

Sensitivity and Monte Carlo Analysis Guides for Mass Production in Industry

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Abstract: - In many industries, different components are used/assembled for mass production. Because of the inherent nature of the components' variation, the final output value deviates from the intended one. So, we have to ensure that the variation of the final value is within a specified limit otherwise the produced items do not serve the purpose resulting a financial loss to the industry. In this paper, a sample electronic circuit (Maximum Power Point Tracker)[1] is taken into consideration and guidance is given for mass production taking components variation into consideration. These variations (caused because of manufacturing, aging, and environmental condition etc.) fluctuate the output which is not desired. In this paper, it is described how statistical analysis like sensitivity and Monte Carlo can help to identify and minimize the effect of variation.

Keywords- Sensitivity Analysis; Monte Carlo Analysis; Robust Design; Mass production

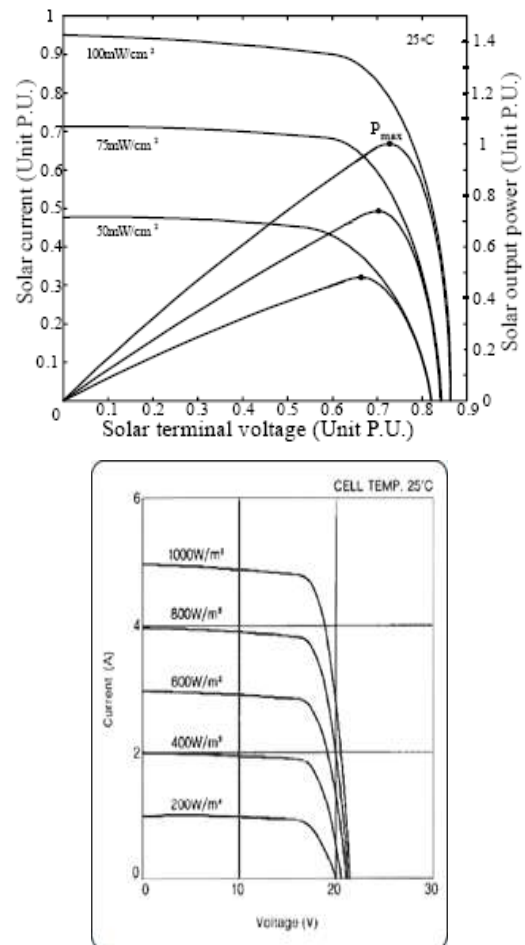
I. INTRODUCTION

In manufacturing process, different components are taken and assembled together to create a new product. Variations in the components can be seen mainly because of the environmental effect, aging and manufacturing inequalities. So, there is inherent variation in the components used for production. Because of this variation, output of the product/circuit is not within the specified values. So, different steps have to be taken into consideration to minimize the effect of variation in the output. While doing mass production, these changes plays very crucial role for profitability. As per the predefined criteria, if the output fluctuation exceeds the limit, those units are not salable which leads to loss of revenue. So, it is important to minimize the output fluctuation while doing a large scale production. Sensitivity and Monte Carlo analysis helps to identify the components which affects the output a lot. Over design, gives the desired output at the higher cost level and under design does not meet the requirement. So, after identification, tolerances [2] of those components are tightened to an appropriate value instead of doing it for all the components.

II. THE CIRCUIT UNDER CONSIDERATION

The circuit taken into consideration is a Maximum Power Point Tracker (MPPT) used at the output of the solar cell to extract maximum power out of it [3]. The maximum power point of a PV module is the point on the I-V curve that corresponds to the maximum output power possible for the

module. Maximum Power Point Tracking (MPPT) is an electronic circuit that extracts the maximum power from the output of the solar cells. Fig 1 [4] shows the locus of the MP (Maximum power) points at different radiation. Simple Tracking circuit shown in Fig 2 enables the solar cells to operate at MPP at different radiation level. For the analysis, PV cell is modeled by a voltage source connected by a variable series resistor whose resistance is changed according to the solar radiations.



(a) Output of PV cell at different radiation (b) KC-80 PV Cell Characteristic [4]

Fig-1 Output Characteristic curve of PV cell

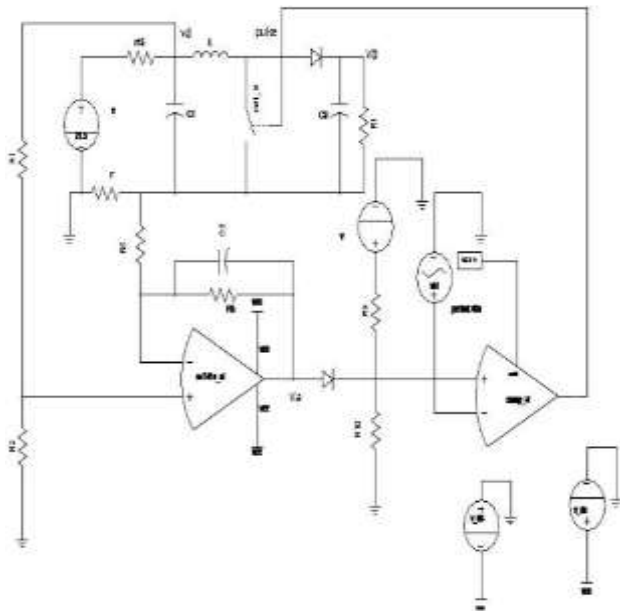


Fig -2 Simple MPPT Circuit (KC-80) for radiation of 1.0 kw/m²

III. CIRCUIT ANALYSIS AND OUTPUT

The module KC-80's I-V characteristic is shown in Fig 2 whose V_{mpp} (voltage corresponding to maximum power) is 16.9V and current corresponding to the maximum power is 4.73A for 1kw/m² radiation at a temperature of 25 degree centigrade. The open circuit voltage and short circuit current of the above module are 21.5V and 5A respectively. The incremental resistance of the portion left to the maximum power point is infinite (practically speaking it is very high). When voltage raises above V_{mpp} the change in current is also appreciable (fig-3) and circuit operates in closed loop until the incremental change in voltage is not tending to zero. After MPP (Maximum Power Point) there is a drastic change in slope compared to the slope of the left portion of MPP[5]. The operating point cannot enter into the left portion of MPP because of the very high incremental resistance which makes the pulse width unchanged. So basically this MPPT circuit operates on the right portion of MPP region, which can be visualized from the circuit configuration and below derived equations. MPP can be defined as an operating point above which the circuit enters in to the high resistance region if the curve is traced from the Open circuit voltage point. The desired output is 42V and is seen from the simulation result but we have not considered the components' variation. When the variations are taken into consideration, output can be seen from the figure 5. It means that the above variations can be seen in real practice if we do not take measure steps to minimize it.

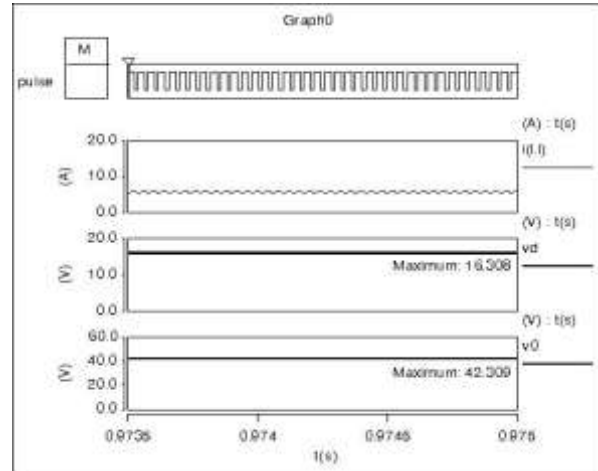


Fig-3 Simulation result of MPPT circuit for the radiation level of 1kw/m² (shows pulse, inductor current, input and output voltage of converter)

IV. CONCEPT OF ROBUST DESIGN: GUIDANCE FOR MASS PRODUCTION

Robust design (guidance to mass production) is an engineering methodology for optimizing the product and process conditions which are minimally sensitive to the various causes of variation, and produces high quality products with low development time and manufacturing cost. The focus is the robustness (quality) of the product performance. A robust product is one that works as intended regardless of the variation in a product's manufacturing process, variation resulting from deterioration, and variation in use. Robust design can be implemented when the designer understands these potential sources of variation and takes steps to desensitize the product to these potential sources of variation. One of the methods to use for the robust design is tolerances design. [6] Designing for quality signifies to minimize the defective units by testing and reworking for the failing parts or removing the cause of internal and external variations. This is not economically feasible and easy. So the concept of using robust design is becoming popular and is the simplest method for the most cost effective designs that meets performance specifications and promises the highest reliability.

V. SENSITIVITY ANALYSIS

Sensitivity analysis describes how the uncertainty in the output of a system can be related to different sources of uncertainty in its inputs[7]. This is a technique used to determine how different input values will impact the output to fluctuate. The sensitivity analysis analyzes the impact of all input variables on output and find out which variables cause a large change. Moreover, if inputs of the model are uncertain, which is usually the case; sensitivity analysis helps assess the importance of these uncertainties. SA (Sensitivity Analysis) can be simply stated as $dY/dx(i \text{ to } .j)$. Where Y is the output and $x(i \text{ to } j)$ are the inputs. Because of the tradeoff between

the cost of components with tight tolerances and the cost of variability in output, it is important to see if the variability in the output is too high due to variability in the components used in the design. Prior to this we need to know which components of the design are responsible for variation in the output[11]. It can be determined by running the Sensitivity Analysis. The below mentioned Sensitivity report shows the parameters with the most influence on the above MPPT circuit for the variation in output. The bar chart indicates the relative sensitivity of the measured signal(s) to the component value that was varied. The greater the number of ticks on the bar chart, greater is the influence of that component on the output. So, r1 has the highest impact on the output fluctuation followed by r15, r9 and so on. By performing sensitivity analysis on the above circuit (fig-2), we get to know which parameters are influencing the output result. The negative sensitivity value indicates that as the parameter value is increased, the overshoot in the output curve decreases, and vice-versa. The most influencing parameters from this analysis are used for Monte Carlo Analysis considering the random variation in their tolerance values.

Sensitivity Report Options				
Minimum sensitivity magnitude to report:		0		
Report sorted by:		Value		
Sensitivity normalization:		Normalized		
Normalization threshold:		100E-15		
Sensitivity of Overshoot of v0 in file to_sens				
Nominal Value = 32.966m				
Instance	Part Type	Parameter Name	Nominal Value	Sensitivity Bar-chart
r.r1	resistor	rnom	22	0.284
r.r15	resistor	rnom	973m	-0.209
r.r10	resistor	rnom	1k	0.199
r.r9	resistor	rnom	15k	-0.127
r.r	resistor	rnom	100m	-0.0462
c.c5	capacitor	c	500u	-0.0114
c.c1	capacitor	c	40u	0.0114
l.l1	inductor	l	400u	0.0114
r.r1	resistor	rnom	22.9k	0.0114
r.r2	resistor	rnom	1.5k	0
r.r8	resistor	rnom	10k	0
c.c2	capacitor	c	5u	0

Fig-4 Sensitivity report of the circuit

VI. MONTE-CARLO ANALYSIS

In a Monte Carlo analysis, a random value is selected for each of the tasks, based on the range of estimates. The model is calculated based on this random value. The result of the model is recorded, and the process is repeated. A typical Monte Carlo analysis calculates the model hundreds or thousands of times, each time using different randomly-selected values. When the analysis is complete, we have a large number of results from the model, each based on random input values. A realistic distribution for the values of these parameters based on manufacturing data will be added in the simulation model [8]. These distributions will allow us to look at the variability of the output due to variability in the components. If the variability in the output is too high, tolerances will have to be tightened which increases the cost of the system. So one needs to know the variation as to which

component affects the output. Monte Carlo allows all parameters to randomly vary in their tolerance band and compute the co-relation between the variations in performance and variations of each of the independent parameters[12]. These results are used to describe the likelihood, or probability, of reaching various results in the model. In a simple way, we can say that Monte Carlo is just like forecasting with different range of estimates. Tolerances can be uniform, normal or piecewise linear. For example, a 10k resistor with 10% tolerance can be defined in Normal distribution as rnom=normal (10k,0.1) for simulation. The Monte Carlo analysis for 60 runs is shown below. Contrary to sensitivity analysis, Monte Carlo analysis takes the entire component's variation into consideration. It shows that when there is a variation in the tolerances, how the output fluctuates. 2% variation, in r1, when combined with 3% variation with r2, the variation in I1 can be highest. All the correlations among different components are captured here. By doing this MC analysis, we can get to know the maximum variation in the output. When statistical analysis is performed using Monte Carlo analysis for the present circuit an output curve (v0) gives the standard deviation of 0.0912 as shown below. Pareto analysis confirms the most influencing parameters for the output variation taking the MC simulation into consideration.

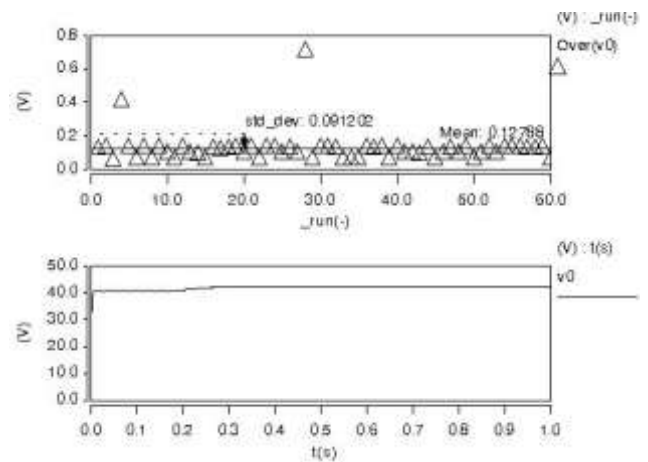
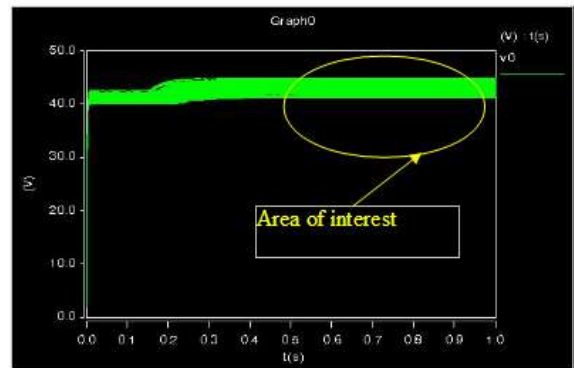


Fig-5 Variation in output after Monte Carlo Runs and the statistical information

VII. PARETO ANALYSIS

Pareto analysis orders the rank of the parameters that have the biggest effect on the variance of the design performance measure [10]. It provides correlation data about the impact of tolerances on the design performance measure [9]. The below mentioned plots are the measures of how sensitive the fluctuation of output voltage is to the system components. This analysis yields some interesting information. For example the overshoot of output voltage is most sensitive to r10 followed by l (inductor) and r9. In the scatter plots (fig-8), the slope of the line corresponds to a bar in the Sensitivity histogram. The variation about each line corresponds to a bar in the R**2 histogram. The Sensitivity histogram shows the percentage change in performance per percentage change in parameter. This is similar to a standard Sensitivity Analysis, but in this case, component tolerances are taken into account. The R**2 histogram shows the %total variation of the measurement as a result of the given parameter. Sensitivity can be thought of as the slope of best fit line of scattered point whereas R2 can be thought of as tightness of scatter points around best fit line. From fig 9 it can be interpreted that rnom (r.r10) has strong positive correlation (sensitivity) and greater relative contribution (R2) to change in the overshoot of v0. This analysis has shown that the most influencing parameters which needs tight tolerance are r10, l(inductance) and r9 to desensitize output. Now the tolerance of the above three components are tightened (from 10% to one percent) and standard deviation of the output curve (v0 shown in fig-9) has dramatically changed from 0.0912 to 0.0306. Instead of tightening the tolerance band of the entire component, the change in tolerance of the particular three components makes the circuit robust.

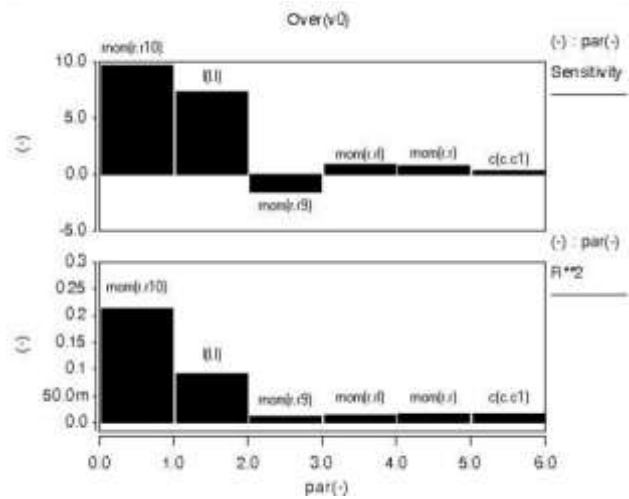


Fig-6 (b) Sensitivity and R**2 Histogram

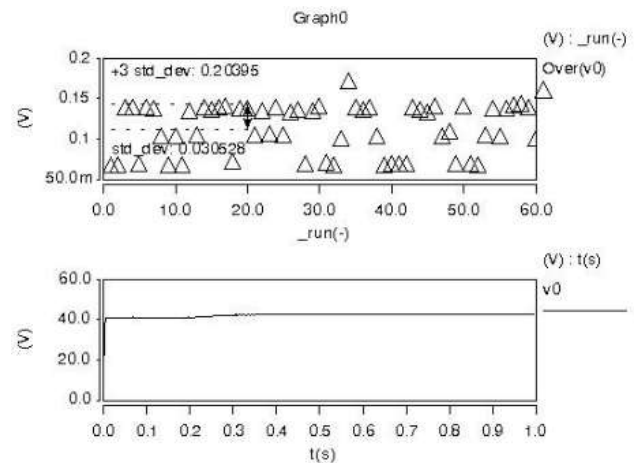


Fig-7 Statistical Result after changing three tolerances

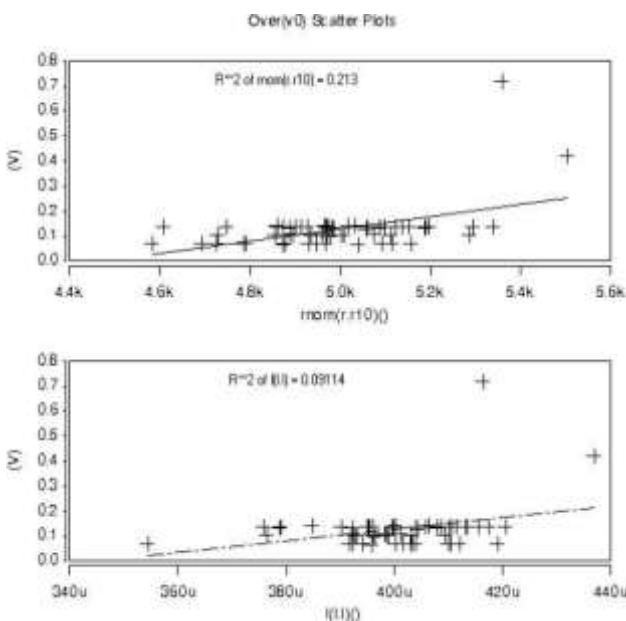


Fig-6 (a) scattered plot of r2 from Pareto analysis

VIII. CONCLUSION

A sample MPPT circuit is taken into consideration for this scenario. Naturally, each manufactured component has some variation and these variations increase because of environmental and aging effect. Usually, the variations are guided by taking into consideration of components tolerance defined by manufacturer. Sensitivity analysis ranks the components which can affect the output without considering the co-relation among them and Monte Carlo analysis (basing on the input of sensitivity) considers the correlation among the components' variation and gives the maximum fluctuation in output. Pareto analysis takes the input from Monte Carlo and ranks the components which affect the output and tightening the tolerance of the exact components help to limit the output variation. Tightening the tolerance of the all the components of the circuit is nothing other than over design and industry has to spend more money which is undesired. Instead of tightening the tolerance of all components only the critical components' tolerance can be tightened resulting in improved

cost effectiveness. So the designer of the circuit becomes aware of the cause and hence minimizes the tolerance band to get the output which leads to the robustness of the design guiding to mass production.

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