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FDO BASED POWER TRANSFERS TO CONSTANT POWER LOADS IN PV BASED DC MICRO-GRID

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Abstract

Solar photovoltaic powered water pumping systems are becoming very successful in regions where there is no opportunity for connecting the electric grid. The photovoltaic technology converts solar energy into electrical energy for operating DC or AC motor-based water pump. In the case of a solar AC motor water pump, it engages two energy conversion stages (DC-DC and DC-AC) in the power conditioning unit. This usually resulted in increased size, cost, complexity and decreases the efficiency of the entire system. The existing two-level inverter (DC-AC) stage generates higher harmonics in output voltage and higher electromagnetic interference that deteriorates directly the AC motor performance. Therefore, as a solution to the addressed problems, in this manuscript, an innovative seven-level inverter with five power semiconductor switches for the operation of 0.5 H. P single phase induction motor pump had been investigated. The proposed multilevel inverter has the capability of providing lesser harmonic voltage which reduces filter requirements, along with this other part components are used lesser when compared to other conventional multilevel inverters. In order to provide better insight into the working and performance of this proposed topology, the simulation is executed in the MATLAB / Simulink environment and hardware implementation of the same is depicted. From the results, it is observed that the proposed multilevel inverter topology obtained a total power loss of 1.6034W and efficiency at 98.11%. This quality output voltage acquired from the multilevel inverter had been fed to drive the induction motor water pump, it pumped the water at the desired flow rate accordingly.

1 Introduction

Globally, solar photovoltaic powered water pumping systems (SPVWP) are progressively used in the areas where there is plentiful sunshine and scarce in power generation systems. Besides, photovoltaic (PV) system hardware prices are declined to 80% in the last two decades. In the last 10 years, the Levelized Cost of Electricity (LCoE) measure has lowered by 75% to USD 69/MWh (Jäger-Waldau 2019). These developments paved the way to enroll PV systems much faster especially the standalone alone PV systems. The acquisition of SPVWP is very simple compared to other conventional diesel or electric-based water pumping systems in consideration of cost and maintenance. Generally, SPVWP is an assembly of a solar PV array, inverter and motor-pump set. A PV array is a combination of electrically wired solar cells they are mounted together on a frame whereas an array designed by connecting several modules together. The solar inverter is an important building block in a PV system which makes the conversion of DC output from PV panel into AC current that able to run a motor pump set for groundwater extraction (Biswas and Iqbal 2018).In addition to that, present SPVWP utilizes electronic systems they majorly help in increasing output power, efficiency and performance of the whole system. The controller also has the capability to track water levels in a tank, control motor speed, and utilizes maximum power point tracking technology to give efficient output (Poompavai and Kowsalya 2019). Furthermore, the authors in (Odeh et al. 2018) suggested that the performance of SPVWP strongly depends on the head of the operation, irradiance factor and PV array size. To improve the efficiency of the pump they recommended to design the pump based on pump-well characteristics, subsystem efficiency, array sizing, an average of system, a frequency distribution of irradiance, etc(Al-Shetwi et al. 2016). The advancements are also occurred in PV panel tracking mechanism from manual tracking to automatic dual-axis tracking systems with the help of microcontroller programming (Chandel, Nagaraju Naik, and Chandel 2015).

In SPVWP, the power conditioning unit (PCU) comprises of all electronic conversion units. Therefore, in the PCU unit, if the system employs a

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DC-DC converter or DC-AC inverter alone is regarded as a single-stage system. Or else, if the system employs both converters are considered as a double stage system (Karampuri, Jain, and Somasekhar 2014).In a double stage system, two PCU's are interfaced, one is applied for extracting maximum power from PV source and the other is used for controlling a motor pump set. The existing two-level inverter or voltage source inverter (VSI) in PCU's required to satisfy power quality issues and it is also found to increase the losses and ripple content in the motor current of the PV system that leads to involve the increased value of filter circuitry (Ramulu et al. 2016).Therefore, there is a requirement of single-stage power conditioning (i.e., single PCU) solution for SPVWP where inverter capable of generating more than the two-level voltage in the output (Packiam, Jain, and Singh 2011; Mishra and Singh 2018, 2016). Multilevel inverters(MLI) provides the ultimate solution for the addressed issue and capable of delivering high power and medium voltage for industrial applications (Kurtoğlu et al. 2019).Moreover, MLI extracts lesser input current functions both at the higher and lower switching frequency, gives lesser dv/dt effects in load side and also reduces filter needs that lead to avoiding stresses in bearings of a motor (Poompavai and Vijayapriya 2017). As of now many MLI topologies are available based on the mechanism of switching and depending on the input source voltage. Of those, the major three topologies commercially preferred in industries are cascaded H-bridge(CHB) multilevel inverter, diode clamped and flying capacitor type (Akagi 2017).
The renewable energy-based systems usually take the foremost cascaded H-bridge type since it involves more isolated DC sources (Amamra et al. 2017) and also it eliminates fluctuation problems, the need of additional clamping diodes and flying capacitors.

However, the issue with this kind is the switch count, it increases whenever the number of voltage level increases that results in a bulky, less efficient and most expensive inverter. In an effort to fix this issue different MLI topologies with reduced switch count had been analyzed (Gupta et al. 2016; Siddique, Mekhilef, Shah, Sarwar, et al. 2019; Siddique, Mekhilef, Shah, and Memon 2019). This type of topologies greatly reduces the requirements of the driver circuit, lowers the size and expense of the entire system. Focusing on this reduced switch count to a maximum and minimize the complexity a novel topology was introduced (Umashankar et al. 2013). It utilized only five switches for seven-level inverter and this is the very least possible reduction of switch count when compared to other proposed topologies. The quality output voltage generated from the topology could able to drive asynchronous motor. To fulfill the water supply needs induction motors are generally chosen for water pumping operation. Furthermore, the production of induction motors is in a mature stage paving a way to use it in developing countries for SPVWP application. The major advantages of induction motor include high starting torque, less cost durability, speed variation, low maintenance cost, easier operation, etc. This induction motor is followed by a centrifugal pump for pumping operation. The speed and flow rate are regulated with the help of multilevel inverters with minimum total harmonic distortion (THD). (Al-Shetwi and Sujod 2018) found the inverse relationship between solar irradiance and THD, they observed whenever there is increase in solar irradiance there THD tends to decrease either in the current and voltage waveform. The quality output voltage waveform obtained from MLI could be controlled with its magnitude and frequency referred to be V/f control. This way permits the induction motor to attain desired speed at different rates.
In this manuscript, the operation of a seven-level inverter with five switches inverter had been tested with 0.5 HP single-phase induction motor water pump experimentally with the help of d-SPACE RTI-1104 platform. This topology uses IGBT as power switches and gate signals are given through a sinusoidal pulse width modulation technique. This proposed system eliminates the need for the DC-DC conversion stage in SPVWP and provides a single-stage solution through the MLI topology. The observed results show that the induction motor pump stayed its operation smoothly by receiving quality output voltage with lesser THD and also with reduced switching losses from seven-level five switch topology. The speed and flow rate are regulated at the desired value with the help of pulses obtained from the proposed MLI topology.

2 Architecture of the proposed system

The solar PV standalone water pumping system framework is depicted in Figure.1. It comprises of

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PV array, followed by five switch seven-level inverter and an induction motor water pump. The proposed multilevel inverter with reduced switches is used to provide pulse width modulated voltage to the input of induction motor and pump assembly with a single-stage solution.

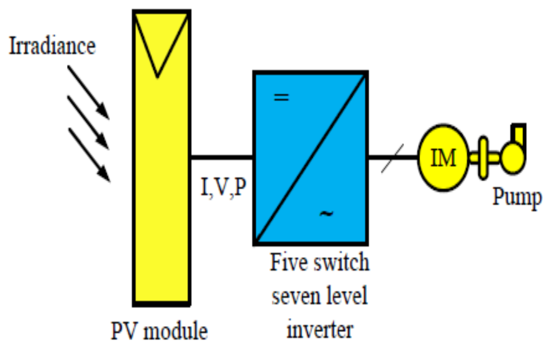


Figure.1. A framework of the proposed system

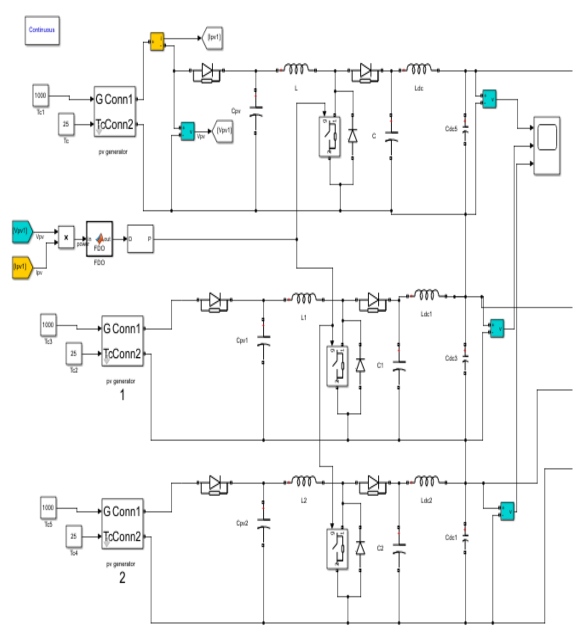
The photovoltaic cells are made of customized PN junction diode that converts the visible light into direct current (DC) and this process is referred to as photovoltaic effect. The PV modules combined in parallel or series to generate higher voltage and currents (Aliyu et al. 2018). The PV unit can be represented by two model's single diode model (SDM) and the double diode model (DDM) (Jordehi 2016; Sudhakar Babu et al. 2016). The SDM model is the most prevailed model that has less complexity and achieve accurate results. It represents
the individual PV cell; a PV module consists of many cells or an array that includes many modules together. The mathematical equation describes the PV system is expressed in Equ (1).

$$I = I_{pv}N_{par} - I_0 N_{par}\left[exp\left(\frac{V+R_s\left(\frac{N_{ser}}{N_{par}}\right)I}{V_t \alpha N_{ser}}\right) - 1\right] - \frac{V+R_s\left(\frac{N_{ser}}{N_{par}}\right)I}{R_p\left(\frac{N_{ser}}{N_{par}}\right)}$$

Where,
Ipv -current produced by incident light(A)
Io-leakage current of a diode(A)
q-charge of an electron (1.60217*10-19C)
k-Boltzmann constant (1.38065*10-23 J/k)
α-diode ideality constant (1< α<1.5)
Rs-Equivalent PV array series resistance(Ω)
Rp-Equivalent PV array parallel resistance(Ω)
Nser- number of cells in series
Npar- number of cells in parallel
T- PN junction temperature(k)
Vt-PV array Thermal voltage(V).

3 Implementation

The seven-level inverter with five switch topology representation is given in Figure.3. It is a very simple topology that involves four isolated dc sources and in the case of nine levels, it would be five dc sources and so on. Since it has isolated dc sources integrating PV as a source is very easy. In this proposed topology the PV panels replaced those isolated dc sources. By using phase opposition and disposition(POD) technique (Dan et al. 2015), the gating signals are generated and given to the five power IGBT switches. A sinusoidal modulating signal having a magnitude of 'Am' and frequency of 'fm' is taken to generate the gate signal where comparison made in between reference and the carrier waves. The signals produced would be equal to the number of carrier signals. The modulation index (Ma) can be represented by



4 Simulation results and analysis

Simulations attained with MATLAB/Simulink environment to verify and confirm whether the

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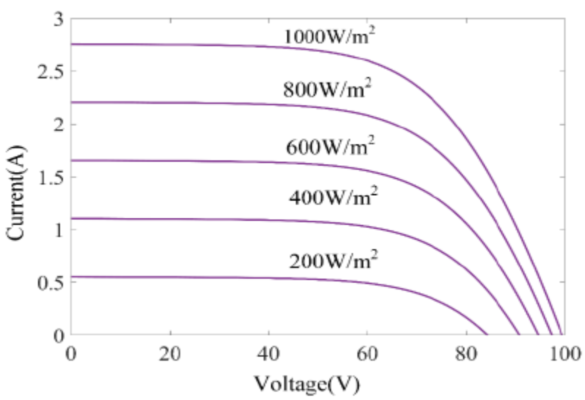
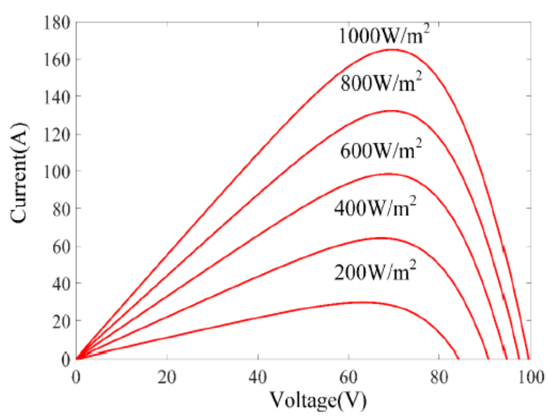
proposed multilevel inverter topology can be practically suitable to solar photovoltaic powered water pumping system or not. Using PV modelling the IV and PV characteristics obtained for the Solyndra SL-001-200 PV panel, taken at different irradiance conditions is represented in Figure.5 and Figure.6. The maximum open-circuit voltage (Voc) of 99.7 V is obtained at the standard irradiance condition of 1000W/m2. At minimum irradiance of 200W/m2 Voc is developing at the range of 84V. At some point of combination in current and voltage, the power reaches a maximum value which locates as Imp and Vmp. In this specific point, the maximum power is produced referred to as maximum power or MPP. The solar PV panel specifications are given in Table 2.





Specifications	Data
STC Power rating	200W
Peak efficiency	10.18%
Power tolerance	-4%/+4%
Imp	2.55A
Vmp	78.3V
Isc	2.78
Voc	99.7V
Temp.Coefficient of power	-0.38%/K
Temp.Coefficient of voltage	-0.289V/K
Series fuse rating	23A
Maximum system voltage	600V

5 Conclusions

The seven-level inverter with five switches had been applied for the investigation of 0.5 H. P single-phase induction motor water pump. The reduced switch count, , lesser requirement of gate driver circuits and dc sources ,increased voltage levels in the output are the main features of the proposed multilevel inverter topology. As a promising source, the photovoltaic system could be able to give constant voltage to the reduced switch multilevel inverter input dc source side that guarantees the standalone operation of a water pump. In summary, the simulation results reveal that the switching losses calculated across each switch are less and the THD content is also very low without any filter compared to other conventional multilevel inverter topologies. The reduced harmonic content in the output voltage made the induction motor to deliver its striking dynamic performance and it pumped water at the desired flow rate with the control in PWM technique. The hardware implementation of the same setup matched with the simulation outcomes which validate the system. Although, when implementing practically, thermal resistance and leakage current in the circuit affects the power quality which differentiates the simulation and practical results. The internal resistance of auxiliary circuit (gate driver board) used to drive the IGBT also tends to create a difference among the simulation and practical results. Therefore, overall system performance found to be satisfactory for operating induction motor water pump which thereby validating system model.

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