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Solar-Grid Connected Single Phase Water Pumping System for Household Application

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The proposed work focuses on the use of a hybrid water pumping system powered through the grid as well as photovoltaic cells, which is capable of operating on single-source availability of either solar or grid. This work reduces multiple stage power conversion by using a novel Modified Universal Converter to replace the diode rectifier, inverter for the hybrid water pumping system. The efficacy of the system has been tested, when operates, solar, grid, and both (solar and grid). The proposed water pumping system is tested on all three modes and also discusses voltage, current, speed, electromagnetic torque when the motor operates on grid, solar and both (grid and solar).

Keywords: Water Pumping System, Grid Supply, PV Panel.

1 Introduction

In the world, energy demand is rising. Renewable energy is most appropriate for economical and environmental aspects to fill energy demand. Now a days, solar energy is one of the most promising and easily harvested renewable energy we have. Due to the cost reduction in solar panel manufacturing[1,2] its suitability has increased extensively for various applications. Among multiple applications, the solar water pumping system has one of the vital uses[3,4]. Water is required for numerous purposes like domestic, agricultural, and industrial applications[5].

In recent work, many solar water pump system issues have been circumvented by using a hybrid water pump system. In a hybrid water pump system, either solar and wind energy or solar and grid energy is used for the water pumping system[6]. The existing literature indicates, the solar water pumping system will be a bonanza for society. Initially, a PV water system with a peak power tracking using a 3-phase inverter was used for supplying power. It is mainly used in rural areas for irrigation and water pumping. Later on, the work focused on the effect of load and voltage variation on the operation of the water pumping system. Simultaneously some other works used different motors like BLDC[7], PMSM[8] for the water pumping system with a 3-phase supply and centrifugal pump. Although, these work shows better efficiency of the water pumping system but at a higher cost. PV water pumping can be accomplished with or without a battery module[9]. Nonetheless, with a battery module, the application can be extended to cloudy days at high maintenance costs. There are some other issues like the water pumping system is plagued with multiple stage power conversion. The previous work also emphasized the reduction of multistage power conversion for the water pumping system[10]. Zeta converter reduces conversion stage for solar water pumping system for three-phase IM motor. This new configuration of converters, minimize multiple stages of power conversion[11]. The previous work mainly focused on solar water pumping systems for rural areas, but in the urban regions almost every day, every house uses a water pumping system. The urban water pumping system is only powered through the grid and uses a single-phase induction motor[12]. A single-phase induction motor is to be used in water circulation for rural and urban areas[13,14]. So an integrated water pump system with grid or wind power with a PV system and hybrid water system came into existence. So some of the work focuses on a hybrid water pump system, either the use of grid power and solar energy or solar and wind energy to supply energy[15,16]. The hybrid solar water pump system with wind energy, the use of the generator and other supporting devices for wind energy extraction, the initial cost for the hybrid water pumping system becomes very high. The operation of

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the system is still dependent on weather conditions, and it will limit the functioning of the water pumping system[17]. To resolve this issue, a grid connected hybrid water pumping system can be operated at low cost without any hindrance[18]. But the other issue of a hybrid water pumping system is the multistage power conversion.

2 Proposed configuration

Figure 1 illustrates the proposed system configuration in which single-phase AC supply and solar photovoltaic's fed water pumping system is used for the household applications in urban as well as in rural areas. The system consists of a single-phase induction motor based water pump, solar photovoltaic's, and modified universal converter, which are used to supply the regulated voltage. On the solar photovoltaic's side, a boost converter steps up the voltage to the reference of DC-link voltage. The proposed hybrid water pump system, a photovoltaic, and grid power is interfaced with a modified universal converter. The photovoltaic cell is connected with a boost converter and step up equal to the peak value of grid voltage. A single-phase induction motor based water pump is connected to a modified universal converter which can be used in rural, urban and industrial areas for water circulation. The operation of the proposed hybrid water pump system depends on the availability of solar energy. If solar energy is sufficient, the water pump is only powered through solar energy else it is powered by grid, Solar or both (grid and solar) as per its availability.

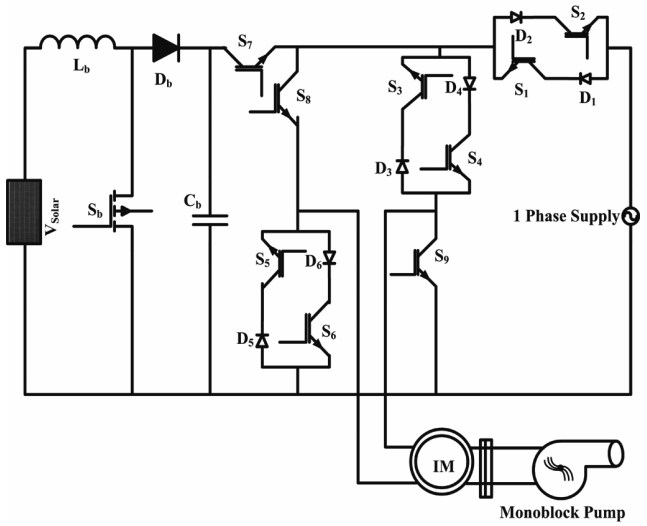

Fig. 1 — Modified Universal Converter

3 Operation of Modified Universal Converter with Water Pump System

Case-I: -Solar and single-phase supply Water Pump System

Mode I

The switches S_1, S_4, and S_6 are connected to AC source, which supplies power to load for duration 0 to t_1 to give an output voltage of square waveform. Switch S_2, S_3, S_5, S_7, S_8, and S_9 remains off during this mode. The flow of current in Mode-I is V_{ac}-S_1-D_1- D_4-S_4-Load-D_6-S_6-V_{ac}.

The voltage is given by

$$V_{0=}V_m \sin\omega t; \quad 0 \leq t_{0 \leq} t_1 \qquad \ldots (1)$$

Mode II,

The Switches S_7, S_4 and S_6 will turn on, and it will connect DC source (which is generated from solar energy) to load for duration t_1 to t_2 while switches S_1, S_2, S_3, S_5, S_8, and S_9 remains inactive. The path of current flow through V_s-S_7-D_4-S_4-Load-D_6-S_6- V_s. The output will be a half Sino-square.

$$V_O = V_S; \; t_1 \leq t_{0 \leq} t_2 \qquad \ldots (2)$$

Mode III

The switches S_2, S_3, and S_5 will turn on and connect AC supply to the load for negative half cycles while switches S_1, S_4, S_6, S_7, S_8, and S_9 are non-conducting. The flow of current is V_{ac}- D_2-S_2-D_3-S_3-Load-S_5- D_5-V_{ac}.

$$V_{0=}V_m \sin \omega t; \quad t_2 \leq t_{0 \leq} t_3 \qquad \ldots (3)$$

Mode IV

In Mode IV, S_7, S_8, and S_9 will connect DC to load for negative half cycles while switches S_1, S_2, S_3, S_4, S_5 and S_6 remain inactive. The flow of current in Mode IV, is V_s-S_7-S_8-Load-S_9-V_s. The final output voltage is in Sino-square waveform and voltage across the load during this mode is

$$V_O = V_S; \; t_3 \leq t_{0 \leq} t_4 \qquad \ldots (4)$$

Case II: - From PV Panel to Water Pump System

Mode I:

In Mode I switches, S_7, S_4, and S_6 are operated for the positive half while switches S_1, S_2, S_3, S_5, S_8, and S_9 remain off, for duration 0 to t_2. The output voltage 0 to t_2 is a positive square waveform.

$$V_O = V_S; \; t_0 \leq t_{0 \leq} t_2 \qquad \ldots (5)$$

The flow of current as is V_s-S_7-S_4-D_3-Load-D_5 -S_6- V_s.

Mode II

In Mode II switches S_7, S_8 and S_9 are operated for the negative half while switches S_1, S_2, S_3, S_4, S_5, and

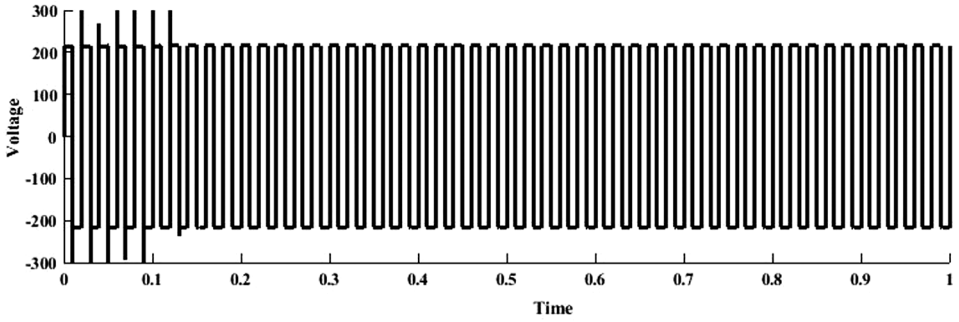

Fig. 2 — Output Voltage (Solar Power).

S_8 remains inactive. For duration t_2 to t_4 the output voltage is a Square waveform.

$$V_O = -V_S;\ t_2 \leq t_0 \leq t_4 \quad \ldots (6)$$

The flow of current is through V_s-S_7-S_8-Load -S_9- V_s.

CASE III: From Grid power to Water Pump System

Mode I

In Mode I, switches S_1, S_4, and S_6 are operated while switches S_2, S_3, S_5, S_7, S_8, and S_9 remain in non-conducting mode for 0 to t_2. The output voltage for 0 to t_2 is a sinusoidal waveform.

$$V_{0=} V_m \sin\omega t;\ 0 \leq t_0 \leq t_2 \quad \ldots (7)$$

The flow of current is V_S-D_1-S_1-D_4-S_4-Load-D_6 -S_6- V_s.

Mode II

In Mode II switch S_2, S_3 and S_5 are on while switches S_1, S_4, S_6, S_7, S_8 and S_9 remain off are operated for t_2 to t_4. The output voltage for t_2 to t_4 is

$$V_{0=} V_m \sin\omega t;\ t_2 \leq t_0 \leq t_4 \quad \ldots (8)$$

The flow of current is V_s-S_2-D_2-S_3-D_4-Load -D_6-S_5- V_s.

4 Result & Discussion

The system performance in Mode-I has been discussed in this section. In this Mode, the motor is powered through a PV panel**.** The output of PV voltage has been taken from 20x10 parallel, model SOLTECH1STH-220-P (Inbuilt model in MATLAB 2018). The output of the PV panel is taken at 25^0 with radiation of 600w/m^2 and the voltage is 120 V. The voltage is step by boost converter, and it is 220V. This voltage is converted into AC using a modified universal converter is depicted in Fig. 2. The peak value for the square waveform is 220V is used to run single-phase induction motor water pump. The speed of the motor is 1200 rpm and current withdrawn is 4 ampere as shown in Figs. 3 & 4 respectively.

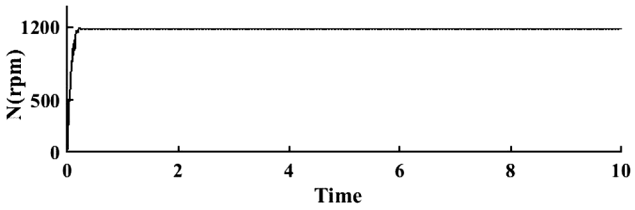

Fig. 3 — Speed of Motor (Solar Power).

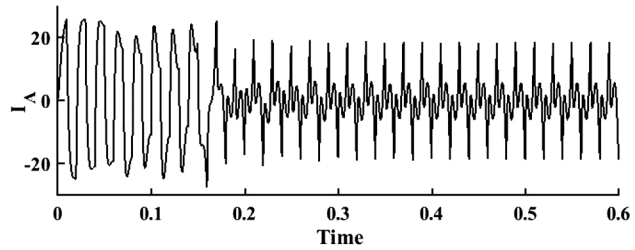

Fig. 4 — Armature Current (Solar Power).

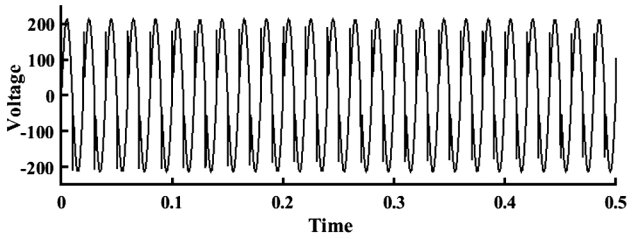

Fig. 5 — Output Voltage (Grid Power).

In Mode-II, The system performance is discussed when the hybrid water pump system is powered through a grid. Solar energy is not available during this time. The grid voltage is 220V AC, 50 Hz is shown in Fig. 5. The speed attains by the hybrid water system is 1200 rpm is depicted in Fig. 6. Figure 7 (a) depicts the electromagnetic torque which is sinusoidal**,** and it is varying between **-7** to 7Nm. with armature current 4A AC illustrated in Fig. 7 (b).

In this mode, solar energy is insufficient to deliver full power to the water pumping system. So during this mode energy supplied through the grid as well PV

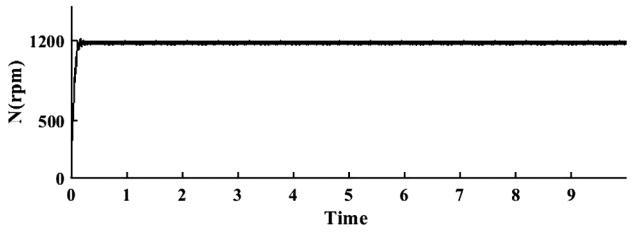

Fig. 6 — Speed of Motor (Grid Power).

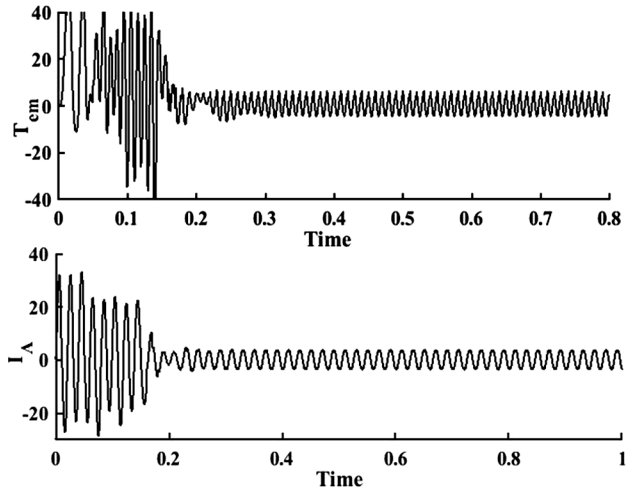

Fig. 7 — (a) Electromagnetic Torque (T_{EM}). (b) Armature current (I_A)

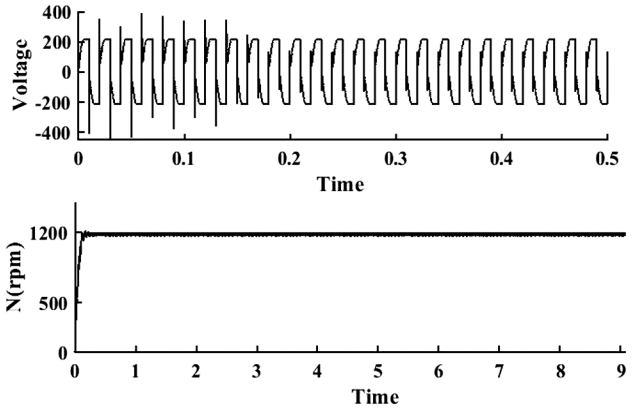

Fig. 8 — Output Voltage (Sino-Square) (b) Speed of Motor-N (rpm)

panel. The peak value of single-phase grid supply and output of boost converter is equal *i.e*. 220 V. As the figure shows that PV voltage is 80 V and irritation is reduced to 350 W/m^2. The boost converter is operating at a duty ratio of 0.8. The output voltage for this mode is sino-square which is the combination sine and square waveform depicted in Fig. 8 (a). The final speed attains by the motor is 1200 rpm as depicted in Fig. 8 (b)

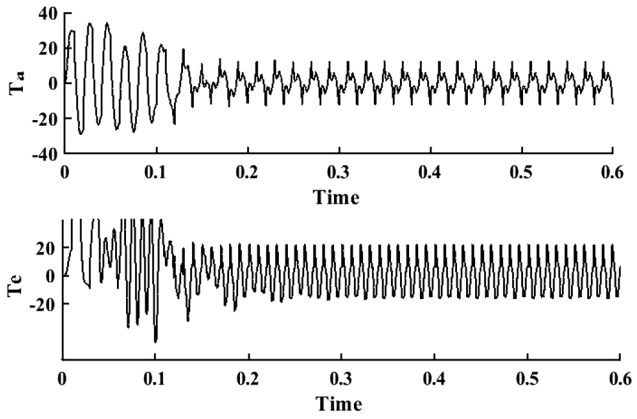

Fig. 9 — (a) Armature current (I_A) (b) Electromagnetic Torque (T_e)

The current drawn is 4A as shown in Fig. 9 (a). The electromagnetic torque is shown in Fig. 9 (b) which is 12 Nm.

5 Conclusion

A hybrid water pumping system has been integrated with a novel modified universal converter and it has been validated using MATLAB. The system eliminates the diode rectifier and mitigates the multiple power conversion, which is one of the major issues as discussed in the literature survey. The proposed system uses Sinusoidal AC power directly when it is operated on the both (grid and solar) and grid. This improves system reliability and efficiency. The system had been tested on all three modes and it can operate in all weather conditions.

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