Two-phase Induction Motor fed from Solar Power via Programmed Wave Inverter

Ayman Ali, Salama Abo Zayd, Abdel Samie Kotb

Abstract—The solar power is a dc power and if dc loads are available, we can build a simple and economic solar system at remote locations. The most important load is a dc drive which is capable of driving heavy loads such as water pumps, washing machines and refrigerators. The single phase induction motor is commonly used in such domestic applications so we selected it as a base for our new solar dc drive, however we will rewind it to operate by low voltage with identical main and auxiliary windings (low voltage two-phase motor). In this paper we will design a novel simple programmed wave inverter which collects the advantages of the two commercially available inverters: low harmonics and low cost in addition to small size, so it can be integrated with the motor as a reliable dc drive.

Index Terms— dc drive, dead time, Programmed wave inverter, solar drive, solar water pump, TPIM, two-phase induction motor, 2-phase Induction Motor

1 INTRODUCTION

THE single-phase induction motors have been widely employed in low or middle power level fields, especially in households where a three-phase supply is not available. The single-phase induction motor requires the auxiliary winding to produce the starting torque. For example, the capacitor-starting motor produces the starting torque with the aid of the auxiliary winding and series-connected capacitor. Accordingly, it operates as the asymmetrical two-phase induction motor at starting, but operates as a pure single-phase induction motor while running after a centrifugal switch is opened [4]. Normally, three-phase induction motors are chosen for the heavy duty for suitably manipulating the energy consumption and cost. In contrast, low power applications, for instance, small water pump, washer, air conditioning, are suitable for single-phase induction motors with the identical reason as three-phase induction motors. Single-phase induction motors are widely used where a three-phase supply is not available. However, due to the complexity of reducing electromagnetic torque ripple, single-phase induction machines are attractive to researching groups. Two-phase induction machines can be modified from single-phase induction machines and supplied with a three-leg voltage source inverter (VSI) in order to improve performance [3].

The two-phase induction motor is composed of two symmetrical windings. That is, the number of windings of phase A is the same as that of the windings of phase B, and displaced 90 electrical degrees between the two windings. When the symmetrical two phases are supplied by the balanced voltage source, the motor operates without negative torque. However, the two-phase induction motor has not been well accepted in spite of high efficiency because it does not have any advantages from the viewpoint of speed control [4]. In our case we concern with the fixed speed domestic applications and the proposed inverter will open the way to the motor control.

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2 TWO-PHASE INDUCTION MOTOR DRIVE

Conventional capacitor-start single-phase induction motor has two windings, the main winding and the auxiliary winding. A capacitor is placed in series with the auxiliary winding, thus a 90 degree phase difference in current is obtained. Consequently, a torque is developed and motor becomes a self-starting motor. After the motor starts, the auxiliary winding is disconnected usually by means of centrifugal switch that operate at about 75 percent of synchronous speed. Finally the motor runs because of the main winding. Since this is being single-phase, some level of humming noise is associated with motor during running. To run this single-phase induction motor with two-phase supply, modification is done. Capacitor and centrifugal switch is cut off first. The auxiliary winding is made of thin wire compared to that of main winding which has thick copper wire. Single-phase operation auxiliary winding is connected to the supply only for a few times during staring. So, transformation is made to the auxiliary winding to have the same thick copper wire and number of turns as that of the main coil [2]. In our case we will completely rewind the motor for a new design for low voltage two-phase operation.

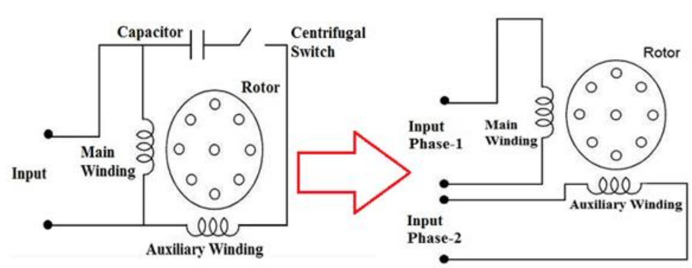

Fig (1) 1-phase to 2-phase Induction Motor Conversion

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Normally, variable voltage variable frequency supply can be obtained from inverter with constant DC input voltage which is provided by rectifier circuits. However, with the advent of renewable energy resources, photovoltaic (PV) array is often considered the best power source for DC supplies voltage. It is necessary to obtain higher voltage for three-leg VSI driving TPIM with rated flux. Therefore, a boost converter is included with MPPT to achieve sufficient DC link voltage and increased of the system efficiency [1].

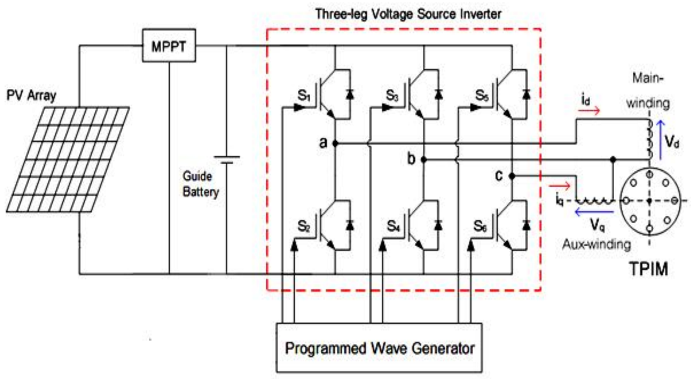

Fig (2) 2-phase I.M. driven by PV powered three-leg VSI

In this paper, we concern with a PV powered three-leg VSI fed symmetrical type TPIM drive system using low voltage to avoid the boost converter need and without speed control as we aim to the domestic loads which are already driven by single phase induction motors. The guide battery here is to inform the voltage regulator (MPPT controller) by the required system voltage.

3 Electric Drive Classification

Electric drives can be classified based on the type of the motor being used. This may be AC or DC motor. Drives can also be classified based on types of control functions (e.g. position control drives, variable speed drives, torque control drives, etc.) however it is not common. A third classification can be based on the definition of electric drive which considers the source type or input type.

Definition and composition: An electric drive is the electromechanical system that converts electrical energy to mechanical energy of the driven machine.
So we can define the dc drive as an electromechanical unit which converts dc power to mechanical power i.e. its input is a dc supply and its output is a mechanical rotation.

The possible forms of drive motors are:

- i) dc motors fed from dc supply
- ii) dc motors fed from ac supply
- iii) ac motors fed from ac supply [7]
- iv) ac motors fed from dc supply

We can consider (i & ii) as dc drives and (iii & iv) as ac drives if we classify according to motor type or consider (i & iv) as dc drives and (ii & iii) as ac drives if we classify according to supply type.

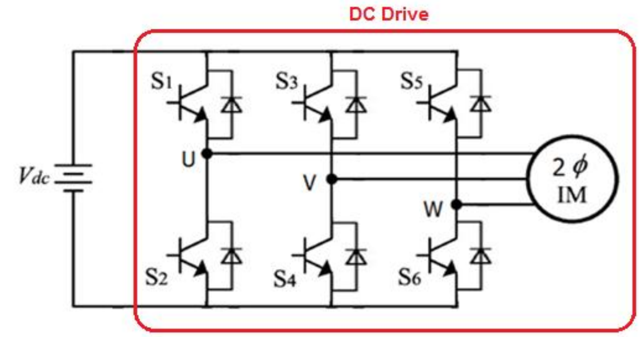

Fig (3) Integrated motor & inverter fed from dc power

If we classify according to the supply we can consider the TPIM which is integrated with the inverter as a dc drive.
From my point of view the last classification is the most realistic one for the following reasons:

1- Classification according to supply type helps the user to select a suitable type and avoid confusion during connection.
2- After controllers' development, the electric drives become able to meet load requirements regardless the motor type.
3- If we compare the electric drive to combustion engine, the later is commonly referenced to its input (fuel) type as diesel, benzene or gas engine.

4 Programmed Wave Two Phase Inverter

Most of commercially available inverters are divided into two types: modified wave inverters and sine wave inverters.
The modified wave inverter is designed using a simple oscillator to output a modified square wave which is a normal square wave with a dead band between positive and negative half cycles.
The sine wave inverter is designed using PWM technique to give nearly pure sine wave output. However this inverter cost is three to four times the modified wave one.
Due to cost considerations commercial systems usually use the modified wave inverter with most applications which aren't affected by harmonic distortion like lighting, heating, static instruments as computers and also for light load motors as fans. The sine wave inverter is mandatory for heavy load motors as washing machines, refrigerators, pumps … etc as they will be highly affected by harmonic contents.
The proposed programmed wave inverter is an intermediate design between modified wave and sine wave inverters which collects their advantages where it has a simple, cheap construction and low harmonic contents and could be suitable for all domestic applications. We consider that domestic loads are our target if we concern with small village electrification by solar power. Also we concern with a small and reliable controller to be integrated with a suitable motor as a single dc drive unit compatible with solar power source. This idea will enforce the distributed generation policy in remote locations, reduce power conditioning equipments and therefore reduce generation system primary cost.

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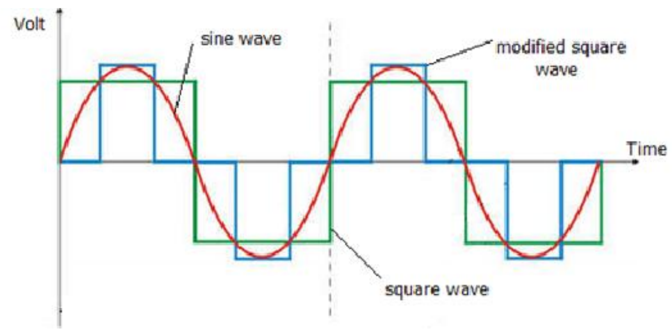

Fig (4) Sine wave, Square wave & Modified square wave

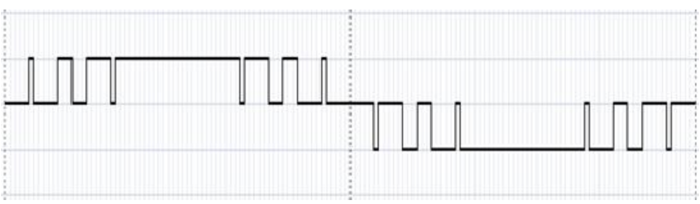

Fig (5) Programmed wave pattern

4.1 Circuit Description

The proposed controller (programmed wave inverter) is consisted of power module and control module. The power module is a regular six MOSFETs or IGBTs power module which is commonly used in three phase inverters.

The control module is a simple microcontroller based circuit which contains a microcontroller IC (PIC16F628A), driver IC (7414), six optocouplers (TLP250) and three voltage isolators (B1212S-1W). The microcontroller single chip is programmed to directly generate the required timing control signals which will be applied to IGBTs gates in order to produce the required wave form via the power module. These signals are conditioned via inverter / buffer IC and sent to power module via optocoupler / driver ICs.

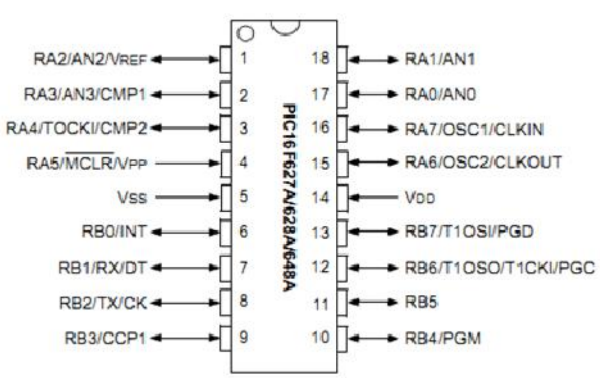

Fig (6) Microcontroller PIC16F628A Pin assignment

The circuit is designed to operate by 12 / 5V dc power supply, where the 5V will supply the microcontroller circuit and 12V to supply optocoupler isolation circuit.

As shown in Fig. (6) the microcontroller IC (PIC16F628A) has eighteen pins. We will use only six as follows:

Pin14 is 5V, pin 5 is 0V, pin3 & 4 are input high via 10K ohm resistors and pin 17 & 18 are the outputs. These two outputs are the direct and quadrature signals which are capable of driving the two phase programmed wave inverter.

The program which is installed on the microcontroller is written in assembly language.

The next stage is the Hex Schmitt-trigger Inverter (IC 7414) which will do three functions:

It will generate the complementary signals for the direct and quadrature signals; It is an essential part of dead time circuit; It will drive the optocoupler circuit without affecting the microprocessor IC i.e. it will act as a buffer.

After complementary generation the direct and quadrature signals became four signals: direct, complementary direct, quadrature and complementary quadrature signals. These four signals will feed the six IGBT gates as follows:

1) direct signal will feed gate 1 and gate 6.
2) complementary direct signal will feed gate 2 and gate 5.
3) quadrature signal will feed gate 3.
4) complementary quadrature signal will feed gate 4.

However these signals will pass through isolation / driver circuits which are consisted of six opto-isolators ICs TLP250.

Each photo-coupler or opto-isolator will transfer one gate signal to one IGBT gate or will drive one IGBT.

The individual control signal for the switches needs to be provided across the gate (base) and source (emitter) terminals of the particular switch. The gate control signals are low voltage signals referred to the source (emitter) terminal of the switch. For n-channel IGBT and MOSFET switches, when gate to source voltage is more than threshold voltage for turn-on, the switch turns on and when it is less than threshold voltage the switch turns off. The threshold voltage is generally of the order of +5 volts but for quicker switching the turn-on gate voltage magnitude is kept around +15 volts whereas turn-off gate voltage is zero or little negative.

4.2 Dead Time Circuit/ Shoot-through Protection

The high-side and the low-side switches of a bridge on the same leg should never ever be turned on at the same time. If that happened, you would create a very low resistance path between your power supply and ground. There are several outcomes of such an experiment and none of them are pleasant. At best, you have some sort of short-circuit protection that trips and your circuit simply loses power. If not, a lot of current will start flowing through your circuit. This current will start heating things up and eventually something will break. It will heat up the battery (because of its internal resistance). It will heat up the wires which can melt their plastic insulation. It will heat up the PCB traces and destroy the board. It will heat up your FETs and can destroy them as well. You don’t want any of these, so you don’t want shoot-through. Avoiding static shoot-through is fairly simple: just make sure you never close both FETs on the same leg at the same time. To avoid shoot-though in PWM controlled voltage source inverters (VSI), dead-time, a small interval during which both the upper and lower switches in a phase leg are off, is introduced into the control of the standard VSI phase leg. However, such a

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blanking time can cause problems such as output waveform distortion and fundamental voltage loss in VSIs [5] if its period is more than required.

The more serious problem is dynamic shoot-through: when you turn one FET off, while turning the other on, for a short period both the low and high-side FETs are potentially conducting to a certain degree, creating a relatively low resistance path for the supply to flow to ground. This results in a current spike. To prevent this, you have to delay the turn-on of the low-side FET by at least as much as the turn-off time of the high-side FET. The same goes of course for the other transition, when you switch from low-side to the high-side. This technique has many names, dead-time, shoot-through protection, no-overlap PWM. Many modern microcontroller PWM implementations give you the option to use two pins that output versions of a single PWM signal, with a programmable no-overlap zone between them. If you are using a part without such protection or are building your own driver, you'll have to make sure that proper shoot-through protection is implemented.

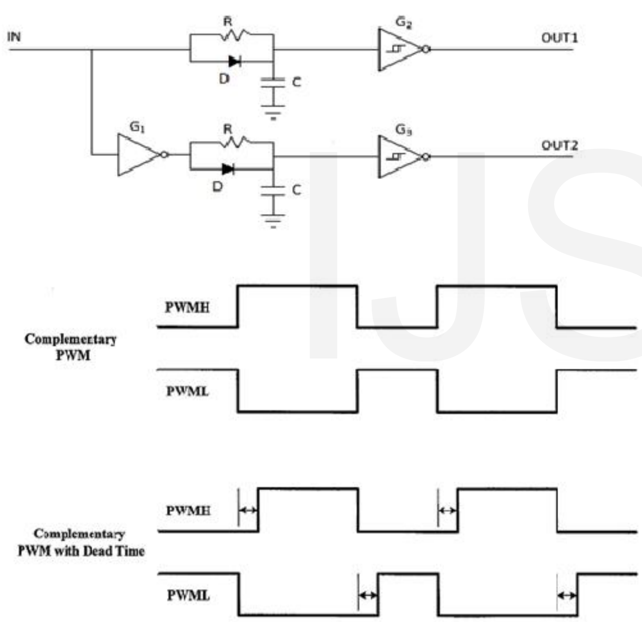

Fig (7) dead time circuit and output diagram

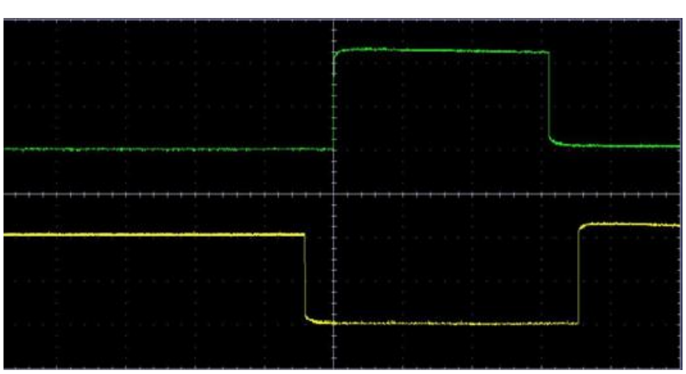

Fig (8) dead time between signals on the oscilloscope

External shoot-through protection circuits uses the R/C circuits to delay the edges of the two outputs, and the diodes to make sure only one of the two edges get delayed. The Schmitt-trigger inverters are needed to clearly define the point where the output switches due to the slow changing of the output of the R/C circuit. With many Schmitt-trigger circuits having their lower and higher threshold voltages set at 1/3 and 2/3 way between 0 and Vcc, both time delays end up roughly R*C value.

4.3 Floating Power Supplies/ Ground Isolation

It is to be remembered that the two switches of an inverter-leg are controlled in a complementary manner. When the upper switch of any leg is 'on', the corresponding lower switch should remain 'off' and vice-versa. When a switch is 'on' its emitter and collector terminals are virtually shorted. Thus with upper switch 'on', the emitter of the upper switch is at positive dc bus potential. Similarly with lower switch 'on', the emitter of upper switch of that leg is virtually at the negative dc bus potential. Emitters of all the lower switches are solidly connected to the negative line of the dc bus. Since gate control signals are applied with respect to the emitter terminals of the switches, the gate voltages of all the upper switches must be floating with respect to the dc bus line potentials. This calls for isolation between the gate control signals of upper switches and between upper and lower switches. Only the emitters of lower switches of all the legs are at the same potential (since all of them are solidly connected to the negative dc bus) and hence the gate control signals of lower switches don't need isolation among themselves. As should be clear from the above discussion, the isolation provided between upper and lower switches must withstand a peak voltage stress equal to dc bus voltage. Gate-signal isolation for inverter switches is generally achieved by means of optical-isolator (opto-isolator) circuits.

The circuit on the output side is connected to a floating dc power supply. The control circuit supply ground is isolated from the floating-supply ground of the output.

This configuration necessitates four control power supplies, one supply for control circuit in addition to all the lower IGBTs and three individual supplies for the upper IGBTs with proper isolation circuit. Supply voltage of each pre driver is usually in the range of 10 V to 20 V with 15 V being typical value [6]. The transformer-based power supplies take up a significant amount of printed circuit board (PCB) space and require layout design considerations.

Bootstrap power supplies can be used to reduce the number of isolated power supplies or DC-to-DC converters. This helps to reduce cost and the PCB space as compared to transformer-based power supplies. The bootstrap output power supply circuit is used to power the top-bridge gate drives by making use of the inverter operating conditions to store (in a capacitor) and deliver the necessary power charges.

In our project we tried two methods to avoid the multi power supplies need. The first one is the bootstrap ICs IR2110 & IR2111 however it did not give accepted results. The second method is DC/DC converter isolator which gave good results. So we used three of the above mentioned IC B1212S-1W to get a three floating power supplies for the three upper IGBTs.

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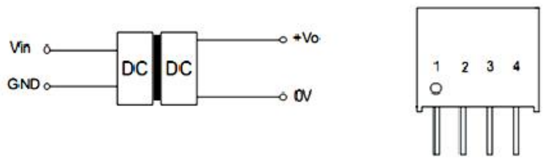

FOOTPRINT DETAILS	
Pin	B_S-1W
1	GND
2	Vin
3	0V
4	+Vo

Fig (9) DC / DC converter or isolator

4.4 Circuit Wiring & Output Waveforms

Fig. (10) illustrates the direct and quadrature timing signals which output from the microcontroller to dead time conditioning circuit. The later outputs four firing signals. As illustrated in Fig (11) these four signals input the IGBTs driver circuit and the output are six firing signals for the six IGBTs gates. When these signals are transferred to IGBTs gates of switches (S1, S2, … S6) of Fig (3) it will convert the dc input power into two phase ac power on terminals U, V, W. terminal V will be neutral for phases U & W which are shifted by 90 degrees.

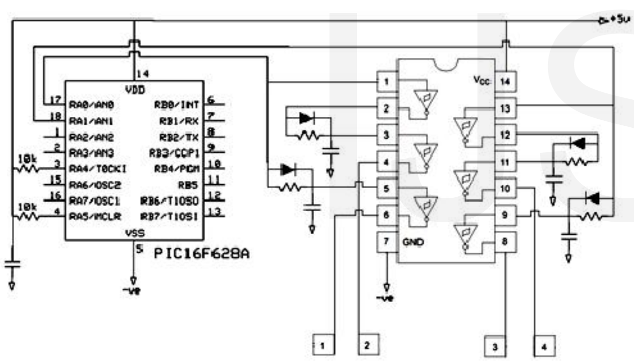

Fig (10) micro controller / dead time circuit

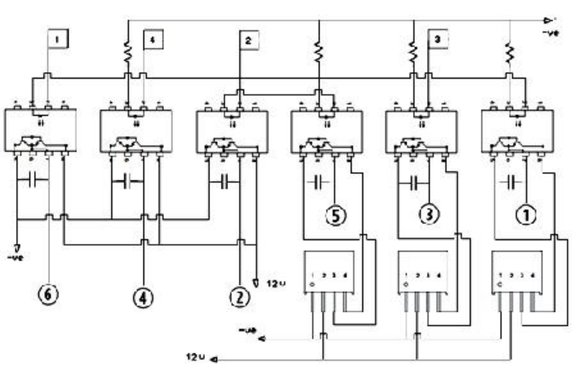

Fig (11) IGBTs drivers circuit

Fig. (12) illustrates the direct and quadrature timing signals on the oscilloscope and Fig. (13) illustrates the output voltages waveforms U & W with respect to V on the oscilloscope.

The next step is to study the TPIM torque performance which will be, for sure, better than single phase motor as the two phases now contribute in torque production.

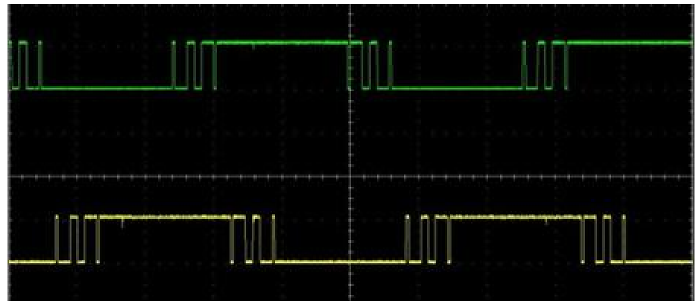

Fig (12) direct & quadrature timing signals

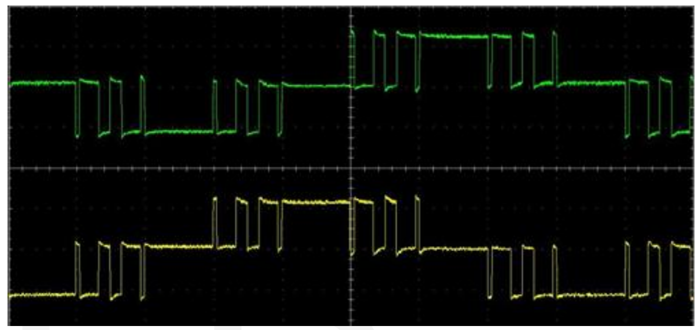

Fig (13) 2-phase output voltages from the inverter

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