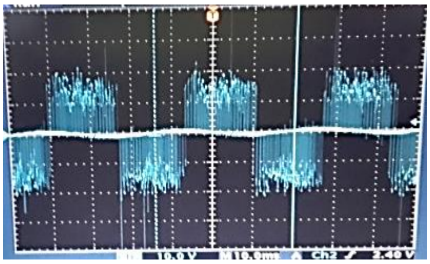

Figure 8. Phase to phase voltage when used as a synchronous motor

If it is figure out in the form of a graph of the relationship of motor frequency with time, the form of the response when the motor operation changes from BLDCM to the motor synchronous with the stator field conditions ahead of the rotor field can be seen in the Figure 9.

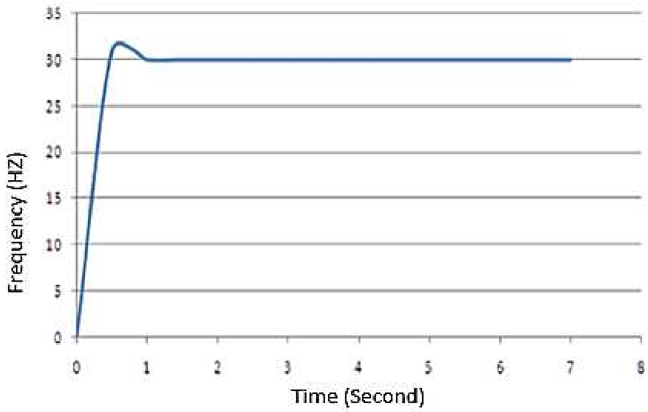

Figure 9. The frequency response of the motor to the time during the transition process with the stator field conditions lead the rotor field

This graph shows that the change is very smooth and only takes 1 second to change operations from BLDCM to synchronous motor operations. This graph also shows that in this condition, the control went well. Whereas when the frequency and phase difference have been fulfilled, but the stator field is left behind (lagging), the motor will eventually change its operation to a synchronous motor, but the changes are not as smooth as the previous conditions. The motor experiences a jerky moment to adjust so that the stator field returns to overtake the rotor field. This condition can be seen as the graph below in Figure 10.

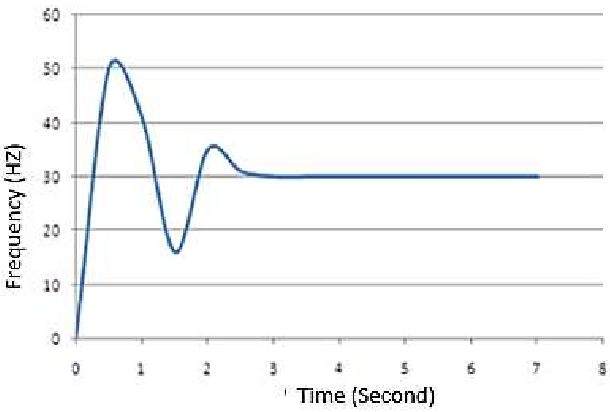

Figure 2. The frequency response of the motor to the time during the transition process with the stator field conditions lags behind the rotor field

The graph shows that when changes occur for a moment when the stator field attempts to overtake the rotor field and the time required to change operations from BLDCM to synchronous motor operation is 3 seconds. Control in this condition is not going well, so this can be one of the studies for further development.

4. CONCLUSION

Instigation of a permanent magnet synchronous motor has been successfully carried out with the starting technique that is the motor is operated first as a BLDCM. The motor frequency is set at a frequency of 30 Hz and the phase difference between the stator field and the rotor field is set in the range of 77^0-84^0. Changes in motor operation when the stator field precedes (leads) the rotor field only takes 1 second and the change is smooth, while when the stator field lags it takes 3 seconds and there is a beat when the stator field tries to overtake the rotor field again. Development can be carried out to control the phase difference between the stator field and the rotor field so that the stator field always leads the rotor field when transferring operations from BLDCM to synchronous motors. Control process can also be applied to shorten the time of the change.

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