PV CELL MODELING USING MATLAB TO FOR STUDY CHARACTERISTICS OF SOLAR CELL UNDER VARYING CONDITIONS

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Abstract: In this work we study the mathematical modeling and its simulation of a real photovoltaic (P-V) panel to evaluate its physical and electrical behavior when changing external environmental parameters: irradiation, temperature, resistance and other basic parameters. Based on the technical data of the manufacturer of this real solar system, a general mathematical model of the photovoltaic system is built in MATLAB/SIMULINK, which takes irradiance and temperature as variables and derives the characteristics of V -I, I¬P and V-P both in steady state and in the shading effect. This system can be used to improve the performance of a photovoltaic module for various engineering and technical applications. The photovoltaic model analysis was carried out to simulate the actual behavior of a photovoltaic module using Matlab - Simulink using the parameters of photovoltaic cells consisting of a single diode, series and shunt resistance. To evaluate the model, typical characteristics of a 175 WP 36 crystalline solar module were used . The characteristic curves were obtained from the manufacturer's data sheet, which shows an exact match of the model, and this proves that the module is reliable.

Keywords: *Photovoltaic module, photovoltaic cells, Matlab , photovoltaic module, simulation. photoelectricity, mathematical modeling.*

INTRODUCTION

One of the most important interests in the energy sector is a significant increase in the demand for electricity due to population growth and a lack of resources to meet the needs of mankind, such as clean water, clean air and electricity. It is well known that energy sources based on fossil fuels are almost drying up and causing harm to the environment (global warming, ozone hole, etc.) [1]. Therefore, in the last decade, there has been a huge focus on renewable energy sources such as solar, wind, biomass and water. These types of energy sources are advantageous in that they never run out and do not affect the environment. Solar energy is the most important compared to other renewable energy sources. It is an ever-growing energy, and it is widespread because it is readily available and free. Photovoltaic panels are used in many applications such as pumping water, rural street lighting, battery charging, and grid-connected photovoltaic systems. The main device of a photovoltaic system is a photovoltaic cell. Solar panels convert solar energy into electrical energy. This phenomenon occurs in materials that have the property of capturing a photon and emitting electrons. It is known that the main materials used in the photovoltaic industry are silicon polycrystalline thin films and single-crystal thin films [2, 3]. The solar cell is a p - n junction semiconductor diode and the solar cell alone can produce approximately 1 to 2 watts [2]. To increase power at a certain level, more solar cells are connected in series and in parallel to create a photovoltaic array or solar cell panel. We know that the current-voltage characteristic (CVC) of a solar cell has an exponential characteristic, and sometimes it has a significantly nonlinear character depending on the internal and external parameters of the solar cell [4]. These curves play a major role in the solar energy system. Many studies have been carried out for a long time to develop a comprehensive model of a photovoltaic module. Recently, a complete model of a photovoltaic system has been developed to simulate the electrical behavior of a photovoltaic model associated with a power system [4]. To study the effect of solar radiation and cell temperature on the performance of the entire model, it has been developed a generalized photovoltaic model [5]. A mathematical model of a photovoltaic system based on Matlab/Simulink was developed in [4, 5]. They take into account three modes of operation: open circuit, maximum power and short circuit points. Using simulations in Matlab, the influence of the environment on the electrical characteristics of a photovoltaic array at various temperatures was studied [5]. Large photovoltaic installations, such as those used in distributed power generation schemes, are a notable case. The PV characteristics become more complex with several peaks in the case of partial shading. The output of photovoltaic modules and the additional change in their I–V characteristics under the influence of various influences was studied in [6, 7].

The main purpose of this article is to provide the reader with fundamental knowledge about the design and construction of photovoltaic module blocks based on mathematical equations using Matlab / Simulink . The values of the model parameters are taken from the passport of a real photovoltaic module. Numerical results show the behavior of the photovoltaic module when changing two environmental parameters. In addition, the article explored the effects of shading using Simpower .

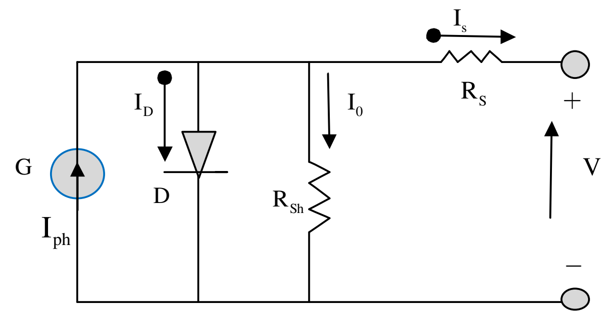

Fig. 1. Ideal single diode model

1. Equivalent circuits of photocells

In order to maximize the extractable power output of a photovoltaic power plant with MPPT control , understanding and modeling the photovoltaic cell is necessary. The ideal solar cell equivalent circuit is a current source connected in parallel with a single diode. The configuration of a simulated ideal solar cell with a single diode is shown in Figure 1. The basic photovoltaic cell is represented by a diode. It consists of n -type silicon and p -type silicon doped semiconductor with a resulting space charge layer. Typically, an unirradiated solar cell behaves much the same as a diode. Therefore, a simple diode can describe an equivalent circuit [8]. The semiconductor is temperature sensitive and the current generated by the irradiance of the photocell is linear with solar radiation and also with temperature. In Fig. 1 shows an ideal photovoltaic cell, and one of the simplified and basic modules consists of a single diode connected in parallel to a current source that generates light, the ratio of the output current and voltage is:

$$I = I_{ph} - I_0\left(\exp\left(\frac{qV}{nk_BT}\right) - 1\right), \tag{1}$$

I_{ph} - photocurrent, q - electron charge , equal to $1.6x10^{-19}$ C, V - diode voltage, k_B - Boltzmann constant, T - junction temperature, n - diode ideality factor (usually from 1 to 2) [9,10].
I-V characteristic of a photovoltaic module depends on the relationship between current and voltage generated in a typical solar cell. I-V characteristic curve and most of the parameters that affect the characteristics of a photovoltaic cell relate to resistances, as well as to the intensity of the irradiation level and temperature. Then we have

$$I = I_{ph} - I_S\cdot\left(\exp\left(\frac{V + IR_S}{nk_BT}\right) - 1\right) - \frac{V + IR_S}{R_{sh}}. \tag{2}$$

I_S is the reverse saturation current of the diode, and R_{sh} and R_S are the cell's own shunt and series resistances, respectively. Usually the value R_{sh} is very large and the value R_S is very small, so they can be neglected to simplify the analysis [7-9]; At the point of maximum power, formula (2) takes the following form

$$I = I_{ph} - I_0\cdot\left(\exp\left(\frac{V_{mp} + I_{mp}R_S}{nk_BT}\right) - 1\right) - \frac{V_{mp} + I_{mp}R_S}{R_{sh}}. \tag{3}$$

where I_{mp} and V_{mp} maximum values of current and voltage of photocells .

2. Modeling photovoltaic devices

Generated current I_{ph} photocells, without taking into account series and parallel resistances, is difficult to determine. The specifications only state the standard short circuit current I_{mp}, which is the maximum current available at the PV module's terminals. The semiconductor is temperature sensitive, and the current generated by the irradiance of the photocell depends linearly on the solar radiation and also depends on the temperature

$$I_{ph} = \left(I_{ph} + K_i (T - T_{rf})\right)\frac{G}{G_{rf}}. \quad (4)$$

The reverse saturation current of the diode I_0 and its dependence on temperature can be expressed as

$$I_0 = I_{os}\left(\frac{T_{rf}}{T}\right)^3 \cdot \left(\exp\left(\frac{qE_g}{nk_B}\left[\frac{1}{T_{rf} - T}\right]\right)\right), \quad (5)$$

E_g is the band gap for the considered type of photovoltaic module. The value E_g is a function of temperature and is related to its value [10-12]

$$E_g = E_g(0)(1 - 0.0002677(T - T_{rf})). \quad (6)$$

Note that for the type of photomodule under consideration, which is polycrystalline silicon, the value E_g is of the order of $E_{gs} = 1.121\ \text{eV}$. The value of the standard reverse saturation current $I_0 = I_{0S}$ is as follows [11]

$$I_{os} = \frac{I_{sc}}{\exp\left(\frac{qV_{os}}{nk_B T_{rf}} - 1\right)}. \quad (7)$$

, I_{mp} we can obtain an expression for the standard short circuit current ,

$$I_{mp} = I_{ph} - I_0 \cdot \left(\exp\left(\frac{V_{mp} + I_{mp}R_S}{n_s k_B T}\right) - 1\right) - \frac{V_{mp} + I_{mp}R_S}{R_{sh}}. \quad (8)$$

From where it is not difficult to find a formula for series resistance for its initial value $R_{SH} = \infty$

$$R_S = \frac{nk_B T_{rf}}{qI_{mps}} \ln\left(\frac{I_{phs} - I_{mps} + I_{0s}}{I_{0s}}\right) - \frac{V_{mps}}{I_{mps}} \quad (9)$$

Although the actual value R_{SH} is still unknown, it is certainly greater than R_s and using (9) we have

$$R_{sh,min} = \frac{V_{mp}}{I_{phs} - I_{mp}} - \frac{V_{osc} - V_{mp}}{I_{mp}}. \quad (10)$$

Determining the parameters R_S and R_{sh} the actual model of a single diode photocell is complex. With more independent parameters, the best fit should be determined iteratively, for example, by the Newton-Raphson method [10]. However, estimating the initial values for R_S and R_{sh} is relatively simple. In standard approaches R_S the calculation was made using (9) [12]. From the slopes at V_{OS} and I_{SC} respectively, one can estimate the series and shunt resistances R_S and R_{SH}.

RESULTS AND DISCUSSION

1. Volt-ampere characteristics

Volt-ampere characteristics (curve I-V) and volt-power (curve P-V), respectively, at different irradiance (solar radiation with values of 1000, 800, 600, 400, 200 and 550 W/m ^{2}) at a constant temperature based on the features presented in the article are shown in Fig. 2.

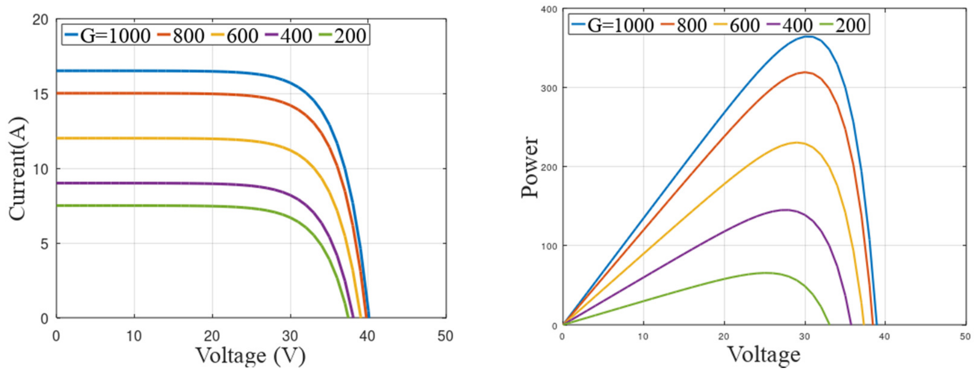

Fig.2. Volt-ampere (curve I-V) and volt-power (curve P-V) characteristics at different irradiance (solar radiation with values of 1000, 800, 600, 400 and 200 W/m ^{2}) at a constant temperature, respectively.

In real work, solar radiation with values of 1000, 800, 600, 400 and 200 W/m ^{2} , which is the average value at a natural temperature of 25° C. The graph shows that the photoelectric camera current depends on the case temperature. However, during irradiation, the current and voltage of the photocell increase. This results in power output in that operating state. With increasing solar radiation, it becomes clear that the short circuit current and open circuit voltage increase, as shown in the figure. This is because when more sunlight hits the solar cell, the electrons get higher excitation energy, thereby increasing the mobility of the electrons and thus more energy is generated, as shown in Fig. 2.

2. Effect of temperature on the performance of a fixed emission photovoltaic system

An increase in temperature around the solar cell negatively affects the ability to generate electricity. An increase in temperature is accompanied by a decrease in the value of the open circuit voltage, as shown in Fig. 3 . Increasing the temperature causes the band gap of the material to increase, and therefore more energy is required to overcome this barrier. Thus, the output power will be reduced and therefore the efficiency of the solar array will be reduced. Fig.3 shows V - P and I - P curves characteristics when the temperature of the solar cell changes.

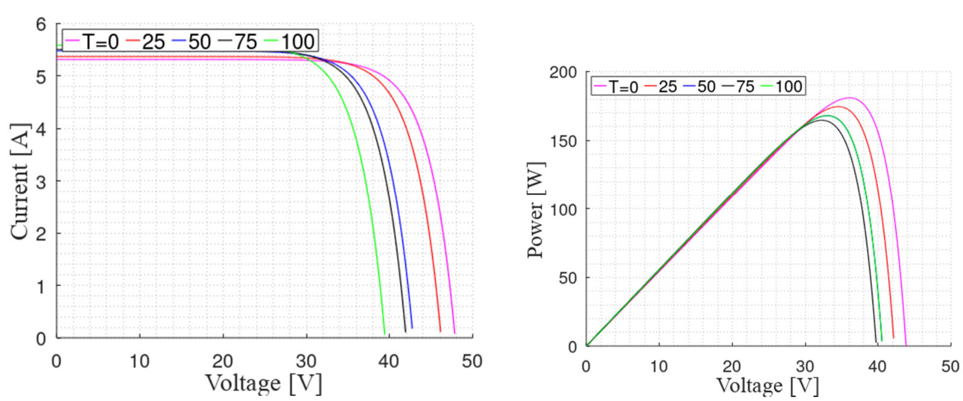

Fig. 3. Volt-ampere (curve I - V) and volt-power (curve P - V) characteristics at different temperatures (temperatures with values of 0, 25, 50, 75 and 100 °C) under constant sunlight, respectively.

3. Influence of series resistance (R_S)

The series resistance is the slope in the region where the photovoltaic cell behaves like a voltage generator, it does not change the open circuit voltage, and when it is high, it reduces the value of the short circuit current. An increase in series resistance results in a decrease in the slope of the power curve. The series resistance of the photocell is low and can be neglected in some cases. However, to make the model fit for any given photocell, one can vary this resistance and predict the effect of changing it on the output of the photocell. The effect R_S on the characteristics I - V and P - V is shown in Fig. 4. The simulation is done for four different values of R_S: 0, 0.05, 0.1, 0.15 and 0.2.

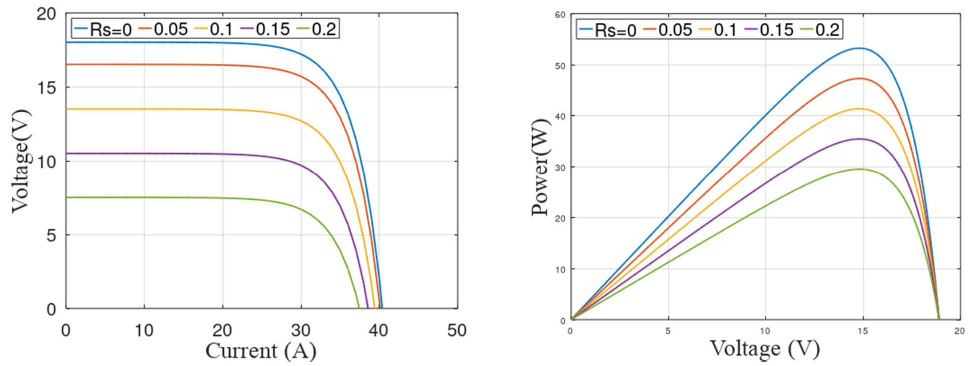

Fig 4. Volt-ampere (curve I-V) and volt-power (curve P-V) characteristics for different series resistance (series resistance with values of 0, 0.05, 0.1, 0.15 and 0.2) at a constant temperature T = 25° C and solar irradiance G = 1000 W/m ^{2}.

The change R_S affects the I-V slope, resulting in a deviation of the maximum power point (i.e., a decrease in series resistance leads to an increase in output power, as well as a deviation of the maximum power point). It shows that all no-load voltage values are at the same point on the voltage axis, despite the change in series resistance, thus it confirms that, no-load voltages do not depend on series resistance values, but, as can be seen, an increase series resistance values caused a large difference in current-voltage characteristics. Thus, an increase in series resistance will result in a decrease in power. Figure 4 clearly shows that the parameter that is most affected by the series resistance is the duty cycle and, therefore, the output power.

4. Influence of shunt resistance (R_{Sh})

The change in shunt resistance is simulated to know its effect on the performance of the P-V module by setting the irradiance and temperature ($G = 1000$ W/m^2, $T = 25°$ C) and changing the shunt resistance to (R_{Sh} = 0, 0.01, 0.03, 0.05,0.08). The result of modeling the characteristic of the voltage curve in accordance with these conditions is shown in Fig. 5. The results shown in the figure show that the open circuit voltage changes slightly as the shunt resistance decreases, i.e. a decrease in the shunt resistance will cause a slight decrease in the open circuit voltage. The shunt resistance affects the maximum power, i.e. the higher R_{Sh}, the more power. It is clearly seen that the largest parameter, which is affected by the shunt resistance, is the duty cycle and, consequently, the maximum power.

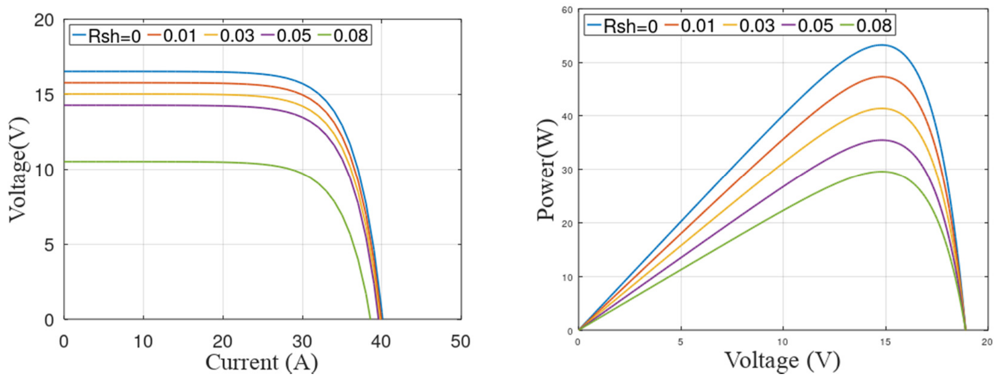

Fig. 5. Volt-ampere (I-V curve) and volt-power (P-V curve) characteristics for various series resistances (series resistance with values of 0, 0.05, 0.1, 0.15 and 0.2) at a constant temperature of 25°C and sunlight 1000 W/m^2.

The effect of the change R_{Sh} is much less obvious in the P-V model compared to R_S, and it only becomes noticeable when it (R_{Sh}) decreases too much. Because for a low shunt resistor, the P-V cell current drops more sharply, which means higher power losses. It is noticed that the smallest value R_{Sh} causes a sharper drop in the current of the photocell, which indicates higher power losses. Therefore, all practical photovoltaic cells must be high value R_{Sh} and low value R_S to provide more power output.

5. Changing the diode ideality factor

The variation of the diode ideality factor is simulated to find out its effect on the performance of the photovoltaic module, by setting the irradiance G =1000 W/m^2 and temperature T =25° C and changing the diode ideality factor to be (n =10, 20, 25, 45, 55). The result of CVC modeling in accordance with these conditions is illustrated in Fig. 6.

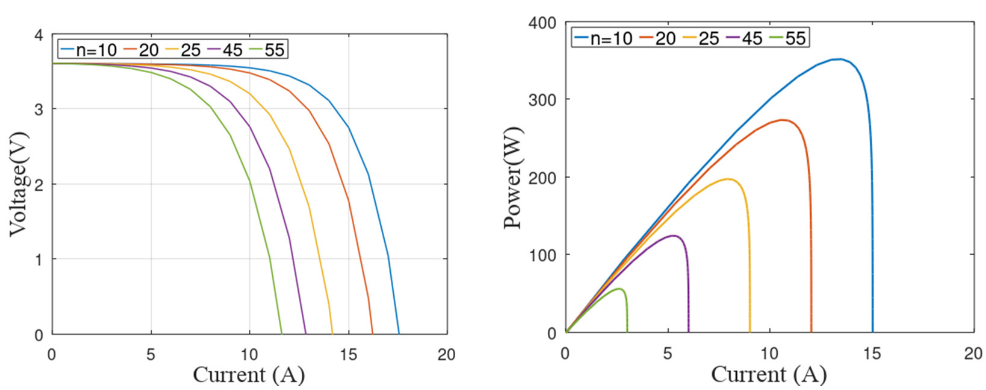

Fig.6. Volt-ampere (curve I-V) and volt-power (curve P-V) characteristics for different coefficient of ideality (factor of ideality with values 10, 20, 25, 45 and 55) at constant temperature

Our results show that one of the electrical parameters most strongly dependent on the diode ideality factor is the fill factor. Fig. 6 shows a slight decrease in the open circuit voltage as the diode ideality factor increases n. Thus, the ideality factor of the diode significantly affects the maximum power of the photocell, and the smaller the value n, the greater the power.

CONCLUSION

The article has developed and presented a model of a real photovoltaic solar array based on the equations of the fundamental circuit of a photovoltaic solar array using Matlab. The simulation results are confirmed by the manufacturer's passport and taking into account the influence of solar radiation and cell temperature on the electrical characteristics (curves V-I , V-P and I-P). It has been observed that the open circuit voltage decreases with cell temperature values while the irradiance value remains constant. It has also been observed that the voltage generated by a photovoltaic array during an open circuit and the short circuit current increase with increasing levels of solar radiation. The developed model of a photovoltaic array not only helps to predict the behavior of any photovoltaic cell under various physical and environmental conditions, but can also be considered as an intelligent tool for extracting the internal parameters of any solar cell, including series and shunt resistance. The key parameters needed to simulate a solar PV array are taken from the specifications of a typical 175W solar PV array. The results of the Matlab model show an excellent fit to the manufacturer's published curves.

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APPENDIX

k_B = 1.381 e-23; Boltzmann constant, J/K

q =1.602e-19; Electronic charge, C

N = 1.3; Diode quality facror

E_g =1.12; Band gap voltage,V

N_s =36; Number of cells in series

T_{ref} =0+273;% Temperature for which values are known

T_a =25; Temperature for which values have to be found

V_{oc} =22.06; Open circuit voltage, V

I_{sc} =8.63; Short circuit current, A

G =1000; Irradiance, W/m^2

V_{tref} =k*Tref/q;

K_0 =0.0058; Temperature coefficient

I_{ph} - the current generated by the incident light, A

I_s - the diode reverse bias saturation current, A

I_{sh} - the shunt resistance current, A

I_{sc} - short circuit current, A

I_{pv} - the output current, A

V_{pv} - the terminal voltage, V

V_{ph} - the photovoltaic voltage, V

I_d - the diode current, A

V_{oc} - open circuit voltage, A

R_s - series resistance, Ω

R_{sh} - shunt resistance, Ω

n - the ideality factor of the diode

V_{mp} - Voltage at the maximal power point,V

I_{mp} - Current at the maximal power point, I

Electrical characteristics of solar modules PS-P36 150 Wp	
Maximum power (Pm)	150.04 W
Voltage at Pmax (Vmp)	18.41 V
Current at Pmax (Imp)	8.15 A
Short-circuit current (Isc)	8.63 A
Open-circuit voltage (Voc)	22.06 V
Temperature coefficient of Isc (KI)	0.058 A/°C
Temperature coefficient of Voc (KV)	-0.33 V/°C
Number of cells in series (Ns)	36

PV technology	**Ideality factor**
Si-Mono	1.2
Si-Poly	1.3
a-Si-H	1.8
a-Si-H tandem	3.3
a-Si-H triple	5
cdTe	1.5
CTs	1.5
AsGa	1.3

Rsh input	Rs input	Voc(V)	Ioc (A)	Vmp(V)	Pmp(W)
37.9	0.021	22.06	8.63	18.53	150.13
50		22.06	8.63	18.53	150.13
100		22.06	8.63	18.53	150.13
400	Rs	22.06	8.63	18.53	150.13

T input	Voc(V)	Ioc(A)	Vmp(V)	Imp(A)	Pmp(W)
100	16.76	9.065	13.18	8.15	107.0713
75	18.5	8.92	14.94	8.1303	121.6776
50	20.25	8.775	16.72	8.118	136.0576
25	22.06	8.63	18.53	8.1	150.13
10	23.1	8.54	19.6	8.08	158.4124

Appendix B Relevant input and output data

G	Voc	Ioc	Vmp	Imp	Pmp
input	(V)	(A)	(V)	(A)	(W)
1000	22.06	8.63	18.53	8.1	150.13
800	21.8	6.904	18.31	6.5	118.5924
600	21.47	5.178	18.019	4.85	87.4303
550	21.33	4.746	17.92	4.43	79.7169
400	20.92	3.462	17.587	3.23	56.82