Fault Detection In PV Strings Using SSTDR

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***Abstract*— We present spread spectrum time domain reflectometry (SSTDR) analysis for finding faults in live PV arrays. SSTDR has been applied to a combination of PV modules, and responses are recorded and analyzed for various discrete discontinuities. An internal complex circuit diagram for a PV module is presented for the better understanding of the effect of the SSTDR signal inside the PV modules. Analysis of the SSTDR results is helpful to find the exact position of faults in PV arrays.**

Keywords—Spread Spectrum Time Domain Reflectometry (SSTDR), photovoltaic(PV).

I. INTRODUCTION

In the past few decades, the ever-growing need for electricity has paved way towards utilizing the abundant solar energy for powering electrical equipment. This rise in demand has led to rapid increase in deployment of photovoltaic (PV) systems to convert solar energy to electrical energy. These deployed PV systems are subjected to harsh environmental conditions like corrosion, stress, humidity etc. which increase the occurrence of electrical faults and in turn damage the overall functionality of the system. Several protective devices are used to mitigate faults including ground fault interrupters (GFCI), residual current circuit breakers (RCCB), over current protection devices (OCPD), etc. Knowing the location of the fault when one of these devices trips is necessary to enable timely repair. Spread Spectrum Time Domain Reflectometry (SSTDR) [1] has been used for fault location on other types of live systems. SSTDR is a reflectometry method that transmits a high frequency sine or square wave modulated pseudo noise (PN) sequence through the system, where it reflects at impedance discontinuities and returns to the transmitter. The incident and reflected PN signals are correlated to find the distance to fault. The PN code can be used below the noise margin of the system, which makes SSTDR an ideal candidate for detecting both hard and soft faults in high voltage live electrical systems [2][3]. In previous work, SSTDR has been used to detect ground faults, line-to-line faults and arc faults in PV systems with resistive, open circuit and short circuit loads [4][5]. In the current article, we apply SSTDR for detection of faults in PV systems with complex (capacitive) loads.

II. EXPERIMENTAL SETUP

The asymmetric panel configuration shown in fig.1 uses three de-energized PV panels connected to a WILMA W50A000F SSTDR device. A 40-foot-long 10 AWG PV wire with a characteristic impedance of ~157Ω was used as a leader cable to connect the SSTDR to the PV panels. The velocity of propagation (VOP) of the leader cable was calculated to be 0.69 c. To obtain a baseline calibration for the PV system, the SSTDR waveform for just the 40 foot 10 AWG PV leader cable with an open circuit on the end was measured. This baseline is then used as a calibration for the remainder of the measurements. The boxes labeled with the letters, A, B, C, and D in fig.1 represent industry standard MC-4 PV panel connectors with the positive end of the connectors connected to the positive PV terminal and the negative end of the connectors connected to the negative PV terminal. The length of the PV strings connecting the PV panels and MC-4 connectors is ~1.5 foot. Each of the MC-4 connectors were systematically disconnected to identify the effects of open circuits (faults) at discrete points in the system. The effect of disconnecting the top breaks (B^+, C^+, D^+), one after another, on the SSTDR waveforms are shown in fig.2. The SSTDR waveforms after disconnecting the lower breaks (A^-, B^-, C^-) are shown in in fig.3.

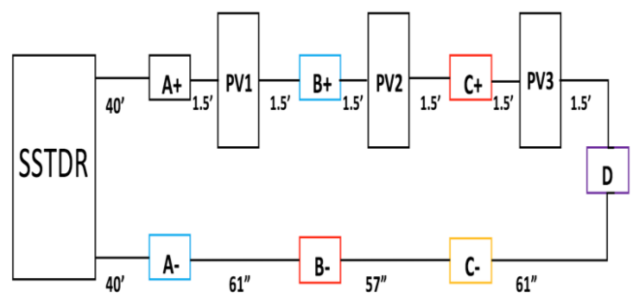

Fig.1. Experimental setup of asymmetric PV panel configuration.

Each PV panel has two cables that can be used to connect to successive panels through MC-4 connectors. These cables can be modelled using a standard RLGC transmission line model shown in fig.4, where R (Ω/m) and G (S/m) models the loss in the cable, and L (H/m) and C (f/m) forms the resonant circuit of the cable. Further, each PV panel is composed of a number of cells which in turn can be modelled by passive circuit elements shown in fig.4. Each cell in the panel is modeled as a combination of series resistance R_s, series inductance L_s, diffusion resistance R_{diff}, diffusion capacitance C_{diff}, depletion capacitance C_{dep} and shunt resistance R_{sh}.

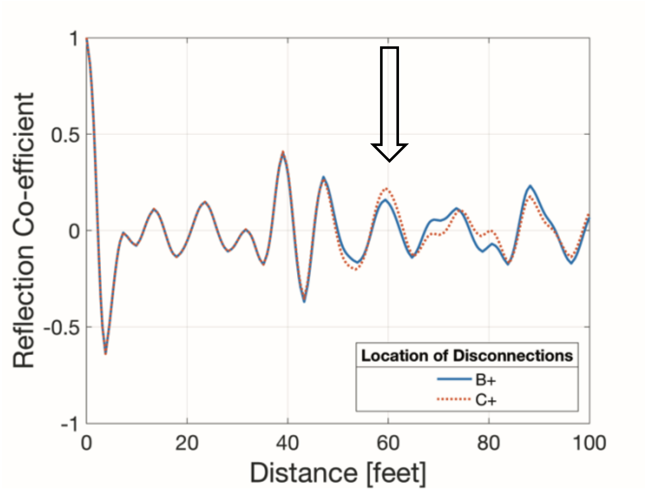

Fig.2. Open circuit measurements taken while disconnecting MC-4 connectors at B+ and C+ in fig.1

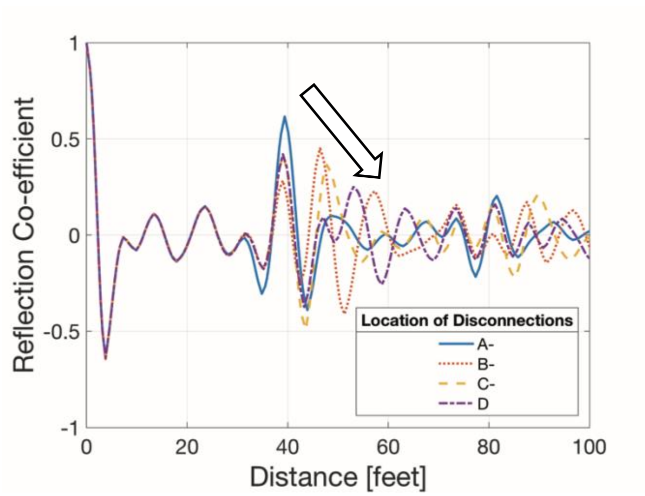

Fig.3. Open circuit measurements taken while disconnecting MC-4 connectors at A-, B-, C-, D in fig.1.

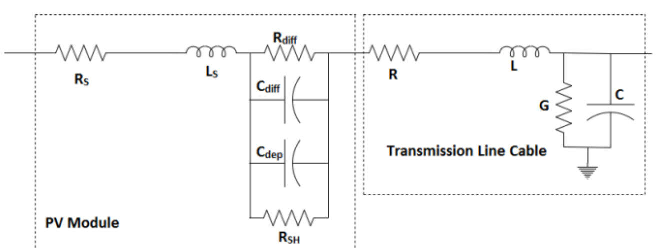

Fig.4. Circuit level schematic of PV module and connecting transmission line cable

III. Results

In fig.2. we note that the peak of the SSTDR signature (normalized to give reflection co-efficient) increases in magnitude when disconnecting the system at B+ and C+. This indicates a change in the overall impedance of the circuit. When more panels are connected, there is an increase in the impedance (capacitance). By contrast, disconnecting the lower wire (breaking this cable) triggers a shift of peaks to the right, as shown by the arrow in fig 3. Additional multiple reflections are seen throughout this system, making the peaks difficult to analyze. This analysis is the goal of our current work.

IV. Conclusion

In this paper, we describe the application of SSTDR to locate faults in PV arrays. Two different discontinuities of PV modules are described with corresponding responses in the SSTDR signals. The changes in impedances due to discontinuities of the PV modules have been analyzed. Fault detection in the arrays of PV panels is possible using their SSTDR response from the PV arrays. Location is possible, but more difficult.

Acknowledgment

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