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Performance evaluation of PV configurations considering degradation rate and hot spots

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ABSTRACT

The rapid emergence and evolution of renewable energy sources such as solar energy has become a vital component of the global effort to meet the energy needs of the future. The major concerns for continuous solar photovoltaic (PV) generation are degradation rate, hot spots. These factors lead to the negative impact on PV mismatch losses, fill factor, maximum power and efficiency. To improve the performance of PV system, the simplest solution is PV panel configuration hence in this paper spider web tie (SWT) based PV Panel configuration in proposed. The proposed configuration is implemented on KC200GT PV Panel of 5×5 size PV panels considering degradation rate, hot spot. The performance of SWT configuration is compared with series-parallel (SP), bridge-link (BL), triple-tied (TT), and photovoltaic (PV) panel configurations and performance parameters such as Vmp, Imp, Pmp, Voc, Isc. FF, ΔPml, and η are calculated in all the cases. In all the cases the proposed SWT configuration exhibited the improved performance.

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1. INTRODUCTION

Despite the various challenges that solar photovoltaic (PV) system face, such as the high cost of electricity, they are still considered to be the best option for addressing the future energy needs of nations. In the next decade, the cost of renewables is expected to come down, making PV systems an ideal alternative to fossil fuels. The rapid emergence and evolution of PV markets are attributed to various factors. Some of these include the increasing demand for energy, the government's support for renewable energy sources and the technological advancements that have occurred in the field. Nevertheless, the performance of the PV system is of major concern. The output of the PV panels is effected by various factors. Degradation rate and hotspots are notable parameters affect the output of the PV panel [1]–[3]. Degradation rate of PV panel lead to decrease in PV output over a period of time [4], [5]. This leads to the increase in PV mismatch losses and decrease in efficiency and fill factor [6]. In a PV module, a hot spot represents an over proportional heating of a single solar cell or a cell part compared to the surrounding cells [7]. When the operating current of a PV module exceeds the short-circuit current due to the faulty or shadowed cell, it can cause overheating. This condition can cause the affected cell to get forced into reverse bias, which then dissipates the power in the form of overheat and this leads to the hot spot [8]–[11]. Deng *et al.* [12] analysed the effects of hotspots in the PV panels using ANSYS simulation software. Studies in [13]–[15] reviewed the impact of panel degradation rates.

To improve the performance of PV system, the simplest solution is PV panel configuration hence in this paper spider web tie (SWT) based PV panel configuration in proposed. The proposed configuration is implemented on KC200GT PV Panel of 5×5 size PV panels considering degradation rate, hot spot. The performance of SWT configuration is compared with series-parallel (SP), bridge-link (BL), triple-tied (TT), and PV panel configurations and performance parameters such as Vmp, Imp, Pmp, Voc, Isc. FF, ΔPml, η are calculated in all the cases. In all the cases the proposed SWT configuration exhibited the improved performance.

2. DEGRADATION RATE

PV panels are made up of PV cells that convert sunlight into electricity. Over time, PV panels can experience a decrease in their energy output, which is known as degradation [16]–[18]. There are various factors that contribute to the degradation rate of PV panels, such as temperature, humidity, UV radiation, mechanical stress, and quality of material and manufacturing. The degradation rate of PV panels can have several effects on their performance and overall efficiency. Some of the most notable effects of degradation rate are reduced energy output, reduced lifespan, reduced return on investment, environmental impact, and safety concern.

3. HOTSPOTS

A PV panel hotspot refers to an area on a PV panel where the temperature is significantly higher than the surrounding area. This can occur when a portion of the panel becomes shaded or damaged, leading to reduced power output in that area [19]–[22]. The reduction in power output causes the shaded or damaged area to absorb more energy than it can dissipate, resulting in an increase in temperature.

3.1. Failures in PV systems due to hotspots

There are several types of failures in the PV systems due to the hotspot. Oufettoul *et al.* [23] suggest about 49% of the failures in the PV systems are due to the hotspots [24], [25]. Some of the common failures due to the hotspots are cracking, delamination, encapsulation material damage corrosion, bypass diode failure, interconnection failure, arc fault, shading and soiling and mismatch fault. PV panel hotspots can have several negative effects on the performance and reliability of PV systems as reduced power output, thermal stress, risk of fire and reduced lifespan.

4. RESULTS AND DISCUSSIONS

The proposed configuration is implemented on KC200GT PV panel of 5×5 size PV panels considering degradation rate, hotspot. The performance of SWT configuration is compared with SP, BL, TT, and PV panel configurations and performance parameters such as Vmp, Imp, Pmp, Voc, Isc. FF, ΔPml, and η are calculated in the following cases:

- Performance evaluation considering degradation rate.
- Performance evaluation considering hotspot.

4.1. Performance evaluation considering degradation rate

In this work 1.37% and 2.7% of PV panel degradation rate for 10 years of operation is considered. PV panels with degradation rates are considered as follows, the rest of the PV panels are not affected by the PV panel degradation rate as shown in Figure 1. The above PV panel degradation rate condition is implemented in Simulink on a test case of a KC200GT 200 W solar panel system as shown in Figure 2.

- The PV panels PV (12), PV (22), PV (32), PV (42), PV (52)-2.7% for 10 years of operation.
- The PV panels PV (14), PV (24), PV (34), PV (44), PV (54)-1.37% for 10 years of operation.

The performance of the SWT, SP, BL, and TT configurations are evaluated. Performance parameters such as Vmp, Imp, Pmp, Voc, Isc. FF, ΔPml, and η are calculated in all the cases and tabulated in Table 1. It is observed that in the PV panel degradation rate condition the SWT configuration exhibits the improved performance when compared to SP, BL, and TT configurations.

- The efficiency is improved from 13.039% to 13.587%,

– Fill factor is improved from 74.385% to 74.874%,
– PV mismatch losses are reduced from 8.553% to 4.172%.

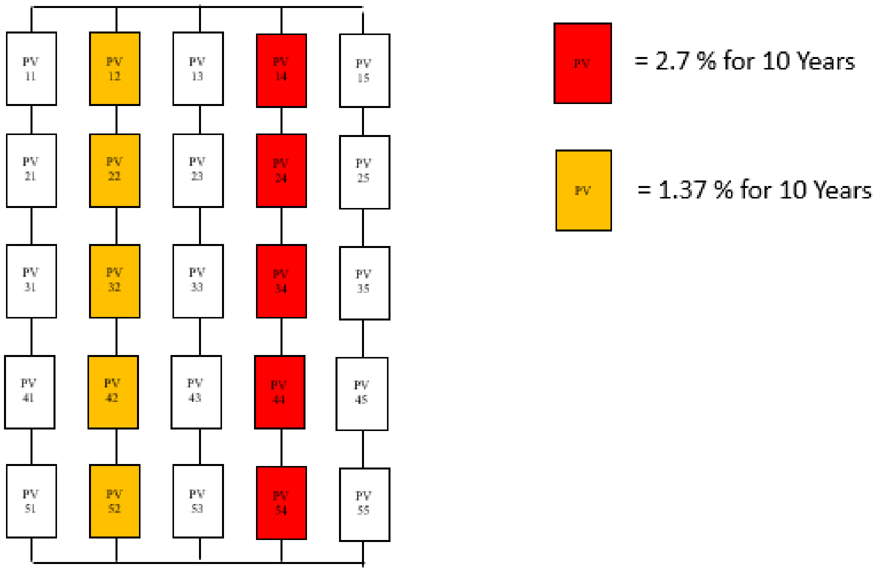

Figure 1. PV panel considering degradation rate

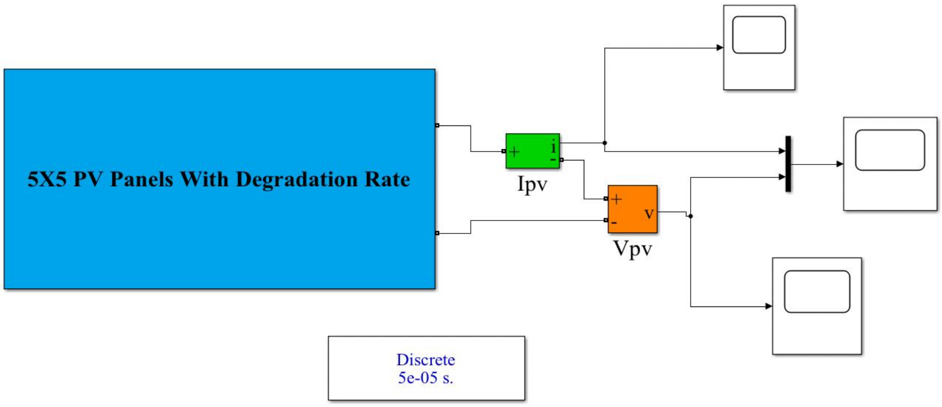

Figure 2. Simulink implementation of degradation rate

Table 1. Performance parameters under degradation rate

Configuration Type	V_{mp} (V)	I_{mp} (A)	P_{mp} (W)	V_{oc} (V)	I_{sc} (A)	FF (%)	ΔP_{ml} (%)	η (%)
SP	131.805	34.97276	4609.585	163.665	37.864	74.385	8.553	13.039
BL	131.988	35.02371	4622.710	163.811	37.899	74.460	8.245	13.076
TT	132.341	35.765	4733.176	164.248	38.612	74.633	5.719	13.389
SWT	132.971	36.124	4803.444	164.635	38.967	74.874	4.172	13.587

4.2. Comparison analysis

A comparison analysis is then carried out for the various parameters of the solar PV system, such as the PV Mismatch losses Pml (%), fill factor FF (%), efficiency η (%), maximum power Pmp (W). Detailed comparison charts are presented in Figures 3 to 6 respectively. Figure 6 maximum power Pmp (W). In degradation rate, it is observed that the SWT configuration exhibited improved performance in comparison with SP, BL, and TT configurations.

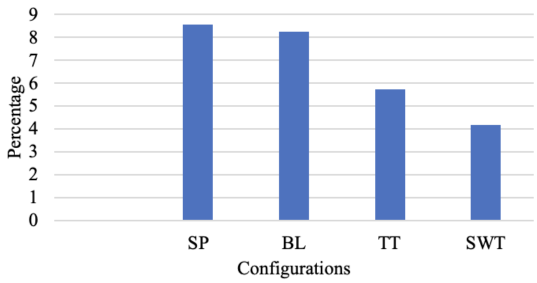

Figure 3. PV mismatch losses Pml (%)

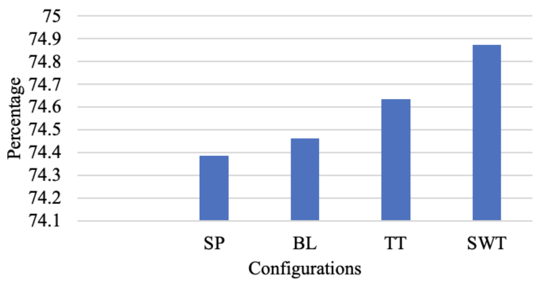

Figure 4. Fill factor FF (%)

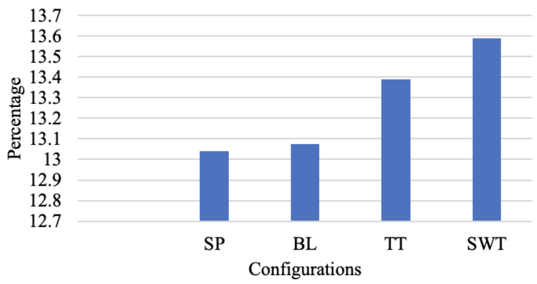

Figure 5. Efficiency η (%)

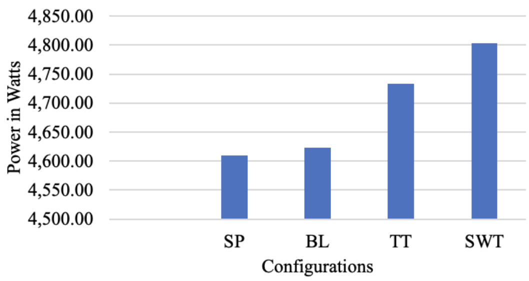

Figure 6. Maximum power Pmp (W)

4.3. Performance evaluation considering hot spots

In this work, 50% and 30% effect of hotspot condition is considered. The percentage of PV panels that are effected by hotspots is as follows. The rest of the PV panels are not affected by the hotspots as shown in Figure 7, the Simulink model is presented in Figure 8.

- The PV panels PV (12), PV (14), PV (23), PV (32), PV (34), PV (42), PV (44), PV (53)-50% effected by hotspots.
- The PV panels PV (13), PV (22), PV (24), PV (43), PV (52), PV (55)-30% affected by hot spots.

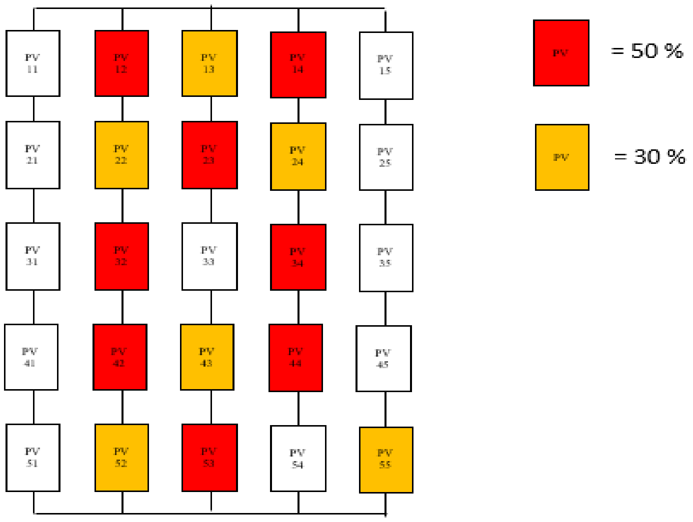

Figure 7. PV system considering hotspots

The performance of the SWT, SP, BL, TT configurations evaluated. Performance parameters such as Vmp, Imp, Pmp, Voc, Isc. FF, ΔPml, and η are calculated. All these cases are tabulated in Table 2. In the

hotspot condition, it is observed that the SWT configuration exhibits improved performance compared to SP, BL and TT configurations.
- The efficiency is improved from 9.550% to 10.402%.
- Fill factor is improved from 53.881% to 62.720%.
- PV mismatch losses are reduced from 48.213% to 36.074%.

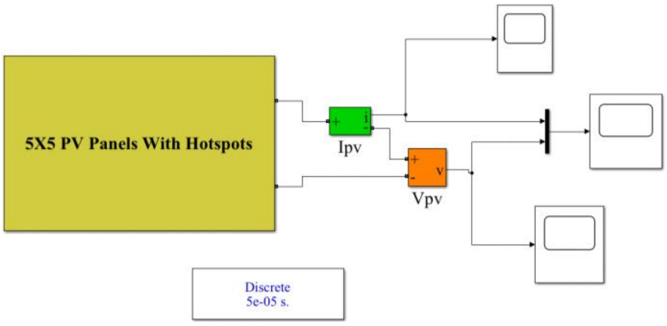

Figure 8. Simulink implementation of hot spots

Table 2. Performance parameters under hot spot condition

Configuration type	V_{mp} (V)	I_{mp} (A)	P_{mp} (W)	V_{oc} (V)	I_{sc} (A)	FF (%)	ΔP_{ml} (%)	η (%)
SP	137.085	24.627	3376.121	162.285	38.610	53.881	48.213	9.550
BL	137.121	24.712	3388.534	162.290	36.331	57.470	47.670	9.585
TT	137.445	24.898	3422.104	162.33	36.122	58.360	46.221	9.680
SWT	137.663	26.71225	3677.288	162.345	36.114	62.720	36.074	10.402

4.4. Comparison analysis

A comparison analysis is then carried out for the various parameters of the solar PV system, such as the PV mismatch losses Pml (%), fill factor FF (%), efficiency η (%), maximum power Pmp (W). Detailed comparison charts are presented in Figures 9 to 12 respectively. From the above it is observed that the proposed SWT configuration exhibited improved performance in comparison with SP, BL, and TT configurations.

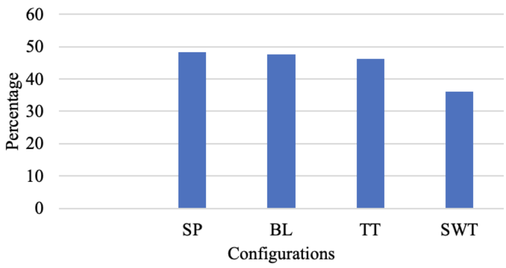

Figure 9. PV Mismatch losses Pml (%)

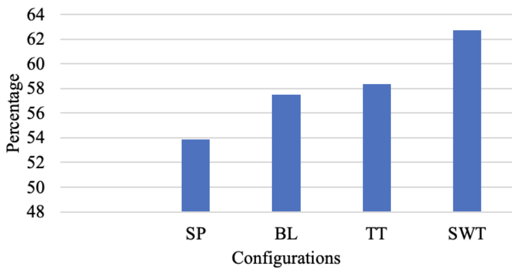

Figure 10. Fill factor FF (%)

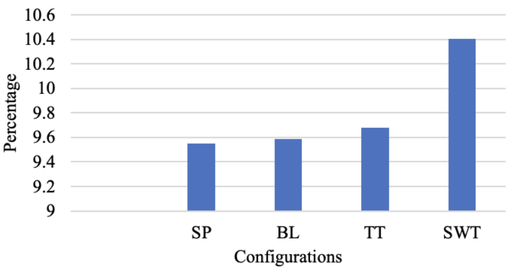

Figure 11. Efficiency η (%)

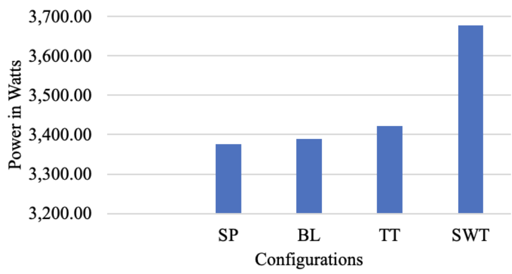

Figure 12. Maximum power Pmp (W)

5. CONCLUSION

To improve the performance of PV system, SWT based PV Panel configuration in proposed in this paper. The proposed configuration is implemented on KC200GT PV panel of 5×5 size PV panels considering degradation rate, hotspot. The performance of SWT configuration is compared with SP, BL, TT, and PV panel configurations and performance parameters such as Vmp, Imp, Pmp, Voc, Isc. FF, ΔPml, and η are calculated in all the cases. In all the cases the proposed SWT configuration exhibited the improved performance. In the degradation rate condition, PV mismatch losses are reduced from 8.553% to 4.172%. In the hotspots condition, PV mismatch losses are reduced from 48.213% to 36.074%.

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