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Original Research Article

Design and analysis of PV fed SRM system

Serhat Berat Efe [1,*], Dilan Demir Aktaş [2]

[1] *Department of Electrical and Electronics Engineering, Faculty of Engineering, Bitlis ErenUniversity, Bitlis, Turkey*
[2] *Msc. Student, Department of Electrical and Electronics Engineering, Faculty of Engineering, Bitlis ErenUniversity, Bitlis, Turkey*

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* Corresponding author
s.beratefe@gmail.com

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ABSTRACT

Renewable energy sources supplied motor applications are being studied widely by researchers. As it is especially focused on design and control of such systems, studies on performance analysis approach is limited. It is vital to determine the operating behaviour of motor loads when they are supplied by limited energy sources like photovoltaic (PV) systems. According to this necessity, in this study, a switched reluctance motor (SRM) which is supplied by a PV system is analysed in terms of speed, current and torque data. Because of its advantages as it can be controlled over a wide range, its reliability and stability, SRM was used for analysis. Such data are observed in two cases, PV system irradiance change and fault conditions. System is designed as direct-fed, which is not include any storage unit. Therefore, any changes at supply system directly affect motor parameters. These effects and results are discussed by using the graphs that obtained from various points of system for both cases.

Keywords: Switched reluctance motor, photovoltaic system, renewable energy, MATLAB

1. Introduction

Because of rapid increment at energy demand, it is necessary to integrate renewable energy sources as photovoltaic (PV) systems to conventional generating units to meet this issue. As such systems have limited capacity of energy generation, it is vital to analyse load characteristics in detail for using the generated energy most efficient. In addition, it is important to determine properties and operational performance of load while supplied by a renewable energy source.

PV generating reaches to 100 GW by 2018 around the world. As it is the most preferred renewable energy source, PV systems are studied widely in literature. The recent studies are varies among design [1-3], analysis [4] and grid integration [5-8] issues. These studies are both on single phase and three phase systems. Researchers were investigated such systems in detail in terms of efficiency and control in these studies.

Similar as this study, there are also valuable works on PV supplied motor applications. These applications vary on large industrial systems. While the most of these studies are focused on the water pumping systems [9-13], especially for agricultural applications, researchers also investigated control techniques and performances of systems with motor loads used in other residential and industrial areas [14-17]. Because of their advantages like to be used in a very large speed range, also developments in control systems, in recent years switched reluctance motors (SRMs) take a valuable place in these studies.

In this paper, a SRM that is energized by a PV system is analysed. According to this aim, a system that consist of SRM, which is supplied by a PV system is designed under MATLAB / Simulink platform. System is designed as direct-fed structure, which means it is not include any storage unit like battery. After validation of system in normal operating conditions, various analyses are performed. As there are

studies on PV supplied reluctance motors in literature [18-19], in this study analysis is performed in two parts. In the first part of study, possible effects of the energy source, which is PV system in this study, are investigated, where in the second part effects of possible to occur at any point of the whole system are examined.

2. PV System Modelling

Detailed analysis and study is necessary for an appropriate design of PV systems. Therefore, it should be started from cell level for better understanding. PV panels are formed by connecting photovoltaic cells series and parallel, which are created by semiconductor materials. General structure of a PV cell is given in Fig. 1. [20-22].

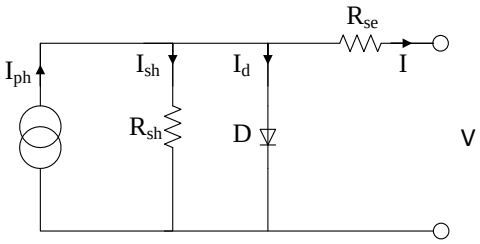


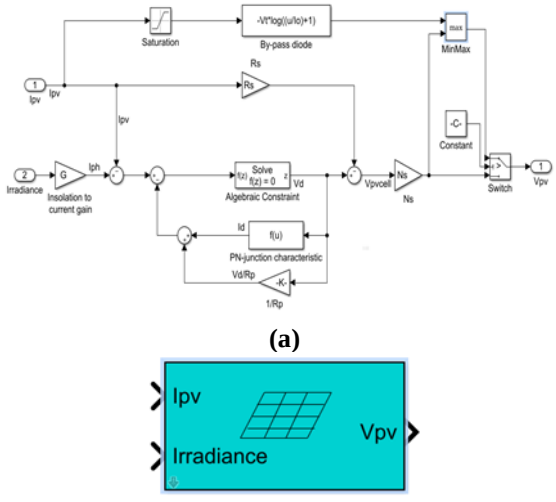
Figure 1. PV cell structure

According to the given equivalent circuit, mathematical model of a PV cell can be described as:

$$I = I_{ph} - I_d - I_{sh} \quad (1)$$

$$I = I_{ph} - I\left[e^{q(V+IR_{se})/kT} - 1\right] - \frac{V + IR_{se}}{R_{sh}} \quad (2)$$

In (2), I shows the current, V represents the terminal voltage, electron charge is shown by q, Boltzmann constant is shown by k and T shows ambient temperature, which is in terms of Kelvin.



(a)

(b)

Figure 2. a) Internal structure and b) block of PV panel

According to the purpose of study, a PV system is designed under MATLAB / Simulink platform. Internal structure and block representation of PV panel is shown in Fig. 2 a and b respectively, where Fig. 3 shows the designed PV system for application.

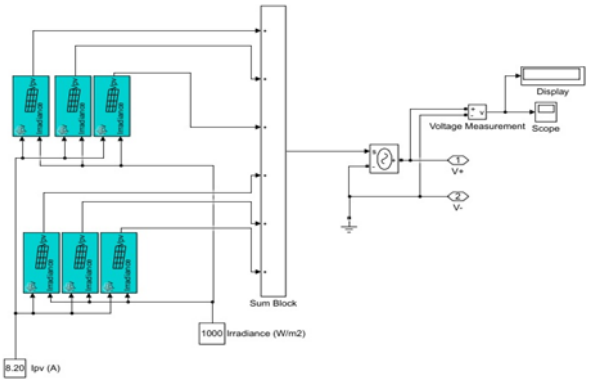


Figure 3. Designed PV system

Each PV panel has properties that shown in Fig. 4.

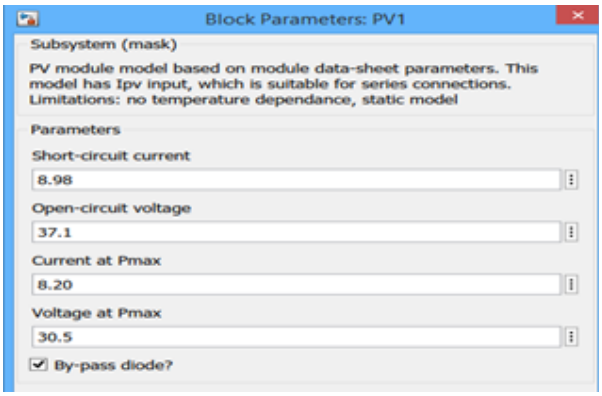


Figure 4. PV panel properties

3. Switched Reluctance Motor

Switched Reluctance Motors (SRMs) have advantages such as high-speed operation, high degree of independence between phases, short end-turn, and low inertia [23]. They are increasingly being considered as alternatives to other motor drives in many variable speed applications [24]. Developments for SRMs are not only on better design of the machine itself, but also on advanced control strategies [25]. Because of their valuable advantages, SRMs are being widely used in industrial, agricultural and electric vehicle applications [26-30]. The physical appearance of a SRM is similar to other rotating motors. The construction of 6/4 (6 stator poles, 4 rotor poles) SRM is given in Fig. 5.

Such motors are defined by ratio of their stator poles to rotor poles. The electromagnetic torque Te that can be obtained from the motor is given as:

$$T_e = \frac{1}{2} i^2 \frac{dL(\theta, i)}{d\theta} \quad (3)$$

Figure 5. Structure of the 6/4 pole SRM [31]

where i is the current in amperes and θ is rotor angle. The torque-speed operating point of an SRM is essentially programmable and determined almost entirely by the control. This is one of the features that makes the SRM an attractive solution for various applications. Similar as other motors, torque is limited by maximum allowed current, and speed by the available terminal voltage, which is illustrated in Fig. 6 [32].

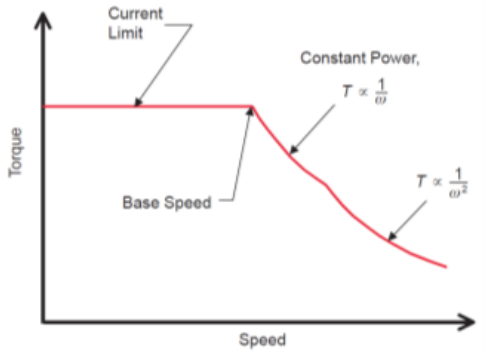


Figure 6. SRM Torque – Speed Characteristics

In this study, system is designed by using a 6/4 SRM. General properties of used SRM are summarized in Fig. 7.

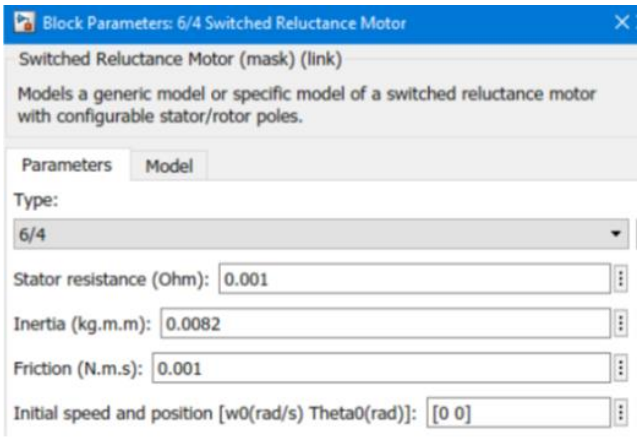


Figure 7. SRM Block Parameters

4. System Design

According to the aim of this study, a designed whole system structure is shown in Fig. 8.

The study system is consist of PV system, switched reluctance motor and converter unit as main components. In addition, there are controller blocks and display units as secondary ones [33]. SRM is energized by converter, which is supplied by PV unit. In addition, a simple closed-loop control is used for stability.

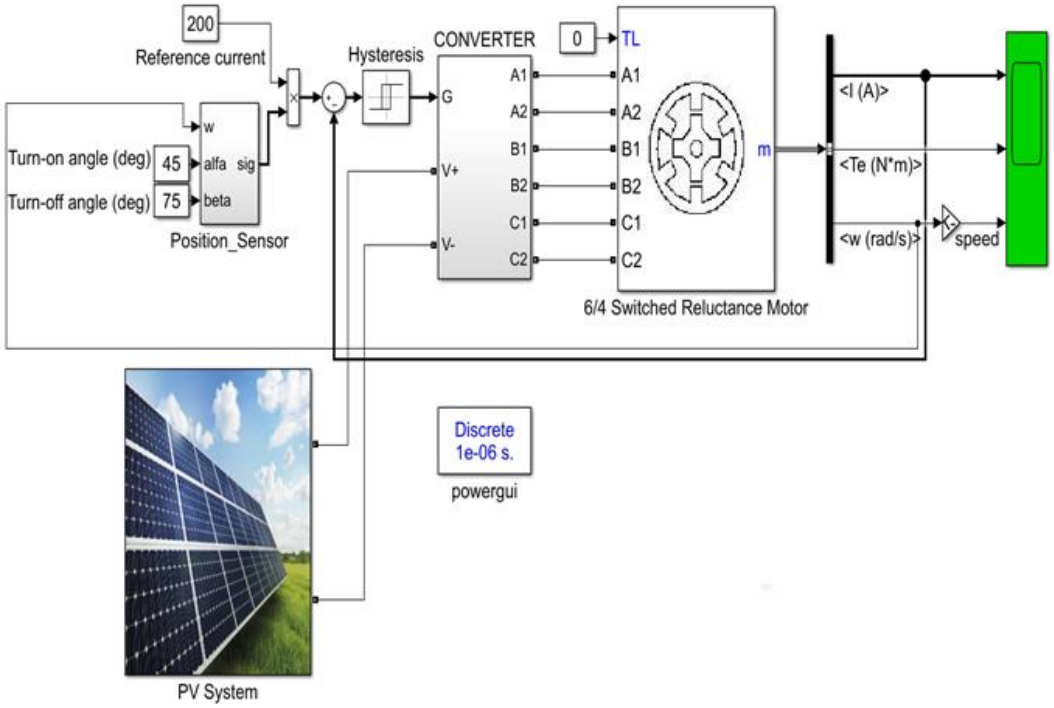


Figure 8. Study system

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5. Results and Discussion

Simulation parameters are adjusted for the system given in Fig. 8 and system is observed during simulation. Two main analyses are performed for detailed observation of system behaviour. These can be classified as observing the effects of PV system and effects of faults.

5.1. Analysis of PV system effects

PV system energy generating performance depends on some parameters strictly. Irradiance and shading can be defined as the most important parameters. Different values of irradiance are applied to PV system and effects of such variation are observed by using the graphs. Fig.9 represents the change of irradiation and Fig.10 shows impact of this variation on generated DC voltage from PV system.

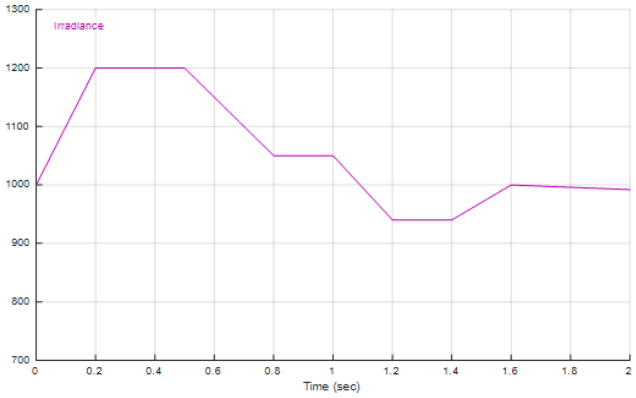

Figure 9. Irradiance change

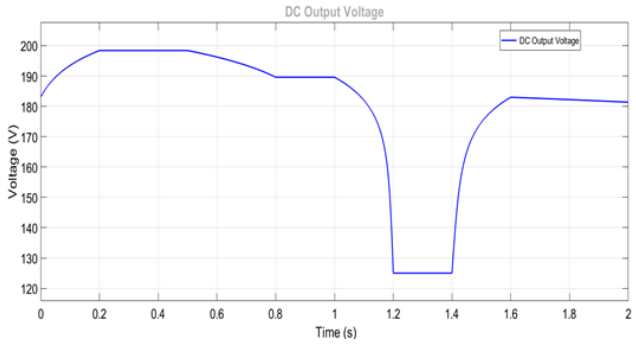

Figure 10. Output DC voltage of PV system

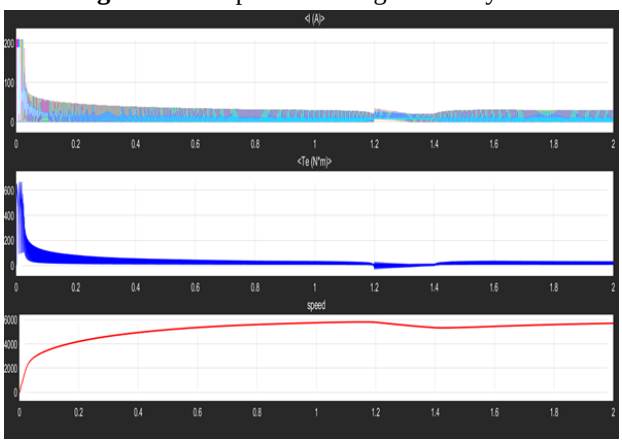

Figure 11. Response of SRM parameters

DC output voltage is applied to converter unit and possible effects of the changes are observed. Fig.11 shows the current, torque and rotor speed graphs respectively.

It is clear from figures that current, torque and speed values affect from change of generating values proportionally, where motor speed is more stable among these parameters.

5.2. Fault condition analysis

It is possible to occur any types of faults in a system. In this study, effects of a three phase to ground fault that possible to occur at input terminals of the SRM are investigated. Irradiance was kept constant at 1000 W/m^2 value during the fault condition analysis to observe effects of faults clearly. Fault is applied to system at 0.5th and restored at 1.2nd second. It is supposed that fault was occurred at A1B1C1 terminals of the SRM. Fig.12 shows the current, torque and speed graphs respectively during fault conditions.

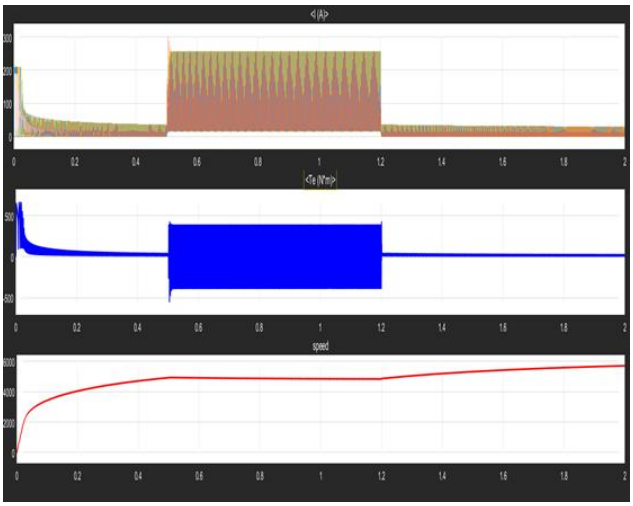

Figure 12. Fault conditions graphs

It is observed from Fig. 12 that current reaches about 10 times of its normal operating value. In addition, a negative torque is occurred during fault. This can be proposed as the most significant inference for the fault condition. On the other hand, speed is relatively stable during fault, as simulation results show. No protection device is added to system for a clear observation of the upper limits of parameters during fault. Therefore, high values are occurred during simulation.

6. Conclusion

Increment in electrical energy demand, directs customers to use generated energy at most efficient way. According to this necessity, both sources and loads have to be analysed in detail. If the loads are supplied by the renewable energy sources, appropriate analysis become vital. In this study, a SRM supplied by a PV system is analysed. Analysis is performed in two sections to observe the source and load side effects. Results are discussed by using the graphs that obtained from various points of whole system. Although the

system is designed as proper as possible, it may be differences at results when compared by an actual installed physical system. According to this disadvantage, authors are in progress of constructing a physical system as a future work for validation of proposed paper. This system will be same as proposed study, which is consist of a PV unit supplying SRM. Analysis results of actual system will be compared with this study and results will be shared by researchers.

Acknowledgment

This study is an extended and revised version of the paper "Analysis of PV Supplied SRM for Different Operating Conditions" which is presented at ICAT2018 conference.

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