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Line losses reduction techniques in puzzled PV array configuration under different shading conditions

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ABSTRACT

The SuDoKu puzzled (SDKP) configuration is a technique to magnify the execution of PV array due to the occurrence of partial shading conditions (PSCs) but more wiring losses exit in this array. This paper focuses on both in terms of power enhancement and wiring loss reduction of PV arrays under PSCs. Moreover, performance of the existing SDKP configuration is contrasted with the proposed Latin Square puzzled (LSP) and Ken-Ken Square puzzled (KKSP) based configurations to moderate the effects of shading situations. An investigation is carried out based on considered various ranges of shading situations such as short narrow, long narrow, short wide and long wide in terms of power generation, power dissipated, execution ratio and fill factor of PV arrays. Further, it is shown that power generation in the proposed configuration is 6.81% more as compared to SDKP configuration. The wiring loss is found to be 18.86% minimum while power loss is 771 W less in the proposed configuration as compared to SDKP configuration under the considered shading situations. Overall, execution of the proposed KKSP configuration is found to be superior to the SDKP configuration.

1. Introduction

The power generation of grid connected solar PV arrays depends on various conditions such as irradiance and temperature levels of PV modules (Silvestre et al., 2009; Lappalainen and Valkealahti, 2017a). There are multiple causes of shadings such as (i) self shading, (ii) cloud, (iii) wind and dust, (iv) high rise hospitals and buildings, (v) running aeroplane, (vi) tall tree, and (vii) exhaust gases emitted by the chimneys of the factories, as seen in Fig. 1, and performance of the PV arrays are dependent on the partial shading conditions (PSCs). Due to PSCs, the output power of PV arrays is reduced and they create misleading effects such as various maximum power points (MPPs), local maximum power points, global MPPs (GMPPs), mismatch power losses on P-V curves and the shadings directly affect the short-circuit current (SCC) of the PV modules, as portrayed in Fig. 2. There are many conventional arrangements of PV modules such as series, parallel, series-parallel, total cross-tied (TCT), bridge link (BL) and honeycomb (HC). Moreover, the generated power of PV arrays depends on associations of the PV modules in various shading conditions and result shows that the generated power of TCT PV array has better performance than the other conventional PV arrays (Zhou and Jin, 2017; Lappalainen and Valkealahti, 2017b, 2017c).

The researchers have proposed some novel PV array configurations for enhancing the performance of PV arrays with the help of various re-arrangement techniques for PV modules *i.e.*, puzzle pattern, power electronics and various fault detection algorithms etc. (Lappalainen and Valkealahti, 2017c, 2017d; Qing et al., 2017; Belhaouas et al., 2017; Rodriguez et al., 2018; Gao et al., 2009).

In this paper, an extensive range of research papers for PV arrays under PSCs has been reviewed and contributions of various research articles have been discussed as part of literature review. The normalized power of parallel configuration based PV array is superior to series configuration under quickly varying shading conditions (Gao et al., 2009). Refs. (Ziar et al., 2011; Tian et al., 2013) highlight that the behavior of series parallel (SP) PV array configuration with the help of binary coding method is superior to series and parallel interconnection under three different realistic conditions. The power of TCT configuration is more than SP configuration under 36 randomly generated values of solar irradiance (Wang and Shu-Syuan Lin, 2012). The modified equivalent circuit based TCT configuration is more capable to reduce the mismatch power losses as compared to SP and BL configurations (Rodriguez et al., 2013; Hamdi et al., 2014). In Paja et al. (2012), a new algebraic equation based modeling of TCT array has been proposed at uniform or mismatching environment. The power handling capacity of TCT PV array is increased by 5.84% and 10% with the use of bypass and without bypass diode, respectively, as compared to SP and

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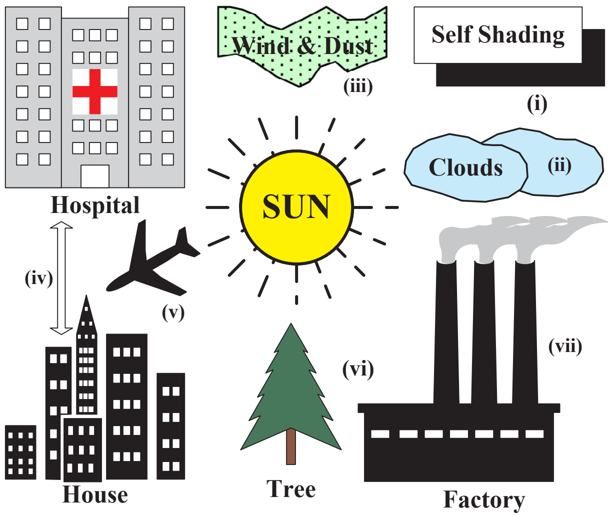

Fig. 1. Various causes of PSCs.

BL configurations under five different types of shading scenarios (Jazayeri et al., 2014). The TCT configuration reduces the bypass diode stress under row and column wise shading conditions (Khatoon et al., 2015). The performance of TCT PV array is more suitable than SP, BL and HC configurations in different shading circumstances (Belhachat and Larbes, 2015). The radiation levelling technique based SP configuration has been reported in Cipriani et al. (2014) and it tracks the maximum output power. Rani et al. (2013) have investigated that, a GMPP of SuDoKu PV array is higher than the TCT configuration under PSCs (26.1% maximum and 3.6% minimum). The rearrangements of SP, TCT, BL, HC and ladder (LDR) PV array configurations offer enhanced output power, fill factor (FF) and reduced power dissipations due to shade dispersion by SuDoKu (Vijayalekshmy et al., 2014). In Yadav et al. (2015), Yadav *et al.* have reported that the GMPP of SuDoKu configuration is increased by 13.29% as compared to SPTCT configurations under different shading condition. The performance of SuDoKu pattern based rearranged TCT (RTCT) configuration has increased by 23.26% due to moving cloud conditions (Vijayalekshmy et al., 2015). The PV array configuration reported in (Sahu and Nayak, 2014) is found to be handling 28.59% more power than TCT under PSCs. The location of GMPP in the PV array configuration reported in (Sahu and Nayak, 2014) is more than TCT configuration under shading conditions (18.7% maximum and 4.6% minimum). The optimal SuDoKu configurations reduce the line losses or wiring losses as compared to predetermined SuDoKu configuration due shading condition (Potnuru et al., 2015). Namani et al. (2015) reported that a magic square PV array configuration produces 44.23% maximum generated power as compared to TCT architecture (Namani et al., 2015). A new number place based PV array methodology was reported in (Jalil et al., 2016) that offers 6.7% increased output power and the same reduces the multiple peaks as compared to the conventional configurations under PSC. The reported Futoshiki PV array configuration of Sahu et al. (2016) has achieved 46.15% more power than TCT configuration under shading condition. The highlighting feature of the work reported in Yadav et al. (2016) is that the reported NS-1 and NS-2 configurations offer improved maximum power (by 19.44%), reduced power loss (by 464 W) and increased FF (by 2.02%) as compared to TCT configuration. The optimized SuDoKu PV array scheme surfaced in (Horoufiany and Ghandehari, 2018) may produce more power than non-optimized SuDoKu PV array under mutual shading conditions. Malathy and Ramaprabha (2018) reported that static PV array arrangement offers better shade dispersion and produces more power than SuDoKu arrangement under PSC. A central converter type of PV system has more efficiently performed in (Zheng et al., 2014) as compared to string converter and micro inverter type of PV system under irregular shadings. The current sensing algorithm based reconfigured TCT array power has enhanced by 37.1% with the help of switching matrix (Parlak, 2014). The work of Phiouthonekham and Chaitusaney (2015) has emphasized that the adaptive PV array based structure reduces the number of MPPs with respect of conventional SP and TCT configurations under PSCs (Phiouthonekham and Chaitusaney, 2015). The half and full reconfigurable PV arrays reported in Pareek and Dahiya (2016) are having 22.37% enhanced output power with respect to TCT under PSC (Pareek and Dahiya, 2016). The genetic algorithm (GA) based RTCT configuration is reported in Karakose et al. (2014) and it is found that it decreases the rate of PSCs and their impacts as compared to conventional SP, BL and TCT PV array configurations. GA based PV array configuration of Deshkar et al. (2015) has 15% more power handling capacity than SuDoKu configuration. Braun et al. (2016) have proposed fault detection algorithm based reconfiguration of conventional PV arrays and its maximum power is optimized under a variety of operating conditions. In Balato et al. (2016), an objective function based rearranged SP PV array is proposed that extracts the maximum energy under localized heating conditions and avoids thermal stress during lifetime. In Manna et al. (2014), the electrical array reconfiguration (EAR) strategy of TCT connection is found to be superior for new plant designs as well as also improves the energy production for grid connected PV generators (Quesada et al., 2009). Munkres algorithm improves the life of switches due to the occurrence of non-uniform and shading conditions (Sanseverino et al., 2015).

From motivation of above the literature review, a research has been carried out in this paper on SDKP, LSP and KKSP configurations using shade dispersion effect while its impact on wiring losses, dissipated power, ER and FF have been investigated. In this direction, the novel contributions in this paper are as follow:

(a) The wiring losses of the proposed KKSP and LSP configurations are found to be reduced.
(b) The proposed KKSP and LSP configurations can more effectively distribute the different range of shading factors as compared to SDKP configuration.
(c) The performances of the proposed KKSP and LSP configurations are compared to SDKP configuration in terms of GMPP, PD, FF and ER.

The rest of the paper is organized as follows. In Section 2, the PV array configurations under PSCs are discussed. Various shading patterns and shade dispersion effects at STC are analyzed in Section 3. The results are discussed in Section 4 while Section 5 concludes the present paper.

2. PV array configurations under PSCs

The SCC of PV array configurations depends on the different range of shading factors (0–1). The value of shading factor is unity means that the module is unshaded and when the shading factor varies between 0 and 0.9, the module is shaded. Let us assume that some rows of the PV array configurations containing m_1, m_2, m_3, m_4, ...m_{n-1} and m_n PV modules with the possibilities of multiple values of shading factor as F_{S1}, F_{S2}, F_{S3}, F_{S4}, ...$F_{S(n-1)}$ and 1, respectively. Under these conditions, the rows of a PV arrays have maximum shading and provide minimum SCC as compared to the other rows. The SCC of a PV array is given by Eq. (1).

$$I_{m-A} = I_m \times (m_1 F_{S1} + m_2 F_{S2} + m_3 F_{S3} + ...+ m_{(n-1)} F_{S(n-1)} + m_n \times 1) \quad (1)$$

Let, there be i number of rows that have a module current of I_{m-A}. The puzzled based rearrangement of PV modules of an array is distributed in the impact of shading in a similar row or nearly shaded modules. If there is one less shaded modules of shading factor F_{S1} in a row, then SCC of a PV array will be given by Eq. (2).