

A solution using solar energy to supply three-phase power to a 2.2 kW water pump motor using MATLAB

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Abstract — In recent years, the rapid technological advancements have made the exploitation of renewable energy sources easier. The field of solar power, in particular, has seen rapid growth. Thanks to new technologies improving the efficiency of solar panels, their cost has also decreased significantly. The development of power electronics technology has led to the creation of flexible and affordable power converters. Furthermore, government policies are aligned with this trend, stimulating the strong development of solar power and making it easily accessible to the public. In line with this trend, our group has proposed a solution: using solar energy to power water pumps for agricultural irrigation. To implement this solution, we designed, simulated using Matlab software, and operated a 2.2kW solar-powered water pumping system model. The model's results show that it works well on sunny days and when the water level is not lower than 1.2m above the field surface, meeting the urgent needs of rice fields affected by drought during the dry season, reducing cultivation costs, increasing profits for farmers, and protecting the environment.

Keywords — *Solar battery, single phase DC/AC inverter, SinPWM control technique.*

I. INTRODUCTION

Every year, when the dry season arrives, the river water level drops, and the rice fields suffer from drought and water shortage. To save their rice fields, farmers have to spend a considerable amount of money supplying water to their fields in various ways: using diesel or gasoline-powered pumps (for fields far from residential areas and without low-voltage power lines), or electric pumps (for fields near houses or near low-voltage power lines). This reduces farmers' profits.

Today, with the global policy of exploiting renewable energy sources such as wind and solar power instead of fossil fuels like coal and oil, there is great interest. Along with the development of the 4.0 Industrial Revolution, the rapidly developing semiconductor industry has created favorable conditions for solar energy technology, making it easier for farmers to access and use this energy source at a low cost.

Vinh Long has the advantage of high solar radiation conditions of 5kWh/1m²/day, and a high number of sunny days in the year of 320 days. On average, 1kWp yields 4.5kWh/day [1-4]. Because of this advantage, Vinh Long province currently has many projects and models for exploiting renewable energy to serve the needs of electricity use from households and industries, typical examples are as follows:

1) The first project: Pilot Installation of a 5kWp Solar Power System at the Tra Vinh Department of Industry and Trade Headquarters. Lead Unit: Tra Vinh Department of Industry and Trade. Implementation Period: March 2018 to March 2019.

Table 1: Data obtained from Goodwe's software.

Unit of measurement: kWh

March 2018	April 2018	May 2018	June 2018	July 2018	Aug. 2018
776.2	742.7	596.3	539.6	558.6	568.5
Sept. 2018	Oct. 2018	Nov. 2018	Dec. 2018	Jan. 2019	Feb. 2019
558.9	690.2	590.6	571.2	671.5	672.3

2) The second project: 100kWp Rooftop Solar Power System on the Administrative Building of Tra Vinh University. Lead Unit: Tra Vinh University. Operational Period: From December 25, 2019 to present.

Table 2: Data collected on power output from the 100kWp system at Tra Vinh University (TVU).

Unit of measurement: kWh

Jan. 2020	Feb. 2020	March 2020	April 2020	May 2020	June 2020
16057	15780	15757	15200	13633	10856
July 2020	Aug. 2020	Sept. 2020	Oct. 2020	Nov. 2020	Dec. 2020
12711	12219	12583	10363	12555	11214

3) The third project: The Trung Nam Tra Vinh Solar Power Plant is built in Giong Gieng hamlet, Dan Thanh commune, Duyen Hai town, Vinh Long

province. The total capacity is 140 MW, comprising 32 DC/AC converter stations. The average current of the stations is $I_{mpp} = 6.2$ (A), the average voltage of the stations is 1058.79 (V), and the conversion efficiency is 90.9%.

The survey results from the three models above show that the energy output and conversion efficiency of the batteries are very high ($> 85\%$), creating favorable conditions for people to use this inexhaustible energy source. Vinh Long is located in the southeastern part of the Mekong Delta with a natural area of 6,296.2 km², situated between two major rivers, the Tien River and the Hau River. It borders Dong Thap province to the north; the East and Southeast border the East Sea; and the West and Southwest border Can Tho province. With over 130 km of coastline, the climate is divided into two distinct seasons: the rainy season from May to November and the dry season from December to April of the following year. This allows for three rice crops per year: the winter-spring, summer-autumn, and autumn-winter crops; of which the winter-spring and summer-autumn crops require the most irrigation due to the difference in water levels between canals and fields ranging from 0.1 to 1m.

Currently, in Hoa Thuan ward, Vinh Long province, the main method of irrigating rice fields is using a D6 diesel engine (6hp). The pumped water volume is 50-70 m³/h, meeting the needs of approximately 500-700m² of rice field surface area, as shown in Figure 1. The machine has a total weight of over 100kg. The interval between two pumping sessions is 3-5 days, and the number of pumping sessions per crop is 7-10 times/crop. Thus, the cost for a crop is quite high if investing in a diesel machine. Diesel machines have a short lifespan (4-5 years) and low efficiency (45-65%), plus transportation, maintenance, and fuel costs. If renting a pump, with the rising fuel price of approximately 40,000 VND/liter, the cost could reach (100-150,000) VND/hour, making the cost for a crop increasingly higher.



Figure 1: Using a diesel engine to pump water from a well and ditch.

Studies outside the province and the world: some large companies specializing in solar energy have created solar-powered water pumping systems such as: Saigon Trading Company, Vu Phong's solar water pump [5] specializes in supplying and installing

solar energy equipment combined with installing DC-AC power converters to serve industry and civil use.

In the world, research works on solar energy and applications are very widespread, such as: The work "Pumping Water for Irrigation Using Solar Energy" [6] analyzed the data and structure of solar cells, the ability to absorb solar energy and convert it into electrical energy, or in other words, the efficiency of the solar panel. The method of connecting solar panels. Analysis of the energy conversion process in the pumping system, energy loss in the irrigation system. The work "Solar Powered Water Pumping Systems" [7] mentioned the application of solar energy from solar panels in the form of DC power through a controller to run DC motors to create power for water pumping systems, as well as power for other equipment serving agriculture. However, the pumping system used for many different purposes is not suitable for a specific purpose such as pumping water into rice fields, which has the characteristic of a low water level difference between the field and the water storage canal (less than 1.3m). Therefore, the group designed a suitable pumping mechanism to This increases pump efficiency by 2-3 times compared to conventional pumps.

Based on the local situation, the specific characteristics of the soil, and the infrastructure at the Faculty of Electrical and Electronic Engineering, College of Engineering and Technology, Tra Vinh University, our team researched, designed, and installed a solar-powered water pumping system (2.2kW) to irrigate rice fields, at a reasonable cost of 20-25 million VND.

II. PROPOSED SOLUTION

To design and install a water pumping system for rice fields, the group surveyed the water level difference between the canal and the field, studied the characteristics of solar panels, and investigated the power output and efficiency of solar panels in Hoa Thuan ward. They calculated and selected the solar panel capacity and the number of panels to be used. A power converter was designed to convert DC power to 3-phase AC power to supply a 2.2 kW 3-phase asynchronous motor driving a water pump with a capacity of 60 m³/hour.

A. Schematic Diagram of the Proposed Solar-Powered Pumping System

The schematic diagram of the control circuit and power circuit of the 2.2 kW water pumping system is shown in Figure 2.

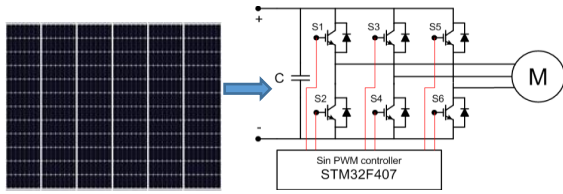


Figure 2: Schematic diagram of a pumping system using a solar-powered pump.

The design of a water pumping system includes the following basic components:

1) Determine the number and specifications of the solar panels and support frames.

a) Solar panel specifications: Based on a load power of 2.2kW, we selected 6 solar panels connected in series, each with the following electrical and mechanical specifications [Table 4] and system operating parameters: Open circuit voltage: 289.2V; Rated current: 9.66A; Voltage V_{mpp} : 242V; Power P_{mpp} : 2340W.

Table 4: Specifications of the solar panel

390 Wp solar panel		
Electrical specifications	Rated power at STC (P_{mpp})	390Wp
	Open-circuit voltage (V_{oc})	48.2V
	Short-circuit current at STC (I_{sc})	10.17A
	MPP voltage (V_{mpp})	40.4V
	Current (I_{mpp})	9.66A
	Operating temperature	25°C - 85°C
Mechanical specifications	Number of cells in the solar panel	144[2x(12*6)]
	Dimensions (L*W*H) m	2000*992*35m
	Weight	22.5 kg
	Frame technology	Aluminum anodizing
	Standard	IP68
	Maximum load	5400Pa

b) Design of the solar panel support frame: The solar panels are fixed on a stainless steel frame with dimensions of 6m in length, 1.4m in width, and 1.6m in height. It is easy to assemble and disassemble thanks to a locking system, designed for easy installation and removal during transportation.

2) Design of a 3-phase DC/AC inverter system

The DC power converter from the output of 6 solar panels to 3-phase AC power for the motor uses SinPWM modulation technique [8-9] to control the switching on/off of the semiconductor: IGBT

FGH40N60SFD 40A as shown in Figure 3. The pulse generator circuit uses the STM32F407 board and the control code is written in Matlab software and Weijung 17.03a library.

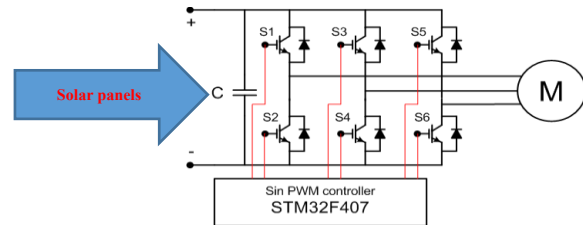


Figure 3: Schematic diagram of a 3-phase DC to AC converter circuit.

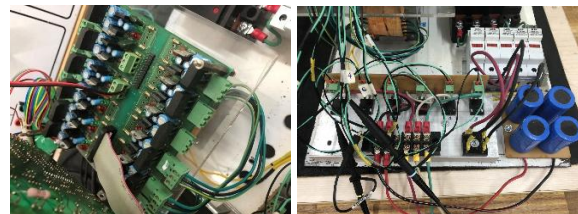


Figure 4: Trigger power supply circuit and power amplifier circuit



Figure 5: Complete inverter hardware

C. Experiment with the inverter Three-phase AC with load R and motor

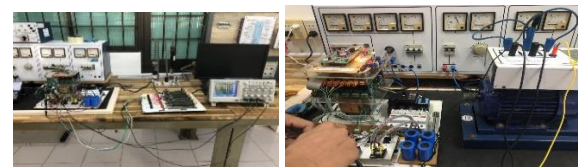


Figure 6: 2R phase load connected in series (a); Asynchronous motor load (b)

1) In the case of a resistive load: Single-phase supply voltage 50Vac, DC voltage across the capacitor 70VDC, three-phase output voltage at 50Hz, the frequency can be changed by adjusting the control waveform frequency.

2) In the case of a 3-phase asynchronous motor load: Single-phase supply voltage 220VAC, DC voltage across the capacitor 310VDC, 3-phase AC input voltage 220VAC at 50Hz, the frequency can be changed by changing the control waveform frequency.

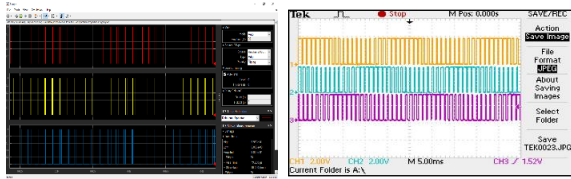


Figure 7: IGBT S1; S3; S5 trigger pulses, simulation and experiment

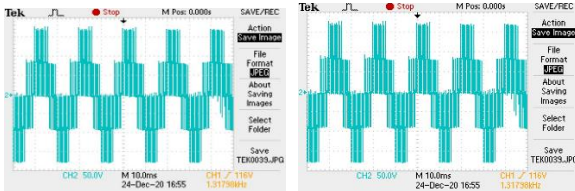


Figure 8: Output waveforms of single-phase and three-phase inverters

3) Engine selection calculation

Based on the power output from the inverter, the water pump motor is selected as an "Asynchronous" motor with the following specifications:

Table 5: Engine specifications

Rated power P _d	Rated voltage	Rated current I	Number of poles: 2p	Frequency f	Speed of ndm
2.2kW	200V	8.65A	2	60Hz	2840 rpm

Simple, robust construction, and low cost. Widely used in both domestic and industrial applications. A wide power range from a few tens of watts to several megawatts. Easy for farmers to find and repair.

III. DISCUSSION RESULTS

1) Model Operation and Data Collection

The model was installed and operated during the daytime from 7:00 AM to 4:55 PM at the crop cultivation practice area of the Faculty of Agriculture and Fisheries, Tra Vinh University, and the following parameters were collected: Frequency (f); Real-time (h); Flow rate (seconds/60 liters) (s/l); Volume (cubic meters/hour) (m³/h); alternating voltage (Vac). Parameters were collected during the model's operation at a frequency of 10 minutes/time from 7:00 AM to 5:00 PM, equivalent to 62 samples/day, and collected over 5 days with a total of 310 samples. Sampling was performed manually, and the data was recorded and processed as shown in [Table 6], [Table 7].

The sampling procedure is as follows:

- Prepare a 60-liter water container, a video camera, and a data recording board.
- Sampling begins at 7:00 AM at a frequency of 26Hz. Fill the 60-liter container completely and repeat

the process three times, recording each step with the video camera.

c) Based on the sampling table, increase the inverter frequency (f) from 26Hz to 60Hz. At each frequency, perform sampling similar to that at 26Hz.

2) From the results of the data tables [Table 6], [Table 7], we see that the lowest frequency f_{min} = 26Hz at 7:00 AM and gradually increases to 60Hz at 12:50 PM. In the afternoon, the opposite happens, the frequency gradually decreases from 60Hz to 26Hz at 4:55 PM. This also corresponds to the minimum water pumping rate of 10.8 m³/h at frequency f_{min} = 26Hz and the maximum rate of 86.4 m³/h at frequency f_{max} = 60Hz.

From the results collected in the data tables, we have the relationship between the parameters: Real-time (h) during the day and frequency (f) [Figure 10]; Real-time daytime (h) and output alternating voltage (Vac) [Figure 11] and Real-time daytime (h) and water volume (m³/h) pumped [Figure 12]



Figure 9: Pumping system and flow measurement and sampling equipment.

Table 6: Data collected in the morning: (7:00 AM - 4:55 PM)

Time(h)	Frequency (f)	Seconds /60 liters (s/l)	cubic meters/hour (m ³ /h)	Voltage (Vac)
7:00 AM	26	20	10.8	85.30
7:10	27	15	14.4	88.70
7:20	28	13	16.6	91.40
7:30	29	11	19.4	94.50
7:40	30	9.0	24.0	97.60
7:50	31	8.5	25.4	100.4
8:00 AM	32	8.0	27.0	103.5
8:10	33	7.5	28.8	105.9
8:20	34	6.9	31.3	109.0
8:30	35	6.4	33.8	112.3
8:40	36	6.0	36.0	115.7
8:50	37	5.7	37.9	119.6
9:00 AM	38	5.5	39.3	123.2
9:10	39	5.2	41.4	125.0
9:20	40	5.0	43.2	126.8
9:30	41	4.7	46.0	129.7

9:40	42	4.5	48.0	133.0
9:50	43	4.3	50.2	137.6
10:00 AM	44	4.2	51.4	139.3
10:10 AM	45	4.0	54.0	140.4
10:20	46	3.9	55.4	141.8
10:30 AM	47	3.8	56.8	147.6
10:40 AM	48	3.7	58.4	151.3
10:50 AM	49	3.6	60.0	153.6
11:00 AM	50	3.5	61.7	155.7
11:10 AM	51	3.4	63.5	156.9
11:20 AM	52	3.3	65.4	158.3
11:30 AM	53	3.2	67.5	159.8
11:40 AM	54	3.1	69.7	162.2
11:50 AM	55	3.0	72.0	164.7
12:00 PM	56	2.9	74.5	167.3
12:10 PM	57	2.8	77.1	169.2
12:20	58	2.7	80.0	171.4
12:30 PM	59	2.6	83.1	175.0
12:40 PM	60	2.5	86.4	176.7

Table 7: Data collected in the afternoon: (12:50 PM – 5:00 PM)

Time (t)	Frequency (f)	Seconds/60 liters (s/l)	cubic meters/hour (m ³ /h)	Voltage (Vac)
12:50 PM	60	2.5	86.4	178.1
13:00	59	2.6	83.1	176.7
13:10	58	2.7	80.0	174.0
13:20	57	2.8	77.1	171.4
1:30 PM	56	2.9	74.5	169.4
13:40	55	3.0	72.0	167.3
13:50	54	3.1	69.7	164.0
2:00 PM	53	3.2	67.5	162.2
14:10	52	3.3	65.4	159.2
14:20	51	3.4	63.5	158.3
2:30 PM	50	3.5	61.7	157.0
14:40	49	3.6	60.0	153.6
14:50	48	3.7	58.4	151.3
3:00 PM	47	3.8	56.8	147.6

3:10 PM	46	3.9	55.4	144.8
3:20 PM	45	4.0	54.0	142.8
3:30 PM	43	4.2	51.4	138.3
3:40 PM	41	4.5	48.0	133.0
3:50 PM	39	5.2	41.4	126.8
4:00 PM	37	5.7	37.9	123.2
4:10 PM	35	6.4	33.8	115.7
4:15 PM	34	6.9	31.3	113.0
4:20 PM	33	7.5	28.8	109.0
4:30 PM	31	8.5	25.4	103.5
4:40 PM	29	11	19.4	97.60
4:50 PM	27	15	14.4	91.40
5:00 PM	26	20	10.8	85.30

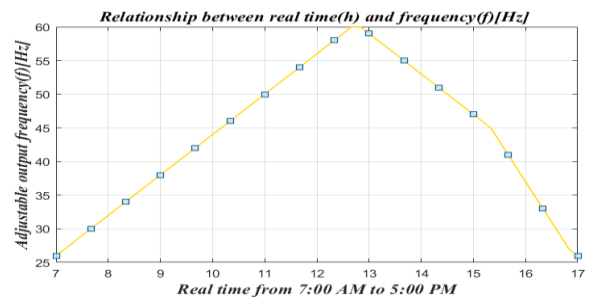


Figure 10: Frequency (f) adjusted over time during good sunny weather.

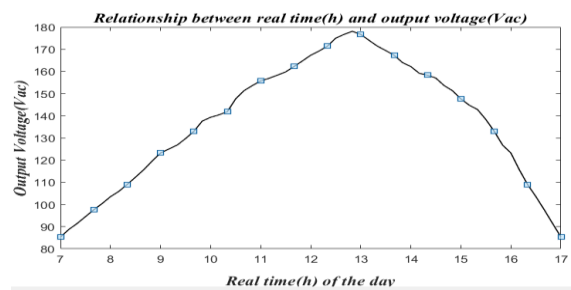


Figure 11: Output voltage (Vac) supplied to the motor during good sunny weather.

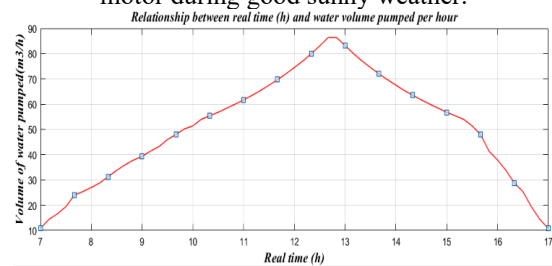


Figure 12: Water volume (m³/h) pumped during good sunny weather.

CONCLUSION

This article presents a solution using solar energy through a 3-phase DC/AC power converter with output voltage controlled by Matlab software to operate a water pumping system with a 2.2kW 3-phase asynchronous electric motor. The experimental model was tested over 5 days from April 4th to April 8th, 2025, in a rice field belonging to the Department of Agriculture, Faculty of Agriculture and Fisheries, Tra Vinh University, with a water level difference between the canal and the rice field ($H = 1.2\text{m}$).

With the 2.2kW solar-powered water pumping system, the flow rate achieved ranged from $10.8\text{m}^3/\text{h}$ to $84.6\text{m}^3/\text{h}$. Operation time was from 7:00 AM to 4:55 PM.

After one year of operation (from April 2025 to April 2026), our team found that the water pumping system designed in this paper is fully applicable to many localities with similar agricultural farming conditions.

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