INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

# DC Motor Load performance in DC system with reconfiguration of PV Array

**Y P Soni**[1]*, **E Fernandez**[2]

**1** Research Scholar, Electrical Engineering Department, Indian Institute of Technology Roorkee, Roorkee, 247667, India. Tel.: +91 9098520305
**2** Associate Professor, Electrical Engineering Department, Indian Institute of Technology Roorkee, Roorkee, 247667, India

OPEN ACCESS
**Received:** 07.12.2020
**Accepted:** 13.03.2021
**Published:** 12.04.2021

**Citation:** Soni YP, Fernandez E (2021) DC Motor Load performance in DC system with reconfiguration of PV Array. Indian Journal of Science and Technology 14(11): 964-970. https://doi.org/10.17485/IJST/v14i11.2197

* **Corresponding author**.
Tel: +91 9098520305
yuvraj.soni21092@gmail.com

**Funding:** None

**Competing Interests:** None



Published By Indian Society for Education and Environment (iSee)

**ISSN**
Print: 0974-6846
Electronic: 0974-5645

## Abstract

**Objectives:** To examine if the changing of the series-parallel configuration of photovoltaic (PV) array can influence a simple DC drive performance. **Methods:** In this study, a simulated investigation is carried out for a PV system consisting of 30 panels arranged in 3*5 and 5*3, 3*6 and 6*3, 5*6, and 6*5 configuration. Two motors of rating 5 HP and 10 HP are used for the simulation. The first category includes the mentioned configuration in which the number of series PV panels $(N_s)$ is higher than the number of the parallel panel $(N_p)$ such as 5*3, 6*3, and 6*5. The second category includes the combination in which the number of PV panels connected in parallel is higher, such as 3*5, 3*6, and 5*6. **Findings:** The performance of the 5HP motor gets increased by 173.36%, and the performance of the 10 HP motor gets risen by 121.26% in 18 PV panel system when $N_s$ is higher than $N_p$ . Also, the system's overall efficiency gets improved when $N_s$ is higher than $N_p$ . **Novelty**: Usually, to vary the performance of the DC motor, power electronics circuitry is implemented. However, the performed simulated result shows that certain configurations will give better performance. Therefore, control for the DC motor's enhanced performance can be accomplished without the power electronics control system.

**Keywords:** PV array combination; DC motor load; Performance analysis; Simulink-Matlab

## 1 Introduction

For the rural and isolated areas, complex systems with power electronics interfaces may not be favorable in view of limited available local expertise for repairs and the small population being served. In such cases, alternative and simple control strategies may be tried. If a DC drive is used in rural areas for small cottage industries' mechanical power requirements, a simple control strategy would be helpful. An attempt in this direction was initiated by Salameh and Dagher [1]. Thereafter, many attempts have been made in analyzing the PV system deployed for numerous applications.

Kumar et al. [2] investigated the variation in operating points in numerous PV series-parallel arrangements. Hong et al. [3] studied the PV system for rooftops under partial shading conditions. Based on the load consumption and cost analysis total 16 PV panels are recommended for the installation in four by four configurations.

Kumar and Kumar [4] investigated the PV system with three converter types to improve the system performance. Modified zeta converter is seen as an appropriate converter to be implemented with brushless DC motor (BLDCM); However, the system's cost also increases with additional components.

Among the various applications, water pumping system energy supplied by PV array is also the most common deployed system. Mudlapur et al. [5] investigated the performance of water pumping systems under partial shading conditions. The proposed method discusses the implementation of a system with a sole configuration of the PV array. Matam et al. [6] proposed a reconfigurable system for water pumping. The proposed system modifies its structure based upon the insolation value. Shebani and Iqbal [7] proposed a water pumping system for Libya, incorporating a permanent magnet DC motor (PMDCM) fed through a PV array. The conclusion is drawn for motor speed, which significantly affects the system's overall performance. Errouha et al. [8] proposed direct torque control technique through fuzzy which improves the performance of induction motor in PV based water pumping system. Earlier, to improve the performance, indirect field-oriented control is implemented [9]. The proposed method reduce the losses and increase in efficiency is observed ar different irradiation which is an extension of the work proposed in [10] by Errouha et al. In [10], optimization along with the control for induction motor is incorporated in PV based water pumping system.

Das et al. [11] discuss the control techniques suitable for the PV-based Microgrid encompassing PV, wind turbine, and energy storage connected with a non-linear load. The proposed method utilizes wavelet operation to control the gate pulse fed to the inverter. Hamdi et al. [12] suggested sliding mode control to enhance performance by integrating the neuro-fuzzy method technique. The proposed system is robust and operates satisfactorily with MPPT. Sowmya et al. [13] discuss the feeder's reconfiguration for harmonics elimination in PV based system. The proposed system illustrates the analysis to improve the voltage and performance of the system.

On exploring the literature, it is observed that most discussion on performance improvement for a PV system is achieved through complicated power electronics circuitry installation. One question that arises is whether a simple strategy of reconfiguration of the existing number of solar PV panels can influence the DC motor's performance supplied by the panels. Hence, this study addresses this issue and examines the DC drive's behavior with varied PV array configurations. The work addresses two different rated DC motors connected directly with the PV system without any intermediate converters. The above analysis is performed in the Matlab-Simulink platform.

Further, this study is organized as follows: Section 2 discusses the system modeling followed by system description for simulation in Section 3. Section 4 addresses the simulation results and related discussions. Section 5 concludes the findings.

## 2 System Modelling

### 2.1 PV Array

Combining several PV cells makes up a solar PV module, and a series-parallel combination of PV modules constitutes a solar PV array. PV array generates the power which can be utilized to operate loads for different applications. The solar PV array is regarded as a current source that depends upon ambient irradiance and temperature. The modeling of a solar PV module can be designed in Matlab by equation (1) [14].

$$I_{pv} = I_{ph} - I_O \left( \exp \frac{q\,(V_{pv} + R_s I)}{aKTN_s} - 1 \right) - \left( \frac{V_{pv} + IR_s}{R_{sh}} \right) \tag{1}$$

The voltage or current output from solar PV (concerning the load supplied) is modified in terms of the number of modules connected in series and parallel. Many combinations may exist for the same power output. Voltage and current can be adjusted by increasing or decreasing the number of modules connected in series and parallel.

### 2.2 DC Motor

A DC wound motor can be modeled in Simulink. The equation used to represent the mechanical part implementation is shown in equation (2).

$$J\frac{d\omega}{dt} = T_e - T_L - B_m * \omega - T_f \tag{2}$$

Further, the operation of the motor is governed by equations (3) – (4)

$$V_t = E_a + I_a^* R_a \tag{3}$$

$$T_e = K_T * I_a \quad (4)$$

Where, $T_e$ and $T_L > 0$

The electrical torque output depends upon the magnitude of the armature current. The rotor speed can be calculated from equation (2). Mechanical and electrical torque should be greater than zero to operate DC machines in the motoring region.

## 3 System Description

In this study, the solar PV array is modeled with various combinations of PV modules. The terminal voltage and current of the solar PV array can be varied by changing the number of modules connected in series and parallel. On increasing/decreasing the number of the series module, the voltage will increase/decrease. Similarly, on increasing/decreasing the number of modules connected in parallel, the current will increase/decrease. The parameters of a single PV module used here are shown in Table 1. Two different rated DC motors are used for the investigations, whose specifications are shown in Tables 2 and 3.

**Table 1.** Solar PV Module Parameter

| | |
|---|---|
| Maximum Power | 213.15 Watt |
| Open Circuit Voltage | 36.3 Volts |
| Short Circuit Current | 7.84 Ampere |
| Temperature Coefficient of $V_{oc}$ (%/deg.C) | -0.36099 |
| Temperature Coefficient of $I_{sc}$ (%/deg.C) | 0.102 |

**Table 2.** DC Motor Specification 1

| | |
|---|---|
| Power Rating | 5 HP |
| Voltage Rating | 240 Volts |
| Rotational Speed | 1750 RPM |
| Armature Resistance & Inductance | 2.581 Ω & 0.028 H |
| Field Resistance and Inductance | 281.3 Ω & 156 H |
| Field – Armature Mutual Inductance | 0.9483 H |
| Total Inertia, Viscous friction coefficient, and Coulomb friction torque | 0.02215 kg.m$^2$, 0.002953 N.m.s & 0.5161 |

**Table 3.** DC Motor Specification 2

| | |
|---|---|
| Power Rating | 10 HP |
| Voltage Rating | 240 Volts |
| Rotational Speed | 1750 RPM |
| Armature Resistance & Inductance | 1.086 Ω & 0.01216 H |
| Field Resistance and Inductance | 180 Ω & 71.47 H |
| Field – Armature Mutual Inductance | 0.6458 H |
| Total Inertia, Viscous friction coefficient, and Coulomb friction torque | 0.04251 kg.m$^2$, 0.003406 N.m.s & 1.046 |

Six combinations of the different solar PV module arrangements are considered to examine the performance. These arrangements are further divided into two categories.

1. When the number of PV modules connected in series $(N_s)$is greater than the number of modules connected in parallel $(N_p)$ i.e $(N_s > N_p)$ .
2. When the number of PV modules connected in parallel $(N_p)$is greater than the number of modules connected in series $(N_s)$, i.e $(N_s < N_p)$. The various combinations that have been chosen are shown in Table 4.

Table 4 represents the several configurations of PV arrays in categories I and II. It is to be noted that type II is just the reverse of type I, interchanging the number of panels connected in series and parallel. However, the rated power will be the same for each pair. For example, if we consider series-parallel configurations 3X5, both the designs will have the same power rating.

The capacitor is attached at the input side of the PV to reduce the voltage ripple. After arranging the system PV configuration (as shown in Table 4) with DC Motor, performance at a torque output of 15 N-m is simulated to examine the motor's power output, rotor speed, armature current, and system's overall efficiency.

**Table 4.** Details of PV Combination

| Category | Series X Parallel Configuration |
|---|---|
| Category Type I ($N_s > N_p$) | 5X3 |
| | 6X3 |
| | 6X5 |
| Category Type II ($N_p > N_s$) | 3X5 |
| | 3X6 |
| | 5X6 |

## 4 Results and Discussions

The system shown in Figure 1 is simulated, considering the PV configuration connected with the DC motor with a constant torque of 15 N. Motor performance is inspected based on the power output, rotor speed, and armature current.

Figure 2 shows the power, speed, and current, respectively, for a given configuration of PV array at which $(N_s > N_p)$ is shown on the left column and $(N_p > N_s)$displayed on the right column. The above figures are the representation of the performance of 5 HP DC motors as specified in Table 2. Figure 3 show the power, speed, and armature current, respectively, for 10 HP motors as specified in Table 3 for $(N_s > N_p)$ on left column and $(N_p > N_s)$on the right column.

From a study of Figures 2 and 3 , the following observations can be made for both the motors of 5 HP and 10 HP. Similar trends are observed, and considering the cases of $(N_s > N_p)$versus, $(N_p > N_s)$we follow that:

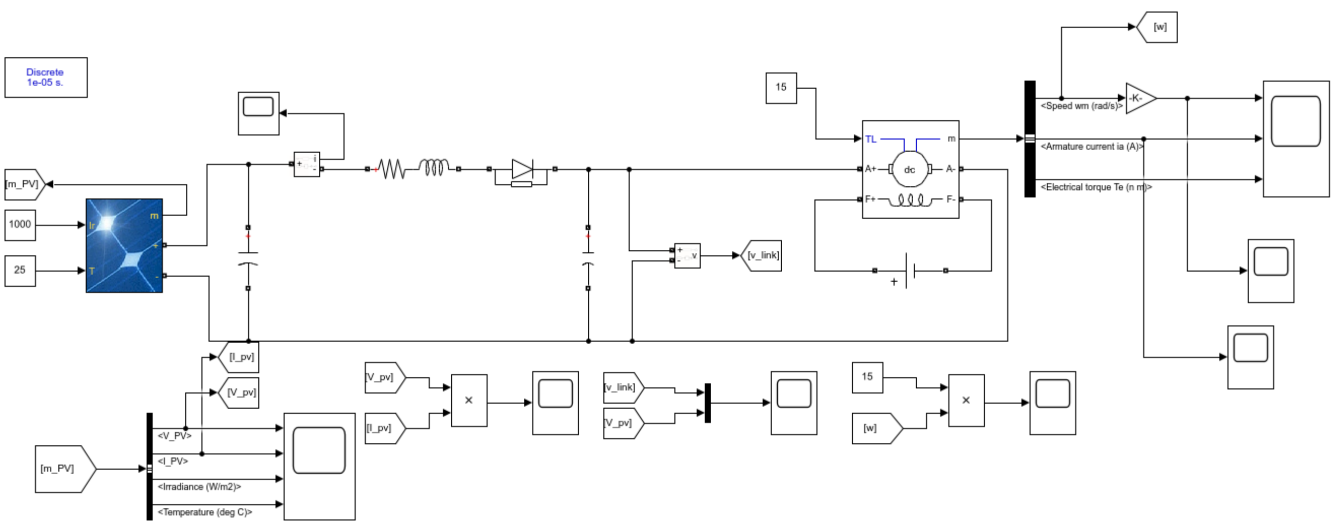


**Fig 1.** Performance of 5 HP DC Motor

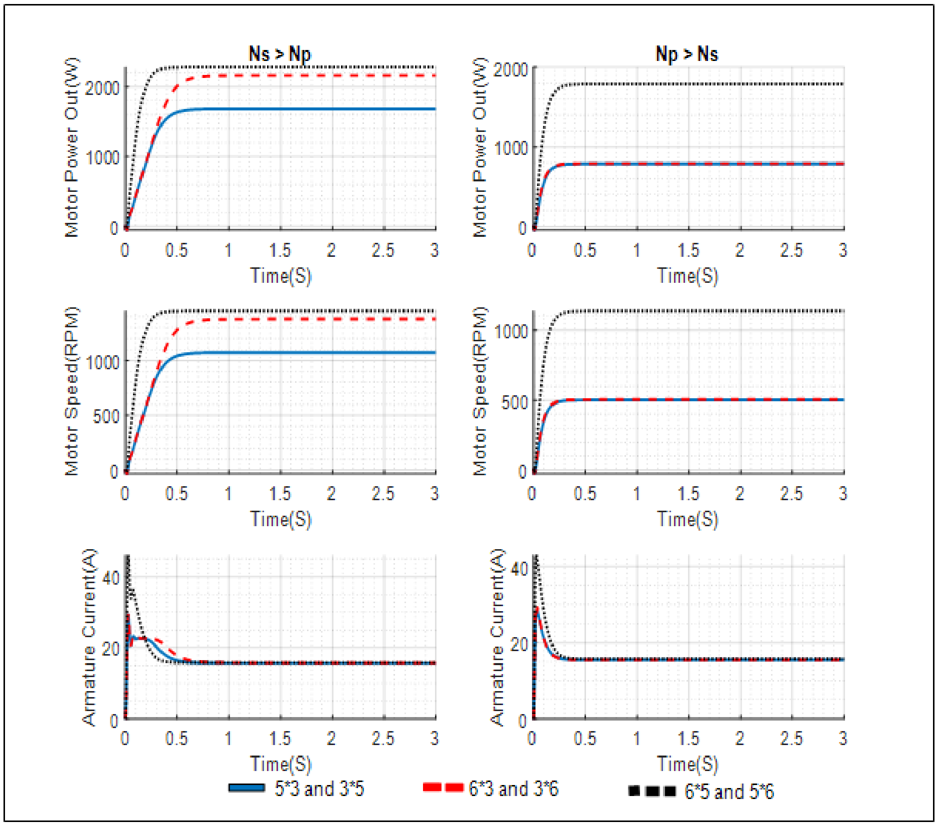


**Fig 2.** Performance of 5 HP DC Motor

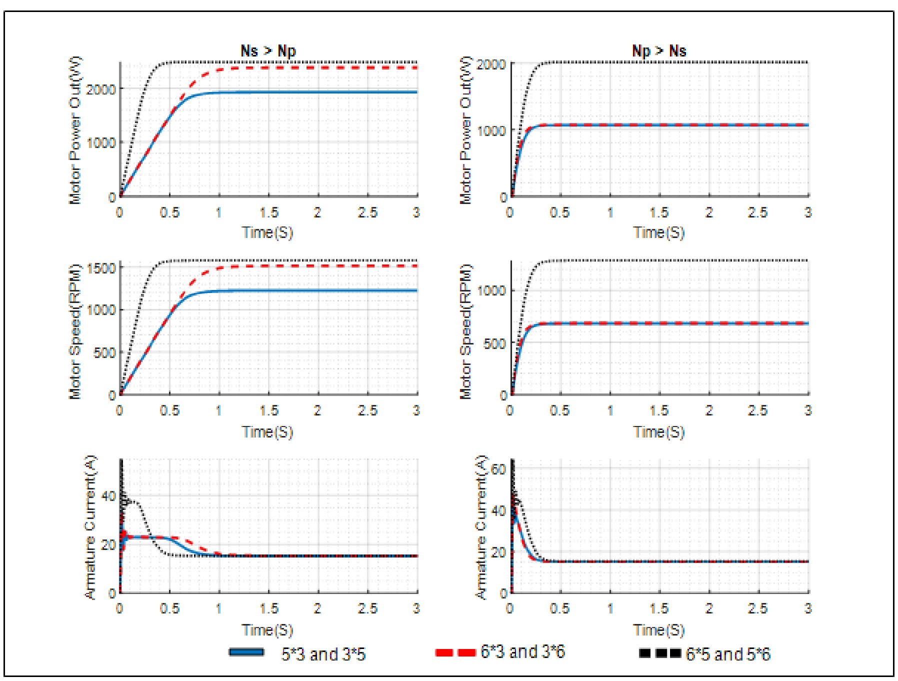


**Fig 3.** Performance of 10 HP DC Motor

- In 5 HP motor, performance is improved by 113.27%, 173.36%, and 27.4% when the number of panels connected in series is higher than the parallel-connected PV panels in 15 panels, 18 panels 30 panels system respectively.
- In 10 HP motor, performance is improved by 79.37%, 121.26%, and 23% when the number of panels connected in series is higher than the parallel-connected PV panels in 15 panels, 18 panels, and 30 panels system respectively.
- The speed of the motor varies proportionally to its power output.
- The arrangement $N_s > N_p$( i.e., $5 \times 3, 6 \times 3,$ and $6 \times 5$) yield more considerable output power than the corresponding $N_p > N_s$ arrangements (i.e., 3X5, 3X6 and 5X6).
- The same observation is true for the speed of motors 1 and Motor 2, i.e., the arrangement $N_s > N_p$yield larger motor speeds than the corresponding $N_p > N_s$arrangement.
- In the armature current, we see that both the configuration $N_s > N_p$ and $N_p > N_s$draws the same value of current by respective motors.
- Response time of the system gets improved in the case of $N_p > N_s$. The settling time of the motor's current and speed is approximately 0.5 seconds, whereas the configuration of $N_s > N_p$the settling time is about 1 second.

**Table 5.** Overall System Efficiency for Each Configuration

| S. No. | Configuration (Ns * Np) | System Efficiency with 5HP Motor | System Efficiency with 10HP Motor |
|---|---|---|---|
| 1 | 3*5 | 49.95 % | 69.59 % |
| 2 | 5*3 | 66.1 % | 77.01 % |
| 3 | 3*6 | 50.08 % | 69.65 % |
| 4 | 6*3 | 70.28 % | 78.77 % |
| 5 | 5*6 | 67.15 % | 77.43 % |
| 6 | 6*5 | 71.07 % | 79.07 % |

Table 5 shows the overall system efficiency with the considered different PV panels series-parallel configuration. The efficiency of the system gets increased when $N_s > N_p$ for the same number of PV modules. The system's performance improved with increasing load, which is obvious as it happens due to a change in the load's impedance, making PV draw more power. Around 20 % increase is observed from 5HP to 10 HP motor when $N_p > N_s$for same number of PV panels and approximately 10 % improvement is from 5HP to 10 HP motor when $N_s > N_p$. However, these differences slowly decrease with an increase in the total number of panels.

The above analysis shows that the arrangements of the array for which $N_s > N_p$are more efficient from the perspective of steady-state performance output of the DC drive as compared with the alternative format in which, for the same $N$, $N_p > N_s$ . However, the transient performance $N_p > N_s$is preferable.

It is observed that the DC motor's performance connected directly with the PV system can be utilized for small application purposes without investing much of a cost for the performance. However, it has to be noted that in the case of grid integration or AC drive installation [3–5], an additional cost of the inverter and controlling technique will be required.

The system's settling time is around 0.5 seconds; however, it can be further improved with subject to more investment for the converter as in literature [7]. Also, the difference in transients is around 0.3 seconds which does not make much of a significance in the small application such as the cotton industry to invest more for a fraction of seconds. The steady-state performance of the system is satisfactory and efficient when it is operated with $N_s > N_p$.

It draws comparatively more power which increases the output of the system.

## 5 Conclusion

This study has examined two different rated DC motor performances with varying configurations of PV array. The study analysed for different arrangements of modules in series and number of parallel strings such that their product N (where, $N = N_s X N_p$ ) is constant. It is seen that the arrangements of the array for which $N_s > N_p$are more efficient from the perspective of performance output of the DC drive as compared with the alternative arrangement in which, for the same $N$, $N_p > N_s$ . This work involves a manageable size of N. However, when N increases, optimization will be helpful in deciding the most favorable configuration. As an extension, the following work will be carried out in future –

1. Optimization can be used to arrive at most suitable combination rather than to be simulation based on direct choice of combination.
2. Studies can be carried out with other rating and variation in load type.

3. The performance of the system can be examined at partial shedding condition which effects in the performance of PV array.

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