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Design and Analysis of Artificial Intelligence Based Approach for Control of Wind Turbine

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ABSTRACT

Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. The model of wind turbine is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. In this paper, variable speed wind turbine driving permanent magnet synchronous generator with current controlled voltage source inverter has been proposed. Detailed modeling and control strategies of the overall system has been developed. It is found that under the proposed control strategy the system runs smoothly under randomly and quickly varying wind condition. During both symmetrical and unsymmetrical fault conditions, the system is found stable. Results shows that by using Current Source Inverter (CSI) stability of wind power can be achieved. By using CSI-based Controller voltage source inverter or any separate storage energy system is not required. A model is used to determine the behavior of the wind turbine, induction generator and load.

KEYWORD: *Turbine, Renewable, Inverter, synchronous, Controller*

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1. INTRODUCTION

Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Amongst the above mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind. Wind is the motion of air masses produced by the irregular heating of the earth's surface by sun. These differences consequently create forces that push air masses around for balancing the global temperature or, on a much smaller scale, the temperature between land and sea or between mountains.[3]

Wind energy is not a constant source of energy. It varies continuously and gives energy in sudden bursts. About 50% of the entire energy is given out in just 15% of the operating time. Wind strengths vary and thus cannot guarantee continuous power. It is best used in the context of a system that has significant reserve capacity such as hydro, or reserve load, such as a desalination plant, to mitigate the economic effects of resource variability.[4]

1.1. Wind Turbines:

A wind turbine is a rotating machine which converts the kinetic energy in wind into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a wind generator, wind turbine, wind power unit (WPU), wind energy converter (WEC), or aero generator. Wind turbines can be separated into two types based by the axis in which the turbine rotates. Turbines that rotate around a horizontal axis are more common. Vertical-axis turbines are less frequently used.[6]

1.2. Future Trends in Power Sector:

In estimation with per capita GDP growth at 7.5% and electricity price grows at the rate of 2% per year the electricity consumption in 2011-12, 2016-17 and 2021-22 would be 457639 GWh, 514802 GWh and 595134 GWh respectively. A capacity addition of 78,700 MW is planned for 11th plan i.e. till 2011-12. This is however not anticipated to be achieved (likely achievement will be around 50 %) and the 12th Plan will commence with a deficit addition. The long term forecast of electrical energy consumption at the end of 11th Plan, 12th Plan and 13th Plan may be 7582.547 GWh, 7133809 GWh and 3093266 GWh respectively.

The predicted electricity consumption (in GWh) of different sector is shown in the figure below.

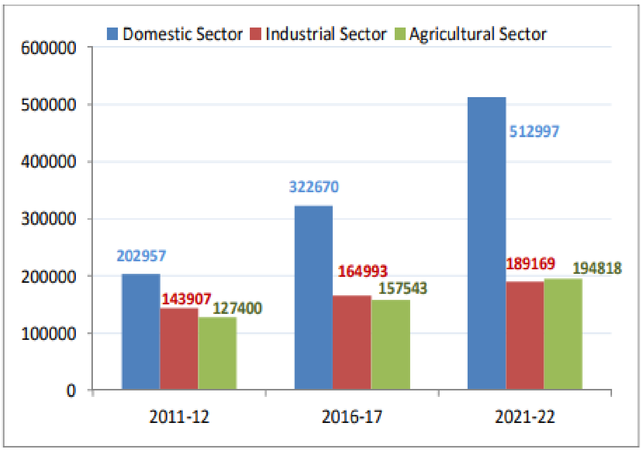

Figure 1.1 the predicted electricity consumption (in GWh)

In the above figure the consumption in domestic sector is estimated with conditions of GDP growth at 8% and while agriculture sector is estimated to grow at 4% and industrial sector which has recovered from the recession with a positive growth rate is estimated with a growth rate of 10%. In all these cases, the electricity price is rising at 2% per year. The peak electricity load in the country estimated to rise up to 298253 MW in 2021-22. In the near future, in 2011-12 the peak load may go up to 302806 MW from the current level of 14672 MW.

2. PROPOSED MODEL

The main consideration for sitting a wind project in a certain site is the wind resource. Other considerations include site accessibility, terrain, land use and proximity to transmission grid for grid-connected wind farms. The main sources of the global wind movements are the earth rotation, regional and seasonal variations of sun irradiance and heating. Local effects on wind include differential heating of the land and the sea (land heats up faster), topographical nature such as mountains and valleys, existence of trees and artificial obstacle such as buildings.

At any location wind is described by its speed and direction. The speed of the wind is measured by anemometer in which the angular speed of rotation is translated into a corresponding linear wind speed (in meters per second or miles per hour). A Standard anemometer averages wind speed every 10 minutes. Wind direction is determined by weather vane. Average (mean) wind speed is the key in determining the wind energy potential in a particular site. Although long-term (over 10 years) speed averages are the most reliable data for wind recourse assessment, this type of data is not available for all locations. Therefore, another technique based on measurement, correlation and perdition is used. Wind speed measurements are recorded for a 1-year period and then compared to a nearby site with available long-term data to forecast wind speed for the location under study.

2.1. Wind Turbine:

The model of wind turbine is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine must be combined with those of the generator coupled to the turbine. The Simulink model of the Wind Turbine is shown in Fig 1.2

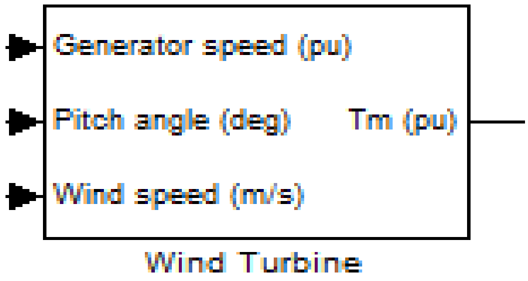

Fig.1.2 Block of Wind Turbine

The output power of the turbine is given by the following equation [1].

Pm $= C_p(\lambda, \beta)\, \rho A/2\, v_w{}^3$

Where Pm is the mechanical output power of the turbine (W), C_p is the Performance coefficient of the turbine, ρ is the air density (kg/m3), A is the turbine swept area (m^2), V_w is the wind speed (m/s), λ is the tip speed ratio of the rotor blade tip speed to wind speed, β is the blade pitch angle (deg).

2.2. Speed and Power Control of Wind Turbines:

Wind acts on rotor blade by two types of forces. The first is the drag force, which ties to move the blade in the same direction as the wind; this force causes the cup anemometer to rotate, for a wind turbine rotor this force act perpendicularly to the blades and hence it slows the rotor down . The second and the desirable force for a wind turbine is the lift force which a buoyancy force according to Bernoulli principle in fluid dynamics, this force causes the blades to rotate about the hub. As seen in Figure 1.3 the blade section has unsymmetrical sides for aerodynamic purpose, when wind flows (vw) the upper surface of the section experiences high speed flow (under pressure) and the lower experiences low speed flow (under pressure). The pressure difference produces lift force which moves the blade and rotates the rotor with velocity u (linear speed of the blade's outermost tip).

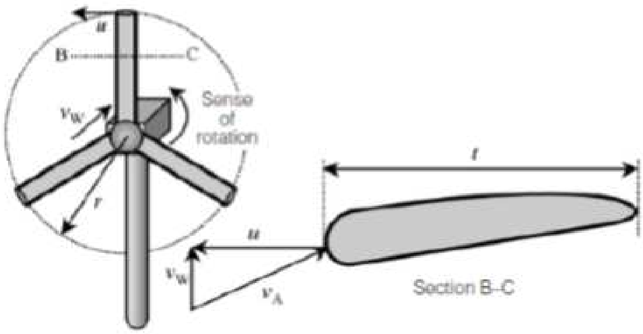

Figure 1.3 Wind turbine rotor motion and blade cross-section [2]

The apparent wind velocity (V_A) is produced from real wind speed (V_w) and rotor blade tip speed (u) that is

$|V_a| = \sqrt{|U|^2} + \sqrt{|Vw|^2}$

An important ratio is called the Tip Speed Ratio (TSR) λ

$\lambda = \mu / v_w$

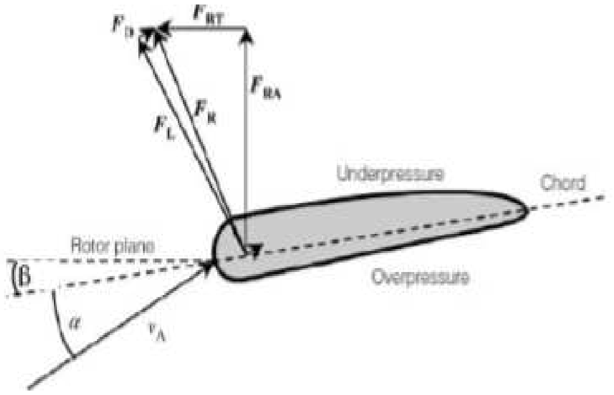

Figure 1.4 Wind forces on rotor blade [2]

As illustrated in Figure 1.4, lift force (FL) and drag force (FD) provide a resultant force (FR). The resultant force can be decomposed into tangential component (FT) which produces rotational torque and the axial component (FA) pushing the blade backward. Rotor speed control in pitch-controlled turbines utilizes the fact that changing the blade pitch angle (α) with respect to rotor plane changes the wind angle of attack (β) and the resultant wind force on the blade, and that changes the tip speed (u) at a given wind speed (vW). This consequently alters the tip speed ratio. The tip speed ratio affects the rotor power coefficient and therefore varies the power captured by the turbine. In pitch-controlled rotors, to start-up the turbine (low tip speed ratio) high pitch angles are chosen to increase the rotor speed. On the other hand, at higher wind speeds lower angle of attack is chosen by increasing pitch angle to decrease the power captured by the blades. Pitch control is also helpful in storm condition when wind generator is shut down for protection. This is achieved by adjusting the blades in the feathered position which effectively decreases the mechanical power input of the turbine.

For small wind turbines with no pitch control, passive or self-regulatory speed control method at high wind speeds is implemented and that is the stall control Rotor blades are aerodynamically designed such that in storms above a certain wind speed lift or buoyancy force is destroyed by flow separation which limits the mechanical power extracted from the flowing wind stream, without adjusting rotor pitch angle. The rotor's rotational speed (or tip speed) remains constant but tip speed ratio drops at high wind speeds for stall-controlled wind turbines.

To summarize the above, rotor speed control must be implemented in wind turbines for the following objectives:

1. To maximize power extracted from wind.
2. To protect the turbine components from overload due to over-speed wind.
3. When the turbine is not loaded (generator is disconnected for some reason), the rotor must to be protected from over speeding which can destroy it.

2.3. Output of Wind Turbine

Fig 3.1 shows the output of wind speed with power generated. As the wind speed increases the generation of power also increases. Wind turbine parameters used in simulation is as in Table 1.1.

Symbol	Quantity
Nominal mechanical output power (W)	1.5e6
Base power of the electrical generator (VA)	1.5e6/0.9
Base wind speed (m/s)	12
Maximum power at base wind speed (pu of nominal mechanical power)	0.73
Base rotational speed (p.u. of base generator speed)	1.2
Pitch angle beta (beta >=0) (deg)	0

Table: 1.1 Parameters of Wind Turbine

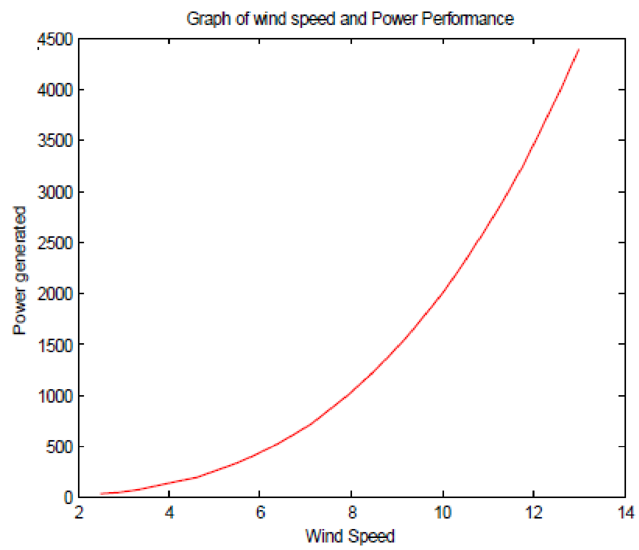

Fig.1.5 Wind speed and Power performance

The performance coefficient Cp of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (beta). Cp reaches its maximum value at zero β.

2.4. Simulink Model of the Proposed Design

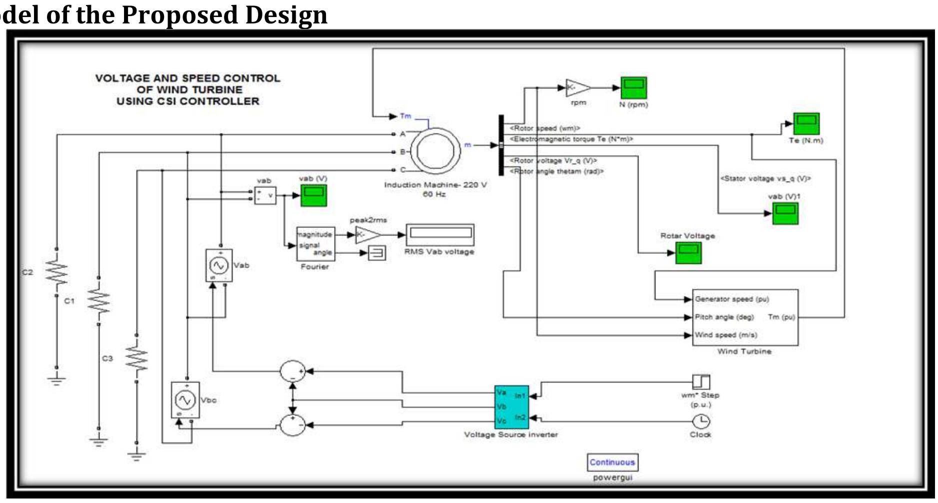

Fig.1.6 Simulink Model of Voltage and Speed Control Of Wind Turbine Using CSI Controller

The whole model is simulated for the stability of wind power by using current source inverter as a controller as shown in Fig.1.6. A self-excited induction generator, current source inverter connected in parallel to the load, a 3-phase induction motor as a load and a control scheme has been applied for controlling electromagnetic torque of the motor. Three-phase asynchronous machine (squirrel cage) modeled in a selectable dq reference frame (rotor, stator, or synchronous). Stator and rotor windings are connected in wye to an internal neutral point. Three resistances are connected in parallel to the supply for protecting the system from over current. Voltage measurement block has been used for measurement of instantaneous voltage between two electric nodes. By applying the variable supply or suddenly change in load the Simulink model shows the stability results for voltage, electromagnetic torque and stator voltage of wind energy conversion system. Parameters used for induction machines have been shown in Table 1.2.

Symbol	Quantity
Nominal power Pn(VA)	3*746
Voltage (line-line) Vn(Vrms)	220
frequency fn(Hz)	60
Stator resistance Rs(ohm)	0.435
Stator inductance Lls(H)	2*2.0e-3
Rotor resistance Rr'(ohm)	0.816
Rotor inductance Llr'(H)	2.0e-3
Mutual inductance Lm (H)	69.31e-3

Table 1.2 Parameters of Induction Machine

The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (beta) in degrees. The third input is the wind speed in m/s. The output is the torque applied to the generator shaft in per unit of the generator ratings. The turbine inertia must be added to the generator inertia.

The overall purposed system has been demonstrated through computer simulations in terms of the power system shown in Fig.1.6. Parameters of wind turbine, induction machines used in simulations are shown in and in Table 1.1 and Table 1.2 respectively.

2.5. Variable Waveform of System Voltage

Unregulated waveform of system voltage has been shown in Fig.1.7. This voltage is given as input to the self-excited induction generator. This variable voltage has been controlled by using CSI as a controller.

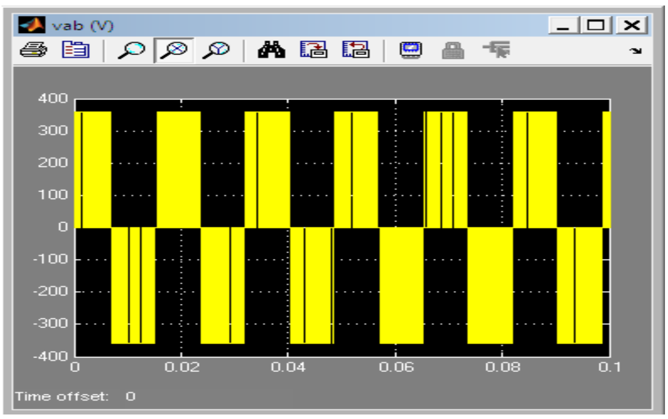

Fig 1.7: Unregulated waveform of system voltage

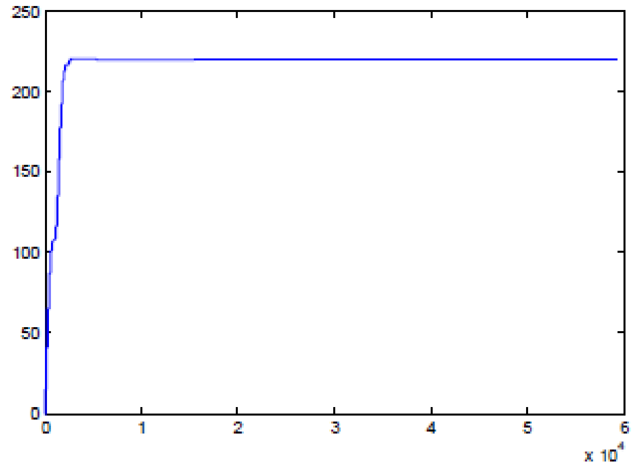

Fig.1.8 Regulated waveform of system voltage

Regulated Voltage

Fig.1.8 shows the regulated waveform of system voltage. CSI has been used as a controller. After a little fluctuation the system voltage becomes constant.

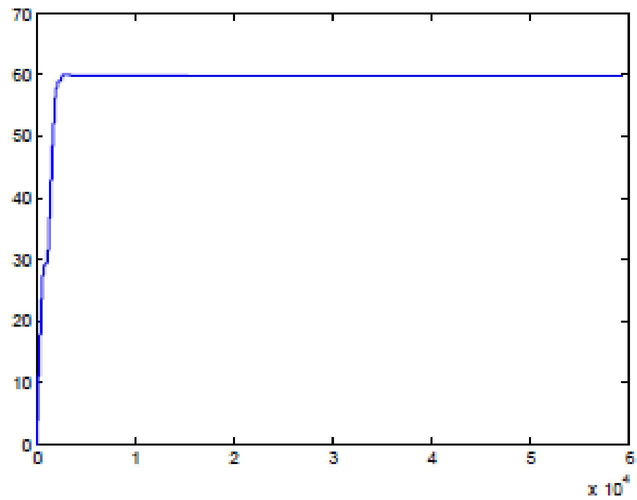

Fig.1.9 Regulated frequency of system

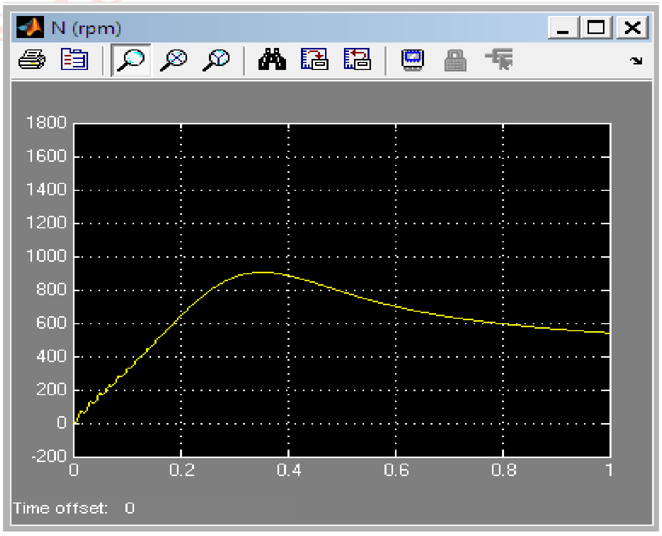

Fig.1.10: Regulated Rotor Speed of system

2.6. Output Waveforms of Stator Voltage and Electromagnetic Torque

Fig 1.11 shows the constant output waveforms of electromagnetic torque and stator voltage by taking different wind speeds and pitch angles. After wind fluctuations the output of the system has been controlled. By using the control scheme of current source inverter, constant power of wind turbine has been achieved.

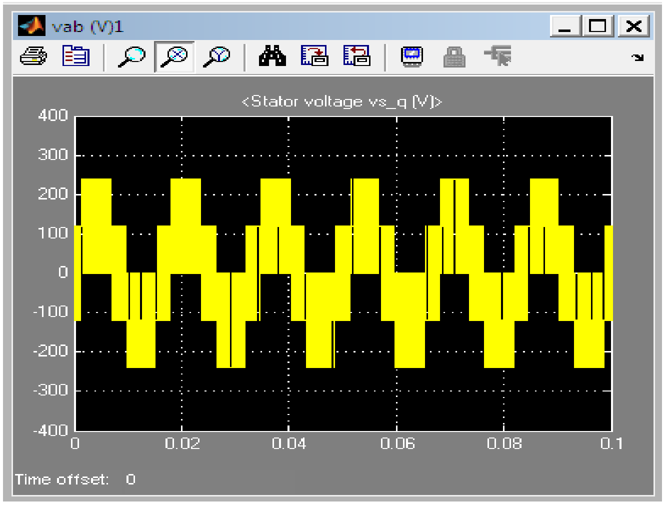

Fig.1.11: Constant Stator voltage

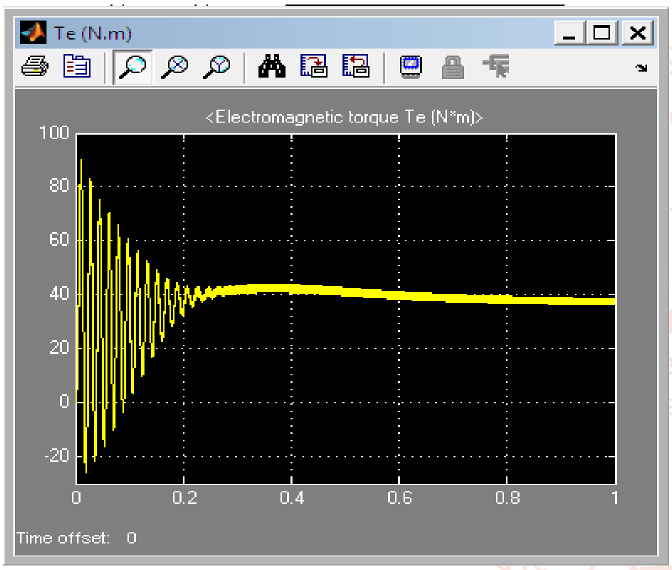

Fig.1.12 .Constant output of electromagnetic torque

3. CONCLUSION

In this paper, variable speed wind turbine driving permanent magnet synchronous generator with current controlled voltage source inverter has been proposed. Detailed modeling and control strategies of the overall system has been developed. It is found that under the proposed control strategy the system runs smoothly under randomly and quickly varying wind condition. During both symmetrical and unsymmetrical fault conditions, the system is found stable. Results shows that by using Current Source Inverter (CSI) stability of wind power can be achieved. By using CSI-based Controller voltage source inverter or any separate storage energy system is not required. A model is used to determine the behavior of the wind turbine, induction generator and load.

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