A CIRCUIT ANALYSIS- BASED FAULT FINDING ALGORITHM FOR PHOTOVOLTAIC ARRAY UNDER L-L/L-G FAULTS

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Abstract

In photovoltaic (PV) array including blocking diodes, line to line faults and line to ground faults are difficult to diagnose. In our research work, we will be discussing 4 types of fault that are commonly observed in PV array which are single line to ground fault (L-G), single line to line fault (L-L), line to line fault between two strings and partial shading. The above mention faults may appear at any strings of PV array and if not dealt with properly can cause irreversible damage to the PV modules. In this research work, this complex problem will be resolved in 2 steps-

1) DC circuit analysis of PV array under different fault conditions.
2) Summarization of all the observations and presenting fault finding algorithm (FFA) based on statements presented during summarization.

At the end, the proposed FFA along with the statements will be verified by MATLAB program and simulation and compared with different existing methods.

Student 1 (Anirudh Gaur) contribution-

Presenting a study of different types of fault occurring in PV array as discussed above in the abstract and performing a DC circuit analysis of PV array under different fault conditions discussed. After the circuit analysis, doing a summarization of all the observations.

Student 2 (Samved Rajvanshi) contribution-

Presenting fault finding algorithm (FFA) based on statements presented in summarization by Anirudh and verifying the proposed FFA by MATLAB program and simulation.

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Chapter 1
Introduction

As the usage of photovoltaic plants has been increasing around the world, the need for fault diagnosis in PV array is necessary to provide a reliable and stable working system of PV plant. The most frequent and prominent fault in PV array are line to ground fault, line to line fault, mismatch fault and arc fault. Due to the existence of blindspots caused by varying irradiance level and other factors, PV array may also be in the danger of fire hazards. This situation is further complicated as L-L and L-G fault have certain resemblance to partial shading which would be explained later in the report. Below is a brief description of various types of faults in PV array.

Faults in PV array

1. **Partial Shading and role of Bypass diode-** Partial shading (PS) is a frequent phenomenon that occurs when some modules within an array receive different irradiance level. Since the shortcircuit current of a PV module is proportional to the irradiance level, the modules under PS start producing less current, while the un-shaded modules continue to operate at a higher photocurrent. As the string current must be equal through all the series-connected modules, the shaded modules as a result operate in the reverse bias region to conduct the larger current of the unshaded modules. The shaded modules consume power due to the reverse voltage polarity. Therefore, the maximum extractable power from the shaded PV array decreases. This may even lead to creation of hotspot and to avoid this, bypass diode are connected in parallel to PV module which get activated when reverse voltage across the shaded module increases, thus providing an additional current path.
2. **Line to Line fault-** A line to line fault is an accidental short circuiting between two points in PV array with different potentials. They are difficult to detect and clear by the means of conventional protection devices. The fault location are not specific in this case and may occur between any two points in the PV array.
3. **Line to Ground fault-** This type of fault in PV array is caused due to an accidental short

circuit involving ground and one or more normally designated current carrying PV modules. They generate more attention compared to Line to line fault as they generate DC arcs at the fault point which may even lead to fire hazard. Causes of this fault may vary from insulation cable failure, solar cell deterioration, impact damage, etc.

1.1 Project Work:

This project revolves around identification and classification of L-L, L-G faults and temporary faults such as partial shading of PV array. A simple and fast method has been developed for L-L and L-G fault and each PV module has been represented as current source with diode in parallel. Based on this, certain statements have been proposed which have been used to give a fault finding algorithm (FFA) which has been verified through simulation.

The circuits for inducing various types of faults have been designed using MATLAB Simulink and a comprehensive analysis has been done to identify a pattern based on which an algorithm has been presented to distinguish between various faults. Due to the coronavirus restrictions and non-availability of hardware, the hardware circuit analysis for the same might not be possible but we will try our best to do it in the 2nd half of the semester. We have also mentioned our current work and the future scope of improvement along with the work to be done for later half of the semester.

Chapter 2

Literature Survey

We will look at the various merits and demerits of research papers we have referred. Some of these papers have tried implementing various other means to tackle fault detection in PV array which will also be discussed.

2.1 Role of Protection Devices

To safeguard PV array from the faults we had discussed above in introduction, overcurrent protection devices (OCPD), ground fault protection devices (GFPD) had been used. These devices are installed on each string but still blind-spots are caused due to varying irradiance level [1],[2]. These protection devices in these cases are unable to disengage the faulty string leading to deterioration in stability and reliability of the system.

2.2 Other Models proposed by researchers

For solving this complex problem related to PV system, researchers in the past suggested strategies based mainly upon comparison between expected data and real-time data of PV array [1],[3]. Some of these schemes are described below along with their merits and demerits-

1. **Statistical Methods-** A statistical t-test model was used in paper [3] and paper [2] and [4] employed a more scientific approach. The demerits of these research work was that [3] and [2] required costly irradiance sensor while [4] required high number of voltage sensors. Another work [5] was optimal in identifying L-L and L-G faults effectively but had a complex mechanism of wavelet packet transformers. Another major flaw in all these research papers was that they contain relatively less literature about the classification of faults.

2. **Machine Learning/ Artificial Intelligence Methods-** Papers [6] and [7] have proposed neural-networks based methods which are complex in nature having high implementation cost as the dataset is quite large and model training in this case is a cumbersome task.

3. **Virtual Image Methods-** Papers [7] and [8] observe the thermal behavior of PV modules by utilizing infrared cameras. The image captured is observed for abnormality check which indicates if fault is present or not. These cameras are very expensive and not practical for usage in large PV arrays as large quantity of such cameras would be required along with consistent monitoring of the data available by the pictures from these cameras.

2.3 Behavior of String under fault

The entire PV system can be characterized into two categories: 1) dc subsection that mainly contains PV array with blocking/bypass diodes and storage systems [3] and 2) ac subsection where converter/inverter and grid-tie devices are present. In PV array, the current imbalance between the PV modules due to temporary faults such as partial shading, dust and bird's dropping is dealt with bypass diodes. The same situation between the strings is tackled through blocking diodes [10]. The role of bypass diode has been explained in the introduction section but unfortunately, presence of blocking diodes leads to creation of numerous blind spots for conventional protection devices when PV array is under L-L and L-G fault [9].

Chapter 3
Work Done

Apart from reading research papers and writing about their certain merits and demerits, the work we have done till now focuses on making a circuit using MATLAB Simulink and analyzing partial shading, L-G fault and L-L fault effects on it compared to standard conditions.

3.1 Circuit Description

We have added the following blocks from Simulink in our circuit- PV array, constant block, diode, voltage and current measurement, product block, x-y graph, scope, series RLC branch and power GUI block. The PV array block model has been chosen such that it has a maximum power of 1000W at maximum voltage point 26.3 V.

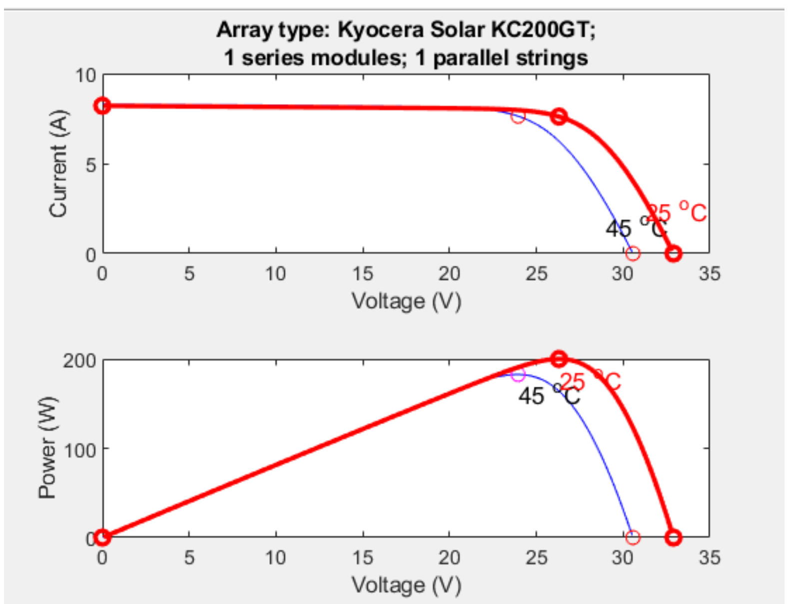

Fig 3.1 Rating of PV module

Next we connect a bypass diode across each PV module and arrange these module in such manner that 3 modules are in series forming a string and 2 strings are in parallel thus forming a 3X2 PV array. The constant blocks for each PV module are set to value 1000 and 25 and are responsible for irradiance level and standard temperature respectively.

A blocking diode is also connected to each string. Current and voltage sensors are connected along with series RLC branch block to measure current and voltage. Product block us used to calculate power and X-Y graph block along with scope are used to visualize P-V curve and voltage and current measurements.

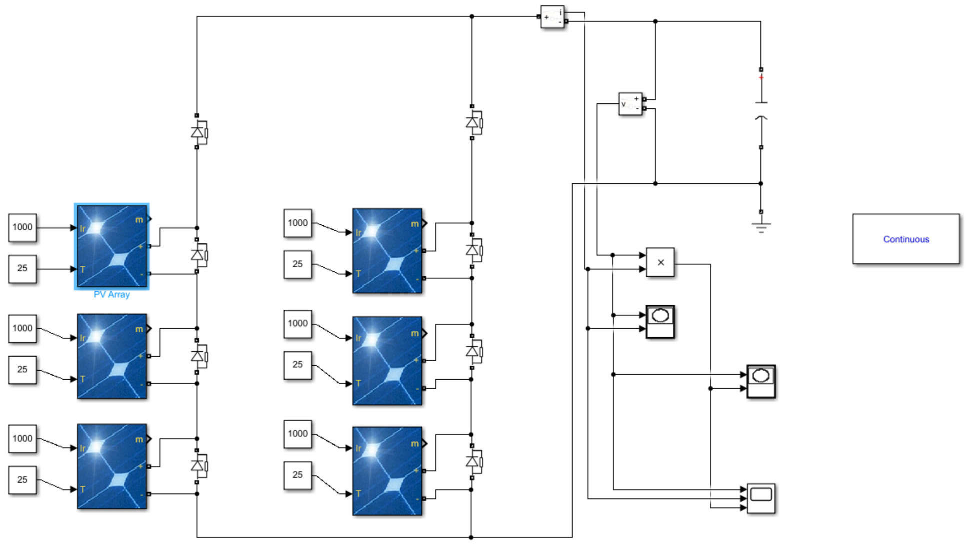

Fig 3.2 Circuit Diagram

3.2 Observation under various test conditions

Under standard test conditions i.e. temperature 25 degree and 1000 W/meter square irradiance, the results are shown in below figure.

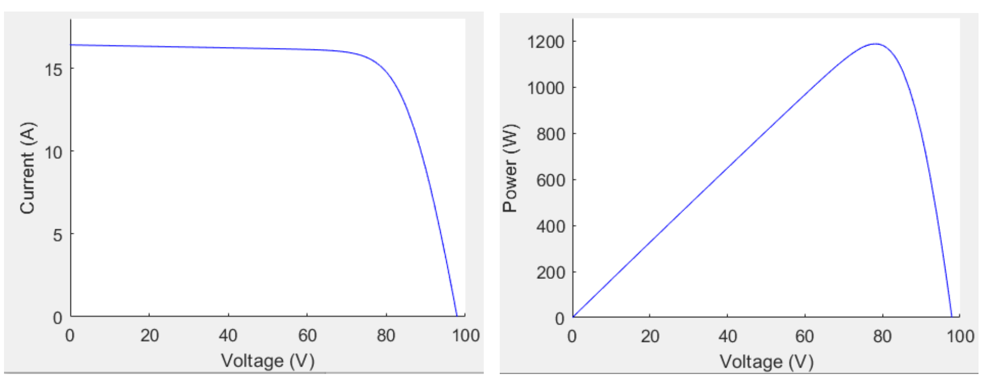

Fig 3.3 a) denotes Current vs Voltage and fig 3.3 b) denotes Power vs Voltage graph

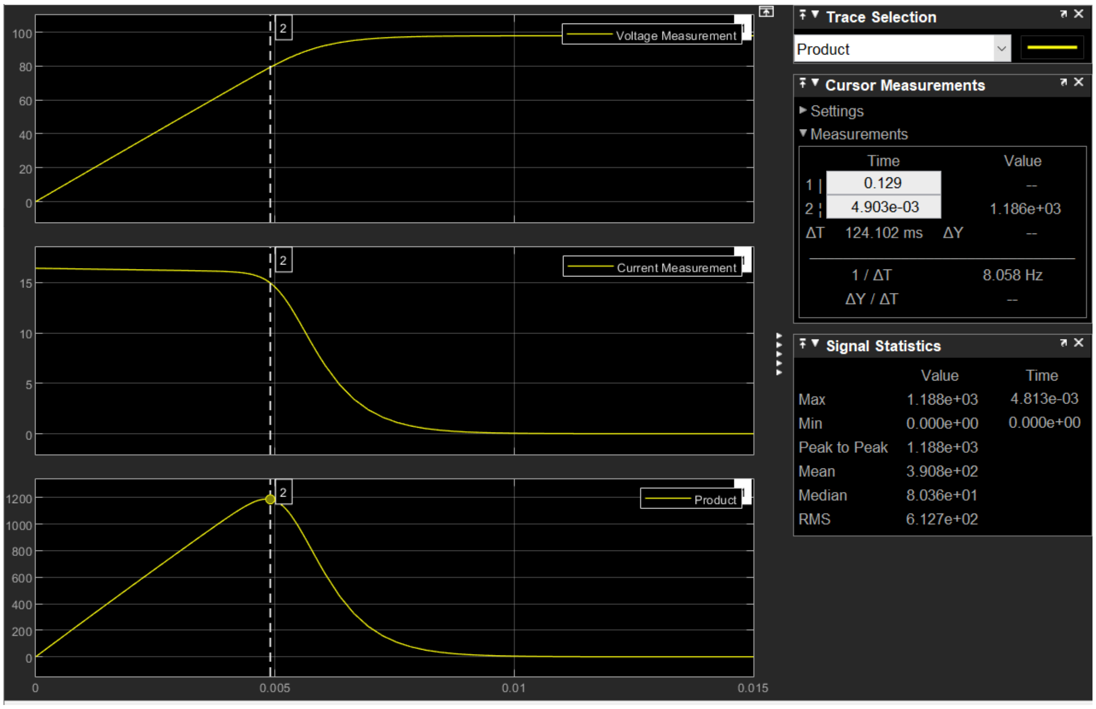

Fig 3.4 Measurement at No fault

Fig 4 denotes the value of voltage, current at power from the given circuit arrangement. It is clearly observable the maximum power point value is around 1188 Watt and its corresponding voltage value is 97 volts which it should be as voltage of individual PV module is around 32 volts and 3 modules are in series resulting in voltage of approximately 97 volts. The current corresponding to maximum power point is 16.5 A (approx.) which is result of addition of two strings having equal contribution in current.

3.2.1 Under partial Shading

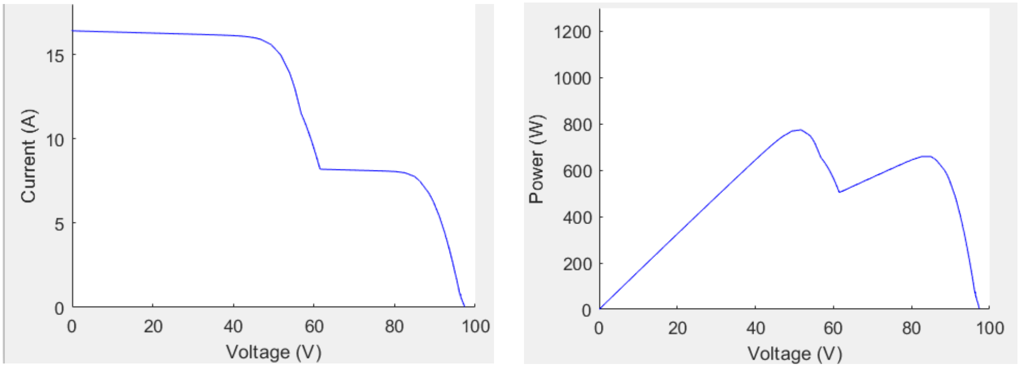

Fig 3.5 a) and Fig 3.5 b) denoting IV curve and PV curve respectively

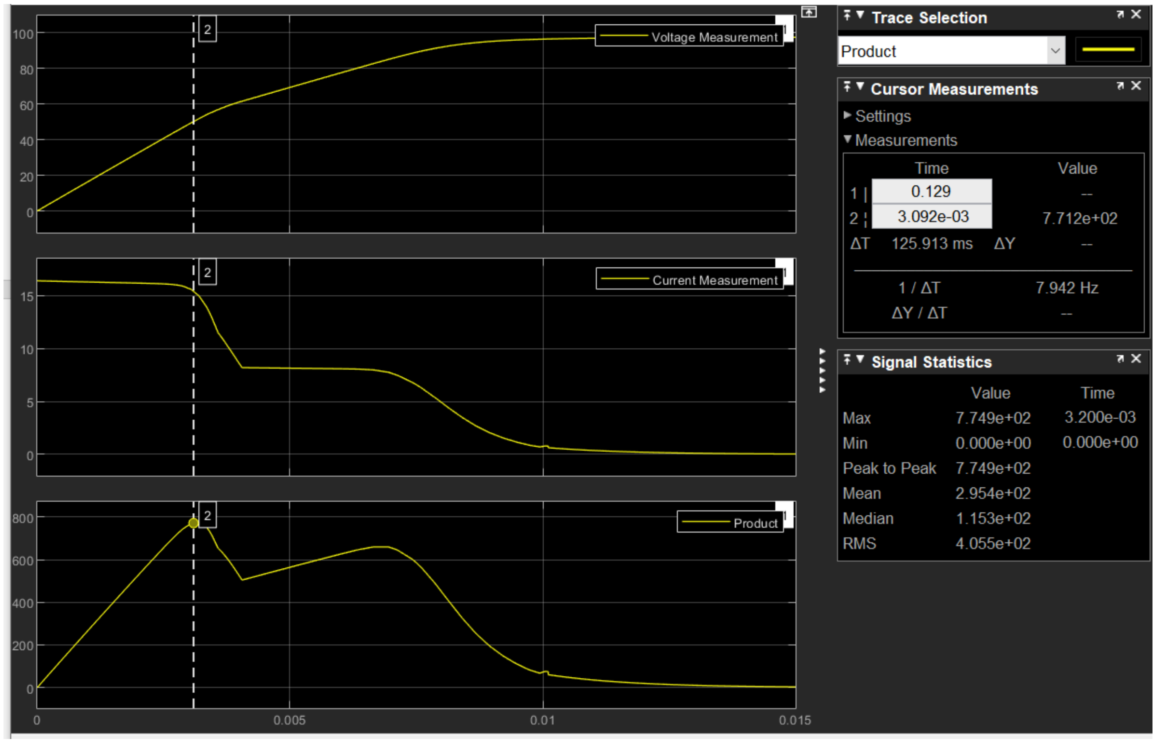

Fig 3.6

After changing the irradiance level of 3rd PV module in 1st string to 300 and 2nd module in 2nd string to 700, we observed the formation of local maxima in IV and PV curves. Also there was a significant reduction in maximum power point noticeable. Other parameters and their changes have been summarized in a table at the end of this section.

3.2.2 Under L-G fault

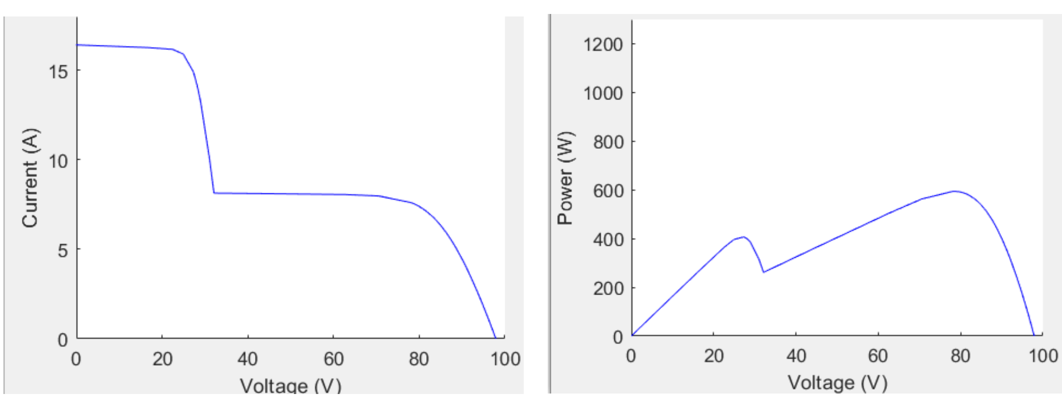

Fig 3.7 a) and 3.7 b) denote the IV and PV curve respectively

Fig 3.8

In L-G fault, we short circuit the lower two modules of string 1 by connecting them to ground leading to 67% mismatch. A staircase like patter is visible in IV curve and local maxima similar to partial shading are also observable. The maximum power point value has decreased and other parameters also have been tabulated later.

3.2.3 Under L-L fault

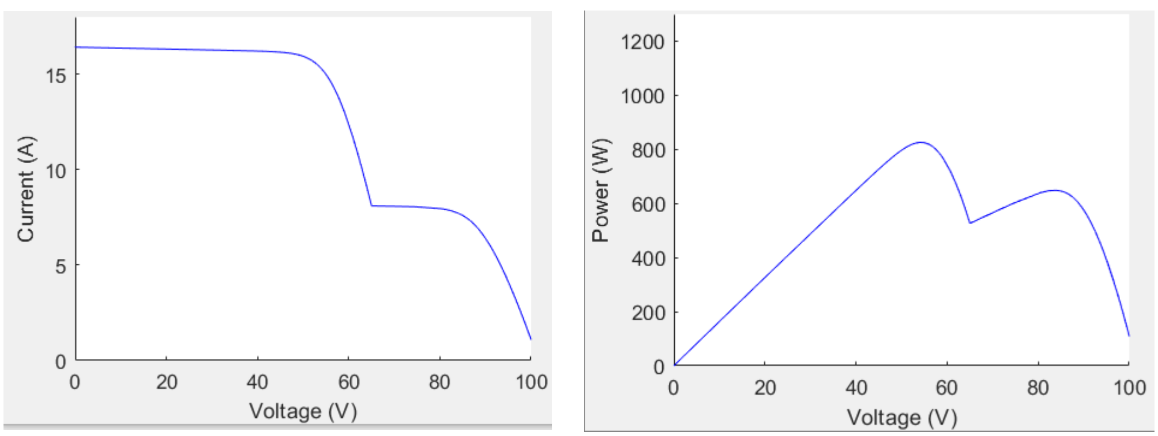

Fig 3.9 a) and 3.9 b) show IV and PV curves respectively

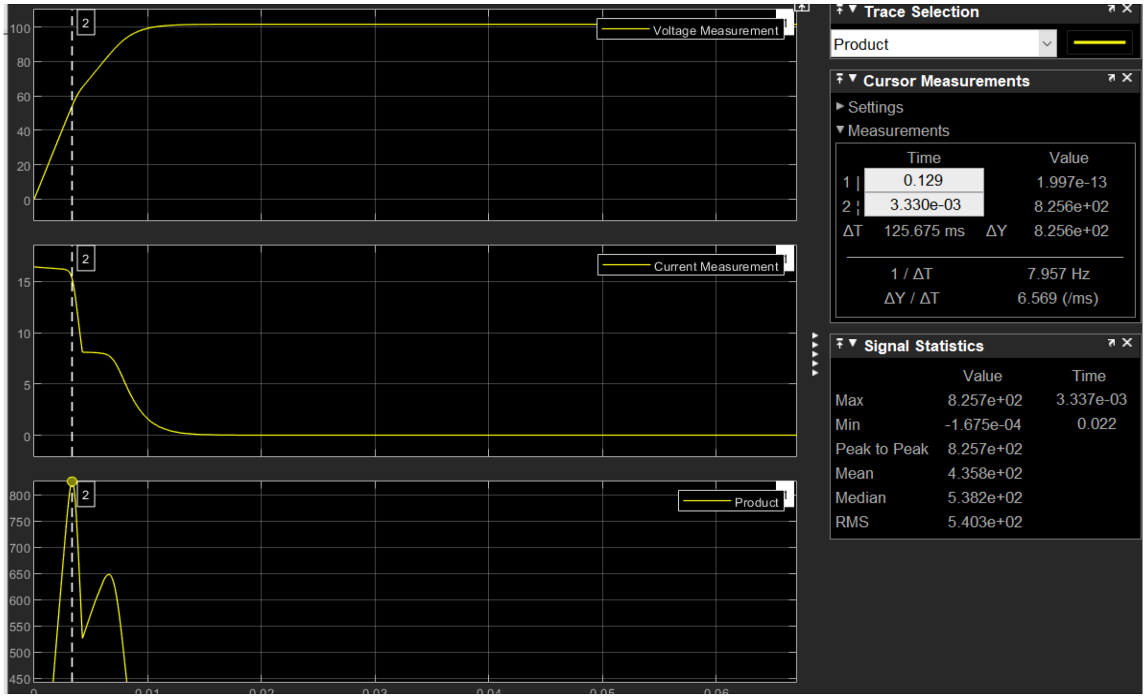

Fig 3.10

In case of L-L fault, we connect module 2 of string 1 to module 1. The maximum power point value is greater than that in case for L-G fault which reiterates our point that L-G faults are more severe than L-L faults. Similar to the cases before, data tabulation has been done at the end of the section regarding these two faults.

3.3 Results and Analysis

Fault Type	I(max)(Amp)	I(mpp) (Amp)	V(max)(Volt)	V(mpp)(Volt)	P(mpp)
None	16.45	15.00	97.9	79.13	1188
Partial Shading	16.45	14.83	97.36	52.04	774.9
Line to ground	16.45	7.41	97.9	79.74	593.7
Line to Line	16.45	15.28	101.6	54.04	825.7

Table 3.1

In the table, mpp stands for maximum power point i.e. where maximum power is obtained. As we can clearly see out of all the faults, line to line fault has least power loss as it has maximum value of power at mpp. The table shows result for a 33% mismatch during L-L fault and 67% mismatch for L-G fault. For simulations having more than one fault e.g. both L-G and partial shading, even though we have not shown the results but the observation was of more than 2 local maxima in that case for PV curve and even greater loss of power compared to L-G fault.

Chapter 4

Plan for Next Half Semester

As of now, we have demonstrated various faults and their effects on the PV module but we are yet to distinguish them with the help of a definite algorithm. Due to the less amount of time present during this half of the semester, our work had a restricted reach which we will surely try to complete in the next half.

We plan to make certain changes in the model such as addition of voltage sensor in each individual string apart from the entire array. We also plan to study double line to ground fault and double line to line fault going forward as they would play a crucial role in formulating and algorithm.

Finally based on all our results and observations we plan to formulate a condition-based fault-finding algorithm (FFA) in which certain threshold parameters would be set up by us. This FFA would be represented in form of conditional blocks and will be based on the behavior of each individual string rather than the entire array in response to different faults. If possible we would also like to do a hardware simulation of entire PV circuit which depends upon the cost of material and availability.

4.1 Future Plans Summarized

The plans for next half semester are listed below in brief-

1. Making additions in the circuit at each individual string level to get better analysis of different faults.
2. Result formulation for double L-G and double L-L faults.
3. Stating a fault-finding algorithm based on the observations we have made which will be crucial in identifying which type of fault is being carried out.
4. If possible, doing a hardware analysis of the circuit (Depends upon availability of material along with time and cost restrictions).

References

[1] Z. Yi and A. H. Etemadi, “Line-to-line fault detection for photovoltaic arrays based on multiresolution signal decomposition and two-stage support,” IEEE Trans. Ind. Electron., vol. 64, no. 11, pp. 8546–8556, Nov. 2017.

[2] R. Hariharan, M. Chakkarapani, G. S. Ilango, and C. Nagamani, “A method to detect photovoltaic array faults and partial shading in PV systems,” IEEE J. Photovolt., vol. 6, no. 5, pp. 1278–1285, Sep. 2016.

[3] M. Dhimish and V. Holmes, “Fault detection algorithm for gridconnected photovoltaic plants,” Solar Energy, vol. 137, pp. 236–245, Nov. 2016.

[4] Y. Hu et al., “Online two-section PV array fault diagnosis with optimized voltage sensor locations,” IEEE Trans. Ind. Electron., vol. 62, no. 11, pp. 7237–7246, Nov. 2015.

[5] B. P. Kumar, G. S. Ilango, M. J. B. Reddy, and N. Chilakapati, “Online fault detection and diagnosis in photovoltaic systems using wavelet packets,” IEEE J. Photovolt., vol. 8, no. 1, pp. 257–265, Jan. 2018.

[6] W. Chine, A. Mellit, V. Lughi, A. Malek, G. Sulligoi, and A. M. Pavan, “A novel fault diagnosis technique for photovoltaic systems based on artificial neural networks,” Renew. Energy, vol. 90, pp. 501–512, May 2016.

[7] D. S. Pillai and N. Rajasekar, “A comprehensive review on protection challenges and fault diagnosis in PV systems,” Renew. Sustain. Energy Rev., vol. 91, pp. 18–40, Aug. 2018.

[8] Y. Hu, W. Cao, J. Wu, B. Ji, and D. Holliday, “Thermography-based virtual MPPT scheme for improving PV energy efficiency under partial shading conditions,” IEEE Trans. Power Electron., vol. 29, no. 11, pp. 5667–5672, Nov. 2014.

[9] Y. Zhao, J.-F. de Palma, J. Mosesian, R. Lyons, and B. Lehman, “Line–line fault analysis and protection challenges in solar photovoltaic arrays,” IEEE Trans. Ind. Electron., vol. 60, no. 9, pp. 3784–3795, Sep. 2013.

[10] R. Ahmad, A. F. Murtaza, H. A. Sher, U. T. Shami, and S. Olalekan, “An analytical approach to study partial shading effects on PV array supported by literature,” Renew. Sustain. Energy Rev., vol. 74, pp. 721–732, Jul. 2017.

[11] W. Xiao, N. Ozog, and W. G. Dunford, “Topology study of photovoltaic interface for

maximum power point tracking," IEEE Trans. Ind. Electron., vol. 54, no. 3, pp. 1696–1704, Jun. 200

[12] W. Wang, A. C.-F. Liu, H. S.-H. Chung, R. W.-H. Lau, J. Zhang, and A. W.-L. Lo, "Fault diagnosis of photovoltaic panels using dynamic current–voltage characteristics," IEEE Trans. Power Electron., vol. 31, no. 2, pp. 1588–1599, Feb. 2016.

[13] C.-L. Kuo, J.-L. Chen, S.-J. Chen, C.-C. Kao, H.-T. Yau, and C.-H. Lin, "Photovoltaic energy conversion system fault detection using fractionalorder color relation classifier in microdistribution systems," IEEE Trans. Smart Grid, vol. 8, no. 3, pp. 1163–1172, May 2017.