A Simple Method for Power Diodes Parameter Measurement

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ABSTRACT: Switches are heart of power electronics. Plenty of switches are available today. Diode is one of the most wide spread switches which has a lot of application in power electronic and small signal electronics. Diode, has a non-linear I-V characteristics. Diode I-V relation is governed by Shockley diode equation. Two parameters are in Shockley equation: Reverse saturation current(I_s) and emission coefficient(n). This parameters are vary from device to device. Reverse saturation current is very small for modern silicon diodes, generally in the range 10^{-12} A to 10^{-8}A, very hard to measure it directly. A simple method for measuring these parameters is proposed here. No expensive measurement device is required. This method can also be used for fault detection of power diodes. Laboratory results shows the success of given method.

KEYWORDS: Emission coefficient, Power diodes, Reverse saturation current, Shockley equation.

I.INTRODUTION

Power electronics is the application of solid-state electronics to the control and conversion of electric power.

power conversion systems can be classified according to the type of the input and output power:

- AC to DC (rectifier),
- DC to AC (inverter),
- DC to DC (DC-to-DC converter),
- AC to AC (AC-to-AC converter).

Plenty of power switches have been introduced: Diode, Silicon Controlled Rectifier(SCR),Thyristor,Gate Turn Off Thyristor(GTO),Bipolar Junction Transistor(BJT),Power MOSFET, etc.

A computer simulation is an attempt to model a real life or a hypothetical situation on a computer. Power electronic circuits can be simulated in Matlab®,Psim®,Multisim®,etc.

Accuracy of simulation,i.e. how much simulation results are similar to laboratory results, is greatly dependent on accuracy of model which has been used.

Diode is an important, unipolar, uncontrolled switch which is used in many converters.

A cheap and simple method of measuring diode parameters is described here.

II.DIODE I-V CHARACTERISTICS

A *diode* is a two-terminal electronic component that conducts primarily in one direction; It has low (ideally zero) resistance to the flow of current in one direction, and high (ideally infinite) resistance in the other. Diode I-V characteristics is governed by *Shockley ideal diode equation* or the *diode law* The following equation is called the *Shockley ideal diode equation* when *n*, the ideality factor, is set equal to 1 [1]:

$$I = I_S \left(e^{\frac{V_D}{nV_T}} - 1 \right), \qquad (1)$$

where

I is the diode current,
I_S is the reverse bias saturation current,
V_D is the voltage across the diode,
V_T is the thermal voltage, and
n is the *ideality factor*, also known as *emission coefficient*. The ideality factor n typically varies from 1 to 2 (though can in some cases be higher), depending on the fabrication process and semiconductor material used.

The *saturation current (or scale current)*, more accurately, the *reverse saturation current*, is that part of the reverse current in a semiconductor diode caused by diffusion of minority carriers from the neutral regions to the depletion region. This current is almost independent of the reverse voltage[4].

I_S, the reverse bias saturation current for an ideal p–n diode, is given by [2]:

$$I_S = eA \left(\sqrt{\frac{D_p}{\tau_p}} \frac{n_i^2}{N_D} + \sqrt{\frac{D_n}{\tau_n}} \frac{n_i^2}{N_A} \right), \qquad (2)$$

where

e is elementary charge
A is the cross-sectional area
$D_{p,n}$ are the diffusion coefficients of holes and electrons, respectively,
$N_{D,A}$ are the donor and acceptor concentrations at the n side and p side, respectively,
n_i is the intrinsic carrier concentration in the semiconductor material,
$\tau_{p,n}$ are the carrier lifetimes of holes and electrons, respectively.

The saturation current is *not* a constant for a given device; it varies with temperature. The thermal voltage V_T is approximately 25.85 mV at 300 K. At any temperature it is a known constant defined by [1] :

$$V_T = \frac{kT}{q}, \qquad (3)$$

where k is the Boltzmann constant, T is the absolute temperature of the p–n junction, and q is the magnitude of charge of an electron. A typical diode I-V characteristic is shown in figure1:
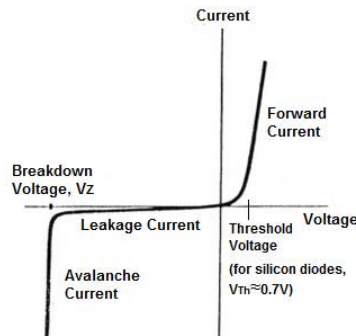
Figure 1: Diode I-V characteristics.

Diode can be in either forward bias($V_D>0$, I>0) or reverse bias ($V_D<0$, I<0). There is an another point which must be mentioned here: in reverse bias region, where diode voltage is well below break down voltage diode current is nearly constant irrespective of diode voltage. It means diode can be modeled as a constant current source of value I_S. Saturation current(Is) and emission coefficient(n) are diode parameters that must be extracted from measurements in order to model diode in simulation programs. For example, Multisim® model of 1N4003 diode is shown in figure 2.As seen saturation current (Is) and emission coefficient (n) must be entered.
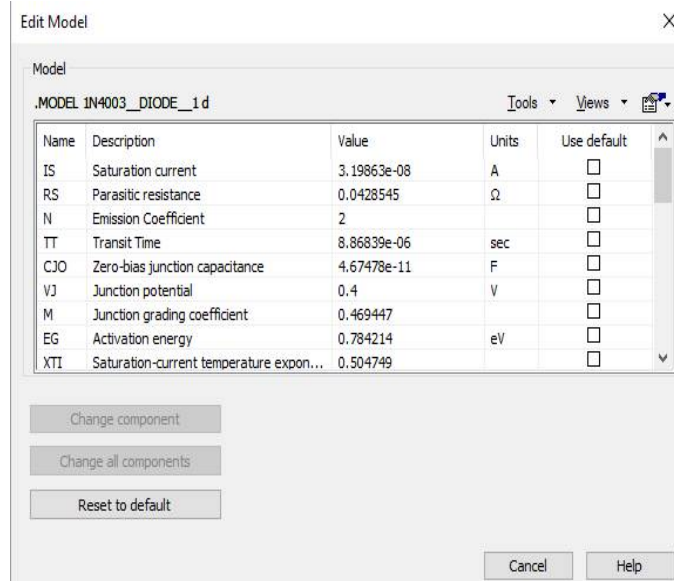

Figure 2:Model of diode in Multisim®.

Here is the definition of problem which this paper will focus on :"For a given diode, find a method to measure saturation current(Is) and emission coefficient(n)." Suggested method is studied in the next section.

III.PROPOSED METHOD

As seen in the previous section, diode current is nearly independent of diode voltage in the reverse bias part of I-V curve. When diode is reverse biased, diode current is equal to saturation current(Is). Saturation current is a very small current .It can not be measured with ampere meter. It is in the order of 10^{-12} (A) to 10^{-8} (A) for silicon diodes. So direct measurement is not possible. In order to measure saturation current following circuit is suggested:
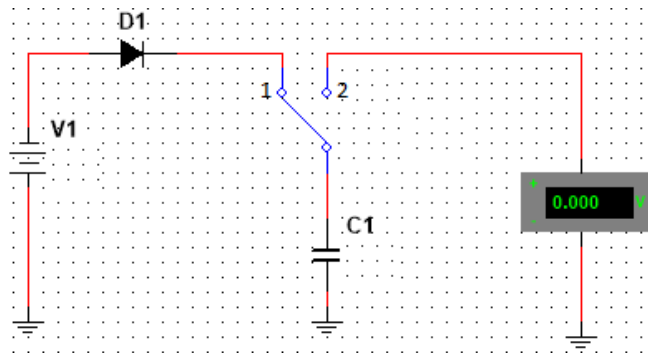
Figure 3:suggested topology.

V_1 is a value lower than reverse break down voltage of diode. For instance break down voltage of 1N4007 is about 700 volts, so $V_1=10$ V can be a choice. It is assumed that capacitance of capacitor is known. At t=0 ,switch is in the 1 position. At t=0, Capacitor C1 has no charge,i.e. its voltage is zero.

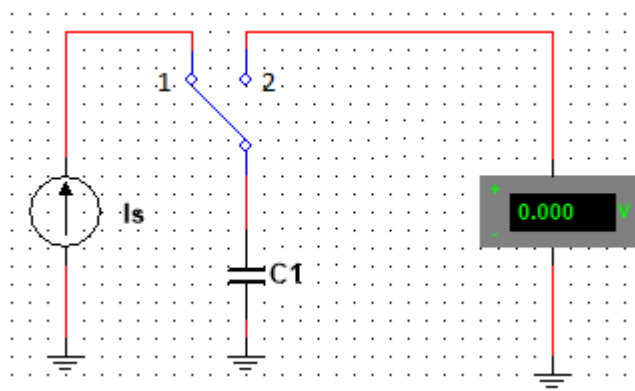Equivalent model of this region is drawn in figure 4.

Figure 4: equivalent circuit when switch is at 1 position.

Equation of instantaneous capacitor voltage is given by:

$$Q_{c1}= C_1 \times V_{c1} \qquad (4)$$

$$Q_{c1}= I_s \times t \qquad (5)$$

$$V_{c1} = \frac{I_S \times t}{C_1} \qquad (6)$$

which conservation of electric charge is used for derivation of above formula. After time Δt is passed ,key is switched to position 2,where capacitor voltage can be read. Reading must be done as quickly as possible in order to avoid discharge of capacitor through voltmeter internal resistance. Saturation current can be calculated as:

$$I_S = \frac{V_{c1} \times C_1}{\Delta t} \qquad (7)$$

So saturation current can be calculated using equation (7) . In order to measure diode emission coefficient following circuit is suggested:
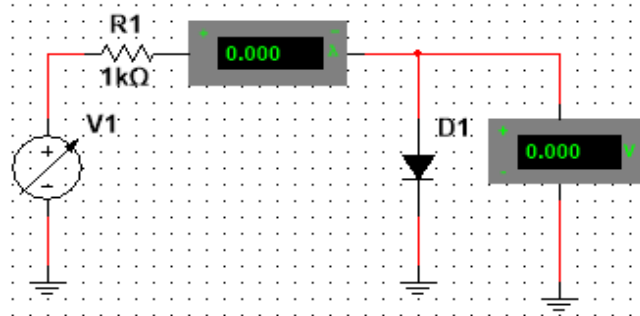
Figure 5:circuit for measuring emission coefficient(n).

Here V_1 is a variable DC power supply. V_1 forces D1 into the forward bias region. Diode voltage and currents are measured for different V_1.So an I-V table results. Applying Mean Square Error(MSE) algorithm to data's in this table, emission coefficient of diode can be calculated[6].

In order to do this job, Matlab® and Curve fitting toolbox is used.

IV.LABORATORY RESULTS

Here is the results of applying proposed method to a power diode. Diode under test is 1N4007. C_1 is 9.4 uF,V_1=10V and Δt=600s.Temperature of room is equal to 24˚C(= 297.15K). After 600 seconds capacitor voltage is 2.65V. Multimeter internal resistance is 10MΩ.When it connects to 9.4uF capacitor, time constant is:

$$\tau = R \times C_1 = 94\,s \qquad (8)$$

Which is sufficiently large to avoid discharge of capacitor in the reading interval(Generally, reading takes 2-3 seconds). Applying equation 7, gives I_s=4.15×10⁻⁸A or I_s=4.15×10⁻⁵mA . So I-V relation of diode under test(at T=297.15K) is as follows:

$$I = 4.15 \times 10^{-8} \times (e^{\frac{V_D}{n.V_T}} - 1) \qquad (9)$$

where V_T=25.6mV and $\dfrac{1}{V_T} = 39.0625$.

In equation 9, emission coefficient (n) is unknown and must be calculated.

Table 1, gives measured current-voltage pairs:

Table1: Diode forward voltage and currents.

Diode Current(mA)	Diode Voltage(V)
0.50	0.50
0.97	0.53
1.44	0.55
1.93	0.57
2.42	0.58
3.40	0.60
4.38	0.61
5.37	0.62
6.36	0.63
7.34	0.64
17.00	0.68
24.00	0.70
34.00	0.72
39.00	0.73

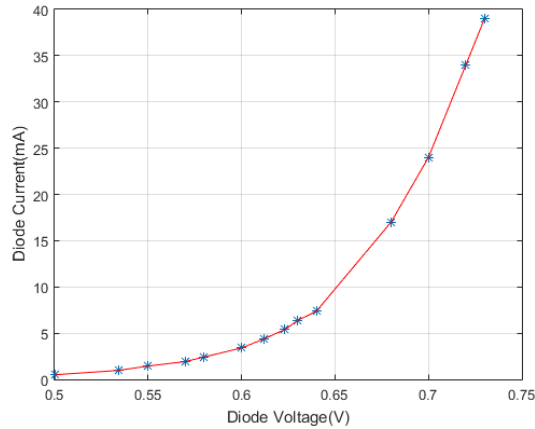This data are shown graphically as figure 5.

Figure 5: Forward I-V characteristics of diode.

using Matlab® Curve fitting toolbox n=2.068. Here is the results of data fitting process:

General model:
  $f(x) = 4.15e\text{-}5*(\exp(39.0625*x/b)-1)$
Coefficients (with 95% confidence bounds):
    $b = 2.068 \ (2.064, 2.071)$

Goodness of fit:
 SSE: 5.158
 R-square: 0.9976
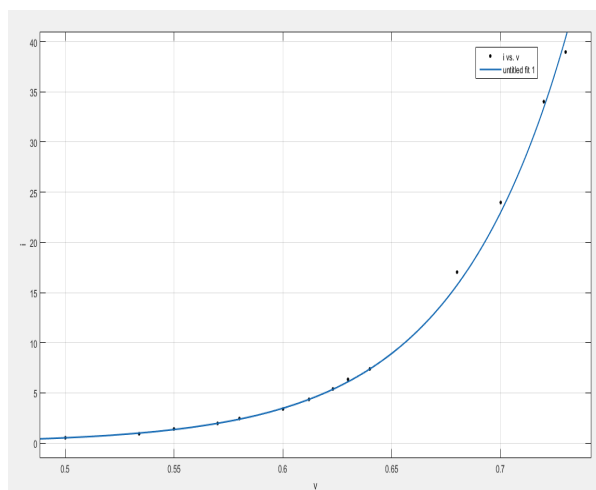 Adjusted R-square: 0.9976
 RMSE: 0.6299

Figure 6: Results of fitting data.

So the device under test I-V equation is as follows:
Saturation current, $(I_s)= 4.15\times10^{-8}$A.
Emission coefficient(n)= 2.068.

So diode current can be written as:

$$I = 4.15 \times 10^{-5}(e^{18.94 \times V_D} - 1)\ mA \quad @\ T = 297.15\ K\ (10)$$

V. ANOTHER APPLICATION

If result of measurement is compared with standard range of must be values, then large deviation can be a sign of fault in diode.

VI. CONCLUSION

In this paper, a method for diode parameter measurement is suggested. Method is fairly easy and cheap. Expensive measurement equipments are not required. This method can be used in order to do more accurate simulations(i.e. entering measured parameters to simulation software's for more accurate simulations), measurement of diode parameters in research laboratories or even fault detection.

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