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RST CONTROL OF DOUBLY FED INDUCTION GENERATOR WITH VARIABLE SPEED WECS

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***Abstract*—In this paper, a new approach to optimize both the power converter performance and the control process of wind energy conversion system using a doubly fed induction generator (DFIG) has been proposed. A RST polynomial Technique control is applied to active and reactive powers. In addition, the control pitch is used to maximize the extracted power point (*MPPT*). In addition, the proposed approach a great improvement the efficiency and robustness results.**

***Index Terms*: Control RST– doubly-fed induction machine – MPPT – Variable speed wind turbine, wecs.**

I INTRODUCTION

Energy is an essential element of civilized societies. Which you need all sectors of society and the urgent need for the conduct of "everyday life", because they are used to operate the plant and move the different means of transport and the operation of appliances and other purposes. Every movement made by the human need and type of consumption of energy derived human capacity to fulfill its manual and intellectual dietary diverse every day because they are burning food in the cells of the body and converted into energy. Energy can be defined as the ability to obtain a significant effect (filled). They are present on several types, including wind power, energy and water flow. Energy can be stored in the traditional material such as fuel (oil, coal, gas).Today the wind energy is up to the task of producing serious amounts of electricity, the turbines vary in size from small 1 kW structures to large machines rated at 1.6 MW.

Wind energy is a prominent area of application of variable speed generators operating on the constant grid frequency [1].

In this paper the performance of doubly fed induction generator (DFIG) with variable speed wind turbine is studied. The conception of the DFIG allows controlling the power exchanged between the stator and the grid by modifying rotor voltages via a bidirectional converter. To achieve this, a vector control of the generator is done with active and reactive stator powers as control variables. The control RST based on the poles placement theory and Linear Quadratic Gaussian based on the minimization of a quadratic criterion is applied. The performances of the system figure (1) are analyzed and compared in terms of reference tracking, robustness, and disturbances rejection.

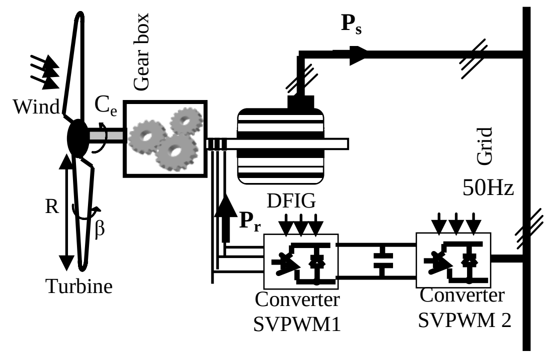


Fig. 1 Wind turbine system with DFIG

II MODELING METHODOLOGY

2.2. Wind Turbine Model

The wind turbine is modeled in terms of optimal tracking, to provide maximum energy capture from the wind.

The aerodynamic model of the wind turbine gives a coupling between the wind speed and the mechanical torque produced by the wind turbine. The mechanical power P_t produced by the wind turbine rotor can be defined as [4]:

$$P_t = C_p . P_V \tag{1}$$

$$\begin{cases} P_v = \dfrac{\rho . S . v^3}{2} \\ P_t = C_p(\lambda, \beta) . \dfrac{\rho . S . v^3}{2} \end{cases} \tag{2}$$

where P_t (W) -the aerodynamic power, P_v (W) - wind power available in the rotor swept area; ρ (kg/m^3)- the air density, S (m[2]) -the rotor disk area, R (m) -the rotor radius, v (m/s) -the wind speed, and Cp -the power coefficient which is a function of the tip speed ratio λ (ratio between blade tip speed and wind speed) and β the pitch angle of rotor blades, The power coefficient is defined by[5].

$$C_p = 0.5 - 0.00167.(\beta - 2).\sin\left[\frac{\pi.(\lambda + 0.1)}{18.5 - 0.3.(\beta - 2)}\right] - 0.00184.(\lambda - 3).(\beta - 2) \quad (3)$$

The maximum value of C_p ($C_{p\max} = 0.4744$) is fixed for $\beta = 2°$ and $\lambda_{opt} = 8.516$ is illustrated in figure (2) .

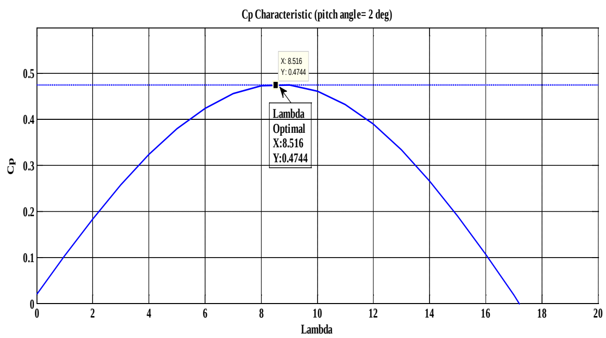


Fig.2. characteristic $Cp = (\lambda_{opt})$

The model of the wind form is illustrated in figure (3).
The input wind speed will be modelled, as [3]:

$$v(t) = \sum_{i=1}^{N} A_i * \cos(w_i * t + \varphi_i) \quad (4)$$

With $\omega_0 = 0, \varphi_0 = 0$ and $A_0 = 0, N = 55$, and the output is the torque applied to the generator shaft. If the optimal relationship between turbine speed and wind speed can be maintained for varying wind speeds, then maximum power capture from the wind can be guaranteed [4]:

$$\Omega_t = \frac{\lambda_{opt}}{R} v \quad (5)$$

The torque at the shaft neglecting losses in the drive-train is given by:

$$T_t = \frac{P_t}{\Omega_t} = \frac{R.P_t}{\lambda.v} = \frac{1}{2}\frac{C_p}{\lambda}\rho\pi R_t^3 v^2 \quad (6)$$

$$\text{and} \quad C_t = \frac{C_p}{\lambda} \quad (7)$$

For our model we'll assume the stiffness and damping are neglected, and then the dynamic equations of the drive-train can be obtained with a model to a mass in this case described by:

$$T_{em} - T_{tr}^{'} = J_{ech}\frac{d\Omega}{dt} \quad (8)$$

the equivalent moment of inertia is:

$$J_{ech} = J_g + \frac{J_{tr}}{G^2} \quad (9)$$

and the equivalent wind turbine torque is given by:

$$T_{tr}^{'} = \frac{T_{tr}}{G^2} \quad (10)$$

Where: G is the gear ratio between the turbine and the generator.

$$G = \frac{\Omega_t}{\Omega_g} \quad (11)$$

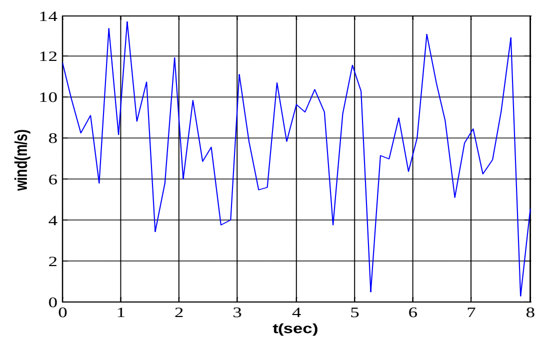


Fig.3. Wind turbine speed

2.3. *Doubly-Fed Induction generator*

A doubly fed induction generator is presented by three phase windings stator and rotor.
The stator is connected directly to the grid while the rotor is connected to the main grid by self-commutated AC/DC converters allowing controlling the slip ring voltage of the induction machine in terms of magnitude and phase angle.
The equivalent circuit of the doubly-fed induction generator, with inclusion of the magnetizing losses, is shown in Figure. (4).

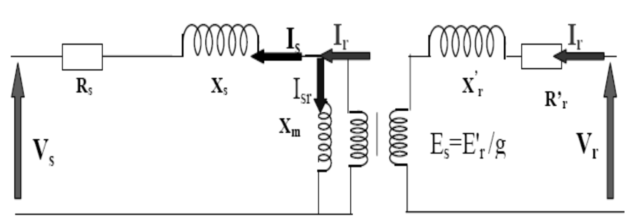


Fig.4. Equivalent Circuit of DFIG

The differential equations of the stator and rotor voltage are presented by [6]:

$$\begin{cases} \overline{V}_s = -R_s\overline{I}_s + \dfrac{d\overline{\psi}_s}{dt} + j\omega_s\overline{\psi}_s \\ \overline{V}_r = -R_r\overline{I}_r + \dfrac{d\overline{\psi}_r}{dt} + j(\omega_s - \omega_m)\overline{\psi}_r \end{cases} \quad (12)$$

The algebraic equations of the flux-linkage are:

$$\begin{cases} \overline{\psi}_s = -L_s\overline{I}_s + M_{sr}.\overline{I}_r \\ \overline{\psi}_r = L_r\overline{I}_r - M_{sr}.\overline{I}_s \end{cases} \quad (13)$$

A d-q reference frame is chosen to model the doubly-fed induction generator [**6**]:

$$\begin{cases} V_{ds} = -R_s I_{ds} + \dfrac{d\psi_{ds}}{dt} - \omega_s\psi_{qs} \\ V_{qs} = -R_s I_{qs} + \dfrac{d\psi_{qs}}{dt} + \omega_s\psi_{ds} \\ V_{dr} = -R_r I_{dr} + \dfrac{d\psi_{dr}}{dt} - (\omega_s - \omega_m)\psi_{qr} \\ V_{qr} = -R_r I_{qr} + \dfrac{d\psi_{qr}}{dt} + (\omega_s - \omega_m)\psi_{dr} \end{cases} \quad (14)$$

Moreover, the equation of the electromagnetic torque can be expressed according to the current stator and rotor flux as follows:

$$T_{em} = \frac{3}{2}p(\psi_{ds}I_{qs} - \psi_{qs}I_{ds}) \quad (15)$$

Where :

$$\omega_m = \int(\theta_s + \theta_r).dt \text{ and } \omega_m = p.\Omega \quad (16)$$

The active and reactive power is described by:

$$\begin{cases} P_s = V_{ds}.i_{ds} + V_{qs}.i_{qs} \\ Q_s = V_{qs}.i_{ds} - V_{ds}.i_{qs} \end{cases} \quad (17)$$

2.4. Control of the DFIG

The principle control of DFIG consists of the orientation of the flux stator, where $\overline{\psi}_s$ is almost constant, because the stator voltages are constant in amplitude, frequency, and phase [7]:

$$\begin{cases} \overline{\psi}_s = \psi_s = \psi_d ; \psi_q = 0 \\ \dfrac{d\psi_q}{dt} = 0 \end{cases} \quad (18)$$

The equation 18 clearly shows that under stator flux orientation (vector) control, the active power delivered (or absorbed) by the stator, *Ps*, may be controlled through the rotor current *Iqr*, while the reactive power (at least for constant $\psi_s = \psi_d$) may be controlled through the rotor current *Idr*.

Both powers depend heavily on stator flux $\overline{\psi}_s$ and frequency ω_s (that is on stator voltage). This constitutes the basis for vector control of *Ps* and *Qs* by controlling the rotor currents *Idr* and *Iqr* in d-q axis.

The current control operates in AC –voltage oriented reference frame. It contains two current control loops: direct (active-power) and quadrature (reactive-power) axis current components (*Ids* and *Iqs*) .The reference of the direct axis current component (Ids_{-ref}) is set by DC-voltage control. The reference of the quadrature axis current component (Iqs_{-ref}) is kept constant (reactive power).

$$\begin{cases} \dfrac{d\Phi_{ds}}{dt} = V_{ds} + R_s.i_{ds} \\ V_{qs} = -R_s.i_{qs} + \Phi_{ds}.\omega_s \end{cases} \quad (19)$$

$$\begin{cases} \dfrac{d\Phi_{dr}}{dt} = V_{dr} + R_r.i_{dr} + \Phi_{qr}.\omega_r \\ \dfrac{d\Phi_{qr}}{dt} = V_{qr} + R_r.i_{qr} - \Phi_{dr}.\omega_r \end{cases} \quad (20)$$

$$\begin{cases} i_{qs} = -\dfrac{M}{L_s}.i_{qr} \\ i_{ds} = \dfrac{-\Phi_{ds} - M.i_{dr}}{L_s} \end{cases} \quad (21)$$

$$\begin{cases} \sigma = 1 - \dfrac{M^2}{L_r.L_s} \\ T_s = \dfrac{L_s}{R_s} \end{cases} \quad (22)$$

$$\begin{cases} \dfrac{di_{dr}}{dt} = \dfrac{1}{L_r.\sigma}.(-V_{dr} - R_r.i_{dr} + L_r.\sigma.\omega_r.i_{qr} + \dfrac{M}{L_s}.\dfrac{d\Phi_s}{dt}) \\ \dfrac{di_{qr}}{dt} = \dfrac{1}{L_r.\sigma}.(-V_{qr} - R_r.i_{qr} - L_r.\sigma.\omega_r.i_{dr} + \dfrac{M}{L_s}.\omega_r.\Phi_s) \end{cases} \quad (23)$$

$$\begin{cases} e_d = -L_r.\sigma.\omega_r.i_{qr} - \dfrac{M}{L_s}.\dfrac{d\Phi_s}{dt} \\ e_q = L_r.\sigma.\omega_r.i_{dr} \\ e_\Phi = -\dfrac{M}{L_s}.\omega_r \Phi_s \end{cases} \quad (24)$$

$$\begin{cases} P_s = -V_{qs}.\dfrac{M}{L_s}.i_{qr} \\ Q_s = -V_{qs}\dfrac{\Phi_{ds}}{L_s} - \dfrac{M}{L_s}.V_{qs}.i_{dr} \end{cases} \quad (25)$$

III RST Controller Principle

The RST controller representation is extremely useful for the PPC (Poles Placement Control) implementation due to its simple structure. This one is given by [2]:

$$S(q^{-1}).u(t) = T(q^{-1}).c(t) - R(q^{-1}).y(t) \quad (26)$$

The structured control signal introduced by the RST representation is done so that any controllers can be represented through the RST formalized schema, figure (5).

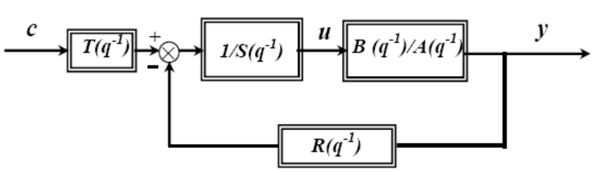


Fig. 5 The RST controller

The polynomials $R(q^{-1})$ and $S(q^{-1})$ are obtained by a pole-placement strategy and are solutions of the Bezout or Diophantine polynomial equation [**8**]:

$$A(q^{-1})S(q^{-1}) - B(q^{-1})R(q^{-1}) = P_D(q^{-1})P_F(q^{-1}) = P_T(q^{-1}) \quad (27)$$

Where $P_T(q^{-1})$ is the desired closed loop poles, this polynom is decomposed in two parts, one representing the desired dominant poles $P_D(q^{-1})$ and the other corresponding to the auxiliary poles $P_F(q^{-1})$ that are necessary to adjust the sensitivity function as described below. When $A(q^{-1})$, $B(q^{-1})$, $P_T(q^{-1})$ are known, the solution of equation (26) exists and is unique if:

$$\begin{cases} d^\circ(S) = d^\circ(R) + 1 \\ d^\circ(S) = d^\circ(A) + 1 \\ d^\circ(P_T) = 2\,d^\circ(A) + 1 \\ P_T = A.S + B.R \end{cases} \quad (28)$$

To obtain a good stability in steady-state, we must have $P_T(0) \neq 0$. The Bezout equation leads to four equations with four unknown terms where the coefficients of P_T are related to the coefficients of polynomials R and S by the Sylvester Matrix:

$$\begin{bmatrix} 1 & 0 & . & . & . & 0 & 0 & . & . & . & 0 \\ a_1 & 1 & . & . & 0 & . & 0 & . & . & 0 & . \\ . & . & . & . & . & . & b_1 & . & . & . & . \\ . & . & . & . & . & 0 & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . & . \\ a_n & . & . & . & . & 1 & . & . & . & . & 0 \\ 0 & . & . & . & . & a_1 & b_n & . & . & . & 0 \\ . & . & . & . & . & . & 0 & . & . & . & b_1 \\ . & . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . & . \\ 0 & 0 & . & . & . & a_n & . & 0 & . & . & . \\ 0 & . & . & . & . & 0 & 0 & . & . & 0 & b_n \end{bmatrix} . \begin{bmatrix} s_0 \\ s_1 \\ . \\ . \\ . \\ s_n \\ r_0 \\ . \\ . \\ . \\ . \\ r_n \end{bmatrix} = \begin{bmatrix} d_0 \\ d_1 \\ . \\ . \\ . \\ d_n \\ d_{n+1} \\ . \\ . \\ . \\ . \\ d_{2n+1} \end{bmatrix} \quad (29)$$

The parameters of RST regulators used to the rotor current, active and reactive powers and mechanic speed are shown in the table1.

W_m	P_s & Q_s	I_{dr} & I_{qr}
a_0= 1.0e-03	a_{pq0} = 0.0137	ai_0= 1.3e-03
a_1= 0.0024	a_{pq1} = 0.021	ai_1= 2.2e-02
b_1=1	b_{pq1}=3.7441e-04	bi_1=1
s_{w0} =1.0e-03	s_{pq0} =72.9862	si_0 =73.1391
s_{w1} =0.9	s_{pq1} =6.5576e-04	si_1 =6.47e-03
r_{w0} =2.5842e-05	r_{pq0} =-32.2752	ri_0 =2.46e-03
r_{w1} =24e-06	r_{pq1} =3.1465e-03	ri_1 == 24e-03
T_w =2.5842e-05	T_{pq} =-32.2752	Ti_0 =2.46e-03

Tab.1. Parameters of the RST controller

IV SIMULATION RESULTS

In our study, the performance of the doubly fed variable speed in wind system, the PWM applied to AC/DC converters and RST regulator applied to rotor speed, stator active and reactive powers and rotor current are illustrated.

PWM technique utilizes converter more efficiently and generates less harmonic distortion as shown in fig (6),(7), where THD_{pwm}=318.76% for voltage and THD_{pwm}=79.21% for current. The generator is now driven at 300 rd/s. At $t \in [1 \;\; 2]$ the Speed varies from 300 to 250 rd/s, is showing in fig (8).

The figure (9) show that the values of stator active power delivered to the grid, varies between 0 and 1.5 MW at $t \in [3 \;\; 7]$, and exchange of reactive power between the stator of DFIG and the grid 0 MVAR to -0.8 MVAR at $t \in [4 \;\; 6]$. The DC side voltage of PWM strategy applied to converter is controlled by the I_{dr}, I_{qr} currents as shown in figure (10), where $I_{dr\text{-}ref}$, $I_{qr\text{-}ref}$ are obtained by the control of active and reactive powers.

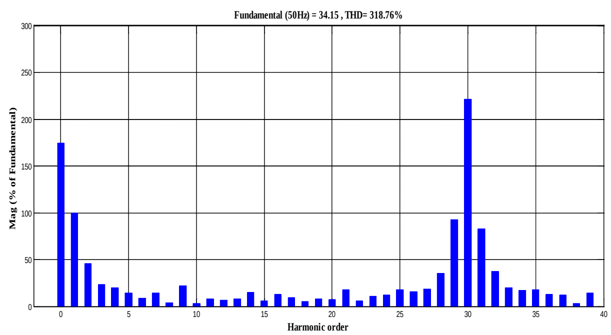


Fig.6 FFT of voltage converter

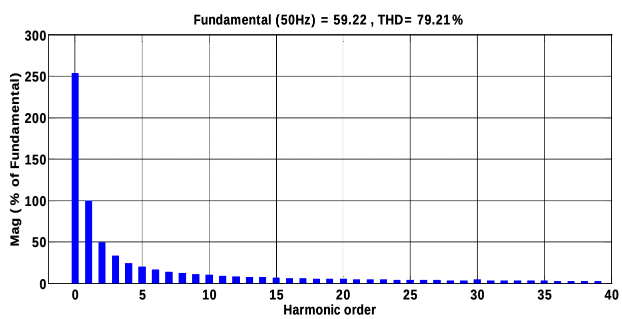


Fig.7 FFT of current converter

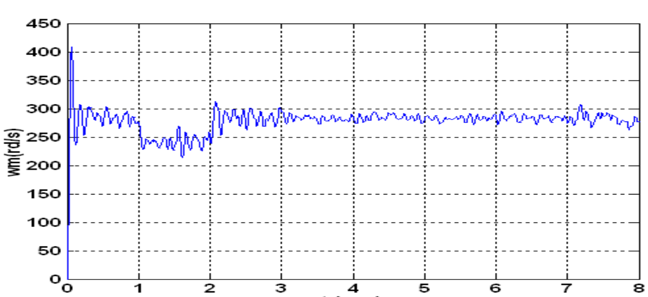
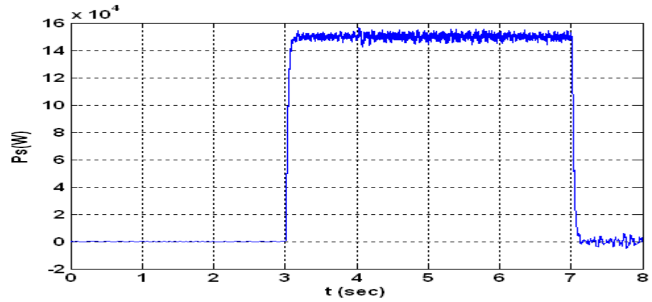
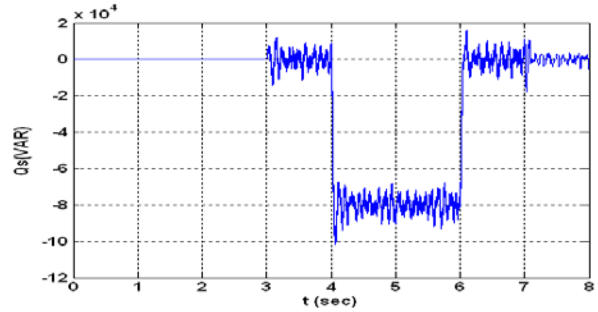


Fig.8 Generator speed

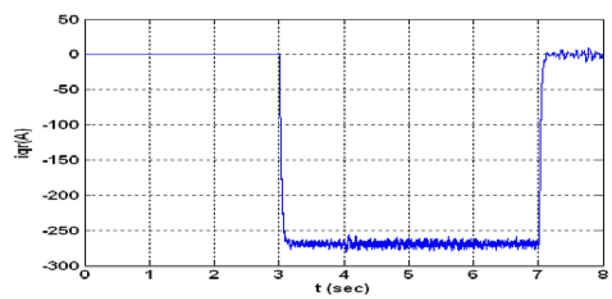


a) Active power

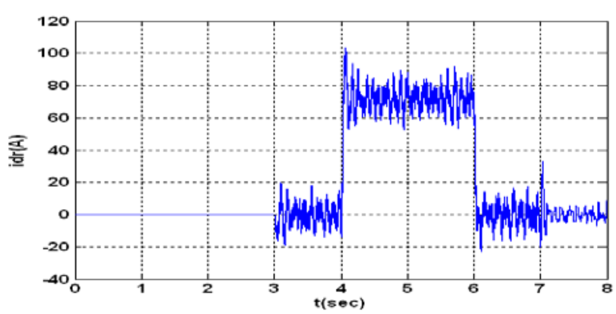


b) Reactive power

Fig.9 Active and Reactive power of the stator



a) Quadrature current of the rotor



b) Direct current of the rotor

Fig.10 Direct and Quadrature current of the rotor

V CONCLUSION

In this paper, a new approach based on coupled equation system including the aerodynamical, mechanical and electrical effects has been proposed to investigate the control mechanism of the extracted maximum power point (MPPT) in order to improve the wind turbine variable speed control performances. The stator field orientation technique has been used to control of the active and reactive powers in order to ensure decoupling between the both powers. This latter allows the full separation between both rotor currents. The proposed RST control provides provided an improvement a performance and efficiently.

VI APPENDIX

WIND TURBINE CHARACTERISTICS
Number of blades 3
R :Rotor diameter 35.25 m
ρ : Air density 1.22 kg/m^3
Rated power 1.5 MW
G: Mechanical speed multiplier 90
J_{tr}: Turbine total inertia 1000 kg m^{-2}

PARAMETERS OF DOUBLY FED INDUCTION GENERATOR
Rated power 1.5MW
Stator voltage 690 V
Rs = 0.0012 Ω, los = 20.372 mH, Rr = 0.021 Ω, lor = 17.507 mH, M = 0.0135 mH, p = 2, Ls=los+M,Lr=lor+M, f=0.0024.

VII REFERENCE

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