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Influence of local shunting on the electrical performance in industrial Silicon solar cells

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ABSTRACT

The paper presents the results of investigation on the influence of an ohmic shunt located at various spatial positions on the solar cell performance by distributed diode model based simulations. By systematically varying the parameters such as shunt resistance, proximity to metallization, shunt area, and irradiance a deep insight about the shunt impact on the solar cell performance have been obtained. Further, effect of spatial positioning of shunts has been investigated by considering shunted region of same area and severity at various locations of the solar cell, via the simulation approach. The presented simulation approach has been experimentally validated. The influence of shunt on the relative power and relative open circuit voltage has been studied considering different irradiance levels. The study revealed new insights about significance of spatial positions of the shunts and the proximity of finger and busbar metallization. A dramatic improvement in the solar cell's electrical performance can be gained by either preventing the occurrence of shunts at the identified critical locations or isolating them by laser or chemical technique or removing them.

1. Introduction

Shunts present in various locations of the solar cell can be detrimental to its performance (Barbato et al., 2014; Botchak Mouafi et al., 2016; Chithambaranadhan et al., 2015; Compagnin et al., 2013; Dongaonkar et al., 2013; Fortes et al., 2014; Giaffreda et al., 2014; Guthrey et al., 2016; Phillips et al., 2015). It would be interesting to understand the possible improvement in the solar cell performance, with either removal of shunts (Hovestad et al., 2015; Zhang et al., 2010) or their isolation (Abbott et al., 2007; Chithambaranadhan et al., 2015; Hao et al., 2014) or preventing them from occurring at least in the most detrimental locations. The aim of the present work is to present a systematic study of influence of ohmic shunts at significant spatial locations in an industrial Silicon solar cell. Distributed diode model, (Foss et al., 2006; Galiana et al., 2005; Gupta et al., 2007a,b; Gupta et al., 2012; Somasundaran et al., 2012; Somasundaran and Gupta, in press; Zekry and Al-Mazroo, 1996), developed based on experimentally measured parameters, has been utilized for the study. Ohmic shunts have been simulated at various critical spatial locations in the solar cell.

Degradation in output power and open circuit voltage have been measured in terms of relative power and relative open circuit voltage which were calculated with respect to the values when the solar cell is not shunted. Important effect of irradiance on shunt related losses has been accounted for by performing simulations at two different irradiance levels. The study has provided further insight into the shunting phenomena.

The influence of shunt on the relative power at each spatial position has been found by comparing the power at MPP for the following two distinct cases: (1) when the shunt is present in the solar cell and (2) when the shunt is *not* present in the solar cell (i.e., after replacing the shunted area by the *shunt-free* area). A comprehensive understanding of the influence of the critical shunt locations in the industrial Silicon solar cell can be useful to achieve a dramatic improvement in the electrical performance of the industrial Silicon solar cells by preventing the occurrence of shunts at the identified critical locations or by detecting and isolating the shunts at the identified critical locations or by removing them and replacing with *shunt-free* area. The localised shunts can be imaged and detected using an IR camera (Chithambaranadhan et al., 2015; Hao et al., 2014) or liquid crystal sheets (Hao et al., 2014). Lock-in Infrared Thermography can be exploited for the imaging and detection of strong shunts in a few seconds of measurement time (Gupta et al., 2007a,b). Based on the criticality, the localised shunts can then be isolated by a combination of laser scribing and chemical

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etching as proposed in Hao et al. (2014) gaining a far improved performance of the solar cell. Further, severe shunts under busbar or finger metallization in multi/mono-crystalline solar cells can be repaired in an effective manner by the chemical etching method proposed in Chithambaranadhan et al. (2015).

2. Model

In distributed diode model, a solar cell is divided into smaller elementary areas wherein each elementary area is represented by the Shockley's one diode equivalent circuit and the model has been utilized to study shunt related losses by comparing illuminated I-V characteristics for various cases of shunting. Since the shunting phenomena most of the time, manifest itself in very small regions in the solar cell, it is necessary to divide the given solar cell area into a large number of elementary areas, so as to represent each small region of the solar cell in the developed model. In the present work, to investigate the effect of shunts on the industrial Silicon solar cell having dimensions of 125 mm × 125 mm, schematic of which is shown in Fig. 1(a) with position of ten shunts, the solar cell was divided into 375 × 375 equal elementary areas as shown in Fig. 1(b), considering the finger thickness into consideration.

Effect of spatial positioning of shunts has been investigated by simulating the extended shunts of same magnitude at ten different locations considering the *effect of metallization* on shunting phenomenon.

Degradation in performance caused by shunts depends not only on their *spatial location* in the solar cell but also their *proximity to the busbar and finger metallization*. Hence shunts have been classified into two major categories: (1) shunt *not under* metallization and (2) shunt *under* metallization. Shunt *not under* metallization includes: shunt between busbars *not under* finger, shunt in close proximity of busbar *not under* finger, shunt on the edge *not under* finger and shunt on corner *not under* finger and have been designated as a, b, c and d respectively in Fig. 1(a). Shunt *under* metallization includes shunt on corner *under* finger, shunt on edge *under* finger, shunt in close proximity of busbar *under* finger, shunt between busbars *under* finger, shunt *under busbar and under finger*, and shunt *under busbar but not under finger* and have been designated as e, f, g, h, i and j respectively in Fig. 1(a).

Area of the extended shunt under consideration is important in quantifying the effect of shunts on the solar cell performance. Each elementary area has a dimension of 1/3 mm × 1/3 mm, since the model was formed by dividing the industrial solar cells of dimensions 125 mm × 125 mm into 375 × 375 equal elementary areas for greater spatial resolution and better accuracy. The extended shunts have been simulated with 90 elementary areas in each spatial positions of shunting, thus yielding a total shunt area of 10 mm^2.

Each elementary area has been modelled by the solar cell equivalent circuit based on Shockley's one diode model consisting of a diode, a shunt resistance and a current source in parallel as seen in Fig. 2.

Current flow in the model can be described based on the Shockley's diode equation:

$$I = I_L - (V + IR_s)/R_{sh} - I_o[\exp\{(q/nkT)(V + IR_s)\} - 1] \quad (1)$$

where I_L is the photo-generated current (A)
I, the net current flowing through the cell (A),
I_o, reverse saturation current (A),
q, electronic charge (C),
V, applied voltage across terminals of cell (V),
n, ideality factor,
k, Boltzmann's constant (J/K),
T, absolute temperature (K).
R_s, the series resistance (Ω),
R_{sh}, the shunt resistance (Ω).

In the dark condition, the equation reduces to the following form:

$$I = I_o[\exp(qV/nkT) - 1] \quad (2)$$

Ideality factor n, and reverse saturation current I_o for the solar cell under study has been calculated by the accurate analytical

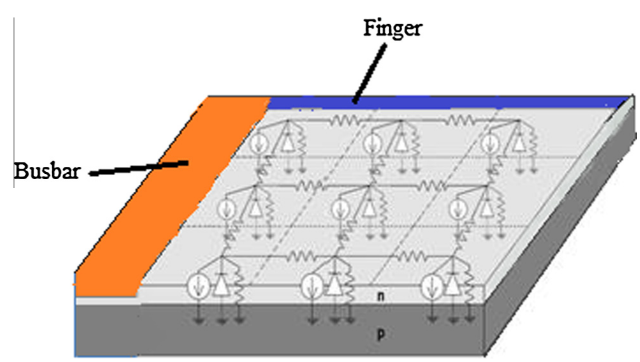

Fig. 2. Distributed diode model of the solar cell showing only 3 × 3 elementary areas and wherein each elementary area is modelled by Shockley's one diode model.

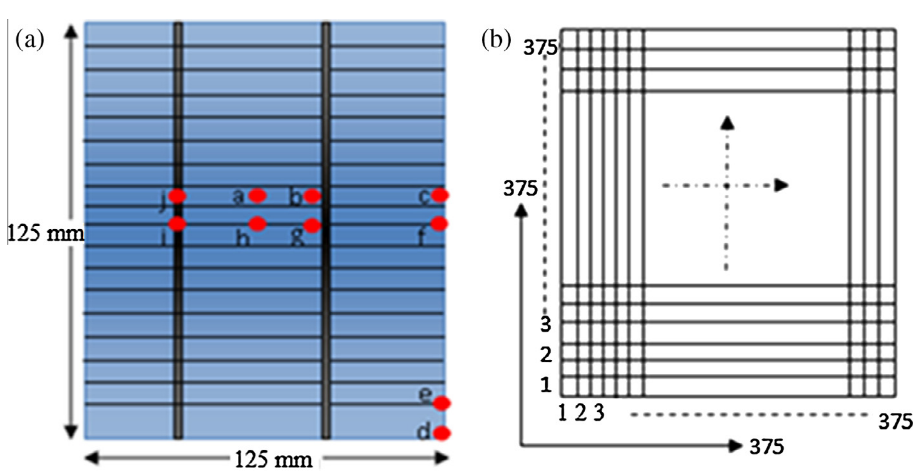

Fig. 1. (a) Schematic of the solar cell having shunt at ten different significant positions. (b) Meshing over the solar cell to divide it into small equal elementary areas.