Markov chain modeling for reliability estimation of the Self-excited induction generator

Y.Naoui , H. Meglouli , S. Abudura

Abstract— A new approach to the prediction of the reliability of Self-excited induction generator is presented in this paper. In this approach, a reliability analysis based on the Markov chain is used to diagnose the parameters that influence on the quality of the produced electrical energy. For this, we have designed mathematical models to the vacuum self-excited induction generator and load. These models are simulated by the MATLAB software to determine the parameters that affect the voltage supplied by the generator .After allowing us to study the influence of failures of devices on the system operation, we perform an analysis of the Failure Modes and their Effects which is a method commonly used in the first step of a reliability study. Then a model of Markov chain of the installation is applied to the system for studying the reliability and determines the failure probability of the installation components.

Keywords—Asynchronous generator (AG), Failure Mode and Effects Analysis (FMEA), Markov Chain, Modeling, Reliability analysis, Self-excited induction generator .

NOMENCLATURE

Symbol	Definition	Unity
C	Capacity of the excitation capacitor bank	F
C_i	Rotation torque indicator of the diesel actuator	N. m
C_m	Mechanical torque loss in the asynchronous generator	N. m
C_r	Resistance torque of the asynchronous generator	N. m
C_{em}	Electromagnetic torque of the asynchronous generator	N. m
g	Slip	
I_{ld} , i_{lq}	Current of the load	A
i_m	Modulus of the generator magnetization current vector	A
i_{rd}, i_{rq}	Rotor current	A
J	Moment of inertia for all moving masses	Kg .m
L_f	Inductance of total losses	H
Lm	mutual inductances Stator and rotor windings	H
Ls, Lr	The proper inductances of Stator and rotor windings	H
r_s, r_r	The stator and rotor phase resistances	Ω
t	Time	s
u_{sd}, u_{sq}	Stator voltages	v
Uw	Crankshaft gear ratio of diesel to the axis of the fuel pump	
W	Rotational speed of the stator magnitudes self-excited induction generator	rad.s $^{-1}$
W_d	Rotational speed of the diesel actuator axis	rad.s $^{-1}$
Wh	Rotational speed of the fuel pump	rad.s $^{-1}$
W_r	Rotational speed of the rotor Self-excited induction generator	rad.s $^{-1}$
Z_c	Impedance of the condenser	Ω
Z_G	Equivalent impedance of the generator	Ω
Ψ_m	Modulus of the generator magnetization flux	Wb
ψ_{rd}, ψ_{rq}	Rotor flux	Wb
ψ_{sd}, ψ_{sq}	Stator flux	Wb

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I. INTRODUCTION

THE electrical energy needs of the industrialized countries continue to increase. Thus, in periods of normal growth, it is estimated that electricity consumption doubles every ten years [1], its needs are also increasing, especially in sites fixtures or in isolated sites, the energy transport to these places is very expensive. So it was necessary to launch projects to produce energy at these locations thanks to autonomous electrical installations (diesel, wind, solar ...) [2].

Thus, the electric energy development program in the future requires providing the energy installations with reliable equipment with better performance parameters from a technical and an economic point of view. Currently, asynchronous machines are considered as the most used electromechanical conversion tools in industry and power plants. This type of machine has long been strongly challenged by the synchronous machine in the fields of high power, until the advent of power electronics. Today found in many applications, particularly in transport (metro, trains, ship propulsion), industry (machine tools) and appliances. It was originally used only in engine, but always with the power electronics, it is increasingly being used as generators in power plants (hydro, wind, nuclear, diesel,)... [3].

The multiple uses of this in generator mode machine are justified by the following advantages [4]:

- The construction simplicities
- A Better mass factor and template.
- The low cost of purchase
- Its mechanical robustness

•Simpler and more practical construction technology in the industry, and the absence of contacts palaces.

• A wide range of dimensional types and a high reliability of operation

Moreover, their main disadvantages are at the level of consumption of reactive power that derives from the network because it does not create its own excitation energy. By contrast, in the case of autonomous operation in a remote site, it will bring him this energy by a capacitor bank connected in parallel to the stator winding to produce the required reactive power [5],[6]. The asynchronous machine used for power generation in an isolated site is considered as an interesting solution, prompting researchers in Electrical Engineering to conduct investigations in order to increase the efficiency and reliability of the electromechanical conversion of one hand, and to improve the quality of the energy supplied on the other hand [7].

So, reliability is a major issue to ensure optimal competitiveness of the production tool of energy because it is one of the most important parameters for the safety of operation. It is discussed every time we want to reliable systems available and safe. Indeed, the reliability is the availability and security of systems. The reliability is involved throughout the life cycle of the product or the system (design, manufacturing, operation).

Several approaches to modeling and reliability analysis are discussed in the literature. Some are quantitative and others are qualitative, some are static while others are dynamic, some are inductive, while others are deductive, some are predictable and others by contrast are experimental ... They are all dedicated to study a part or an aspect of the reliability [8].The Lack for the study and the modeling of the reliability in an integral and a dynamic way for complex systems such as production systems of electric power and especially the self- excited induction generators remains to be filled and has its place in academic research.

In this context, the present work describes the study and the modeling of the reliability by Markov chains method to the vacuum self-excited induction generator and loads, and does an analysis of the operating criteria of this generator to power a remote site into electricity.

II.DEVICE MODELING

The dynamic regime of the Self-excited induction generator is determined by the mutual influence of the physical processes that take place in the diesel actuator, the generators and the loads [9],[10].This is why the mathematical model of this regime takes into consideration the description of the autonomous subsystems (diesel actuator, asynchronous machine, the capacitor bank and load) and their characteristic relations as presented on Fig. 1.

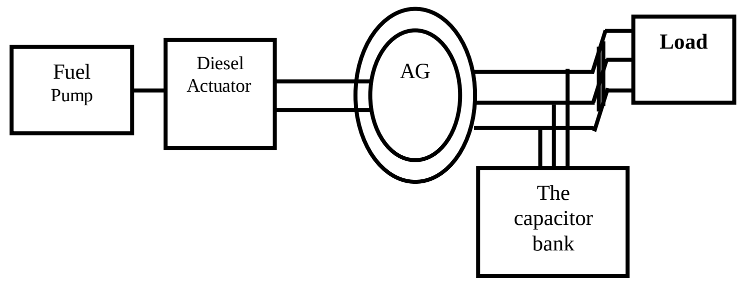

Fig. 1. Self-Excited Induction Generator Bloc Diagram.

A. Diesel Actuator Mathematical Model

The variation of the diesel actuator rotational speed is determined by the following equation:

$$\frac{dw_d}{dt} = \frac{1}{j\left(C_i - C_r.C_{em} - C_m\right)} \tag{1}$$

The link between the diesel actuator and the fuel pump is determined by the form shown in eq. (2) :

$$w_h = U_w.w_d \tag{2}$$

B. Mathematical model of the Self-excited induction generator

It is necessary to perform a conversion of the machine variables so as to get those of the primitive machine. This conversion implies the transformation of the original generator coils to an electrically and magnetically equivalent coil set in d and q axis. This transformation is a particular case of the park transformation [11] ,[12] ,[13].

$$\left.\begin{aligned} -u_{sd} &= \frac{d\psi_{sd}}{dt} + r_s.i_{sd} \\ -u_{sq} &= \frac{d\psi_{sq}}{dt} + r_s.i_{sq} \\ 0 &= \frac{d\psi_{rd}}{dt} + r_r.i_{rd} - w_r.\psi_{rq} \\ 0 &= \frac{d\psi_{rq}}{dt} + r_r.i_{rq} - wr.\psi_{rd} \end{aligned}\right\} \tag{3}$$

The hanging fluxes are related to the generator currents as follows:

$$\left.\begin{aligned} \psi_{sd} &= L_s.i_{sd} + L_m.i_{rd} \\ \psi_{sq} &= L_s.i_{sq} + L_m.i_{rq} \\ \psi_{rd} &= L_r.i_{rd} + L_m.i_{sd} \\ \psi_{rd} &= L_r.i_{rq} + L_m.i_{sq} \end{aligned}\right\} \quad (4)$$

C .Mathematical model of the excitation circuit

The voltages of the excitation capacitor can be represented by the system of differential eqs (5):

$$\begin{aligned} u_{sd} &= c\int i_{sd}dt + u_{sd0} \\ u_{sq} &= c\int i_{sq}dt + u_{sq0} \end{aligned} \quad (5)$$

Where $u_{sq} = u_{sq0}|t=0$ et $u_{sd} = u_{sd0}|t=0$: The initial voltages.
Differentiating both sides of the equation is obtained:

$$\left.\begin{aligned} \frac{du_{sd}}{dt} &= \frac{1}{C}.i_{sd} \\ \frac{du_{sq}}{dt} &= \frac{1}{C}.i_{sq} \end{aligned}\right\} \quad (6)$$

The electromagnetic torque of the asynchronous generators is determined by:

$$C_{em} = \frac{3}{2}.p.L_m(I_{rd}.I_{sq} - I_{rq}.I_{sd}) \quad (7)$$

The empty generator is driven by a diesel actuator and the necessary condition to create a voltage between its edges is the existence of a remaining field. In order to increase this relatively low voltage amplitude to its nominal value, enough reactive power by the capacitor bank magnetization should be supplied to the generator [14] shown in fig. 1.

D. Conditions of self-start up of the empty generator

The self-start up of the generators occurs when both the two following conditions are satisfied:
Total active power =0
Total reactive power =0
What means that the impedance equivalent to a stator phase of the machine is also null ?
$(Z_G \quad j = 0)$

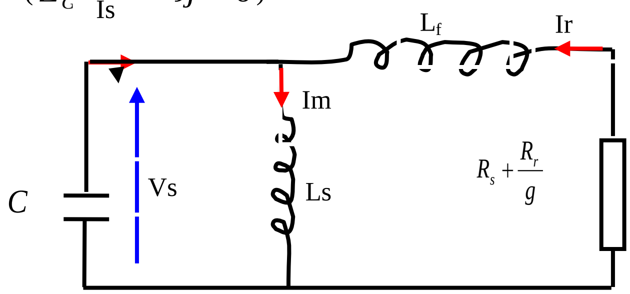

Fig. 2: Simplified equivalent diagram of one phase of the generator brought back to the stator

The diagram of fig. 2. is equivalent to a generator producing on Z_c impedance (as shown on fig. 3).

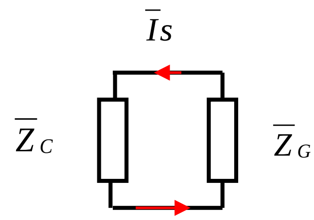

Fig. 3: Transformation of the equivalent diagram

We have:

(5)

$$\left(\frac{1}{\overline{\overline{Z}}_C} + \frac{1}{\overline{\overline{Z}}_G}\right).\overline{V}s = 0 \quad (8)$$

Where:

$$\frac{1}{Z_C} = j.C.w \quad (9)$$

Thus:

$$\frac{L_f.w}{\left(Rs + \frac{Rr}{g}\right)^2 + (L_f.w)^2} + \frac{1}{Ls.w} = C.w \quad (10)$$

The self-start-up of the generator cannot occur unless its produced apparent power corresponds to its absorbed one. For the reactive power part, the following equation should be satisfied (for g.=.g1.=.0).

$$\frac{1}{L_s.w} - C.w = 0 \quad (11)$$

This condition shows that the minimal value leading up to the self-start-up is function of the cyclic stator inductance as well as the rotor pulsation and the sliding thereof [15]. The asynchronous generator does not receive any reactive energy except the one coming from the C capacity [16].

E. Simulation result

To simulate the self-priming vacuum should be resolved voltage equation system taking into account the voltage across the capacitor, the equation system will be written:

$$\left.\begin{aligned} -u_{sd} &= L_s.\frac{di_{sd}}{dt} + L_m.\frac{di_{rd}}{dt} + r_s.i_{sd} \\ -u_{sq} &= L_s.\frac{di_{sq}}{dt} + L_m.\frac{di_{rq}}{dt} + r_s.i_{sq} \\ 0 &= L_r.\frac{di_{rd}}{dt} + L_m.\frac{di_{sd}}{dt} + r_r.i_{rd} - w_r.(L_r.i_{rq} + L_m.i_{sq}) \\ 0 &= L_r.\frac{di_{rq}}{dt} + L_m.\frac{di_{sq}}{dt} + r_r.i_{rq} - wr.(L_r.i_{rd} + L_m.i_{sd}) \end{aligned}\right\} \quad (12)$$

Formed into equation of state: $X' = A.Y$

Using the matrix notation, the eq. (12) can be expressed in the form: $[X'] = [A].[Y]$

$$\left.\begin{aligned}
&L_s.X_1' + L_m.X_3' = -r_s.X_1 - X_5 \\
&L_s.X_2' + L_m.X_4' = -r_s.X_2 - X_6 \\
&L_r.X_3' + L_m.X_1' = -r_s.X_3 - w_r.(L_r.X_4 + L_m.X_2) \\
&L_r.X_4' + L_m.X_2' = -r_s.X_4 - w_r.(L_r.X_3 + L_m.X_1) \\
&X_5' = \frac{1}{C}.X_1 \\
&X_6' = \frac{1}{C}.X_2
\end{aligned}\right\} \quad (13)$$

Where:

$$[X] = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \end{bmatrix} = \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \\ u_{sd} \\ u_{sq} \end{bmatrix} ; \quad [L] = \begin{bmatrix} L_s & 0 & L_m & 0 & 0 & 0 \\ 0 & L_s & 0 & L_m & 0 & 0 \\ L_m & 0 & L_r & 0 & 0 & 0 \\ 0 & L_m & 0 & L_r & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

[L]: inductance matrix

$$[Y] = \begin{bmatrix} -r_s.X_1 - X_5 \\ -r_s.X_2 - X_6 \\ -r_s.X_3 - w_r.(L_r.X_4 + L_m.X_2) \\ -r_s.X_4 - w_r.(L_r.X_3 + L_m.X_1) \\ \frac{1}{C}.X_1 \\ \frac{1}{C}.X_2 \end{bmatrix}$$

Where: $[A] = [L]^{-1}$

Finally for simulation, simply insert the models of the AAG, diesel actuator and the capacitor bank and implanting under the Matlab / Simulink environment.

The simulation block diagram is shown in Fig.4.

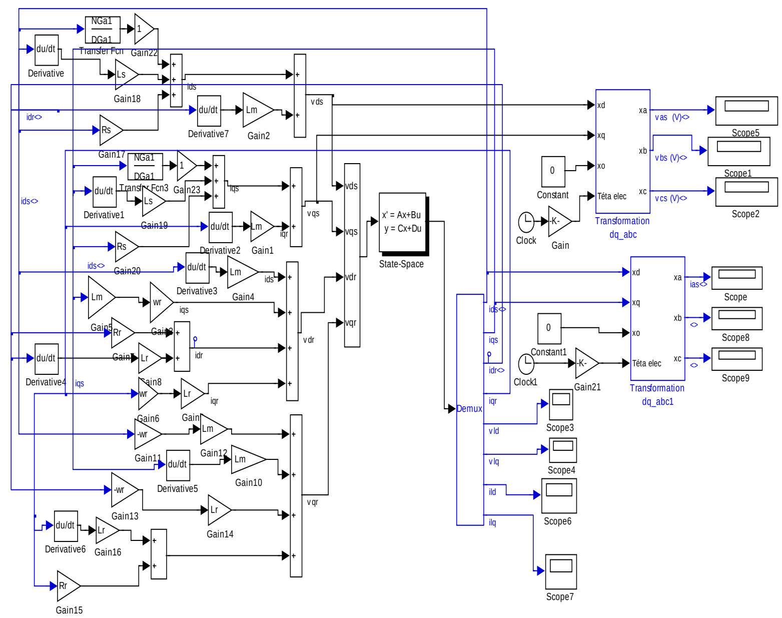

Fig.4: Simulation block diagram

The simulation model allowed us to obtain the results of self-priming vacuum:

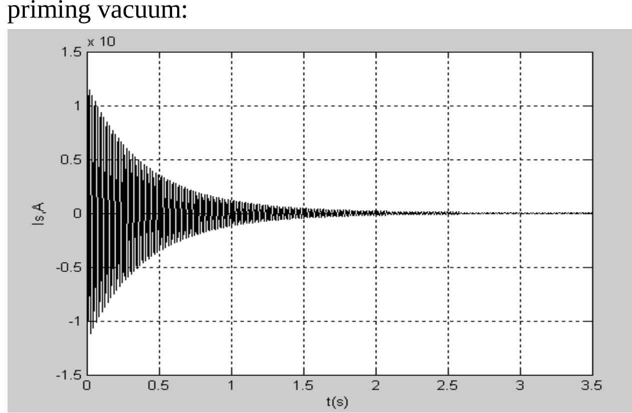

Fig. 5: The current generator with C < Cmi

If the capacitor value is C < Cmin , the current of generator Figure (5) lowers to be canceled , so the self-priming is not possible .

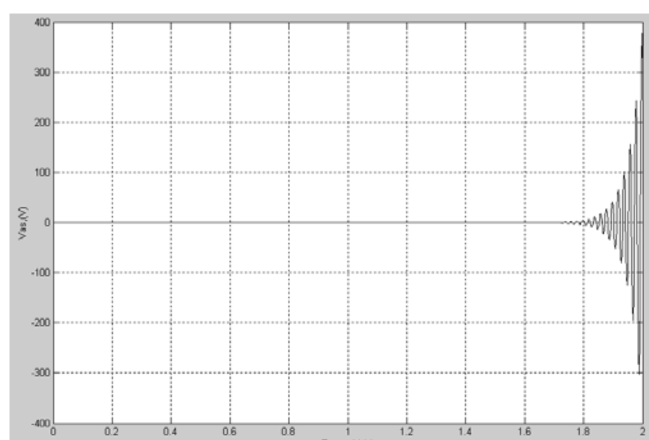

Fig. 6: Voltage of the self startup of an empty generator

It can be noticed on this figure that the induced tension increases indefinitely, in an exponential way, due to the non saturation of the magnetic circuit of the machine

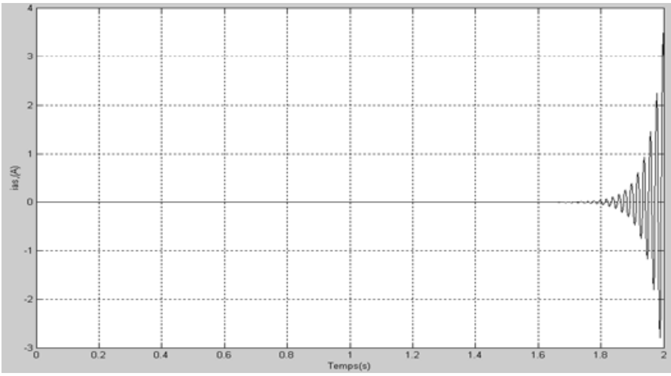

Fig.7: Stator induced current of the empty generator

The induced stator current reaches, in few seconds, a value that exceeds by several times the nominal value, what is very far from the reality.

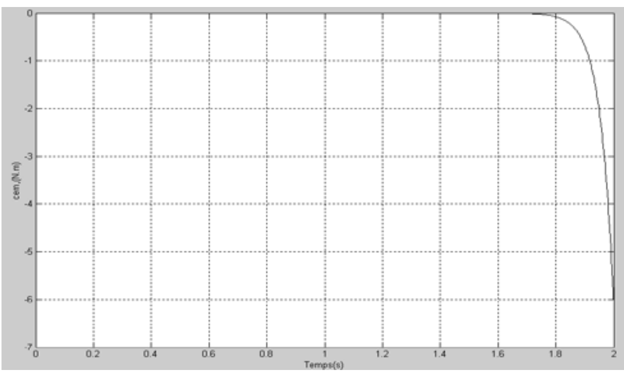

Fig. 8: Electromagnetic torque of the empty generator

When the generator starts itself, its electromagnetic torque rises indefinitely which will increase the active power.

F. Consideration of the magnetic saturation phenomenon

In saturation regime, the fluxes and the currents are no longer proportional. The magnetization characteristic is composed in addition to the linear part, of a part of bend and another called of saturation. This last one will limit the generator magnitudes [17].

$$L_m = \frac{\left|\overline{\psi_m}\right|}{i_m}$$

Expression of the magnetizing current based on stator current and rotor is given by:

$$i_m = \sqrt{\left(i_{sd} + i_{rd}\right)^2 + \left(i_{sq} + i_{rq}\right)^2} \qquad (14)$$

To take account of the saturation magnetic circuit of the machine, it is necessary to model the magnetization curve Fig. 9.

Several spline interpolation functions are used [18], however, there is no function that covers all points of the curve, and modeling remains approximate with minimal error.

For our raised magnetic characteristic, we adopt the approximation of the iron magnetization curve fig.9, by the LANGEVIN function $\left(L(x) = coth(x) - \frac{1}{x}\right)$. [19], [20].

The calculation of the asynchronous machine main magnetic circuit saturation is performed using the LANGEVIN function as an approximation of the iron magnetization curve.

$$L_m = \frac{1}{a.i_m}\left[\frac{1}{\coth(b.i_m)} - \frac{1}{b.i_m}\right] \qquad (15)$$

Which value is obtained by the magnetization graph of the generator free regime test shown in fig. 9.

a, b: Coefficient calculating the approximation obtained by the magnetization curve ,fig.9.

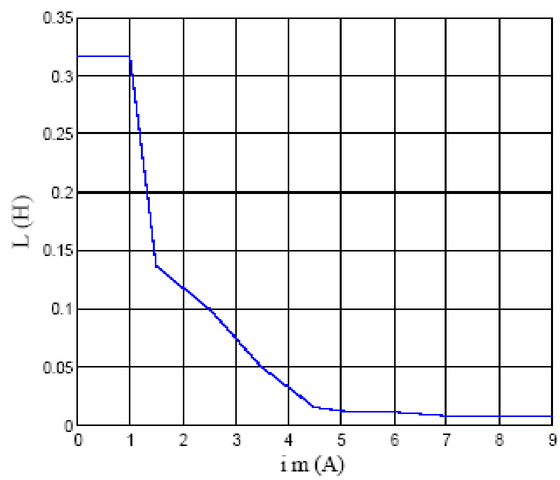

Fig. 9: Variation of the magnetization inductance Lm according to Im

By resolving the equation system (12), and taking in consideration the eq. (15), the saturation of the machine, with a self-start-up voltage, will be obtained as presented on fig.10.

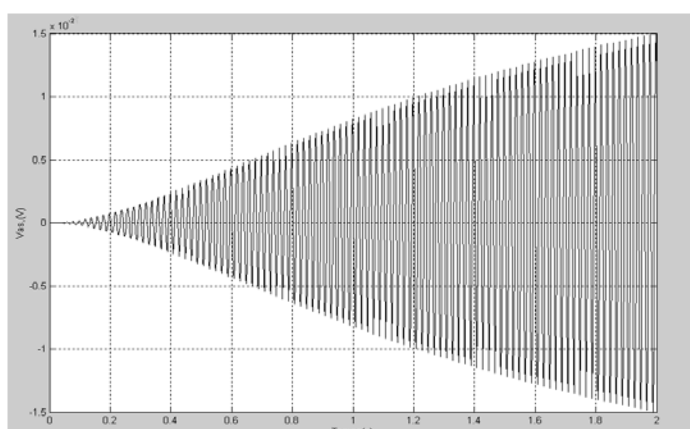

Fig. 10: Self-start-up voltage of the generator at void in saturation regime

At the beginning of the start-up, the voltage increases in a way identical to the linear case, then converges toward a value that depends on the choice of the condenser and speed values.

G. Mathematical model of the Self-excited induction generator supplying an R-L load

This model is obtained by adding to the equations system (6) the following load equations:

$$\left.\begin{aligned} \frac{du_{sd}}{dt} &= \frac{1}{C}\left(i_{sd} - \frac{u_{sd}}{R} - i_{ld}\right) \\ \frac{du_{sq}}{dt} &= \frac{1}{C}\left(i_{sq} - \frac{u_{s\beta}}{R} - i_{lq}\right) \\ \frac{di_{ld}}{dt} &= \frac{1}{L}.u_{sd} \\ \frac{di_{lq}}{dt} &= \frac{1}{L}.u_{sq} \end{aligned}\right\} \quad (16)$$

The equation system (16) solution provides the results of simulation with a variable load speed

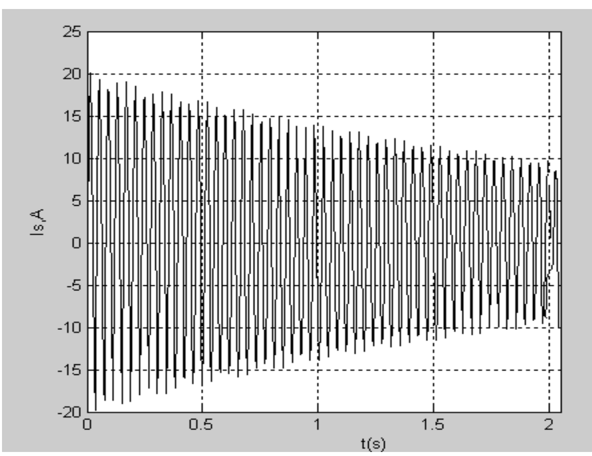

Fig. 11: Self startup voltage of the loaded generator for C=300 μF

It can be noticed on fig. 11 that, when a load is applied, the voltage decreases with a light variation of frequency which is due to the decrease of the speed .

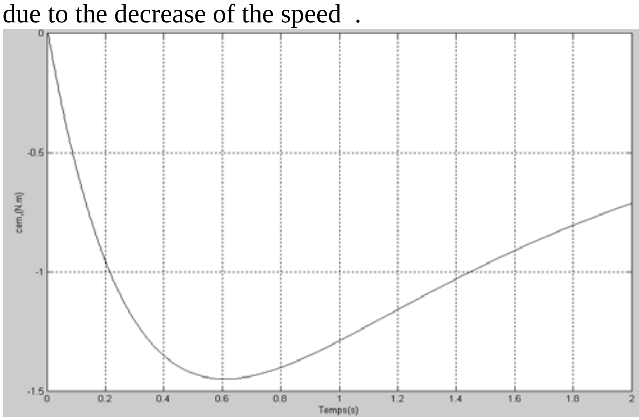

Fig. 12: Electromagnetic Torque of the loaded Generator under loading

The electromagnetic torque passes from a steady state to another steady state defined by the load.

III. Model Validation

The simulation results of the Self-excited induction generator functioning are validated by comparing them with experimental ones obtained for transient regime parameters in natural testing of asynchronous machine. These tests are performed on MA-20M series electric devices.

The three-phase asynchronous machine AM72-4M type is used as an asynchronous generator. The table bellow shows the comparison between the simulation and experimental parameters of a loaded Self-excited induction generator running process.

Experimental		**Simulation**	
U (p.u)	Imax (p.u)	U (p.u)	Imax (p.u)
0	0.45	0	0.4
0.4	2.8	0.09	2.95
0.366	3.9	0.33	3.6
0.91	3.6	0.96	3.3

Table. 1: The comparison between simulation and experimental parameters

Mathematical models for the self-excited empty and loaded Asynchronous Generator have been developed within the scope of this study. Thus, theoretical and experimental functional studies could be performed in addition to evaluating the influence of the regime on the transient regime quality.

There are three parameters that affect the tension delivered by the Self-excited induction generator, which are:

- The value of the excitation capacity
- The rotation speed
- The load
- To perform a system reliability analysis all these three parameters should be considered.

IV. Reliability Study of the System

The first step of a reliability analysis consists of making a deep study of the system. A common approach is to perform a " Failure Mode and Effects Analysis " (FMEA). It allows studying the impact of the devices failures on the system. It is about an inductive analysis method retailing systematically all the system components [21].

The main function of the system is the production of a good quality and reliable electrical energy. To perform a functional analysis of the produced electrical energy quality parameters a set of the AAG running important regimes are considered. In order to control the quality parameters of the produced electrical energy (frequency/voltage) the following processes should be analyzed:

- The reactive energy source (The capacitor bank) of the Self-excited induction generator system.
- The rotation speed of the diesel actuator.
- The connection of a load to the generator terminals.
- The AAG coupling to the network.

A. Failure Modes and Effects Analysis on the Self-excited induction generator

To perform a Failure Modes and Effects Analysis (FMEA), the system should be broken down to simple Elements. Each element behavior can be determined via data collection process, and consequently, all the failure modes effects of each system element can be concluded using the system physical and functional structure (Tab.2) [22], [23].

Element	**Failure modes**	**Mechanism and failure effect on the system**	**Causes**
The capacitor bank	The non apparition of an exit voltage on the generator terminals	Lack of the reactive energy for the generator magnetization	Failure in the source of the reactive energy of the AAG excitation system
Diesel Actuator and Fuel Pump	Variation of the generator voltage of exit	Variation of the residual field in the generator's stator	Change of the rotation speed of the actuator motor
Load	-Decrease in the Output voltage -Variation of the exit voltage frequency	-Variation of the generator's excitation current	The connection of a load to the generator terminals
Asynchronous Generator	Overcharge of the generator and its actuator	System destabilization and the generating lose excitation	The starting and the commutation of the mechanism with Diesel Actuator

Table .2: Failure Modes and Effects Analysis of the Self-excited induction generator

B. Reliability modeling and criteria of good working order of the Self-excited induction generator

Different techniques are available according to the architecture of the studied system, the concerned undesirable events, the criteria to be evaluated and the hypotheses taken into account in the model [8],[21].

The estimated reliability analysis determines the failure rate of each equipment component in the real use conditions. Thus, reliability databases are consulted. They allow the reliability calculation of a circuit including several components. Many models have already been developed to address this issue. Markov chains, [24],[25]. is the one of the most commonly used models.

C. Modeling of the reliability of the self induction generator excited by the Markov chains method

Markov chains method or (Markov process) allows the analysis of reliability of repairable systems for which failure rates and repair components are held constant [26], so it can be applied to our system.

It considers the system as a set of components which can be in a finished number by states of functioning or of breakdown, we shall build a graph nodes of which will correspond to the various system states, and the arrows indicate the directions of transitions (breakdown and repair) between system states. For a system in components, if every constituent (component) has two states (functioning or breakdown), the maximum number of states is 2^n. The calculation of the reliability is realized from various states of the system.

The fundamental interest of the Markov process is its graphical aspect which allows implement without really needing to know about it, in depth, all the theoretical aspects [27].

Our installation contains four components, every component has two states (functioning or breakdown), and the maximum number of states is 2^4.

The description of the components' states of the installation is represented in following table

Operating state	**Failed state**	**Component**
A	$\overline{A}$	Fuel Pump
B	$\overline{B}$	Diesel Actuator
C	$\overline{C}$	The capacitor bank
D	$\overline{D}$	Asynchronous Generator

Table .3: The description of the states of the components of the installation

The construction of Markov state diagram concerning the system is made in two stages:

- Identification of the various states which the system can occupy during its operation, there are four named A, B, C and D.
- Construction of Markov graph according to the identified states by the representation of each of state by a circle, (Operating state / Failure State) and representation of the transitions between states by arrows.

Every transition symbolizes the way the system jumps of a state towards another one. Of the state of perfect functioning E (A B C D), we can jump towards E1($\overline{A}$ B C D) or by E2 (A $\overline{B}$ C D) failure of A or B, of the state E2 we can go or towards the state of breakdown E3 by failure of C or to return to the state E1 by repair of B.

The analysis of the installation through the Markov process is represented on the fig. 13.

The system states may be represented diagrammatically as:

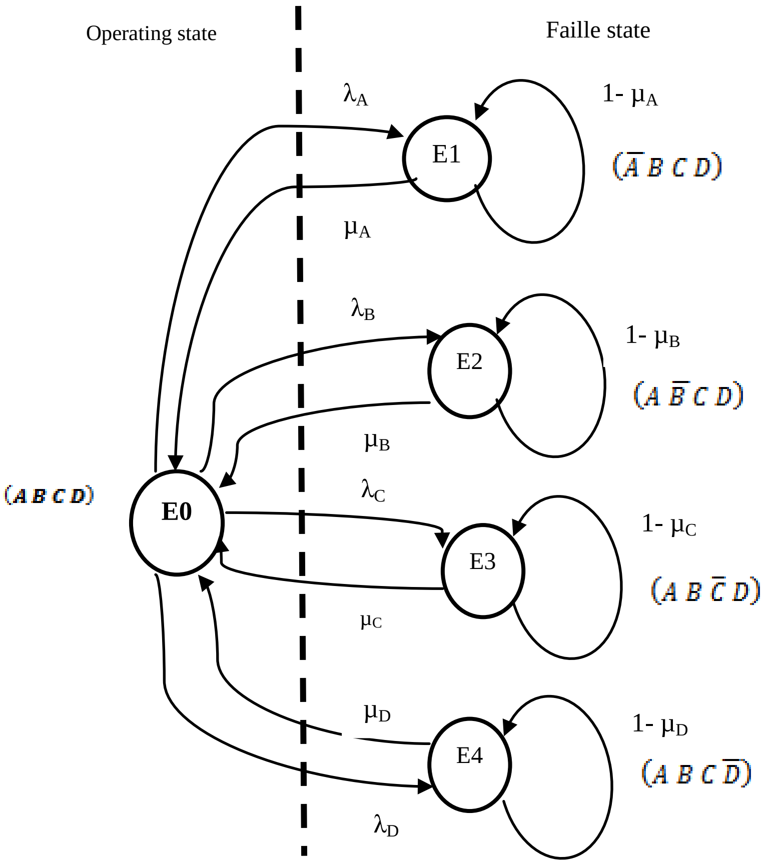

Fig. 13: Markov state diagram of Installation

λ_i : The failure rate of the component

μ_i : The repair rate of the component

One to notice that the graph represents, in a synthetic way, all the paths (ways) (sequences of events) which the system can borrow from its initial state during its evolution in time.

This graph thus contains paths (ways) allowing the system to pass by the state of breakdown (Ei) then to return in a state of functioning (E). Thus it describes the behavior of a system which can be underway at the given moment by having been one or several times out of order previously. Thus it is typically about a model of reliability R(t). The reliability of the system at time (t) is the probability that the system is in states

(E1), (E2),(E3) or (E4):

$$R(t)= [P\,1\,(t) + P\,2\,(t) + P\,3\,(t) + P\,4\,(t)] \tag{17}$$

Pi (t): is the probability that the system is in functioning state at time (t) to be ever having broken down previously, that is the probability to have stayed in good working order on all the duration [0, t].Because Markov-Chain is homogeneous thus the rate of transition is constant what makes leads (drives) to the consideration of a transition (and the only one) between (t) and (t+dt).At the moment (t+dt), the system is in the state Ei:

if it was there and if it does not leave it: $P_i(t)\left(1-\sum_{\substack{j=1\\ j\neq i}}^{n}\alpha_{ij}dt\right)$

Where α_{ij} :is the transition Rate Of Ei towards Ej.

If it was not in Ei but the transition with place enters (t) and

(t+dt) from Ej : $\left(\sum_{\substack{j=1\\ j\neq i}}^{n}P_j(t)\alpha_{ji}dt\right)$

The general shape :

$$P(t+dt)=P_i(t)\left(1-\sum_{\substack{j=1\\ j\neq i}}^{n}\alpha_{ij}dt\right)+\left(\sum_{\substack{j=1\\ j\neq i}}^{n}P_j(t)\alpha_{ji}dt\right) \tag{18}$$

The governing equations :

The full time-dependent equations (including repair transitions) are:

$$\left.\begin{array}{l} P_0(t+dt)=[1-(\lambda_A dt+\lambda_B dt+\lambda_C dt+\lambda_D dt)].P_0(t)+ \\ \mu_A dtP_1(t)+\mu_B dtP_2(t)+\mu_C dtP_3(t)+\mu_D dtP_4(t) \\ P_1(t+dt)=[1-\mu_A dt].P_1(t)+\lambda_A dt\,P_0(t) \\ P_2(t+dt)=[1-\mu_B\,dt].P_2(t)+\lambda_B dt\,P_0(t) \\ P_3(t+dt)=[1-\mu_C dt].P_3(t)+\lambda_C dt\,P_0(t) \\ P_4(t+dt)=[1-\mu_D dt].P_4(t)+\lambda_D dt\,P_0(t) \end{array}\right\} \tag{19}$$

$$\frac{P(t+dt)-P_i dt}{dt}=\frac{d}{dt}P_i(t)=P_i'(t) \tag{20}$$

The equations were:

$$\left.\begin{array}{l} P'_0(t)=-(\lambda_A+\lambda_B+\lambda_C+\lambda_D)P_0(t)+\mu_A P_1(t) \\ +\mu_B P_2(t)+\mu_C P_3(t)+\mu_D P_4(t) \\ P'_1(t)=\lambda_A P_0(t)-\lambda_A P_1(t) \\ P'_2(t)=\lambda_B P_0(t)-\mu_B P_2(t) \\ P'_3(t)=\lambda_C P_0(t)-\mu_C P_3(t) \\ P'_4(t)=\lambda_D P_0(t)-\mu_D P_4(t) \end{array}\right\} \tag{21}$$

Using the matrix notation, these equations can be expressed in the form:

$$[P_0'(t)P_1'(t)P_2(\quad (17) \quad (t)]=[P_0(t)P_1(t)P_2(t)P_3(t)P_4(t)].$$

$$\begin{bmatrix} -(\lambda_A+\lambda_B+\lambda_C+\lambda_D) & \lambda_A & \lambda_B & \lambda_C & \lambda_D \\ \mu_A & -\mu_A & 0 & 0 & 0 \\ \mu_B & 0 & -\mu_B & 0 & 0 \\ \mu_C & 0 & 0 & \mu_C & 0 \\ \mu_D & 0 & 0 & 0 & \mu_D \end{bmatrix} \tag{22}$$

Indicating by P (t) the probability vector and by Λ The transition matrix, we obtain:

$$P'(t) = \frac{d}{dt}P(t) = P(t).\wedge$$

$$P'(t) = P_c(t).\wedge_{cc} \quad (23)$$

Where:

$P_c(t)$: Vector of probabilities of non-defaulting states

$\wedge_{cc}$: Transition matrix between non- failing states

$$\frac{P(t+dt) - P_i dt}{dt} = -P_i(t)\sum_{\substack{j=1\\ j\neq i}}^{n}\alpha_{ij} + \sum_{\substack{j=1\\ j\neq i}}^{n}P_i(t)\alpha_{ji} = \frac{dP_i(t)}{dt}$$

Where: $\alpha_{ii} = \sum_{\substack{j=1\\ j\neq i}}^{n}\alpha_{ij}$

we have : $\frac{dP_i(t)}{dt} = \sum_{j=1}^{n}P_j(t)\alpha_{ji}$

$\frac{dP(t)}{dt} = P(t).\wedge$ And we find

: $P_c(t|P(0)) = P_c(0).e^{-\wedge_{cc}t}$

So the system's behavior is determined by:

The transition matrix Λ

The initial probability vector P(0)

The reliability of the system are given by:

$$R(t) = P_c(0).e^{-\wedge_{cc}t}.1_{Ei}^T \quad (24)$$

Where: 1_{Ei}^T : Column vector of warning

We can have the solution of equation (24) by:

- Truncated series
- Numerical Integration
- The Laplace Transform

The method of solution adopted here is that using Laplace Transforms.
The equation solution $P'(t)$ by Laplace Transforms:

$$L[f(t)] = \tilde{f}(s) = \int_0^\infty e^{-st}f(t)dt \Rightarrow L\left[\frac{df(t)}{dt}\right] = s\tilde{f}(s) - f(0)$$

Where: $L\left[\frac{dP(t)}{dt}\right] = L[P(t).\wedge]$

$$s\tilde{P}(s) - P(0) = \tilde{P}(s).\wedge \Rightarrow \tilde{P}(s) = P(0).(sI - \wedge)^{-1}$$

(23) ere I is the identity matrix

Now the Laplace Transform of equation (24) is given by

$$L[R(t)] = \tilde{R}(s) = \int_0^\infty e^{-st}.R(t)dt$$

Where :

$$\tilde{R}(s) = P(0).(sI - \wedge_R)^{-1}.1_R^T \quad (25)$$

For the calculation of the reliability R(t) It is necessary to delete the arrows (μ_i) characterizing the repair in the matrix of repair Λ.

Where:

$$\wedge_R = \begin{bmatrix} -(\lambda_A+\lambda_B+\lambda_C+\lambda_D) & \lambda_A & \lambda_B & \lambda_C & \lambda_D \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The reliability matrix was:

$$\tilde{R}(s) = [1 \quad 0 \quad 0 \quad 0 \quad 0].(sI - \wedge_R)^{-1}.\begin{bmatrix}1\\1\\1\\1\\1\end{bmatrix} \quad (26)$$

The reliability R(t) of the system at time t is:

$$R(t) = A.e^{s1t} + B.e^{S2t} + C.e^{s3t} + D.e^{s4t} \quad (27)$$

A,B,C and D are the equating coefficients.

D .The quantitative calculates system reliability

To estimate the probability of the events it is necessary to return to the essays of experiment on the installation and the data collections of reliability of the components [28]:

-Fuel Pump

- Fuel Pump life 9400 hours
- λ_A: The failure rate is =10-4/ hours

-Diesel Actuator

- Diesel Actuator life :8000 hours
- λ_B: The failure rate is =10-4/ hours

-The capacitors

The life of a capacitor is calculated by the Arrhenius law:

$$L = L_0 . 2^{\frac{T_{Max} - T_a}{10}}$$

Where :

L : The capacitor estimated life

The capacitor life in the nominal temperature (25 C°,105 C°)

Tmax : Maximal nominal temperature

Ta :Ambient temperature

λ_C: The failure rate is:10-9/ hours

-Asynchronous Generators

Asynchronous Generators life (Operating time): 87000 hours

λ_D: The failure rate is $=10^{-5}$ / hours

Calculation of the reliability system by Markov process:

Time (h)	R(t)
0	1
200	0.04160086
400	0.08241353
600	0.12245358
800	0.16173619
1000	0.20027633
1200	0.23808861

Table .4: Calculation of the reliability system by Markov process

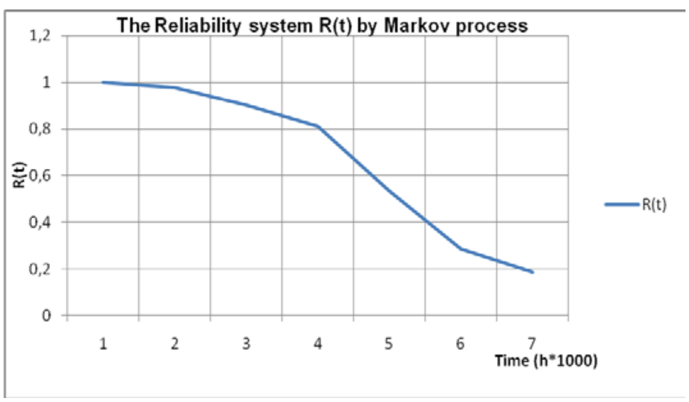

Fig.14 .Reliability graph analysis

V. Conclusion

We have seen that Self-excited induction generator can be a solution for the generation of energy (electricity) in operation in an isolated or connected to the network sites. Load operation of the generator is not a problem, simply choose the value of excitement capacitor and rotational speed, because the latter set the load operating points.

Thereafter, we take into account the magnetic saturation which allows limiting the amplitudes of the voltages and currents in steady.

However, the operation of this generator in load decreases the rotational speed, or a drop in voltage and frequency, therefore, in the case in which the load is critical, it can be completely demagnetized.

Thus the model of the Self-excited induction generator is valid, by simulation for all operating conditions. Nevertheless, it is desirable to take an experimental result and make a comparison. Simulation results are similar to those found experimentally in work if there is a difference , it is only due to experimental survey of the vacuum feature , from its modeling and from the identification method of the machine's parameters that has a great influence on the magnitudes transient and steady state.

The evaluation of the reliability of the Self-excited induction generator in the operational phase is based on an analysis based on the system's structure, from the influence of the failure probabilities of its components on the probability of overall system failure.

Then, the approach consists in observing the behavior of the system considered and in performing statistical processing on the data on the observed failures.

Collecting error data is critical in such a process and it must be provided from the beginning of the system's implementation.

For those records of failure can be useful, it is important that the use of independent asynchronous generator is as representative as possible of the actual loading conditions of the system in its operating environment. The main objective of this observation is to assess the reliability of the system under the conditions of the use (isolated sites).

To obtain a good statistical study, it is necessary to collect enough data to deduce the closest or modeling laws that we have seen during the considered time period

An overview of the methods used for the analysis of reliability of the energy system in the operational phase shows that for qualitative analysis, FMEA method is preferred to determine the dreaded elements and adverse events their causes of occurrence and the consequences of these failures on the systems. By contrast for the quantitative analysis of the reliability of the installation method of Markov chains is used to control the functional behavior / dysfunctional and provided an important opportunity to quantify the reliability and evaluate the probability of failure of the entire system.

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