Uluslararası İleri Doğa Bilimleri ve Mühendislik Araştırmaları Dergisi
Sayı 8, S. 1-8, 6, 2024

Araştırma Makalesi

IJANSER

International Journal of Advanced Natural Sciences and Engineering Researches
Volume 8, pp. 1-8, 6, 2024

Research Article

https://as-proceeding.com/index.php/ijanser
ISSN: 2980-0811

Comparative Study of Power Supply Strategies for the Variable Reluctance Machine 12/8

Chouitek Mama*, Fidouh Nedjwa [2]

[1]*Institute of Maintenance and Industrial Safety. University of Oran 2. Algeria*
[2] *Institutes of Maintenance and Industrial Safety University of Oran 2. Algeria*

**chouitek98@yahoo.com*

(Received: 10 July 2024, Accepted: 24 July 2024)

(4th International Conference on Scientific and Academic Research ICSAR 2024, July 19 - 20, 2024)

ATIF/REFERENCE: Mama, C. & Nedjwa, F. (2024). Comparative Study of Power Supply Strategies for the Variable Reluctance Machine 12/8. *International Journal of Advanced Natural Sciences and Engineering Researches*, 8(6), 1-8.

***Abstract* –** The control of the variable reluctance machine is based on the shape of the currents when it is supplied, but the major disadvantage of the MRV is the ripple of the torque due to the shapes of the phase currents and the machine EMF, and this ripple of the torque is generally harmful to the proper functioning of the device. To remedy this, we used different power supply techniques used in low and medium voltage.

The first technique used is based on the technique of controlling the current by hysteresis; in this power supply mode the torque ripple is not controlled but by adjusting the switching angles it can nevertheless be minimized. However, the use of this technique has shown its limits at low and medium speed.

This led us to use another technique which is control. The second technique uses a new vector control method based on an internal control with two degrees of freedom (2DOF IMC), this control approach makes it possible to specify two independent degrees of freedom. in the design of the regulator, which means it provides more flexibility to adjust performance and flexibility to adjust the behavior of the system according to specific requirements; by adding a simple adaptive disturbance observer (ADO) to estimate and eliminate disturbances online, it will be incorporated into the internal loop system and by adjusting the law of adaptation gains, this strategy made it possible to improve the stability and the convergence of the ADO.

The effectiveness of the latter proposed control strategy is demonstrated by experiments, and the results show that the proposed method can effectively improve the control and disturbance rejection performance of MRV drives.

Keywords – The variable reluctance machine (MRV), current control by hysteresis, vector control based on internal control with two degrees of freedom (2DOF IMC), the simple adaptive disturbance observer (ADO)

I. INTRODUCTION

Variable reluctance motors (MRV) have received much attention due to their robust structure, large starting torque and high reliability in harsh environments, they have been used in electric vehicles, production of wind energy, textile industry, etc. [1, 2,3].

However, this motor saw wide use only at the end of the seventies because of the difficulty of its control, and the power supply mode which limited its wide application in the industrial field, because it was

previously self-piloted. by mechanical devices. The static converter intended to drive this motor simply provides a unidirectional current, which makes it particularly simple and robust.
Some advanced control strategies such as direct torque control (DTC) [8,9], instantaneous direct torque control (DITC) [10,11] and model predictive control (MPC)
[12] are effective in reducing torque ripple. Several static converter topologies have emerged, including those that use a single switch per phase and others that use two switches per phase
We use another technique used at low and medium speeds, this is current control by hysteresis. However, for this conventional hysteresis current control, the performance of set point tracking and interference suppression cannot be satisfied simultaneously by adjusting a single filter parameter. For this reason, a two-degree-of-freedom internal model control structure (2DOF IMC) is proposed to address the aforementioned shortcoming, which can separate the set point tracking response and external interference suppression characteristics of the system [25,26].
However, such robustness cannot be guaranteed by the invariable filter parameter of 2DOF IMC for the SRM system. The reason is that the SRM system suffers from disturbances whose characteristics vary over time and also the variation of these parameters and other unstructured dynamic uncertainties. In addition, unlike other motors, the existence of current regulation on axis 0 increases the complexity of the controller design. Therefore, the 2DOF IMC controller used for the SRM system needs to be further developed to achieve more precise current regulation
The aim of this study is to develop a high-performance current control strategy for the SRM motor based on a 2DOF IMC strategy. This takes into account the coupling relationship between different axes. The proposed controller can provide good control performance using only two setting parameters, and the good performance of set point tracking and disturbance rejection of the controller can be guaranteed simultaneously. Second, an adaptive disturbance observer (ADO) is introduced to eliminate the time-varying disturbance. Additionally, a stability analysis is carried out according to Lyapunov theory and guidelines for ADO payoff selection are given.

II. MATHEMATICAL MODEL OF MRV

Neglecting magnetic saturation and mutual inductance, self-inductance can be described by the Fourier series with DC and fundamental harmonic components:

$$\begin{cases} L_a = L_{dc} + L_{ac} \cos\theta_e \\ L_b = L_{dc} + L_{ac}\cos(\theta_e - 2/3\pi) \\ L_c = L_{dc} + L_{ac}\cos(\theta_e + 2/3\pi) \end{cases} \tag{1}$$

Where L_a, L_b and L_c are the self-inductance of phases A, B and C; L_{dc} and L_{ac} are the coefficients of DC and fundamental harmonic component. The θ_e is the position of the electric rotor and the relationship between θ_e and mechanical angle θ_m can be expressed as:

$$\theta_e = p\theta_m \tag{2}$$

Where the p is the number of rotor poles.
The voltage balance equation of VRM in the three-phase frame of reference can be described as follows:

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = R \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + p\left(\begin{bmatrix} l_a & 0 & 0 \\ 0 & l_b & 0 \\ 0 & 0 & l_c \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}\right) \tag{3}$$

Where u_a, u_b and u_c are voltages in phase A, B and C, i_a, i_b and i_c are currents in phases A, B and C, and R and p are the phase winding resistance and the differential operator.
By using the Park transformation, the model in the rotating frame can be further obtained, and it can be denoted as:

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = R \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} + \omega_e \left(\begin{bmatrix} -l_{ac}\sin 3\theta_e - l_{dc} & -l_{ac}\cos 3\theta_e & 0 \\ l_{dc} - l_{ac}\cos 3\theta_e & -l_{ac}\sin 3\theta_e & \frac{\sqrt{2}}{2} l_{ac} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \right) +$$

$$\begin{bmatrix} l_{dc} + \frac{1}{2} l_{ac}\cos 3\theta_e & -\frac{1}{2} l_{ac}\sin 3\theta_e & \frac{\sqrt{2}}{2} l_{ac} \\ -\frac{1}{2} l_{ac}\sin 3\theta_e & l_{dc} - \frac{1}{2} l_{ac}\cos 3\theta_e & 0 \\ \frac{\sqrt{2}}{2} l_{ac} & 0 & l_{dc} \end{bmatrix} + p \left(\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \right) \tag{4}$$

Where u_a, u_b and u_c are the d-, q- and 0 axis tension; i_d, i_q and i_0 are the currents d, q and 0 axes. The ω_e is the speed of the electric rotor.
The instantaneous torque T_e It is in the rotating reference frame is given as:

$$T_e = \frac{p\sqrt{2}}{2} l_{ac} i_0 i_q - \frac{p}{4} l_{ac} \left({i_d}^2 + {i_q}^2 \right) \sin(3\theta_e + 2\beta) \tag{5}$$

Where the β is the advanced angle.
From (5), it is obvious that the second term does not contribute to the average torque, and it is usually treated as the torque ripple. Therefore, in this paper, to reduce the ripple term, the $i_d = 0$ strategy is adopted and the $\beta = \pi/2$ is selected. Then the T_e is simplified as:

$$T_e = \frac{\sqrt{2}}{2} l_{ac} i_0 i_q$$

III. MACHINE POWER SUPPLY

The 12/8 variable reluctance motor requires an atypical power supply. Thus, the MRV is usually powered from a three-phase asymmetrical half-bridge inverter which is shown in Figure 1. Each of the phases is connected to the source through an asymmetrical half-bridge.
Figure 2 shows the rotation stages of the machine. If, at position 1, phase 1 is excited, the rotor positions itself so as to align one of its pairs of poles with that of phase 1 (position 2), the reluctance is then minimized and the number of lines of the field is maximum, position 2 is therefore an equilibrium position of the rotor. If, at this position, phase 2 is energized, then the reluctance of the machine as seen by the DC source is high and the magnetic field lines are distorted, therefore the rotor still rotates to align with phase 2 The explanation of rotation in terms of motor steps is only a means to facilitate the study. [9]

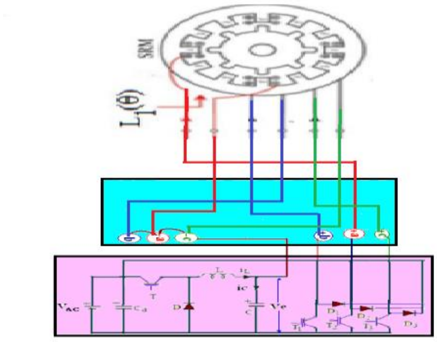
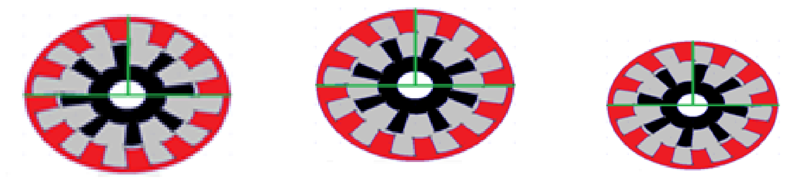


Fig. 1: Power supply of the MRV by an inverter asymmetrical half-bridge



Postion 1 Postion 2 Postion 3

Fig .2. Stages of rotation of an MRV

In practice, the switching of current from one phase to another takes place before the successive equilibrium positions are reached. In this way, a uniform rotation of the rotor is obtained. When the rotor rotates, each phase presents a cyclic variation in its inductance.

A. *Principle Of Control By Hysteresis*

The principle of this control is based on controlling the converter [6] such that the variation of the current in the motor phase is limited in a band surrounding the current reference. Figure 3

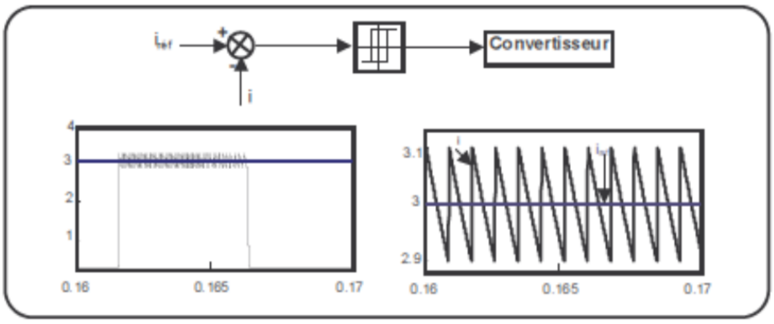


Fig.3: Principle of hysteresis regulator

In order to maintain the torque of the machine constant, we will use this technique which is based on supplying the variable reluctance machine (MRV) with currents predetermined according to the characteristics from a torque setpoint in trapezoid shape which ensures a constant torque over a complete period. This technique has often been carried out using hysteresis current regulators which has the effect of imposing a current reference in a hysteresis band to control the phase currents. Figure 4 .represents the functional diagram of the system to be simulated in closed loop.

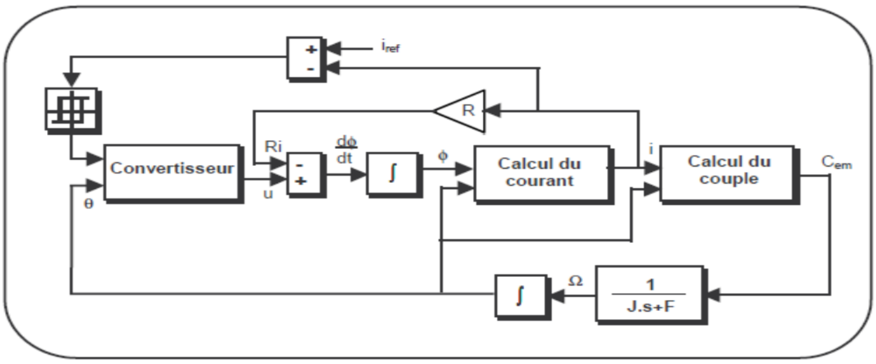


Figure 4: current control by hysteresis

B. CMI 2DDL Strategy for MRV Based on OAP

Figure 5 shows the structure diagram of the CMI 2DDL OAP scheme based on vector control. The 2DDL internal model control is used for the current loop and the traditional PI controller is adopted for the speed loop, an Adaptive Disturbance Observer (OAP) is injected which predicts the disturbances by steepest descent technique and compensates the 2DOF IMC controller in the next control period and improves the stability of the system

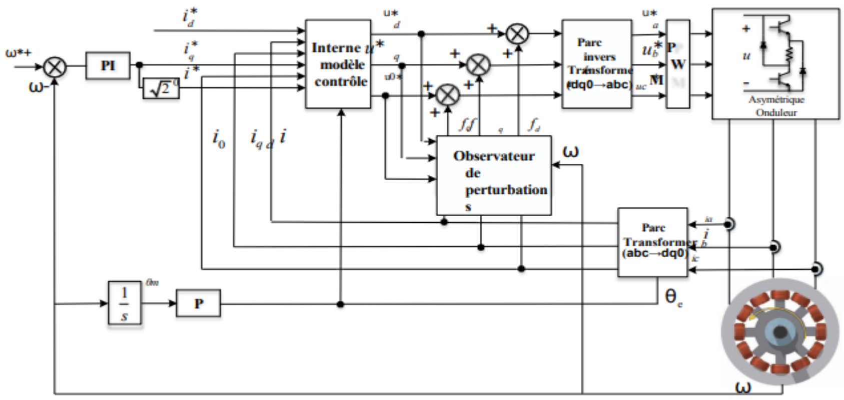


Fig. 5: The structure diagram of the CMI 2DDL OAP schema

C. Design of CMI 2DDL OAP

Considering the parameter variation and unknown uncertainties, the system model can be further described by the following equation

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = R \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} + \omega_e \left(\begin{bmatrix} 0 & -l_{ac} & 0 \\ l_{dc} & 0 & \frac{\sqrt{2}}{2} l_{ac} \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \right) + \begin{bmatrix} l_{dc} & 0 & \frac{\sqrt{2}}{2} l_{ac} \\ 0 & l_{dc} & 0 \\ \frac{\sqrt{2}}{2} l_{ac} & 0 & l_{dc} \end{bmatrix} p \left(\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \right) + \begin{bmatrix} f_d \\ f_q \\ f_o \end{bmatrix} \quad (7)$$

Where the disturbances f_d, f_q et $f_o$sont donnés par are given by

$$\begin{cases} f_d = \Delta R + \Delta L_{dc}\, \rho(i_d) + \Delta L_{ac}\, \rho(i_o) + \epsilon_d \\ f_q = \Delta R + \Delta L_{ac}\, \omega_e(i_o) + \Delta L_{dc}\, \rho(i_o) + \epsilon_q \\ f_o = \Delta R + \frac{1}{2}\Delta L_{ac}\, (i_o) + \frac{1}{2}\Delta L_{ac}\, \rho(i_d) + \Delta L_{dc}\, \rho(i_o) + \epsilon_o \end{cases} \quad (8)$$

In this equation, the ΔR, ΔL_{ac} represent the uncertainties of de R, L_{ac} and L_{dc} . ϵ_d, ϵ_q are the uncertainties on the d-, q- and 0 axes caused by unmodeled dynamics

IV. The Experimental Result With The Change In Load Torque

Figures 6 and 7 illustrate the simulation results of the hysteresis control strategy and the internal model control strategy with two degrees of freedom with the adaptive disturbance observer (CMI 2DDL OAP) [4] the engine used has the parameters indicated in table 1 below.

Table 1 Engine prototype parameters

Settings	value
phase	3
Rotor/stator poles	12/8
Nominal power	1.5KW
Rated torque	9.5N.m
Speed range	100-1500tr/m
Maximum flow binding	0.986Wb
Stator resistance	0.9oh
Nominal voltage	220V

When the MRV operates at 400 rpm with a load of 1 N•m and the time is 2.3 s, the load torque varies from 1 N.m to 4 N.m. Figure 8 shows the experimental results of dq0- axis currents, where i_d^* ,i_q^* and i_o^* .Figure 6 shows the experimental results of rotor speed, total torque and phase current.

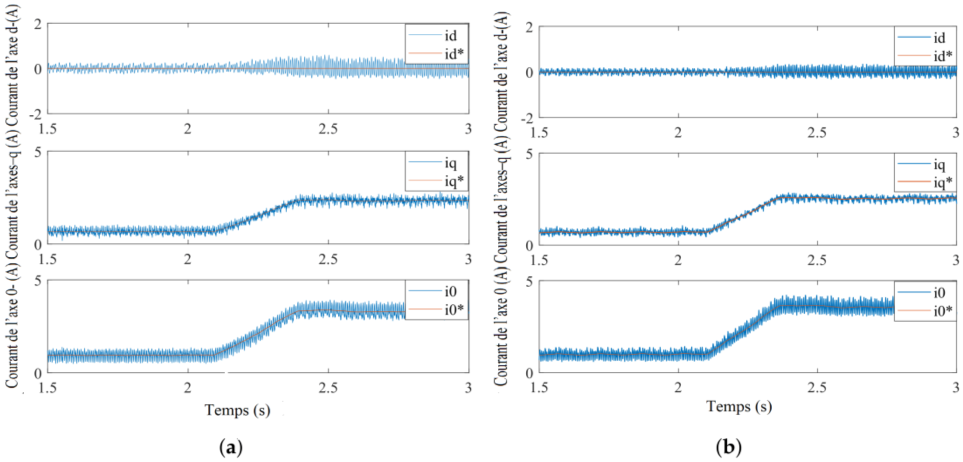


Fig. 6 Experimental results of dq0 axis currents with load torque variation, (a) hysteresis method, (b) CMI 2DDL OAP method

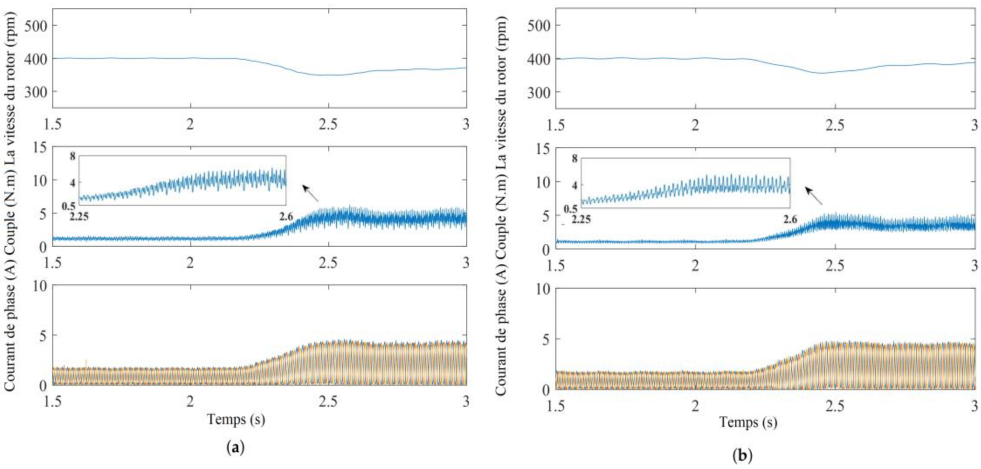


Fig. 7 Experimental results of rotor speed, total torque and phase current with load torque variation, (a) hysteresis method, (b) CMI 2DDL OAP method

It can be seen from Figure 6(b) that the direct d-axis current fluctuations of both methods increase when the load torque changes from 2.3 s. The hysteresis method results in ripples of current i_d of 1.25 A; on the other hand, it is only 0.93 A in the case of the CMI 2DDL OAP method. Moreover, compared to

Figure 6 (a), (b), it is evident that a significant improvement has been noticed in the current tracking performance using the proposed CMI 2DDL OAP method. Similar to the above analysis, considering the characteristics of MRV, the proposed method can achieve good control performance and fast response in a stepped torque load case, as shown in Fig 7. Moreover, as the Adaptive Disturbance Observer (OAP) can eliminate the disturbances due to varying load torque along with the robustness which has been improved as shown in Figures 6 and 7. The CMI 2DDL OAP method provided good current control performance and good torque ripple suppression. Furthermore, it can be seen that when the load torque increased, the regulation time decreased and so did the ripples, see Figure 7(b), which is also consistent with the above analysis.

Table 2 lists the T_r results for both methods. Obviously, in terms of torque ripple suppression, the proposed CMI 2DDL OAP approach outperforms the hysteresis method, and the torque ripple T_r is reduced by 8.25% and 18%. The above compared results indicate that the proposed method can achieve good tracking and disturbance rejection performance under stepped load torque conditions.

Table 2 Torque Ripple Percentages for Both Methods as Load Torque Changes

Method	**Speed (rpm)**	**Load torque (N.m)**	**T_r**
Hysteresis	400	1	65.01%
	400	4	85.73%
2DOF BMI ADO	400	1	56.49%
	400	4	67.73%

V. Conclusion

This communication takes into account a new CMI 2DDL OAP strategy for vector control excited by unipolar current applied to the MRV machine. A hysteresis controller was used to improve the tracking performance of the PI controller. Then, to solve the problem of variable disturbances according to which the hysteresis controller could not manage over time, the CMI 2DDL OAP was introduced into the control system, its adaptive gain μ of the CMI 2DDL OAP was able to ensure the stability and convergence of the system.

The main features and advantages of the proposed control system can be summarized as follows:

The CMI 2DDL OAP can effectively reduce the current tracking errors and quickly converges to stable conditions, when the system is affected by different disturbances, this current controller could improve the control accuracy, it also has good performance in to eliminate torque ripples.

The control performance of the CMI 2DDL OAP controller can be guaranteed even with inaccurate model parameters.

References

[1] Lawrenson, P. (1983). Switched-reluctance motor drives. IEEE Rev. , 29, 144–147. [Google Scholar] [CrossRef].

[2] Chen, H.; Liu, C.Chen, Z. (2012). Simulation and implementation of wind turbine based on switched reluctance motor drive. In Proceedings of the 2012 3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), Aalborg, Denmark,. [Google Scholar].

[3] Valdivia, V. Todd, R. Bryan, F.J and Barrado, A.(2014).Behavioral modeling of a switched reluctance generator for aircraft power systems. IEEE Trans. Ind. Electron. , 61, 2690–2699. [Google Scholar] [CrossRef].

[4] Liu D. Wang G. Liu J. Fan Y. Mu D.(2022) An Improved Vector Control Strategy for Switched Reluctance Motor Drive Based on the Two-Degree-of-Freedom Internal Model Control. Appl. Sci. 12, 5407.

[5] Chouitek. M. (2011).Stratégies d'Alimentation d'un Moteur à Reluctance Variable. ICEO'11 Conférence International on Electronique and Oil.Ouargla Mars 01-02-2011.

[6] [6] Divan M.Venkatoramanan G et R. DeDoncker W. (2005) Design Methodologies for Soft Switched Inverter. trans.ind.IEEE.

[7] Wu S. Li Z. Zhang R. (2020). An improved 2-degree-of-freedom internal model proportional–integral–derivative controller design for stable time-delay processes. Meas. Control. 53, 841–849. [Google Scholar] [CrossRef][Green Version]

[8] .JuwariChin S. Samad Y. Aziz N. (2008).Two degree of freedom internal model control for parallel cascade scheme. In Proceedings of the 2008 International Symposium on Information Technology, Kuala Lumpur, Malaysia, August 26–28-2008. [Google Scholar].

[9] Arthur R. Analytically computing the flux linked by a switched reluctance motor phase when the stator and rotor poles overlap, 36, no. 4, pp. 1996-2003. IEEE Transactions on magnetics, Volume: 36, Issue: 4, July 2000