Magnetic Pole Identification for PMSM at Zero Speed Based on Space Vector PWM

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***Abstract*— This paper contributes to an improved magnetic pole identification based on space vector PWM for an arbitrary initial rotor position of PM Synchronous Machines. The principle of magnetic pole identification is discussed and the N-S pole identification method based on space vector PWM presented. The improved identification method is verified by experiment results.**

Keywords-Magnetic pole identification; space vector PWM; initial rotor position; sensorless control; PM synchronous machine

I. INTRODUCTION

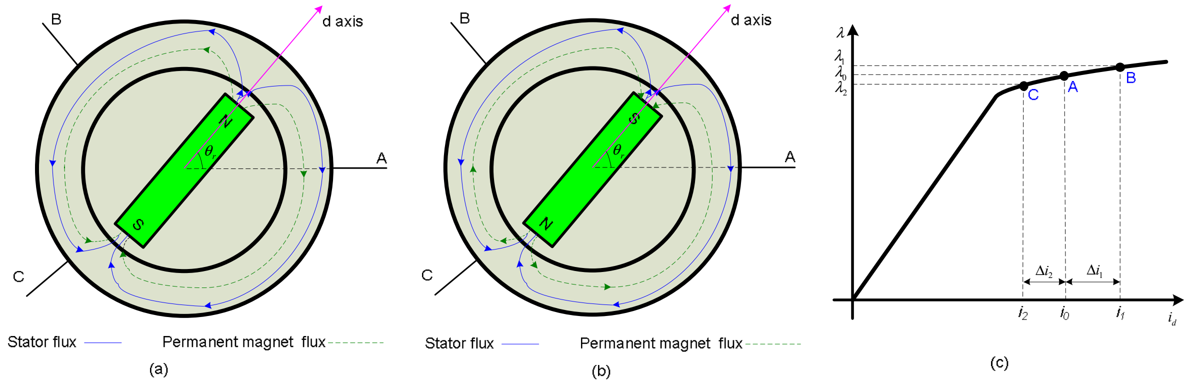
Significant attention has been paid to sensorless control of permanent magnet (PM) synchronous machines recently. For sensorless control of PM synchronous machines at zero speed, both the initial d-axis position and the polarity of the magnetic pole are to be identified. Although a conventional high frequency injection (HFI) method for initial rotor position estimation can identify the axis of the magnets but not the magnetic polarity. The conventional method for the North-South (N-S) pole is determined based on the magnetic saturation [1, 2]. The commonly used scheme is to inject pilot voltages and then detect the corresponding currents to determine the pole polarity.

In this paper, we propose a simple yet effective method to identify the N-S pole based on space vector PWM suitable for arbitrary initial rotor position at zero speed. The principle of the magnetic pole identification is briefly discussed and the proposed method introduced. The validity of the proposed identification method is verified by experiment results.

II. IDENTIFING PERMANENT MAGNET POLARITY

The principle of identifying the magnet pole based on magnetic saturation effects has been discussed in literature and is illustrated in Figs.1 (a), (b) and (c). Initially, the flux increases in direct proportion to the increase of currents. Further increases in currents result in progressively smaller increases in flux because of magnetic saturation. As shown in Fig.1 (c), with the permanent magnet excitation alone, the original operating point is “A”. However, with the stator excitation voltage applied in the same polarity with respect to that of the permanent magnet, the stator currents will increase from i_0 to i_1, and operating point from “A” to “B” due to the deep saturation. On the other hand, when the applied stator excitation voltage and magnetic pole are in the opposite directions, the magnetic path will not be saturated. The stator current will change from i_0 to i_2. At the same time, the operating point moves accordingly from point A to C. In these two cases, the applied volt-seconds are the same but different in polarity. Due to core saturation nonlinearity, the magnitudes of current variations are different. Therefore, we can detect the polarity of permanent magnets mounted on the rotor.

When the magnetic pole is in an arbitrary initial position as shown in Fig.1 (a), we have to detect the axis



(a) (b) (c)

Figure 1. Magnetic pole identification based on saturation effects

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of the permanent magnet first, normally achieved by the high frequency voltage injection method but the polarity of the magnet is left unknown. In the second step, according to the axis direction of the permanent magnet, positive and negative pilot voltages are applied sequentially in a controlled mode such that the volt-seconds are the same in both cases. When the positive voltage is applied, the current incremental is $+|i_1|$ and when negative the current incremental is $-|i_2|$. In the third step, we compare the magnitudes of the current incrementals. If $|i_1|$ is larger than $|i_2|$, the magnetic pole that corresponds to $|i_1|$ is the North and the rotor position in the range from 0 to π. Similarly, when the magnetic pole is in the orientation as shown in Fig.1 (b), the corresponding current ($|i_2|$) with the positive stator excitation applied will be smaller than current ($|i_1|$) with the negative stator excitation applied. Therefore, the magnetic pole that corresponds with $|i_1|$ is the North Pole. In this case, the rotor position angle is actually an angle between π and 2π and the angle will be $\theta_r + \pi$.

III. IDENITFYING POLE POLASRITY BASED ON SPACE VECTOR PWM

In the proposed magnetic poles identification scheme, the principles discussed above are applied but the voltages are based on the space vector PWM that is readily

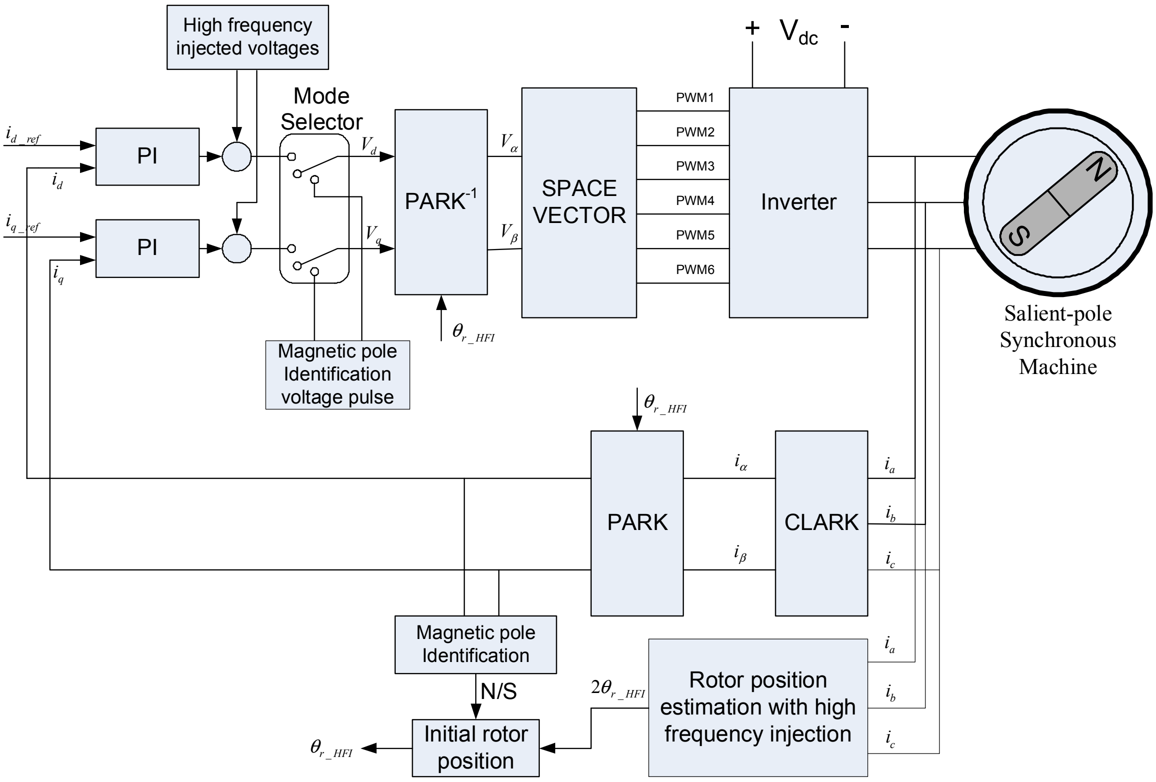

Figure 2. System diagram for rotor position estimation

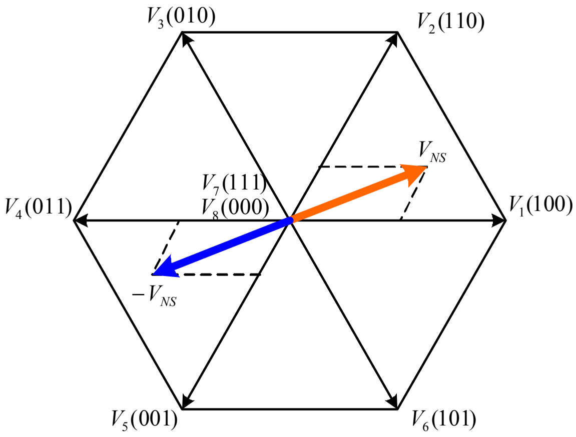

Figure 3. Space vectors

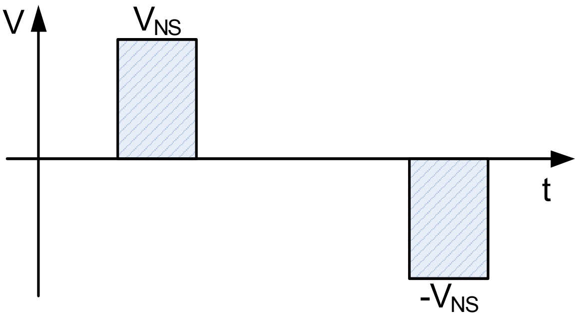

Figure 4. The pilot voltage pulses

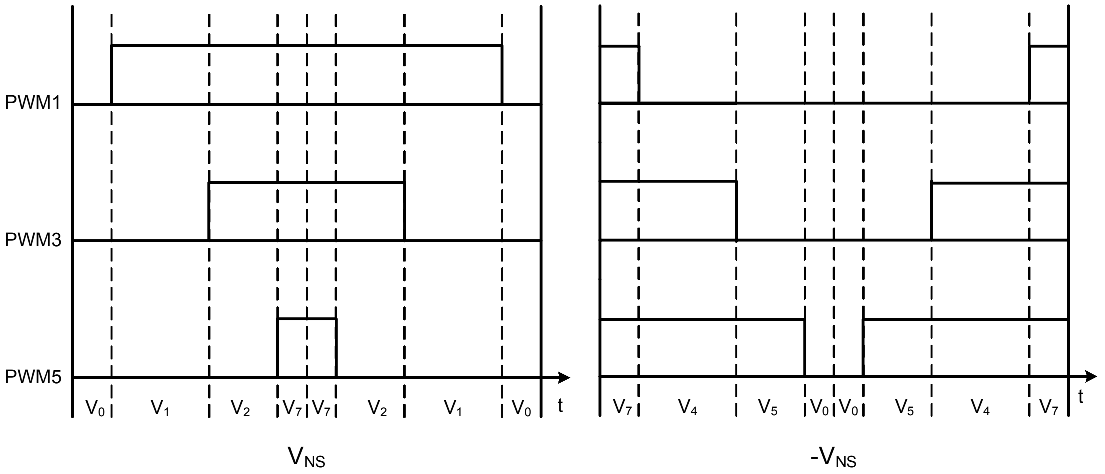

Figure 5. Pilot voltage vectors in one PWM cycle for magnetic pole identification: V_{NS} and $-V_{NS}$

available in the controller hardware and software. The system diagram for rotor position estimation with magnetic pole identification is shown in Fig. 2. The space vector is defined as shown in Fig. 3. When we know the d-axis direction of the rotor, we can conveniently figure out the phase windings closest to the rotor poles. Then, a group of pilot voltage vectors will be applied to the phase windings closest to the rotor axis to detect the magnetic poles. The pilot voltages are composed of one positive pulse and one negative pulse alternatively. Normally, the rotor's initial position could be arbitrary and the magnetic pole is not perfectly aligned with any phase windings. As an example, the V_{NS} and $-V_{NS}$ shown in Fig. 4 are one pair of pilot voltage vectors corresponding to an arbitrary initial rotor position. The applied SVPWM switching signals are shown in Fig. 5. The sensed three phase currents through A/D circuits will be transformed into the synchronous reference frame first to obtain the relative information on the polarity of magnetic pole. If the current in the synchronous reference frame is larger when V_{NS} applied than the current when $-V_{NS}$ is applied, the magnetic pole must be the North pole. Note that the applied voltage vectors should be sufficiently large to cause the magnetic saturation.

One special case is that the rotor magnetic pole is aligned with one of phase windings. For example, only vectors V_1 and V_4 (shown in Fig. 3) would be sufficient to detect magnetic pole provided that rotor magnetic pole is

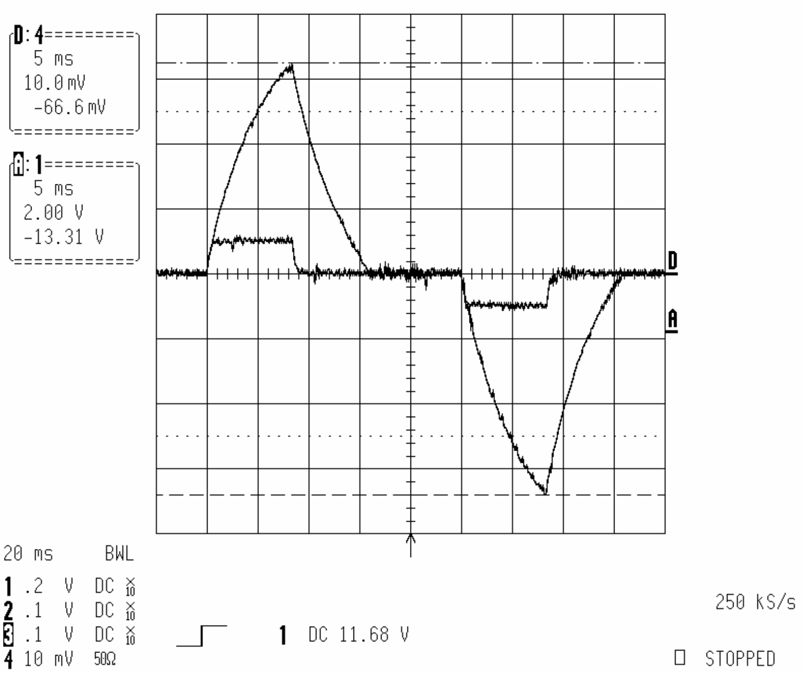

Figure 6. Magnetic pole identification (Channel A: applied voltage pulses; Channel D: The current in synchronous reference frame)

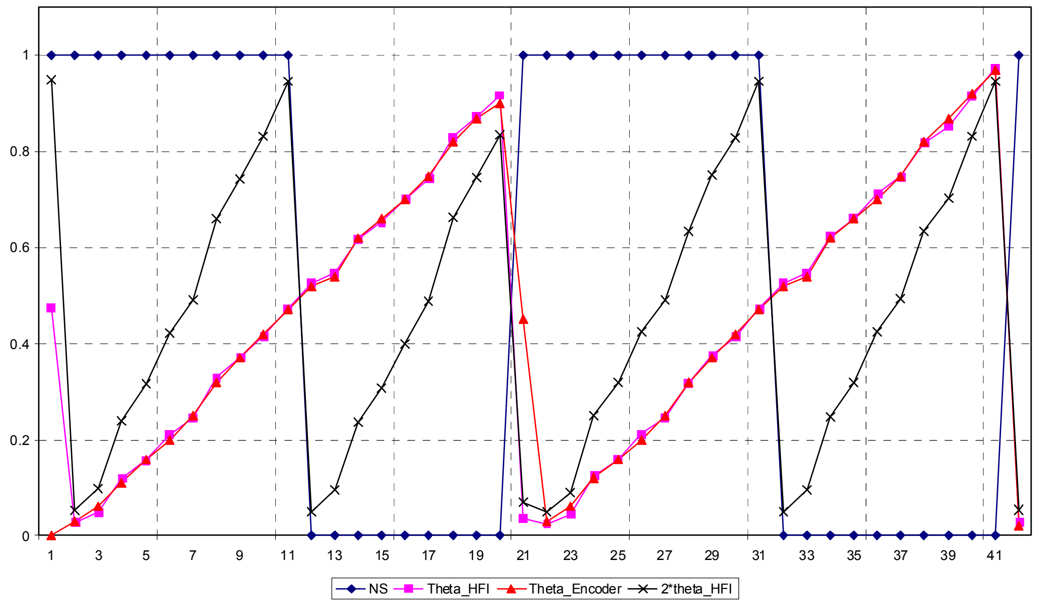

Figure 7. The estimated rotor position θ_{r_HFI} with magnetic pole detection (Calibrated by a 60-pulse encoder ($\theta_{r\_Encoder}$))

aligned with Phase "A" axis. In this case, positive and negative flux linkage is produced only with Phase "A" winding and therefore, we can obtain the N-S pole information by checking Phase "A" current peak value only.

IV. EXPERIMENTAL RESULTS

Experiments have been done based on a 5 HP salient pole permanent magnet synchronous machine. One of the experimental results is shown in Fig. 6. The waveform shown in Channel A is the applied pilot voltage pulses and Channel D the stator current that transformed into the synchronous reference frame at zero speed (10A/div). The magnitude of positive current is 32.5A and the magnitude of negative current is 34A with the aforementioned pilot voltage vectors based on SVPWM (V_{NS} and $-V_{NS}$). Obviously, the magnetic pole corresponding to applied negative current is North pole and accordingly the rotor position angle is between π and 2π .

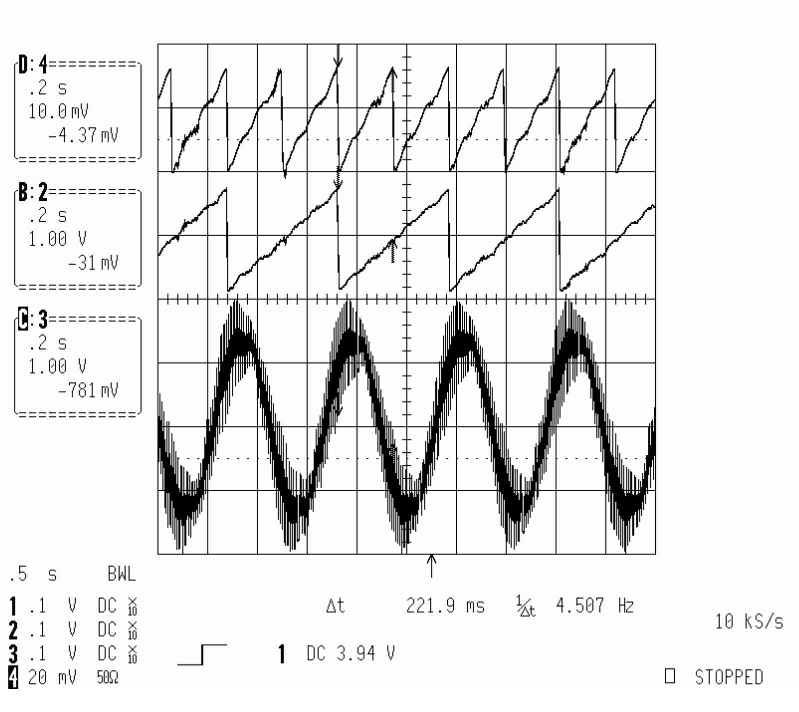

Figure 8. Low speed (2.25Hz) with fundamental current waveforms (top trace is $2\theta_{r\_HFI}$, middel is θ_{r_HFI} and bottom trace is the phase A current)

An encoder mounted on the rotor shaft is used to calibrate the N-S pole detection method. The detected magnetic pole information is applied with $2\theta_{r\_HFI}$ to generate the estimated rotor position θ_{r_HFI} as shown in Fig. 7. The θ_{r_HFI} matches the real rotor position $\theta_{r\_Encoder}$ very well. Fig. 8 shows the estimated rotor position waveforms of $2\theta_{r\_HFI}$, θ_{r_HFI} and phase current in a constant low speed range with regulated currents. The results show that the proposed magnetic pole detection scheme works very well for the estimation of the arbitrary initial rotor position.

V. SUMMARY

In this paper, an improved magnetic pole identification method based on space vector PWM for the arbitrary initial rotor position estimation and sensorless control of PM synchronous machines is presented. Through applying vector controlled pilot voltages by SVPWM, the N-S pole can be identified at any initial rotor positions at any including zero rotor speed without rotor alignment actions. The proposed method can be combined with the conventional initial rotor position and sensorless control scheme to ensure the effective estimation of initial magnetic pole position. The validity of the proposed identification method has been proven through experimental results based on a 5-HP salient-pole synchronous machine drive system.

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