An Investigation of Reliability and Life Time Prediction for Power MOSFET Using Electronically and Statistical Technique

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ABSTRACT

This work is aimed to estimate the life time of the MOSFET power transistor through an empirical implementation work merged with statistical applications. In the empirical part the MOSFET power transistors are subjected to high frequency(50kHz) via an electronically controlled model using advanced driving circuit (IR2113) that reduce the Miller effect of load side reflected to the transistor gate, so minimum voltage noise , to obtain accurate results. The statistical approach is based on developing simulation technique using Weibull distribution to estimate the life time of MOSFET power transistor. Two methods (maximum likelihood and order regression) were applied for simulated data of the actual performance to provide an accurately prediction of the failure time. The transistor was tested by supply variable voltages from zero to break down voltage and different results are observed. The results show that the first of the suggested method gives a best performance for simulation results compared with the two of the conventional methods.

Key words: MOSFET transistors, Weibull distribution, Simulation.

تخمين عمر البقاء لترانزستور القدرة نوع MOSFET باستخدام تقنية الكترونية و تقنية إحصائية

الخلاصة

يهدف البحث إلى تخمين عمر البقاء لترانزستور القدرة power MOSFET باستخدام طريقتين أحداهما تجريبية والأخرى تطبيقية إحصائية.في الجزء التجريبي تم تشغيل النرانزستور بتردد عالي يصل الى (٥٠ kHz) وباستخدام دائرة سيطرة و تشغيل متقدمة تمكن من تقليل التاثيرات الجانبية والضوضاء على الحمل المستخدم للحصول على نتائج دقيقة.إحصائيا تم استخدام تقنية المحاكاة

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لتوزيع ويبل القياسي للتنبؤ بعمر البقاء للترانزستور حيث تم استخدام طريقتين الأولى طريقة الإمكان الأعظم والثانية طريقة الانحدار الشامل للبيانات المحاكاة وتم إجراء التشغيل التطبيقي عن طريق تزويد الترانزستور بفولتيات متغيرة تبدا من صفر فولت وصولا الى فولتية الانهيار التي يفشل الترانزستور فيها عن العمل.إحصائيا أظهرت النتائج أفضلية الطريقة الأولى في التنبؤ رياضيا وتخمين وقت الفشل للترانزستور حيث تم استخدام أسلوب المحاكاة وبدرجة عالية من الدقة للنتائج التجريبية مقارنة بالطرائق المدروسة.

الكلمات المرشدة:- ترانزستور MOSFET , توزيع ويبل , محاكاة .

INTRODUCTION

Estimating survival time (time-to-failure) distribution or long-term performance of components of high reliability products is very important to manufacturers. Most modern products are designed to operate without failure for several years. Thus few of such units will fail or degrade to a significant amount in a test of any practical length based on normal use conditions. [1]

Electrical systems of today's world supposed not to fail. Designers of these systems must be aware of the various points of failure and how to deal with these problems. In most systems the failure pattern changes over time. Depending on the causes of failure, the failure rate can be classified as decreasing constant or increasing with time. [2]

In this paper life time of the MOSFET transistor depends on the operating stresses was experienced during service and analyzed experimentally in specified driver system via utilizing “n” number of transistors. The stresses experienced are usually time dependent. Therefore the need to relate life to stress becomes a necessity to make predictions about the reliability. [3]

The two-parameter Weibull distribution is carried out, so a given set of obtained data were used to model the failure time.

EXPERIMENTS AND STATISTICAL MODEL

The suggested method has been experimented with several power MOSFET transistors as regarding the failure or the burn out of these transistors will occur and will be estimated statistically as shown in Figure (1).

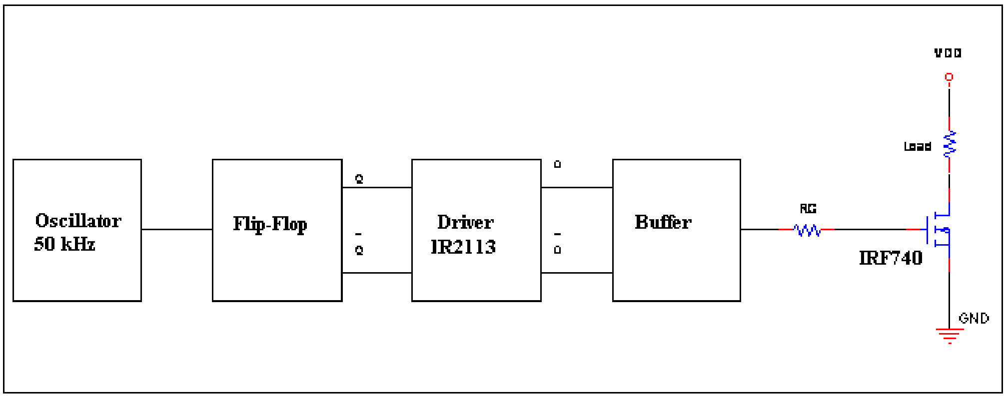

Figure (1) the Proposed System.

The testing is performed by sweeping the power supply voltage *(VDD)* continuously from (0*V)* to (70*V*) range on 10 samples independently (all from the same origin) of power MOSFET transistors (IRF740 NMOS). All these transistors tested simultaneously, and should be known that these transistors have no expiration date, and stored in normal conditions.

The driving circuit shown is used here without feedback protection, hence, the power circuit is not protected against short-circuit to enable the transistor to carry full short circuit current required to burning-out. This is permissible in this paper, because the used power supply has current capability nearly (20) times beyond the burning out current of the power MOSFET.

When the circuit is in the operation, the components are heated and that will lead to change in many parameters. Hence to obtain accurate results all transistors operated in the same time and derived from the same driving circuit and that is the reason why buffer is used.

Statistically, it was considered the time as independent variable and the measured current and voltage changes were considered as dependent variable. The proposed statistical model is shown in Figure (2), where (n) is the number of the employed samples and (n=10).

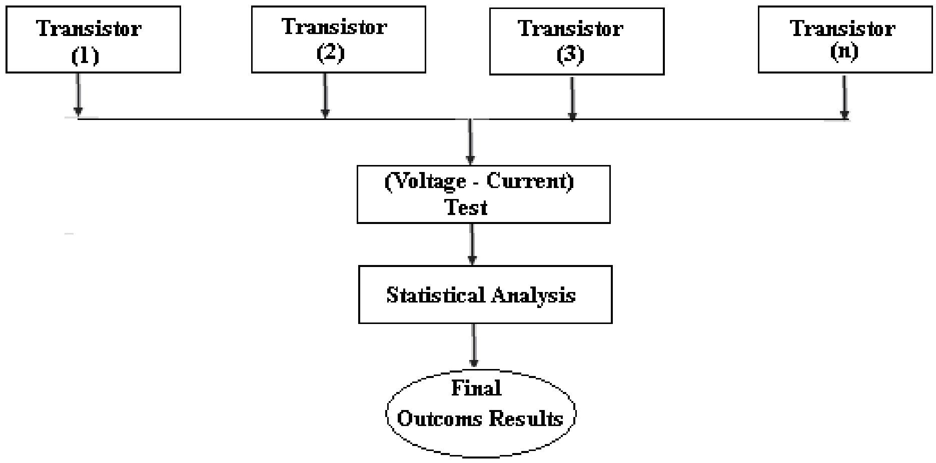

Figure (2) The proposed estimating model of MOSFET transistors.

When a number of parts are put on a test, they don't all fail at the same time, if the values of one variable were changed, this variable which can be controlled is called the independent variable and the other one which can not be controlled is called the dependent variable. Conceptually the statistical distribution is often used to describe the life times of parts and the parameters can be founded using several method. [2]

MOSFET lifetimes are investigated statistically using Weibull Distribution and the object of primary interest is the reliability function, conventionally denoted R, which is defined as [1]:

$$R(t) = \Pr(T > t)...(1)$$

Where

t is some time.

T is the time of death.

Pr stands for probability.

The lifetime distribution function, denoted F, is defined as the complement of the reliability function.

$$F(t) = \Pr(T < t) = 1 - R(t)...(2)$$

If parts fail according to Weibull distribution, the probability that any single part will fail at a particular time, t is [2].

$$F(t) = 1 - \exp\left[-\left(\frac{t}{a}\right)^{b}\right]...(3)$$

Where

"a" is called the scale parameter,

"b" is called the shape parameter

F (t) is called the cumulative distribution function.

The values of (a) and (b) are estimated mathematically from the obtained data by using linear regression method. Hence the reliability function is calculated by the formula;

$$R(t) = 1 - F(t) = \exp\left[-\left(\frac{t}{a}\right)^{b}\right]...(4)$$

Here *t* is the random variable. The scale parameter is the value of *t* for a probability of (1-(1/e)) =0.632 and the shape parameter is related to the scatter of data. According to (2), log (1/ (1- *P*)) versus log (*t*) gives a straight line which is called the Weibull plot. [3]

RESULTS OF EXPERIMENTAL WORKS

The suggested mechanism was carried out in the higher education laboratory of electrical engineering department in college of engineering of the Almustansiryha University to measure the failure and the breakdown parameters of the MOSFETs as shown in Figure (3).

Figure (3) the Test (2) Electronic Circuit.

The testing circuit implemented so that the equipment can measure the required voltage, and current. The power delivered to the load by pulsing a MOSFET gate on and capturing the current response in the equipment as shown in Figure (4). It was noticed that all devices failed at less than (*70 V*) rating, one device is failed as low as (*50 V*) .The results gained experimentally are listed in Table (1). And the statistical results that obtained from simulation process for real data are listed in Tables (2) and (3) respectively

Figure (4) the Samples of Measuring Results.

Table (1) the (I-V) Results for MOSFET Transistors.

(I-V)	V1 10V	V2 15V	V3 20V	V4 25V	V5 30V	V6 35V	V7 4OV	V8 45V	V9 50V	V10 55V	V11 60V	V12 65V	V13 70V	MOSFST Transistor
I_1	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	0.0	0.0	T(1)
I_2	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	0.0	0.0	T(2)
I_3	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	0.0	0.0	0.0	T(3)
I_4	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	0.0	0.0	0.0	T(4)
I_5	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	0.0	0.0	T(5)
I_6	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	0.0	2.98	0.0	0.0	0.0	T(6)
I_7	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	3.52	0.0	T(7)
I_8	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	0.0	0.0	T(8)
I_9	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	0.0	0.0	T(9)
I_{10}	0.54	0.81	1.08	1.35	1.62	1.89	2.11	2.43	2.71	2.98	3.25	3.52	0.0	T(10)

Table (2) Weibull Cumulative Density Function Parameters Estimates for Real and Simulated Data through Applying M.L.E. & Rank Regression. Estimation Methods .

Design	Parameter	Methods of estimate	
		Max. Likelihood	Rank Reg.
Real	Shape	2.34118	1.94075
	Scale	2.28861	2.32114
Simulated	Shape	2.51871	2.51871
	Scale	2.27767	2.27767

Table (3) Weibull Cumulative Density Function for Real and Simulated Data through Applying M.L.E. & Rank Regression Estimation Methods.

F(t) t: Sequence	Real Data		Simulated Data	
	Max. Likelihood Method N=12	Rank Reg. Method N=12	Max. Likelihood Method N=12	Rank Reg. Method N=12
$P(t_1)$	0.033442	0.057300	0.04942170	0.0766228
$P(t_2)$	0.084136	0.121567	0.14731068	0.1893052
$P(t_3)$	0.158321	0.202707	0.23073251	0.2704089
$P(t_4)$	0.252194	0.294825	0.31254153	0.3467029
$P(t_5)$	0.359392	0.392013	0.39748998	0.4218343
$P(t_6)$	0.472121	0.488871	0.47815544	0.4906912
$P(t_7)$	0.562537	0.564399	0.54752141	0.5491309
$P(t_8)$	0.683576	0.664799	0.62505021	0.6128071
$P(t_9)$	0.773583	0.740934	0.70293286	0.6428162
$P(t_{10})$	0.843587	0.802902	0.78152495	0.7045081
$P(t_{11})$	0.896992	0.853653	0.87749403	0.8302203
$P(t_{12})$	0.935422	0.893936	0.96131674	0.9223800
MSE	0.0077986	0.00080108	0.00007518	0.000077986
Note:- F (t) = 1 - EXP (- EXP (Shape*(Ln (t)-Ln (Scale))))				

The final step is to determine the expected value for probable responding estimates which are shown in the next Figure (5). These should be achieves in 12 circle in order to be sure which period of times that each of the studied property would be survived, and enable to compare between the two different methods of estimating as well as the two techniques, real data and Simulation technique which had been applied through generating error term for standard Weibull distribution function, as far as we know this work is done for the first time in Iraq. Mean square error indicator showed that the simulated life time in the both methods of estimates is better than real data outcomes. [4]

The fitted line of Maximum Likelihood Method with Simulated technique represented more reliable and a stationary straight line status compared with the others fitted lines which meaning that the best prediction of the failure time would be that obtained from fitting on the line of Maximum Likelihood Method.

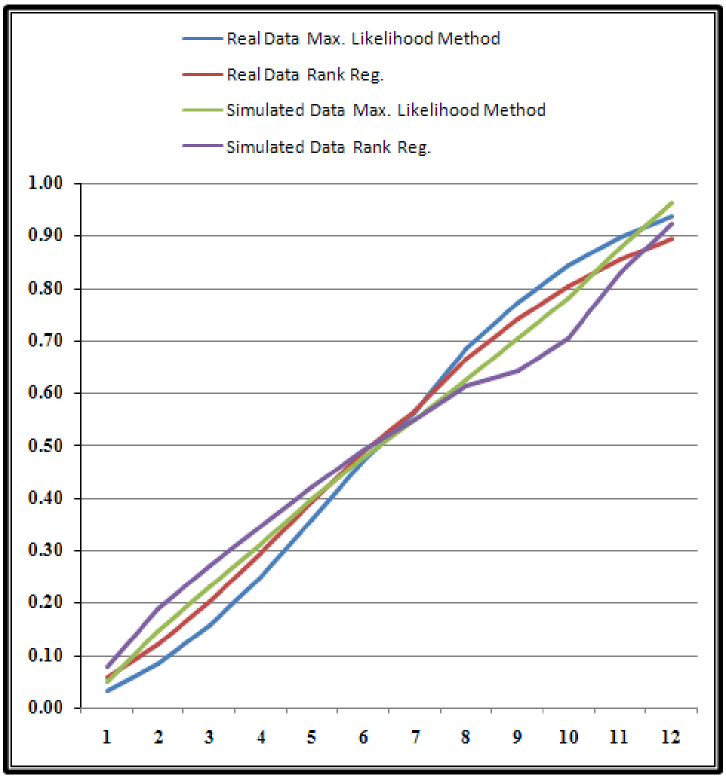

Figure (5) the Expected of the Probable Responding Estimates which are Access.

CONCLUSIONS

1-This work provided the necessary information required for the estimation the life time of power MOSFET transistor and developed a statistical approach using Weibull distribution which is suitable to reliability estimation and prediction of the failure time.

2-As mentioned from the obtained results, it is hoped that this paper with the given procedure will be useful in selecting the optimum design for a required transistor. The required information for estimation is presented and Simulation technique was carried out and the results are compared to obtain the best prediction of the failure time

3-Simulation technique illustrated according to the mean square error (MSE) indicated that the life time predicated in the both methods of estimates are better than real data outcomes which indicates that the generation of error term in the regression model through the standard Weibull distribution function instead of standards normal distribution function were found more successfully indeed .

4-Among the two different estimating methods, Max. Likelihood Method used with simulated technique represents more reliable and a stationary straight line status compared with the others fitted lines, which means that the best prediction of the failure time would be that obtained from fitting on the line of Maximum Likelihood Method.

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