Three Phase Induction Motor Drive Using Flyback Converter and PWM Inverter Fed from a Single Photovoltaic Panel

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Abstract-- **The purpose of this project is to drive a three phase induction motor with the use of a single photovoltaic (PV) panel. The motor will be driven with the available power at the moment, because no battery will be implemented. In order to match the impedance of the panel (to extract the maximum power available) and boost the voltage, a fly back topology is proposed. In output of the flyback a three phase inverter is connected to drive the induction motor. This inverter will be controlled with the PWM unipolar technique. A maximum power point algorithm, the perturbation and observation, is implemented. Simulation results are provided. The panel delivered rated 210W and the motor achieved rated speed in open loop.**

***Index Terms*—solar panel, induction motor, inverter, flyback converter, pulse width modulation, maximum power point tracker**

I. Introduction

With the use of a dependable and renewable energy source a device can operate independently from the grid. The objective is to operate an induction machine using the power from a photo voltaic panel. A power electronics interface is needed in order to operate the induction machine using the PV panel. By using a DC-DC converter combine with a DC-AC inverter it is possible to transfer the power efficiently from the panel to the machine using various methods. These methods are known as Maximum Power Point Trackers and work by changing the parameters of the power electronics components in order to obtain the maximum power available at the moment. A speed control method is also needed in order to drive the induction motor efficiently.

Our proposed system consists of a solar panel followed by a power electronics interface that controls the speed of an induction motor. The system is going to be connected by a black box, that needs the input source (PV) and the Output (Motor). To maximize the available power in the PV, a maximum power point tracker (MPPT) will be implemented.

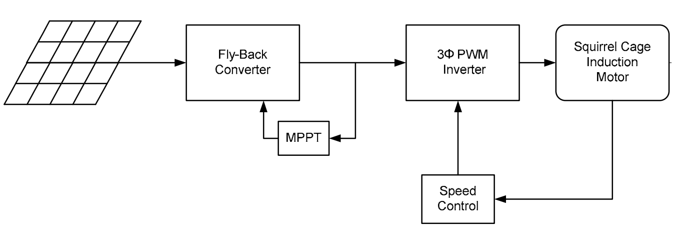

Fig. 1. Proposed system's block diagram

To accomplish this, the Perturb & Observe (P&O) technique is used. The DC/DC converter is implemented to match the impedance between panel and load for maximum power transfer. The DC/DC converter will be using a high frequency transformer because of the big step-up voltage needed. When the voltage is matched an inverter is used to create an AC source, with the possibility of a variable frequency. To maximize motor efficiency, both voltage magnitude and voltage frequency should be controlled.

II. Project Details

A. Photovoltaic panel

A photovoltaic (PV) cell is a device that converts sunlight into electrical energy. An array of cells connected in parallel and/or series is called a PV panel. The power on the PV depends on solar irradiance, panel temperature and operating voltage and current. The current-voltage relationship, called the I-V characteristic, is a complex, non linear function. Various mathematical models have been developed to describe the behavior of the panel. In this project, the only source of power is a solar panel and maximum power needs to be extracted from it.

The following model will be used for the photovoltaic panel [10]:

$$I(V) = \frac{I_X}{1 - \exp\left(\frac{-1}{b}\right)} \cdot \left[1 - \exp\left(\frac{V}{b * V_X} - \frac{1}{b}\right)\right] \quad (1)$$

$$P(V) = V \cdot I(V) = \frac{V \cdot I_X}{1 - \exp\left(\frac{-1}{b}\right)} \cdot \left[1 - \exp\left(\frac{V}{b \cdot V_X} - \frac{1}{b}\right)\right] \quad (2)$$

Where Ix is the short circuit current under Standard Test Conditions (STC), Vx is the open circuit voltage under STC, and b is the characteristic constant of the panel. The parameter b can be approximated as by:

$$b_{(n+1)} = \frac{\left(\frac{V_{op}}{V_X} - 1\right)}{\ln\left[1 - \left(\frac{1}{V_{op} I_{sc}}\right) \cdot \left(P_{max} - P_{max} \cdot \exp\left(\frac{-1}{b(n)}\right)\right)\right]} \quad (3)$$

Where V_{op} is the voltage at which the maximum power is extracted from the panel and P_{max} is the maximum power point of the panel, all under STC. The panel

B. Maximum Power Point Tracker

A maximum power point tracker (MPPT) is a device that, as the name implies, looks for the maximum power point of a source and keeps it operating in that point. There are many techniques [1] used for implementing MPPT. The MPPT tries to match the power source to an impedance that demands the maximum power out of it. This variable impedance is usually a DC-DC converter to maintain very low losses in the system.

The PV is not always operating in its maximum power point, but with the use of an MPPT it is possible to force the PV to give the maximum power at the given irradiance. Different MPPT techniques are available; some are more complex than others [1]. For the project, the perturbation and observation (P&O) technique is going to be used because of the simplicity and the easy implementation. This technique is not running at real time, but considering that it will be implemented in a microcontroller and the internal calculations are done at high speed, it is almost real time. This technique is easily implemented by an algorithm using the power-voltage characteristics of the PV module. Knowing that at the right and the left of the maximum power point the power decreases, the converter's duty cycle is changed depending on the last change in power and if the duty cycle was increased or decreased. To implement the P&O the power needs to be read at a time K, afterwards the voltage is changed. These readings are stored in memory. Next the power in time k+1 is read, if this power is incrementing we increment the duty ratio and by consequence the voltage in the PV. In the case that the power in the K+1 is lower than in the K time we decrement the duty ratio and by consequence the voltage. This technique is operating in the in the boundaries of the MPP. The algorithm of the P&O is presented in the fig. 3:

C. DC-DC Converter

A DC-DC converter is a switching device that takes a direct current (DC) voltage at one level and converts it to a DC voltage at another level. The basic converter consists of inductors, capacitors, diodes and transistors to step-down or step-up a voltage input. The three basic topologies are the buck (step-down), boost (step-up), and buck-boost (step up and down). Because the output of the converter depends on the state of the transistor switch, the converters are controlled by the duty cycle (a percentage of the time spent on the "on" state) of the transistor. By varying the duty cycle, the optimal load impedance for the PV module can be achieved.

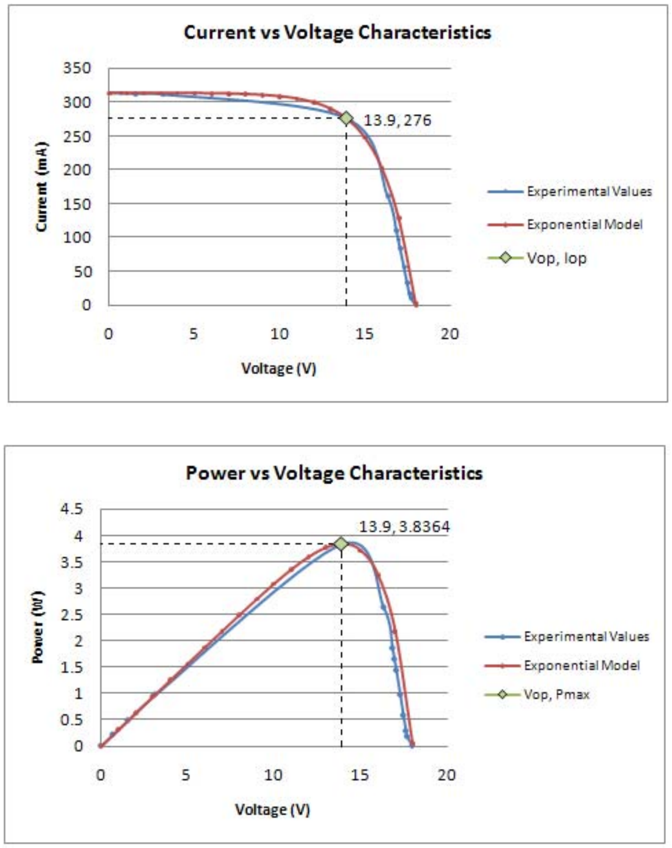

Fig. 2. Model validation graphs. The experimental values (blue) vs. the model (red).

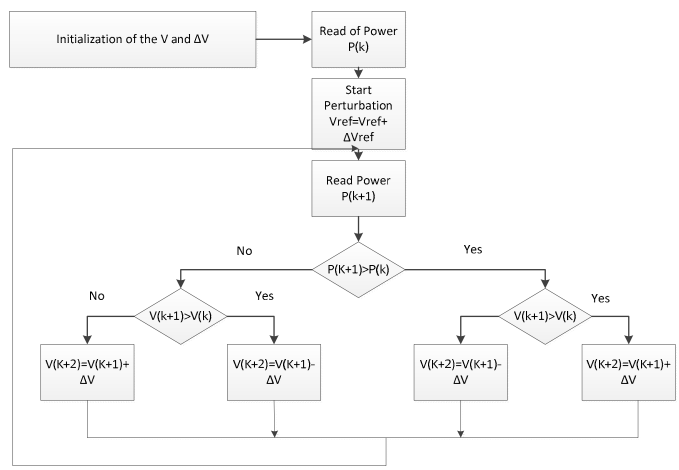

Fig. 3. The Perturbation and Observation Algorithm

The converter that will be implemented in the project is the flyback converter. The flyback has the same duty cycle relationship as the buck-boost except that it is multiplied by a transformer turns ratio gain to step up the voltage even more. This extra gain is useful in matching the panel's 25 volt output to the nominal output of 240 V and keeping the number of converters to a minimum.

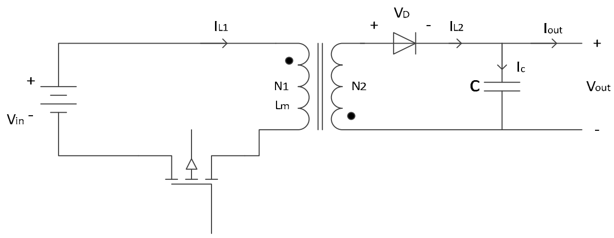

Fig.4 Circuit diagram of flyback converter.

The flyback is shown in figure 4. The dynamic equations of the flyback are:

$$\frac{dI_{L1}}{dt} = -\left(\frac{N_1}{N_2}\right)\left(\frac{1-D}{L_m}\right)V_{out} + \frac{D}{L_m}V_{in} \tag{4}$$

$$\frac{dV_{out}}{dt} = \left(\frac{N_1}{N_2}\right)\left(\frac{1}{C}\right)I_{L1} - \left(\frac{1}{C}\right)I_{out} \tag{5}$$

Where I_{L1} is the current through the primary inductor, C is the output capacitor capacitance, V_{out} is the capacitor voltage, L_m is the primary inductor magnetizing inductance, D is the switch's duty cycle, V_{in} is the input DC voltage, and I_{out} is the output load current. N1 is the number of turns of the primary of the transformer while N2 is the number of turns of the secondary side.

In steady state, the input-output relationships are:

$$\frac{V_{out}}{V_{in}} = \left(\frac{N_2}{N_1}\right)\left(\frac{D}{1-D}\right) \tag{6}$$

$$\frac{I_{in}}{I_{out}} = \left(\frac{N_2}{N_1}\right)\left(\frac{D}{1-D}\right) \tag{7}$$

Where I_{in} is I_{L1}, the input current.

The following analysis determines duty cycle range of existence for flyback converter based on impedance matching using equations (6) and (7):

$$R_{out} = \frac{V_{out}}{I_{out}} = \frac{V_{in}}{I_{out}}\left(\frac{N_2}{N_1}\right)\left(\frac{D}{1-D}\right) = \frac{V_{in}}{I_{in}}\left(\frac{N_2}{N_1}\right)^2\left(\frac{D}{1-D}\right)^2 = R_{in}\left(\frac{N_2}{N_1}\right)^2\left(\frac{D}{1-D}\right)^2 \tag{8}$$

Where R_{in} is the input impedance to the flyback (the panel internal impedance which varies with irradiance and temperature) and R_{out} is the converter's load impedance.

Solving (8) for D:

$$D = \frac{1}{1+\left(\frac{N_2}{N_1}\right)\sqrt{\frac{R_{in}}{R_{out}}}} \tag{9}$$

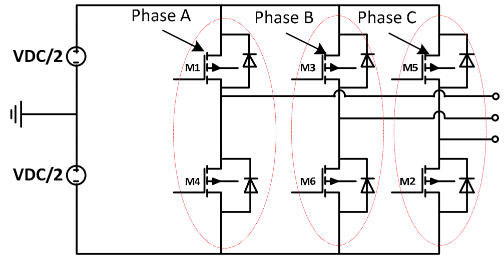

Fig. 5 Six Step Inverter

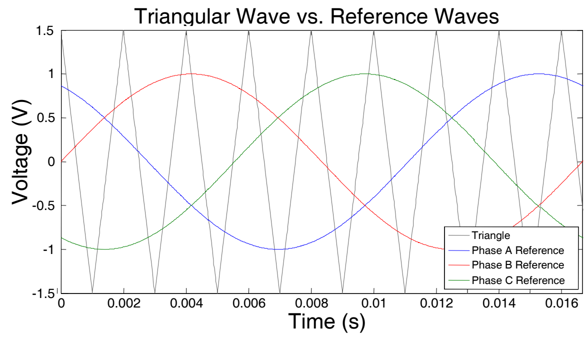

Fig.6 Carrier Signal vs. Reference Voltage

The duty cycle only exists from 0 to 1, so only the positive root was selected. The duty cycle exists for any positive value of R_{in} and R_{out}, of course only positive values exist. The optimal duty cycle occurs for:

$$R_{in} = R_{op} = \frac{V_{op}}{I_{op}} \tag{10}$$

Where I_{op} is the current at which maximum power point occurs.

D. DC-AC converter

The DC-AC converter is commonly called the inverter. This device takes a DC voltage and converts it into an alternating current or AC voltage at a certain frequency. The frequency depends on the switching of the transistors. There are two basic types: single phase inverter and three phase inverter. The quality of the converter is based in the Total harmonic distortion or THD and its efficiency.

The inverter used in this work will be implemented using MOSFET type switches and the switching technique of unipolar pulse width modulation (PWM) to achieve a higher efficiency. PWM switching technique is created comparing a sinusoidal wave (reference signal) and triangular waveform (carrier signal). This technique has great flexibility when creating output waves of different amplitudes and frequency, and filtering the output signal creates a sinusoidal waveform. Two main parameters of this technique are the amplitude modulation (m_a), and the frequency modulation (m_f). The amplitude modulation is defined as:

$$m_a = \frac{V_{sine}}{V_{triangular}} \tag{11}$$

The frequency modulation is defined as:

$$m_f = \frac{f_{triangular}}{f_{sine}} \quad (12)$$

In the case that we want to change the amplitude of the output voltage, we need to change the amplitude modulation, and in the case that we want to change the output frequency we need to change the frequency modulation. In fig. 5 we can see the schematic of the inverter. The principal application of this topology is velocity control of induction motors [8, 9].

To create a three phase system the sine wave (reference signal) in each phase has to be displaced by 120^{o} by each other phase. In the fig. 6 is show the reference signal of each phase with the carrier signal [8]. In each phase of the inverter we have to switches (upper and lower), one switch is the inverse of the other. This means that, when one switch is open the other is closed and vice versa.

E. Induction motor

An induction motor (IM) is an asynchronous AC machine that consists of a stator and a rotor. This motor is widely used because of the rugged construction and moderate cost. In the induction motor a sinusoidal voltage is applied to the stator, this results in an induced electromagnetic field. This field induces a current in the rotor that creates another field that tries to align with the stator field, causing the rotor to spin.

When a load is applied to the motor, a slip is created between these fields. At higher slip values the rotor speed decreases in comparison to the synchronous speed.

The synchronous speed can be controlled by means of the frequency of the stator voltage. By means of power electronics devices the frequency of the voltage applied to the stator can be controlled resulting in an efficient way to control the speed in the motor. The technique used in this paper is using a constant voltage to frequency ratio.

F. Control strategy

The motor will be controlled via the PWM inverter using constant Volts/Hertz control. The amplitude and frequency of the reference (sinusoidal) signals will change according to the desired output speed. The ratio of voltage amplitude to voltage frequency will be held constant to maintain constant magnetic flux in the motor. A PI controller is implemented to regulate the motor speed to the desired setpoint.

III. Results

A. Simulations

Simulations were done on Matlab/Simulink. The simulations presented are of each component working by itself, except for the solar panel which was simulated with the whole system. The whole system is seen on fig. 7.

Table1. System Parameters

Photovoltaic module

Parameter	Value
Manufacturer	Sanyo
Model	HIP-210HKHA6
Open Circuit Voltage (Vx)	50.9 V
Short Circuit Current (Ix)	5.57 A
Characteristic constant (b)	0.0773
Maximum power (Pmax)	210 W

Fly-back:

Components	Value
Input Capacitance	100 mF
Primary Winding Resistance	1 mΩ
Secondary Winding Resistance	10 mΩ
Leakage Inductance	10 mH
Turns Ratio	5
Output Filter	10 mF

Induction Motor Parameters:

Parameter	Value
Stator Resistance	12.9 Ω
Stator Inductance	0.025986 H
Leakage Resistance	1062.74 Ω
Leakage Inductance	0.474149 H
Rotor Resistance	7.286462 Ω
Rotor Inductance	0.025986 H

1. Maximum power point

The power output of the solar panel is plotted in fig. 10. The panel used is a Sanyo HIP-210HKHA6 [21], with 210 watts of maximum power output under Standard Test Conditions (STC). The panel was simulated under STC, a temperature of 25°C and irradiance of 1000 W/m^2. The P&O method keeps the duty cycle on the optimal value for maximum power extraction.

2. Fly back converter

For the flyback transformer design a ferrite U shaped core P material type from Magnetics® will be used. The model is planned to have a turn ratio of 1:10 to produce a step up type transformer. The correspondent design parameters are expected to be for the initial model a 10mH magnetizing inductance and the correspondent leakage inductance of both sizes as small as possible. The design will include a correspondent gap to achieve the wanted properties useful for a flyback topology. A simulation of the fly-back converter is presented in fig. 8. The fly back is coupled to the solar panel. In fig. 8 the output voltage is 220 V.

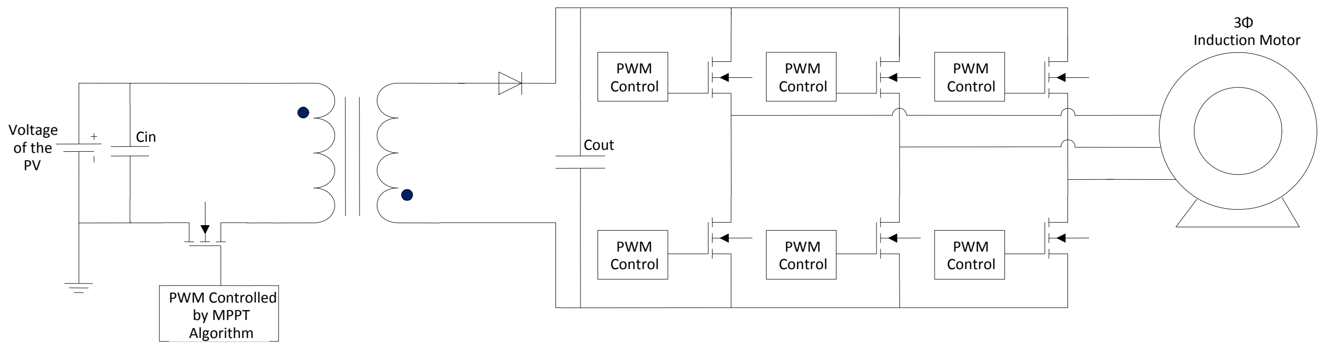

Fig. 7. Complete circuit

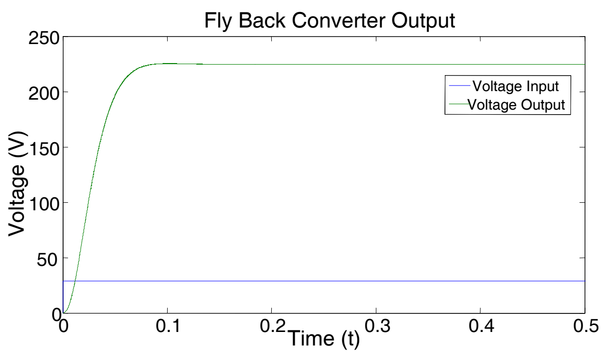

Fig.8 Fly-back Response.

3. Three phase PWM Inverter

A simulation of the three phase PWM inverter is shown in fig. 9. The input is 220V from the flyback converter. The load is a resistive load. If the signal is filtered, a pure sinusoidal can be obtained.

4. Motor speed control

As seen on fig. 11, the motor follows the speed setpoints in less than a second using constant voltage/hertz ratio control. This simulation used a constant voltage source as input to the inverter.

IV. Conclusions

After simulation, we have proven that the induction motor can be driven by a PV panel. Using the P&O MPPT technique is an effective way to extract maximum power from a panel using the flyback converter. The flyback converter proved to be a good interface between panel and load because of the step up and step down properties that provide good impedance matching. The turns ratio of the transformer provided an additional voltage step-up needed to reach higher voltages than a single boost converter could. The three phase inverter controlled by PWM technique effectively controlled the speed of the motor by keeping the voltage to frequency ratio constant. The next step is to implement the proposed system. An effective way to drive a three phase induction motor fed from a single PV panel is presented.

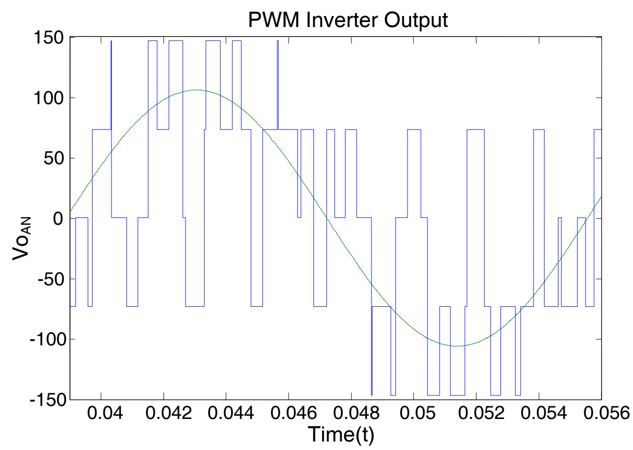

Fig.9 PWM Inverter output

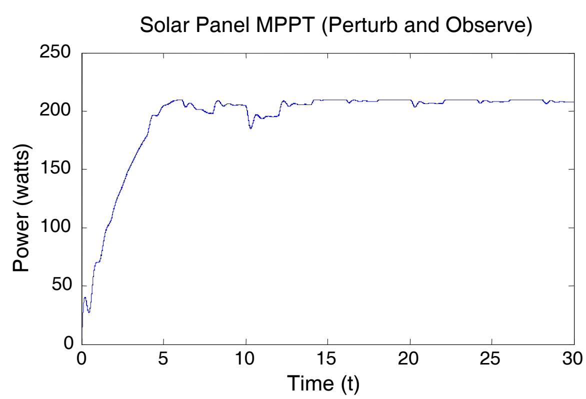

Fig.10 PV panel power output

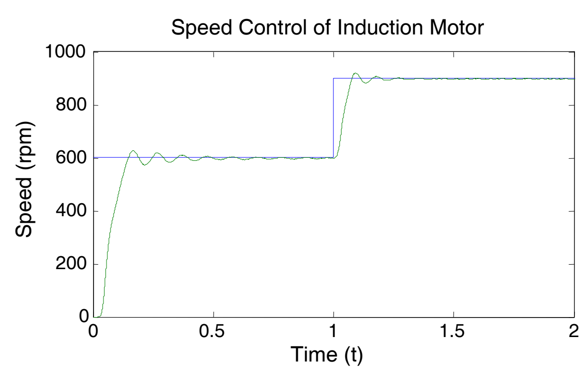

Fig.11. Motor speed vs. time. Closed loop motor control

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