Optimization of sliding mode with MRAS based Speed Estimation for Speed Sensorless Control of DSIM via Genetic Algorithm

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Abstract -This paper presents, one method is proposed to optimize the parameters of SMC controller used in model reference adaptive speed-estimation. In order to achieve a robust system, after trying this technique we found it difficult to find the parameters of the sliding mode, so we suggested using one meteheurstic method to find the optimal parameters which is the genetic algorithm to ensure robust control without a sensorless.
The results presented to Matlab showed a positive effect on the behavior of the system, as presented the genetic algorithm in finding the optimal parameters, which enabled us to obtain a more robust system.

Keywords: Dual Star Induction Motor(DSIM), field oriented control (FOC),sliding mode, model reference adaptative control, genetic algorithm.

I. INTRODUCTION

Strategies have been proposed for rotor speed estimation in sensorless induction motor drives [1]. Among these techniques Model Reference Adaptive Systems (MRAS) schemes are the most common strategies employed due to their relative simplicity and low computational effort [1, 2].

The Double Star Induction Motor (DSIM) has two sets of three-phase windings which are spatially phase shifted by 30 electrical degrees with isolated neutrals. Therefore, modeling and control of this machine in the original reference frame would be very difficult. For this reason, some assumptions must be made in order to obtain a simplified model Park to control it [3, 4].

The field oriented control decoupling between these variables, and the torque is made similar as the one of a direct current machine [5]. One may note that the field oriented control scheme is very sensitive to induction machine parameters variations [6]. However, many problems, in order to apply the sensors, are the mounting of the sensor and the additional costs, etc. [7]

MRAS is one of the best techniques due to its simplicity, good performance and stability. MRAS consists of reference model, an adaptive model and an adaptation mechanism.

Sliding mode controller with speed estimator has been suggested to achieve robust DSIM performance.

The sliding mode controller provides fast dynamic response, stable control system and easy access to hardware and software. Although this control method causes some defects associated with the large torque chattering that appears in steady state. Chattering involves high-frequency control switching and may lead to excitation of unmodelled high frequency system dynamics.

Chattering also causes high heat losses in electronic systems and undue wear in mechanical systems [5]. In order to reduce the system chattering a sign function is used. Genetic algorithm (GA) is one kind of global optimization techniques with the advantage of dealing with the integer variables.

this paper explains the implementation of a high performance sliding mode sensorless control model reference adaptive (MRAS) scheme for a DSIM, with used adaptive heuristic method GA.

The results presented to Matlab showed a positive effect on the behavior of the system.

II. DYNAMIC MODEL OF DOUBLE STAR INDUCTION MOTOR

A schematic of the stator and rotor windings for a machine dual three phase is given in Fig. 1. The six stator phases are divided into two wye-connected three phase sets labelled A_{s1}, B_{s1}, C_{s1} and A_{s2}, B_{s2}, C_{s2} whose magnetic axes are displaced by an arbitrary angle α. The windings of each three phase set are uniformly distributed and have axes that are displaced 120° apart. The three phase rotor windings.
A_r, B_r, C_r are also sinusoidally distributed and have axes that are displaced apart by 120° [8,9].

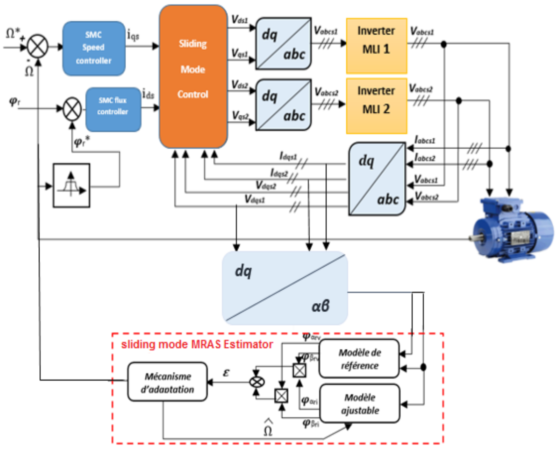

Fig. 1. Sliding mode sensorless vector control of DSIM.

The following assumptions are made:
– Motor windings are sinusoidally distributed;
– The two stars have same parameters;
– Flux path is linear.
The voltage equation is [10]:

$$[v_{abc,s1}] = R_s[i_{abc,s1}] + \frac{d}{dt}[\varphi_{abc,s1}]$$
$$[v_{abc,s2}] = R_s[i_{abc,s2}] + \frac{d}{dt}[\varphi_{abc,s2}] \quad (1)$$
$$[v_{abc,r}] = R_s[i_{abc,r}] + \frac{d}{dt}[\varphi_{abc,r}]$$

$$\begin{bmatrix}[\varphi_{abc,s1}]\\ [\varphi_{abc,s2}]\\ [\varphi_{abc,r}]\end{bmatrix} = \begin{bmatrix}[L_{s1,s1}] & [L_{s1,s2}] & [L_{s1,r}]\\ [L_{s2,s1}] & [L_{s2,s2}] & [L_{s2,r}]\\ [L_{r,s1}] & [L_{r,s2}] & [L_{r,r}]\end{bmatrix} + \begin{bmatrix}[I_{abc,s1}]\\ [I_{abc,s2}]\\ [I_{abc,r}]\end{bmatrix} \quad (2)$$

With :

$[v_{abc,s1}] = [v_{as1} v_{bs1} v_{cs1}]^T$;
$[v_{abc,s2}] = [v_{as2} v_{bs2} v_{cs2}]^T$;
$[I_{abc,s1}] = [I_{as1} I_{bs1} I_{cs1}]^T$; $[I_{abc,s2}] = [I_{as2} I_{bs2} I_{cs2}]^T$;
$[v_r] = [v_{ar} v_{br} v_{cr}]^T$; $[I_r] = [I_{ar} I_{br} I_{cr}]^T$;
$[R_{s1}] = [R_{s2}] = \mathrm{Diag}[R_s]_{(3\times3)}$;
$[R_r] = \mathrm{Diag}[R_r]_{(3\times3)}$;

The detail of the sub matrixes is given in the Appendix.

Where $R_{s1} = R_{s2}$; $L_{s1} = L_{s2}$ and L_{ms} are the stator resistance, leakage inductance and magnetizing inductance; R_r, L_r and L_{mr} the rotor resistance, leakage inductance and magnetizing inductance; M_{sr} Maximal mutual inductance between stator and rotor.

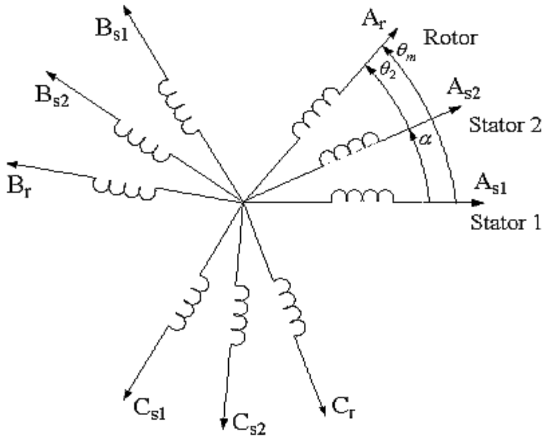

Fig. 2. Windings of the DSIM.

The Park model of DSIM is presented below in the references frame at the rotating field (d,q) [11, 12,13]:

$$\begin{aligned}
v_{ds1} &= R_{s1} i_{ds1} + p\varphi_{ds1} - \omega_s \varphi_{qs1}\\
v_{qs1} &= R_{s1} i_{qs1} + p\varphi_{qs1} + \omega_s \varphi_{ds1}\\
v_{ds2} &= R_{s2} i_{ds2} + p\varphi_{ds2} - \omega_s \varphi_{qs2}\\
v_{qs2} &= R_{s2} i_{qs2} + p\varphi_{qs2} + \omega_s \varphi_{ds2}\\
v_{dr} &= R_r i_{dr} + p\varphi_{dr} - (\omega_s - \omega_r)\varphi_{qr}\\
v_{qr} &= R_r i_{qr} + p\varphi_{qr} + (\omega_s - \omega_r)\varphi_{dr}
\end{aligned} \quad (3)$$

The expressions for stator and rotor flux are:

$$\begin{aligned}
\varphi_{ds1} &= L_{s1} i_{ds1} + L_m (i_{ds1} + i_{ds2} + i_{dr})\\
\varphi_{qs1} &= L_{s1} i_{qs1} + L_m (i_{qs1} + i_{qs2} + i_{qr})\\
\varphi_{ds2} &= L_{s2} i_{ds2} + L_m (i_{ds1} + i_{ds2} + i_{dr})\\
\varphi_{qs2} &= L_{s2} i_{qs2} + L_m (i_{qs1} + i_{qs2} + i_{qr})\\
\varphi_{dr} &= L_r i_{dr} + L_m (i_{qs1} + i_{qs2} + i_{qr})\\
\varphi_{qr} &= L_r i_{qr} + L_m (i_{qs1} + i_{qs2} + i_{qr})
\end{aligned} \quad (4)$$

With $p = d/dt$; $3L_m/2 = L_{ms} = L_{mr} = L_{sr}$.

In the induction machines, rotor windings are short circuited hence, i.e. $v_{dr} = 0$ and $v_{qr} = 0$.

- *Mechanical Equation*

The mechanical is given as follow [14,15]:

$$J\frac{d\Omega}{dt} = T_{em} - T_r - K_f\Omega \tag{5}$$

With :

$$T_{em} = p\frac{L_m}{L_m + L_r}[\varphi_{dr}(i_{qs1} + i_{qs2}) - \varphi_{qr}(i_{ds1} + i_{ds2})] \tag{6}$$

III. FIELD ORIENTED CONTROL OF DOUBLE STATOR INDUCTION MOTOR

The objective of space vector control is to assimilate the operating mode of the asynchronous machine at the one of a DC machine with separated excitation, by decoupling the torque and the flux control. With this new technique of control and microprocessor development we can obtain speed and torque control performances comparable at those of DC machine [16].

By applying field oriented control principle ($\varphi_{dr} = \varphi_r$ and $\varphi_{qr} = 0$) to equations (3) ,(4) (5) and (6), the field-oriented model of the motor is given by the following equation system:

$$\begin{aligned}
\frac{di_{ds1}}{dt} &= \frac{1}{L_{s1}}\begin{bmatrix} V_{ds1} - R_{s1}i_{ds1} - a_2(a_3(i_{ds1} + i_{ds2}) - a_4\varphi_r) \\ + \omega_s[(L_{s1} + a_1)i_{qs1} + a_1 i_{qs2})] \end{bmatrix} \\
\frac{di_{qs1}}{dt} &= \frac{1}{L_{s1}}\left[V_{qs1} - R_{s1}i_{qs1} - \omega_s[(L_{s1} + a_1)i_{ds1} + a_1 i_{ds2} + a_2\varphi_r)]\right] \\
\frac{di_{ds2}}{dt} &= \frac{1}{L_{s2}}\begin{bmatrix} V_{ds2} - R_{s2}i_{ds2} - a_2(a_3(i_{ds1} + i_{ds2}) - a_4\varphi_r) \\ + \omega_s\left[(L_{s2} + a_1)i_{ds2} + a_1 i_{ds1} + a_2\varphi_r\right] \end{bmatrix} \\
\frac{di_{qs2}}{dt} &= \frac{1}{L_{s2}}\left[V_{qs2} - R_{s2}i_{qs2} - \omega_s[(L_{s2} + a_1)i_{ds2} + a_1 i_{ds1} + a_2\varphi_r)]\right] \\
\frac{d\varphi_r}{dt} &= a_3(i_{ds1} + i_{ds2}) - a_4\varphi_r \\
T_{em} &= p\frac{L_m}{L_m + L_r}\varphi_r(i_{qs1} + i_{qs2}) \\
\frac{d\omega_r}{dt} &= a_6 T_{em} - a_6 T_r - a_7\omega_r
\end{aligned} \tag{7}$$

$a_1 = \frac{L_m . L_r}{L_m + L_r}$; $a_2 = \frac{L_m}{L_m + L_r}$

$a_3 = \frac{R_r . L_m}{L_m + L_r}$, $a_4 = \frac{R_r}{L_m + L_r}$

$a_5 = \frac{P . L_m}{L_m + L_r}$, $a_6 = \frac{T_r}{J}$, $a_7 = \frac{K_f}{J}$

The expressions of the rotor currents may be given as:

$$i_{dr} = \frac{1}{L_r + L_s}[\varphi_r - L_m(i_{ds1} + i_{ds2})] \tag{8}$$

$$i_{qr} = -\frac{L_m}{L_r + L_m}(i_{qs1} + i_{qs2}) \tag{9}$$

$$\omega_{gl} = \frac{R_r}{L_m + L_r}(i_{qs1} + i_{qs2}) \tag{10}$$

IV. ROTOR FLUX BASED MRAS

The basis of Rotor flux (RF) based MRAS is that rotor flux may be estimated either using the voltage model or the current model of an induction motor. The structure of reference model (RM) and adjustable model (AM) may be realized as follows:

a) *Reference model*

The reference rotor flux components obtained from the reference model are given by[17]:

$$\begin{cases} \dfrac{d\hat{\varphi}_{r\alpha-v}}{dt} = \dfrac{L_m + L_r}{L_m}\left[V_{s\alpha1} - R_{s1}i_{s\alpha1} - \sigma(L_s + L_m)\dfrac{di_{s\alpha1}}{dt} - \dfrac{L_m L_r}{L_m + L_r}\dfrac{di_{s\alpha2}}{dt}\right] \\ \dfrac{d\hat{\varphi}_{r\beta-v}}{dt} = \dfrac{L_m + L_r}{L_m}\left[V_{s\beta1} - R_{s1}i_{s\beta1} - \sigma(L_s + L_m)\dfrac{di_{s\beta1}}{dt} - \dfrac{L_m L_r}{L_m + L_r}\dfrac{di_{s\beta2}}{dt}\right] \end{cases} \tag{11}$$

b) *Adaptive model*

The adaptive model is described by the current model [24]:

$$\begin{cases} \dfrac{d\hat{\varphi}_{r\alpha-i}}{dt} = \left[\dfrac{L_m}{T_r}(i_{s\alpha1} + i_{s\alpha2}) - \dfrac{1}{T_r}\hat{\varphi}_{r\alpha-i} - \omega_r\hat{\varphi}_{r\beta-i}\right] \\ \dfrac{d\hat{\varphi}_{r\beta-i}}{dt} = \left[\dfrac{L_m}{T_r}(i_{s\beta1} + i_{s\beta2}) - \dfrac{1}{T_r}\hat{\varphi}_{r\beta-i} + \omega_r\hat{\varphi}_{r\alpha-i}\right] \end{cases} \tag{12}$$

c) *Adaptation mechanism*

The error between the reference model and the adjustable model is defined as follows:

$$\varepsilon = \hat{\varphi}_{r\alpha-i}\,\hat{\varphi}_{r\beta-v} - \hat{\varphi}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i} \tag{13}$$

The adaptation law is classically given by a PI controller of the following expression [18]:

$$\hat{\omega} = \varepsilon\left(k_p + \frac{k_i}{s}\right) \tag{14}$$

The speed resulting from (14) is in turn reinjected into the adjustable model in such a way that the error converges to zero.rd

From these results, it is obvious that for the reference model we will take the reference value of rotor flux in (11), and since (12) asks the information of the speed, it will be taken for the adjustable model this is shown in Fig.3.

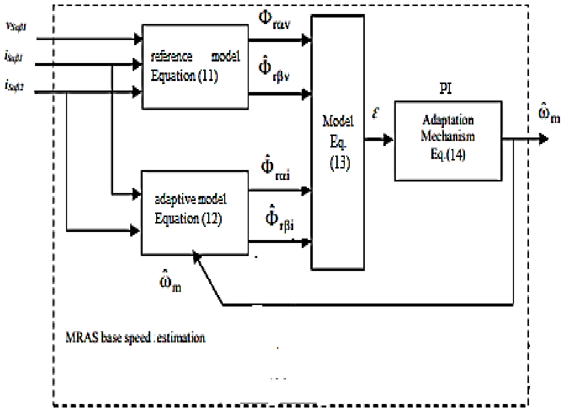

Fig. 3. Block diagram of the classical MRAS technique applied to the DSIM.

In order to give a more robust system, given the unsatisfactory results given by Classic PI, So we introduced a more powerful regulator, which are based on a sliding mode technique .

V. SLIDING MODE CONTROL DESIGN

The basic principle of the sliding mode control consists in moving the state trajectory of the system toward a surface $S(x)=0$ and maintaining it around this surface with the switching logic function U_n. The basic sliding mode control law is expressed as.

$$U_C = U_{eq} + U_n \tag{15}$$

This expression uses two terms, U_C and U_n, U_{eq} is determined off line with a model that represents the plant as accurately as possible. It is used when the system state is in the sliding mode. The term U_n : is a sign function defined as $U_n = k\,\mathrm{sign}(S(x))$, where;

$$\mathrm{sign}(S(x)) = \begin{cases} 1 & \text{if } S(x) \prec 0 \\ -1 & \text{if } S(x) \succ 0 \end{cases} \tag{16}$$

This will guarantee that the state is attracted to the switching surface by satisfying the Lyapunov stability:

$$S(x)\,\dot{S}(x) \prec 0 \tag{17}$$

This strategy enforces the system trajectory to move toward and to stay on the sliding surface from any initial condition. Using a sign function often causes chattering in practice. One solution to reduce chattering is to introduce a boundary layer around the sliding surface [19], [20]. This is expressed by:

$$U_n = \begin{cases} \frac{k}{\varepsilon} S(x) & \text{if } |S(x)| \prec \varepsilon \\ k\,\mathrm{sgn}(S(x)) & \text{if } |S(x)| \succ \varepsilon \end{cases} \tag{18}$$

With k, a positive coefficient and ε , the thickness of the boundary layer. However, a small value of ε might produce a boundary layer so thin that it can excite high frequency dynamics [16].

A) *Sliding Mode Control of Double Star Induction Motor*

- *Design of the switching surfaces*

In this work six sliding surfaces are used and taken as follows since a first order model is used.

$$\begin{aligned} S(\omega_r) &= \omega_r^* - \omega_r \\ S(\varphi_r) &= \varphi_r^* - \varphi_r \\ S(i_{ds1}) &= I_{ds}^* - i_{ds1} \\ S(i_{ds2}) &= I_{ds}^* - i_{ds2} \\ S(i_{qs1}) &= I_{qs}^* - i_{qs1} \\ S(i_{qs2}) &= I_{qs}^* - i_{qs2} \end{aligned} \tag{19}$$

With ω_r^* and φ_r^* are respectively the reference variables of the rotor speed and the flux. $S(\omega_r), S(\varphi_r)$ are related to the outer loops, whereas $S(i_{ds1})$, $S(i_{ds2})$, $S(i_{qs1})$, $S(i_{qs2})$ are related to the inner loops. The i^*_{ds} and i^*_{qs} reference are determined by the outer loops, and take respectively that values of the control variables i_{ds} and i_{qs}.

❖ *Development of the control laws*

By using the equation systems (7) and (19), the regulators control laws are obtained as follows:

For the speed regulator

$$I^*_{qs} = i^*_{qs} + \lambda_1 x_1 \qquad (20)$$

And $i^*_{qs} = i_{qseq} + i_{qsn}$

With $i_{qseq} = a_8 \frac{1}{\varphi^*_r}\left[\dot{\omega}^* + a_7\omega_r + a_6 C_r\right]$

$$a_8 = \frac{J(L_m + L_r)}{P^2 * L_m}$$

$$i_{qsn} = \begin{cases} \frac{K_{\omega r}}{\varepsilon_{\omega r}}.S(\omega_r) & \text{if} \quad |S(\omega_r)| \prec \varepsilon_{\omega r} \\ K_{\omega r}.Sgn(S(\omega_r)) & \text{if} \quad |S(\omega_r)| \succ \varepsilon_{\omega r} \end{cases}$$

For the flux regulator

$$S(\varphi_r).S^{\cdot}(\varphi_r) \prec 0 \Rightarrow I^*_{ds} = i^*_{ds} + \lambda_2 x_2 \qquad (21)$$

And $i^*_{ds} = i_{dseq} + i_{dsn}$

$$i_{dseq} = \frac{1}{a_3}\left[\dot{\varphi}^* + a_4\varphi_r\right]$$

$$i_{dsn} = \begin{cases} \frac{K_{\varphi r}}{\varepsilon_{\varphi r}}.S(\varphi_r) & \text{if} \quad |S(\varphi_r)| \prec \varepsilon_{\varphi r} \\ K_{\varphi r}.Sgn(S(\varphi_r)) & \text{if} \quad |S(\varphi_r)| \succ \varepsilon_{\varphi r} \end{cases}$$

The regulators control laws, for the control variables i_{ds1}, i_{ds2} and i_{qs1}, i_{qs2} of the internal loops are given by:

For the control variable i_{ds1} et i_{ds2}

$$S(i_{ds1}).S^{\cdot}(i_{ds1}) \prec 0 \Rightarrow v_{ds1} = v_{ds1eq} + v_{ds1n} \qquad (22)$$

With:

$$v_{ds1eq} = L_{s1}\dot{i}^*_{ds} + R_{s1}i_{ds1} - \omega_s\left[L_{s1}i_{qs1} + T_r\varphi_r\omega_{gl}\right]$$

$$v_{ds1n} = \begin{cases} \frac{K_{d1}}{\varepsilon_{d1}}.S(i_{ds1}) & \text{if} \quad |S(i_{ds1})| \prec \varepsilon_{d1} \\ K_{d1}.Sgn(S(i_{ds1})) & \text{if} \quad |S(i_{ds1})| \succ \varepsilon_{d1} \end{cases}$$

$$S(i_{ds2}).S^{\cdot}(i_{ds2}) \prec 0 \Rightarrow v_{ds2} = v_{ds2eq} + v_{ds2n} \qquad (23)$$

With:

$$v_{ds2eq} = L_{s2}\dot{i}^*_{ds} + R_{s2}i_{ds2} - \omega_s\left[L_{s2}i_{qs2} + T_r\varphi_r\omega_{gl}\right]$$

$$v_{ds2n} = \begin{cases} \frac{K_{d2}}{\varepsilon_{d2}}.S(i_{ds2}) & \text{if} \quad |S(i_{ds2})| \prec \varepsilon_{d2} \\ K_{d2}.Sgn(S(i_{ds2})) & \text{if} \quad |S(i_{ds2})| \succ \varepsilon_{d2} \end{cases}$$

For the control variable i_{qs1} et i_{qs2}

$$S(i_{qs1}).S^{\cdot}(i_{qs1}) \prec 0 \Rightarrow v_{qs1} = v_{qs1eq} + v_{qs1n} \qquad (24)$$

With

$$v_{qs1eq} = L_{s1}\dot{i}^*_{qs} + R_{s1}i_{qs1} + \omega_s\left[L_{s1}i_{ds1} + \varphi_r\right]$$

$$v_{qs1n} = \begin{cases} \frac{K_{q1}}{\varepsilon_{q1}}.S(i_{qs1}) & \text{if} \quad |S(i_{qs1})| \prec \varepsilon_q \\ K_{q1}.Sgn(S(i_{qs1})) & \text{if} \quad |S(i_{qs1})| \succ \varepsilon_q \end{cases}$$

$$S(i_{qs2}).S^{\cdot}(i_{qs2}) \prec 0 \Rightarrow v_{qs2} = v_{qs2eq} + v_{qs2n} \qquad (25)$$

With:

$$v_{qs2eq} = L_{s1}\dot{i}^*_{qs} + R_{s2}i_{qs2} + \omega_s\left[L_{s2}i_{ds2} + \varphi_r\right]$$

$$v_{qs1n} = \begin{cases} \frac{K_q}{\varepsilon_q}.S(i_{qs}) & \text{if} \quad |S(i_{qs})| \prec \varepsilon_q \\ K_q.Sgn(S(i_{qs})) & \text{if} \quad |S(i_{qs})| \succ \varepsilon_q \end{cases}$$

- For estimated speed sliding mode surface

The sliding surface of the estimated speed is:

$$s(\varepsilon) = \varepsilon + M\int \varepsilon.dt \qquad (26)$$

Where $M \succ 0$ and $\varepsilon = \hat{\varphi}_{r\alpha-i}\,\hat{\varphi}_{r\beta-v} - \hat{\varphi}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i}$

The derivative of $s(\varepsilon)$ gives :

$$s(\varepsilon) = \dot{\varepsilon} + M\varepsilon \qquad (27)$$

Where :

$$\dot{\varepsilon} = \dot{\hat{\varphi}}_{r\alpha-i}\,\hat{\varphi}_{r\beta-v} + \hat{\varphi}_{r\alpha-i}\,\dot{\hat{\varphi}}_{r\beta-v} - \dot{\hat{\varphi}}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i} - \hat{\varphi}_{r\alpha-v}\,\dot{\hat{\varphi}}_{r\beta-i} \qquad (28)$$

the substituting of the adaptive model equation (12) into (28):

$$\begin{aligned}\dot{\varepsilon} &= \hat{\varphi}_{r\alpha-i}\,\dot{\hat{\varphi}}_{r\beta-v} - \dot{\hat{\varphi}}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i} \\ &+ \frac{L_m}{T_r}\left[(i_{s\alpha1}+i_{s\alpha2})\hat{\varphi}_{r\beta-v} - (i_{s\beta1}+i_{s\beta2})\hat{\varphi}_{r\alpha-v}\right] \\ &- \frac{1}{T_r}\left[\hat{\varphi}_{r\alpha-i}\,\hat{\varphi}_{r\beta-v} + \hat{\varphi}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i})\right] \\ &- \hat{\omega}_m\left[\hat{\varphi}_{r\beta-i}\,\hat{\varphi}_{r\beta-v} + \hat{\varphi}_{r\alpha-i}\,\hat{\varphi}_{r\alpha-v})\right]\end{aligned} \tag{29}$$

By letting:

$$\begin{aligned}\chi_1 &= \hat{\varphi}_{r\alpha-i}\,\dot{\hat{\varphi}}_{r\beta-v} - \dot{\hat{\varphi}}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i} \\ &+ \frac{L_m}{T_r}\left[(i_{s\alpha1}+i_{s\alpha2})\hat{\varphi}_{r\beta-v} - (i_{s\beta1}+i_{s\beta2})\hat{\varphi}_{r\alpha-v}\right] \\ &- \frac{1}{T_r}\left[\hat{\varphi}_{r\alpha-i}\,\hat{\varphi}_{r\beta-v} + \hat{\varphi}_{r\alpha-v}\,\hat{\varphi}_{r\beta-i})\right]\end{aligned} \tag{30}$$

$$\chi_2 = \hat{\varphi}_{r\beta-i}\,\hat{\varphi}_{r\beta-v} + \hat{\varphi}_{r\alpha-i}\,\hat{\varphi}_{r\alpha-v} \tag{31}$$

Equation (27) and (29)can be written as :

$$\dot{\varepsilon} = \chi_1 - \hat{\omega}_m\,\chi_2 \tag{32}$$

And

$$\dot{S}(\varepsilon) = \chi_1 - \hat{\omega}_m\,\chi_2 + M\varepsilon \tag{33}$$

By replacing $\hat{\omega}_m$ with equivalent and attractive control $\hat{\omega}_m = \hat{\omega}_{m-eq} + \hat{\omega}_{m-n}$ in aquation (33), we find :

$$\dot{S}(\varepsilon) = \chi_1 - \hat{\omega}_{m-eq}\chi_2 - \hat{\omega}_{m-n}\,\chi_2 + M\varepsilon \tag{34}$$

During sliding mode and in the established regime, we have $S(\varepsilon)=0$ and therefore $\dot{S}(\varepsilon)=0$ and $\hat{\omega}_{m-n}=0$ hence :

$$\hat{\omega}_{m-eq} = \frac{\chi_1 + M\varepsilon}{\chi_2} \tag{35}$$

During the convergence mode, the Lyapunov condition (17) must be checked. By replacing (35) into (34) we obtain:

$$\dot{S}(\varepsilon) = \hat{\omega}_{m-n}\,\chi_2 \tag{36}$$

We take for the attractive control :

$$\hat{\omega}_{m-n} = k_\varepsilon\,\frac{S(\varepsilon)}{|S(\varepsilon)| + \xi_\varepsilon} \tag{37}$$

The block diagram of the sliding mode MRAS estimator is shown in Fig.4:

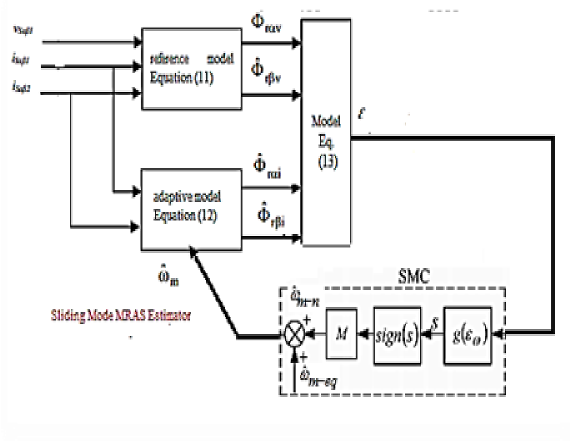

Fig. 4. Block diagram of the sliding mode MRAS technique applied to the DSIM.

To test the sliding system, give good results, and eliminate the problem of finding its parameters, we have added one metaheuristics methods genetic algorithm. And we will explain it in the results obtained.

VI. CONTROLLER OPTIMIZATION

For optimization of K and ξ in sign function SMC MRAS via genetic algorithm Matlab/Simulink model based on fig.1.

A) *GA Optimization of SMC Controller*

Genetic algorithms are powerful general purpose stochastic optimization methods which have been inspired by the Darwinian evolution of a population subject to reproduction, crossover the mutations in a selective environment where the fitness survive. GA combines the artificial survival of the fitness with genetic operators abstracted from nature to form a very robust mechanism that is suitable for a variety of optimization problems. In mathematical terms the goal of genetic algorithm is to minimize an objection function $F(S_k)$, where S_k is the search candidate (optimal solution), which is kth individual in the population S (where the population is set of possible solutions). The individuals of the population are expressed in a binary string form and the GA then manipulates these strings by using genetic operators (reproduction, crossover, mutation) to obtain improved solutions (where the fittest individual survive), until the optimal solution is obtained [21]. It is one of advantages of a GA that is uses stochastic operators instead of deterministic rules to search for a solution. Furthermore, a GA consider many points in the search space simultaneously, not a single point, thus it has a reduced chance of converging to local minimum, in which other algorithms may end up. In order to optimize K and ξ gains SMC of the adaptive mechanism via the Genetic algorithms, the fitness function defined as the difference between measured speed and estimated speed is selected as:

$$e = \frac{1}{n}\sum(w_r - \hat{w}_r) \tag{38}$$

where e is error value, n is number of data, w_r is the rotor speed (Rad/s) and $\hat{w}_r$ is the estimated speed (Rad/s).

The optimization was taken out in 20 generations with size of population of 20 individuals. GA parameters are given in Table 1.

Table 1. GA parameters for SMC controller Optimization.

Generation	20
Population	20
Crossover Fraction	0.8
Mutation Function	Gaussian

VII. SIMULATION RESULTS

The parameters of the simulated system are presented in the appendix A. Simulation tests were carried out to compare the system of DSIM with PI, SMC, SMC_GA. Using an Sliding mode control of dual star induction motor. The tests were performed in both open loop and sensorless modes of operation. Selected simulation results from these tests are shown in the following sections.

Table 2. Parameters of PI, SMC and The best solution obtained by GA .

PI Controller	**Kp_{wr}**	**ki_{wr}**	**Kp**	**Ki**	**$Kp_{w\text{-}est}$**	**$Ki_{w\text{-}est}$**						
	0.78	**3.13**	**110**	**1420**	**0.56**	**1420**						
SMC Controller Gains	**K_{wr}**	**ξ_{wr}**	**$K_{\phi r}$**	**$\xi_{\phi r}$**	**K_{d1}**	**ξ_{d1}**	**K_{q1}**	**ξ_{q1}**	**K_{d2}**	**ξ_{d2}**	**K_{q2}**	**ξ_{q2}**
	100	**0.4**	**120**	**0.01**	**1500**	**0.12**	**1000**	**0.18**	**1500**	**0.12**	**1000**	**0.18**
SMC-GA	**250.84**	**0.623**	**271.9**	**0.142**	**1105.7**	**0.95**	**2706.28**	**0.32**	**4372.03**	**0.47**	**4895.45**	**0.51**

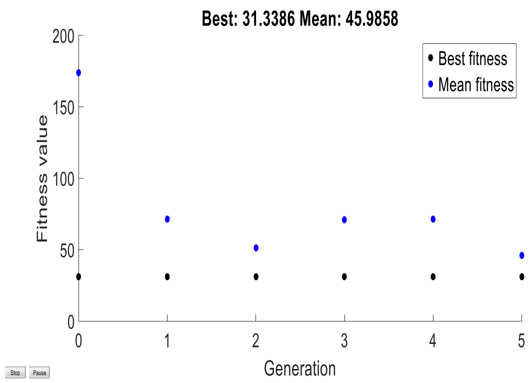

Fig. 5. Best fitness and mean fitness of Genetic Algorithm (GA).

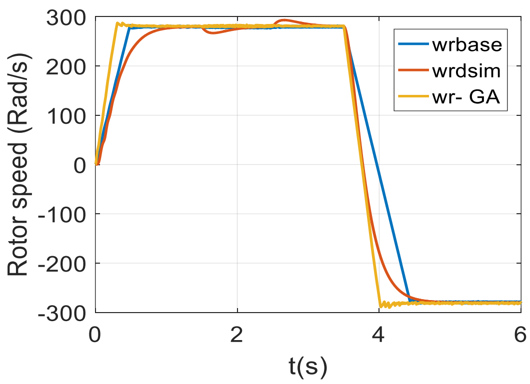

Fig. 6. Representation of estimated speed of DSIM

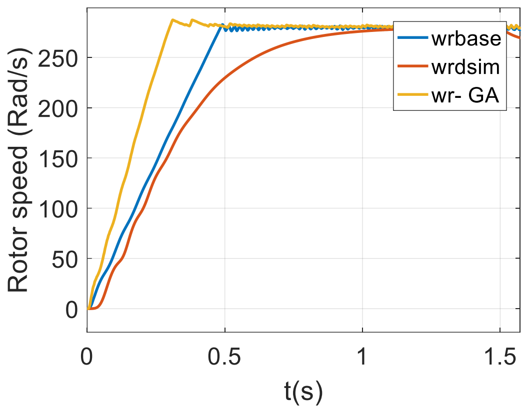

Fig. 7. Zoom of the first positive part.

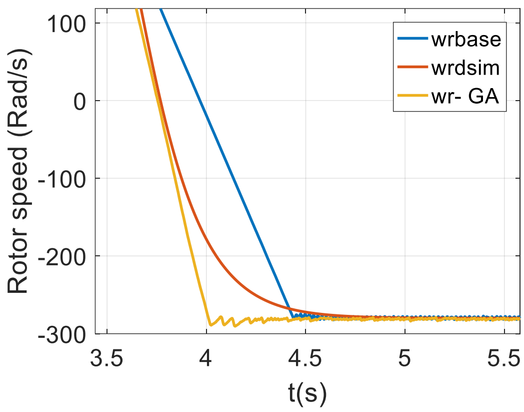

Fig. 8. Representation of estimated speed of DSIM without parametric variation.

Figure 5 shows the best fitness value of genetic algorithm versus iteration. SMC+GA scheme show better transient response compared to the PI scheme, which is due to an optimal speed tuning signal during transients as shown in Figs.6. According to the figs 7-8 which show the zoom of the system's responses in the intervals [0 - 1] and [3.8 - 4.8] The controllers SMC-GA is the faster and more robust when compared with SMC without optimizer, means that the parameters optimizer helps to raise engine efficiency.

VIII. CONCLUSION

In the present paper, a comparative performance study between differents control strategies applied to DSIM. The first strategy is derived from The adaptation law is classically given by a PI controller, and the second one is sliding mode MRAS estimator.

The motor speed is estimated based on the flux rotor model reference adaptive method. Due to the large number of high-order harmonics and noise in the voltage model and the existence of the speed fluctuation problem in the traditional vector control system, the speed estimation accuracy and system dynamic performance are seriously affected. By the introduction of PI controllers, and according to Lyapunov's stability theorem, SMC controllers are designed to replace the PI regulator of sensorless speed system. In order to obtain the optimal value of the speed estimation, we did optimizing the SMC controllers using GA.

The obtained simulation results have been very useful and helpful in illustrating the merits of each method especially SMC with the optimizer GA, and speed estimation accuracy and dynamic performance are obviously improve.

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