WIND AS A RENEWABLE SOURCE OF ENERGY & TORQUE SPEED CHARACTERISTICS OF A WIND TURBINE DRIVEN INDUCTION GENERATOR

A project report submitted in partial fulfillment of the requirements

for the degree of

Bachelor of Technology in Electrical Engineering

By

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Saurav Mallick

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Rourkela-769008, Orissa

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CERTIFICATE

This is to certify that the Project entitled "**WIND AS A RENEWABLE SOURCE OF ENERGY & TORQUE SPEED CHARACTERISTICS OF A WIND TURBINE DRIVEN INDUCTION GENERATOR**" submitted by **Abhisek Das, Saurav Mallick and Sushmee Badhulika** has in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree** in **Electrical Engineering** at **National Institute of Technology, Rourkela** (Deemed University) is an authentic work carried out by them under my supervision and guidance.

Place: NIT Rourkela
Date:

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ABSTRACT

The paper describes a variable speed wind generation system where the torque speed characteristics is carefully regulated to judge the performance of the wind turbine generator system.. A squirrel cage induction generator feeds the power to a double-sided pulse width modulated converter system which pumps power to a utility grid or can supply to an autonomous system. The generation system utilizes IGBT PWM rectifier which scores over other conventional generator converter schemes owing to its low conduction losses and higher impedance. It also lends the system a unity power factor operation and minimizes harmonic distortion in line and machine currents. The turbine characteristics and the torque speed characteristics have been studied in detail by simulation to validate the theoretical concepts established. The modeling of the asynchronous generator connected to the grid is also presented in this article. The uniform reference coordinate is adopted in the whole wind energy conversion system and the simplified model based on the multi-time scale theory is given after establishing the detailed model. In the end, the simulation results assure the validity of the simplified model.

Chapter 1

SCOPE OF WIND IN RENEWABLE ENERGY SOURSES

RES 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, biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat As the sun heats up the Earth unevenly, winds are formed. The kinetic energy in the wind can be used to run wind turbines, some capable of producing **5 MW** of power. The power output is a function of the cube of the wind speed, so such turbines generally require a wind in the range **5.5 m/s (20 km/h)**, and in practice relatively few land areas have significant prevailing winds. Luckily, offshore or at high altitudes, the winds are much more constant. There are now many thousands of wind turbines operating in various parts of the world, with utility companies having a total capacity of 59,322 MW. This has been the most rapidly growing means of electricity generation at the turn of the 21st century and provides a complement to large-scale base-load power stations. Most deployed turbines in the EU produce electricity about 25% of the time (load factor 25%), but under favourable wind regimes some reach 35% or higher. Globally, the long-term technical potential of wind energy is believed to be 5 times current global energy consumption or 40 times current electricity demand. This would require covering 12.7% of all land area with wind turbines. This land would have to be covered with 6 large wind turbines per square kilometer. Offshore resources experience mean wind speeds of ~90% greater than that of land, so offshore resources could contribute substantially more energy. Wind strengths vary and thus cannot guarantee continuous power. Some estimates suggest that 1,000 MW of wind generation capacity can be relied on for just 333 MW of 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. It is particularly useful for India having such a long coast line and high altitude areas. In India

- There is an estimated Gross Potential of 45,000 MW & Technical Potential of 13,000 MW.
- Considerable progress has been made in harnessing the large wind power potential available in the country.

- Installation:

    - India now has the 5th largest wind power installed capacity in the world which has reached 1870 MW.
    - 1805 MW of the total installed capacity has come through commercial projects.
    - About 11.8 billion units of electricity have been fed to various State grids from Wind power projects.

Chapter 2

ASYNCHRONOUS (INDUCTION) GENERATOR

Most wind turbines in the world use a so-called three phase asynchronous (cage wound) generator, also called an induction generator to generate alternating current. This type of generator is not widely used outside the wind turbine industry, and in small hydropower units, but the world has a lot of experience in dealing with it anyway:

One reason for choosing this type of generator is that it is very reliable, and tends to be comparatively inexpensive. The generator also has some mechanical properties which are useful for wind turbines like Generator slip , and a certain overload capability.

The Cage Rotor

It is the rotor that makes the asynchronous generator different from the synchronous generator. The rotor consists of a number of copper or aluminium bars which are connected electrically by aluminium or copper end rings.

Fig 2.1 Cage rotor

Motor Operation

When the current is connected, the machine will start turning like a motor at a speed which is just slightly below the synchronous speed of the rotating magnetic field from the stator. Now, what is happening?

If we look at the rotor bars from above (in the picture to the right) we have a magnetic field which moves relative to the rotor. This induces a very strong current in the rotor bars which offer very little resistance to the current, since they are short circuited by the end rings.

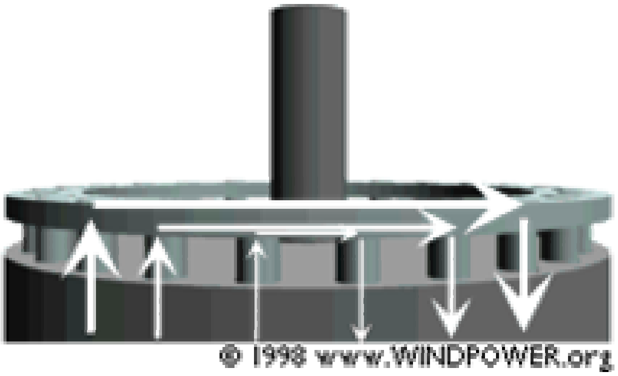
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Fig. 2.2 Motor operation

The rotor then develops its own magnetic poles, which in turn become dragged along by the electromagnetic force from the rotating magnetic field in the stator.

Generator Operation

Since the magnetic field rotates at exactly the same speed as the rotor, we see no induction phenomena in the rotor, and it will not interact with the stator. But what if we increase speed above 1500 rpm? In that case the rotor moves faster than the rotating magnetic field from the stator, which means that once again the stator induces a strong current in the rotor.

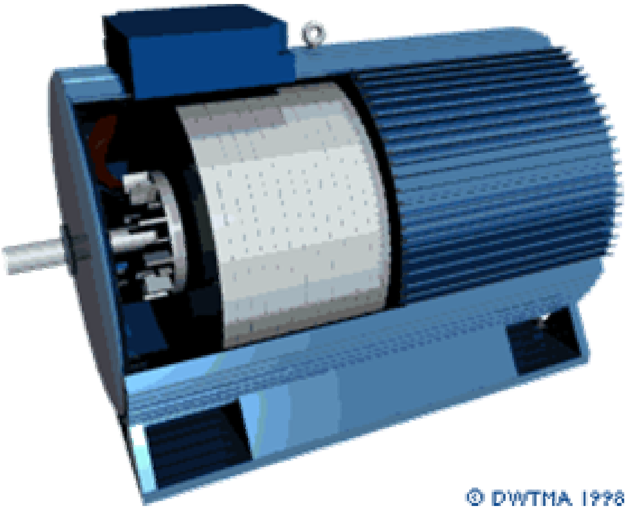
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Fig. 2.3 Generator operation

The harder you crank the rotor, the more power will be transferred as an electromagnetic force to the stator, and in turn converted to electricity which is fed into the electrical grid.

Generator Slip

The speed of the asynchronous generator will vary with the turning force (moment, or torque) applied to it. In practice, the difference between the rotational speed at peak power and at idle is very small, about 1 per cent. This difference in per cent of the synchronous speed , is called the generator's slip. Thus a 4-pole generator will run idle at 1500 rpm if it is attached to a grid with a 50 Hz current. If the generator is producing at its maximum power, it will be running at 1515 rpm.

It is a very useful mechanical property that the generator will increase or decrease its speed slightly if the torque varies. This means that there will be less tear and wear on the gearbox. (Lower peak torque). This is one of the most important reasons for using an asynchronous generator rather than a synchronous generator on a wind turbine which is directly connected to the electrical grid.

Automatic Pole Adjustment of the Rotor

The clever thing about the cage rotor is that it adapts itself to the number of poles in the stator automatically. The same rotor can therefore be used with a wide variety of pole numbers.

Grid Connection Required

In an asynchronous generator the stator is to be magnetised from the grid before it works. You can run an asynchronous generator in a stand alone system, however, if it is provided with capacitors which supply the necessary magnetisation current. It also requires that there be some remanence in the rotor iron, i.e. some leftover magnetism when you start the turbine. Otherwise you will need a battery and power electronics, or a small diesel generator to start the system).

Wind Turbine Generators

The wind turbine generator converts mechanical energy to electrical energy. Wind turbine generators are a bit unusual, compared to other generating units you ordinarily find attached to the electrical grid. One reason is that the generator has to work with a power source (the wind turbine rotor) which supplies very fluctuating mechanical power (torque).

Generating Voltage (tension)

On large wind turbines (above 100-150 kW) the voltage (tension) generated by the turbine is usually 690 V three-phase alternating current (AC). The current is subsequently sent through a transformer next to the wind turbine (or inside the tower) to raise the voltage to somewhere between 10,000 and 30,000 volts, depending on the standard in the local electrical grid.

Large manufacturers will supply both 50 Hz wind turbine models (for the electrical grids in most of the world) and 60 Hz models (for the electrical grid in America).

Cooling System

Generators need cooling while they work. On most turbines this is accomplished by encapsulating the generator in a duct, using a large fan for air cooling, but a few manufacturers use water cooled generators. Water cooled generators may be built more compactly, which also gives some electrical efficiency advantages, but they require a radiator in the nacelle to get rid of the heat from the liquid cooling system.

Design Choices in Generators and Grid Connection

Wind turbines may be designed with either synchronous or asynchronous generators, and with various forms of direct or indirect grid connection of the generator. Direct grid connection mean that the generator is connected directly to the (usually 3-phase) alternating current grid. Indirect grid connection means that the current from the turbine passes through a series of electric devices which adjust the current to match that of the grid. With an asynchronous generator this occurs automatically.

Chapter 3

CONSTRUCTION OF A WIND TURBINE GENERATOR

This aerial view of a wind power plant shows how a group of wind turbines can make electricity for the utility grid. The electricity is sent through transmission and distribution lines to homes, businesses, schools, and so on.

These three-bladed wind turbines are operated "upwind," with the blades facing into the wind. The other common wind turbine type is the two-bladed, downwind turbine.

Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. Utility-scale turbines range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.

Wind Turbine Glossary

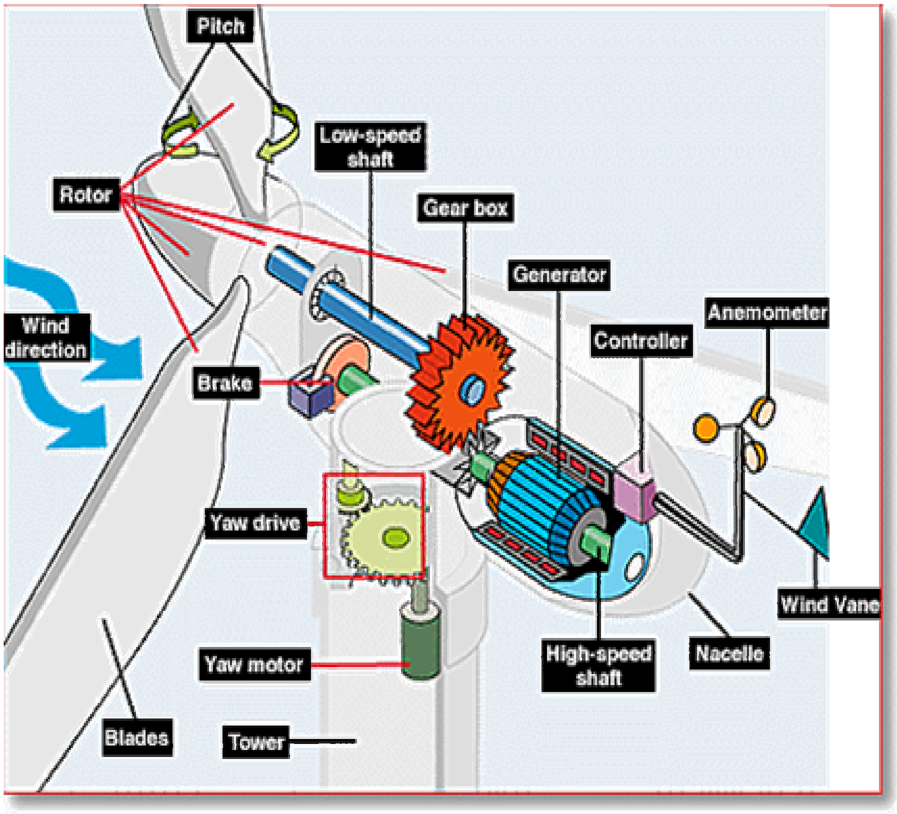

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Fig. 3.1 Parts of a wind turbine

Anemometer: Measures the wind speed and transmits wind speed data to the controller.

Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

Brake: A disc brake which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 65 mph. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat.

Gear box: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

Generator: Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

High-speed shaft: Drives the generator.

Low-speed shaft: The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

Nacelle: The rotor attaches to the nacelle, which sits atop the tower and includes the gear box, low- and high-speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working.

Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

Rotor: The blades and the hub together are called the rotor.

Tower: Towers are made from tubular steel (shown here) or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

Wind direction: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

Yaw drive: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.

Yaw motor: Powers the yaw drive.

A NEW GENERATION SCHEME OF WIND POWER PLANT

I. Introduction

Utilization of wind power by its transformation into electric one by wind power plants (WPP) is connected with certain difficulties arisen from irregularity and inconstancy of wind stream as energy carrier. Also, it should bear in mind that two machines properties of which are not suit for joint work in full measure join in WPP. So, for example, windmill makes maximal power at variable rotational frequency. At the same time, electric generator, as rule, is intended for operation at constant rotational frequency. These complications and variances bring necessity to find new solutions of WPP devices including its electric parts.

II. Main Part

An analysis of WPP modes working at fixed rotational frequency shows that most appropriate variant of WPP is one consisting two electric generators according to low and high speeds of wind stream. Especially, it is actually for asynchronous WPP. It should be noted that many firms – producers of WPP, especially European ones, prefer WPP with asynchronous generators. They think that asynchronous generators in the best way meet requirements of WPP operation characterized by drastic and frequent changes of wind speed; there is noted their great stability, simplicity of lead-in parallel work and etc. As it is known, most time of year WWP works at low speed of wind, accordingly at less power output than installed capacity. Use of two generators for different rotational frequencies allows to increase efficacy of wind power transformation at low speeds [2]. However, usage of asynchronous generators in WPP is connected with necessity to consume reactive power from network system. It should be noted that energy datum of asynchronous generator become worse at low speeds of wind. The reduced facts were conclusive for firms producers at choose of WPP variants with two asynchronous generators including WPP with two-speed asynchronous generator. It is obvious that although a generator with smaller power uses smaller reactive power, nevertheless the mentioned defect remains especially at operation of generator with high power capacity. An asynchronous machine of smaller power (attitude of generator powers is 1:5 on average) makes with phase-wound rotor. Some functions are charged on this machine. First, it is used for soft electric start of WPP (at confined starter current). Second, it works as generator in synchronous mode at low speed of wind. Excitation is realizing by constant current need to rotor winding according to special scheme [3] and is being regulated for keeping of cosφ=1. Third, at high speed of wind, when big generator works, shaft of machine with small power disconnects from reducer shaft by means of special sleeve and it moves into synchronous compensator mode. The installed capacity of this machine is enough to compensate reactive power of big generator. For the following reasons, utilization of luch compensation scheme for asynchronous WPP with high power is more profitable than utilization of static condenser :

- opportunity of full automation of reactive power regulation process; - opportunity of voltage and frequency stabilization, and it’s especially important in the case of weak connection of WPP with power system; - much less overall dimensions and price. Magnetic slip coupling can be used as a sleeve for disconnection of shafts of smaller generator and reducer. To reduce mass and overall dimensions it is enough to have a sleeve with 2,5% slip. Along with stated function a sleeve can be also used for stabilization of rotational frequency of small generator.

III. Conclusion

There is worked out a principally new scheme of WPP allowing:
- to increase power output at low speed of wind;
- to provide full compensation of reactive power of plant;
- to stabilize tension and frequency, and it is more important at weak connection of WPP with power system.

Chapter 4

WIND TURBINES AND POWER QUALITY ISSUES

The buyer of a wind turbine does not need to concern himself with local technical regulations for wind turbines and other equipment connected to the electrical grid. This responsibility is generally left to the turbine manufacturer and the local power company.

For the people who are technically minded, we go into some of the electrotechnical issues involved in connecting a turbine to the grid on this page.

Power Quality

The term "power quality" refers to the voltage stability, frequency stability, and the absence of various forms of electrical noise (e.g. flicker or harmonic distortion) on the electrical grid. More broadly speaking, power companies (and their customers) prefer an alternating current with a nice sinusoidal shape.

Starting (and Stopping) a Turbine

Most electronic wind turbine controllers are programmed to let the turbine run idle without grid connection at low wind speeds. Once the wind becomes powerful enough to turn the rotor and generator at their rated speed, it is important that the turbine generator becomes connected to the electrical grid at the right moment.

Otherwise there will be only the mechanical resistance in the gearbox and generator to prevent the rotor from accelerating, and eventually overspeeding.

Soft Starting with Thyristors

If you switched a large wind turbine on to the grid with a normal switch, the neighbours would see a brownout (because of the current required to magnetise the generator) followed by a power peak due to the generator current surging into the grid. You may see the situation in the drawing in the accompanying browser window, where you see the flickering of the lamp when you operate the switch to start the wind turbine. The same effect can possibly be seen when you switch on your computer, and the transformer in its power supply all of a sudden becomes magnetized.

Another unpleasant side effect of using a "hard" switch would be to put a lot of extra wear on the gearbox, since the cut-in of the generator would work as if you all of a sudden slammed on the mechanical brake of the turbine.

To prevent this situation, modern wind turbines are soft starting, i.e. they connect and disconnect gradually to the grid using thyristors, a type of semiconductor continuous switches which may be controlled electronically. Thyristors waste about 1 to 2 per cent of the energy running through them. Modern wind turbines are therefore normally equipped with a so called bypass switch, i.e. a mechanical switch which is activated after the turbine has been soft started. In this way the amount of energy wasted will be minimized.

Chapter 5

WIND POTENTIAL: INDIA AND ABROAD

Background

India has a rapidly growing economy which requires power to fuel it. In the main this is provided by coal and oil fired electricity. There has been a degree of deregulation to encourage renewable energy development, but smaller companies still find it difficult to make the necessary returns.

The Project

The projects are to install two 0.8 MW wind turbine in Karnataka, India. These will generate renewable electricity, to displace fossil fuel powered electricity from the grid. Each turbine will generate enough electricity each year to power the equivalent of 550 homes in the UK – saving 1,500 tonnes of CO_2 each per year.

Fastest Growing Energy Source

The world added 2,100 megawatts of new wind energy generating capacity in 1998, a new all-time record, and 35 percent more than was added in 1997, according to preliminary estimates by the Worldwatch Institute.

The new wind turbines added in 1998 have pushed overall wind generating capacity worldwide to 9,600 megawatts at the end of this year—double the capacity in place three years earlier. These wind turbines will generate roughly 21 billion kilowatt-hours of electricity in 1999—enough for 3.5 million suburban homes. Wind power is now the world's fastest growing energy source.

Wind power has also become one of the most rapidly expanding industries, with sales of roughly $2 billion in 1998. The wind industry is creating thousands of jobs at a time when employment in manufacturing is falling in many nations.

The nations that could benefit most from further growth of the wind industry are in the developing world, where power demand is growing rapidly, and most countries lack adequate indigenous supplies of fossil fuels. India is the leader so far, with over 900 megawatts of wind power in place, but wind development has slowed there in the last two years, due to a suspension of the generous tax breaks that were enacted in the mid-1990s. Indian observers expect the new government to restore some of these incentives, which could boost wind development in 1999.

Some 80 percent of the global wind power market is now centered in just four countries—which reflects the failure of most other nations to adopt supportive renewable energy policies. Future market growth will depend in large measure on whether additional countries make way for renewable energy sources as they reform their electricity industries.

The countries with the highest total installed capacity are In terms of new installed capacity in 2005, the U.S. was clearly leading with 2,431 MW,

Country	**Installed capacity(inMW)**
Germany	18,428
Spain	10,027
U.S.A.	9,149
India	4,430
Denmark	3,122

Table 5.1 Countries with installed capacity

A number of other countries, including Italy, the UK, the Netherlands, China, Japan and Portugal have reached the 1,000 MW mark of installed capacity.

In terms of new installed capacity in 2005, the U.S. was clearly leading with 2,431 MW, followed by Germany (1,808 MW), Spain (1,764 MW), India (1,430 MW), Portugal (500 MW) and China (498 MW). This development shows that new players such as Portugal and China are gaining ground.

Europe is still leading the market with more than 40,500 MW of installed capacity at the end of 2005, representing 69% of the global total. In 2005, the European wind capacity grew by 18%, providing nearly 3% of the EU's electricity consumption in an average wind year.

World Wind Energy Generating Capacity, 1980-98

Year	**Megawatts**
1980	10
1981	25
1982	90
1983	210
1984	600
1985	1020
1986	1270
1987	1450
1988	1580
1989	1730
1990	1930
1991	2170
1992	2510
1993	2990
1994	3680
1999	4820
1996	6115
1997	7360
1998	9600

Table 5.2 World wind generating capacity

India’s Market Overview of Wind Energy

Overview

1. India has a vast supply of renewable energy resources India has one of the world’s largest programs for deployment of renewable energy products and systems 3,700 MW from renewable energy sources installed (3.5 percent of total installed capacity) 10,000 MW from renewable energy by 2012 Key drivers for renewable energy.

2. Ministry of Power Accelerated Rural Electrification Program – targets 100,000 villages Significant potential: 45,000 MW however only 1870 MW tapped. Many are below 750 kW with newer machines in the range of 600 kW – 1,250 kW.208 potential sites identified 65 MW demonstration projects at 30 locations .

States with strong potential	**Potential MW**	**Installed MW**
Andhra Pradesh	8285	93
Gujarat	9675	173
Karnataka	6620	124
Madhya Pradesh	5500	23
Maharashtra	3650	401
Orissa	1700	1
Rajasthan	5400	61
Tamil Nadu	3050	990
West Bengal	450	1

Table 5.3 States with strong potential: (potential MW /installed MW)

Although the size and direction of the wind is stochastic and the output power of the wind turbine varies with the starting and ceasing of the system, the induction generator has many merits, such as low cost, high credibility and easy servicing. The modes of induction generator connected to grid are adopted in large wind farms. There're two types of wind turbine connected to grid. One is the direct grid-connection mode; the other is connected to grid though a power electronics.

The main drawback of wind power is that its availability is somewhat statistical in nature and must be supplemented by additional sources to supply the demand curve. Traditionally, wind generation systems used variable pitch constant speed wind turbines (horizontal or vertical axis) that were coupled to squirrel cage induction generators or wound-field synchronous generators and fed power to utility grids or autonomous loads. The recent evolution of power semiconductors and variable frequency drives technology has aided the acceptance of variable speed generation systems. In spite of the additional cost of power electronics and control, the total energy capture in a variable speed wind turbine (VSWT) system is larger and, therefore, the life-cycle cost is lower. The following generator-converter systems have been popularly used:

- Doubly fed induction generator with cascaded converter slip power recovery;
- Doubly fed induction generator with cycloconverter slip power recovery.
- Synchronous generator with line-commutated and load commutated thyristor converters.

In addition to the above schemes, squirrel cage generators with shunt passive or active VAR (volt amp`ere reactive) generators have been proposed which generate constant voltage constant frequency power through a diode rectifier and line-commutated thyristor inverter. Recently, a variable reluctance machine and doubly stator-fed induction machine have also been proposed in wind generation systems. The major problems in traditional power conversion schemes are the poor line power factor and harmonic distortion in line and machine currents. The recent IEEE Standard 519 severely restricts line harmonic injection. Therefore, to satisfy the stringent harmonic standard and poor power factor problem, active type VAR and harmonic compensators can be installed at additional cost. Again, the conventional control principles used in these systems make the response sluggish and give nonoptimum performance. Very recently, a doublesided pulse width modulated (PWM) converter system has been proposed to overcome some of the above problems. This paper, a complete simulation study to validate the theoretical concepts (the experimental work is in progress and will be reported later), describes a VSWT system with a squirrel cage induction generator and a double-sided PWM converter where fuzzy logic control has been used extensively to maximize the power output and enhance system performance. All the control algorithms have been validated by simulation study and system performance has been evaluated in detail. An experimental study with a 3.5-kW-laboratory drive system is in progress. It will eventually be transitioned into a 200-kW prototype generation system.

Chapter 6

A VOLTAGE FED DOUBLE PWM CONVERTER GENERATION SYSTEM

WIND GENERATION SYSTEM DESCRIPTION

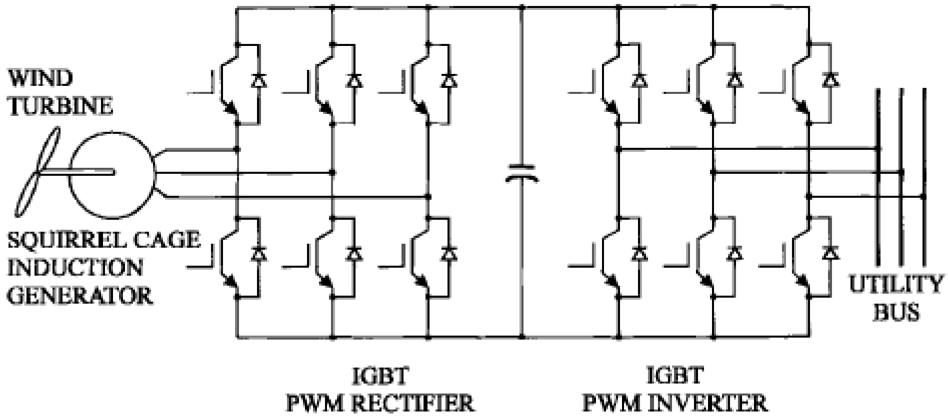

Fig. 6.1 A voltage-fed double PWM converter wind generation system.

Converter System

The voltage-fed converter scheme used in this system is shown in Fig. 6.1. A vertical (or horizontal) wind turbine is coupled to the shaft of a squirrel cage induction generator through a speedup gear ratio (not shown). The variable frequency variable voltage power from the generator is rectified by a PWM IGBT (insulated gate bipolar transistor) rectifier. The rectifier also supplies the excitation need of the machine. The inverter topology is identical to that of the rectifier, and it supplies the generated power at 60 Hz to the utility grid.

Salient advantages of the converter system include the following:

- Line side power factor is unity with no harmonic current injection (satisfies IEEE 519).
- The cage type induction machine is extremely rugged, reliable, economical, and universally popular.
- Machine current is sinusoidal—no harmonic copper loss.

- Rectifier can generate programmable excitation for the machine
- Continuous power generation from zero to highest turbine speed is possible.
- Power can flow in either direction permitting the generator to run as a motor for start-up (required for vertical turbine). Similarly, regenerative braking can quickly stop the turbine.
- Autonomous operation of the system is possible with either a start-up capacitor or with a battery on the dc link.
- Extremely fast transient response is possible.
- Multiple generators or multiple systems can be operatedin parallel.
- The inverter can be operated as a VAR/harmonic compensator when spare capacity is available.

Considering all the above advantages, and with the present trend of decreasing converter and control cost, this type of conversion system has the potential to be universally accepted in the future. Of course, in recent years, soft-switched resonant link and resonant pole topologies have been proposed, but additional research and development are needed to bring them to the marketplace.

Chapter 7

TORQUE SPEED CHARACTERISTICS: ANALYSIS AND SIMULATION

Power coefficient Cp as a function of Lambda.

```
Lambda=[0 1 2 3 4 5 6 7 8 9 9.5];
Cp=[0.00 0.02 0.05 0.175 0.3 0.36 0.36 0.3 0.21 0.075 0.00];
s=polyfit(Lambda,Cp,7);
f=polyval(s,Lambda);
table=[Lambda Cp f Cp-f]
plot(Lambda,Cp,'P',Lambda,f,'c');
axis([0 12 0 0.5]);
xlabel('Tip speed ratio');
ylabel('Power coefficient ');
title('Polynomial function curve fitting of turbine power coefficient ');
```

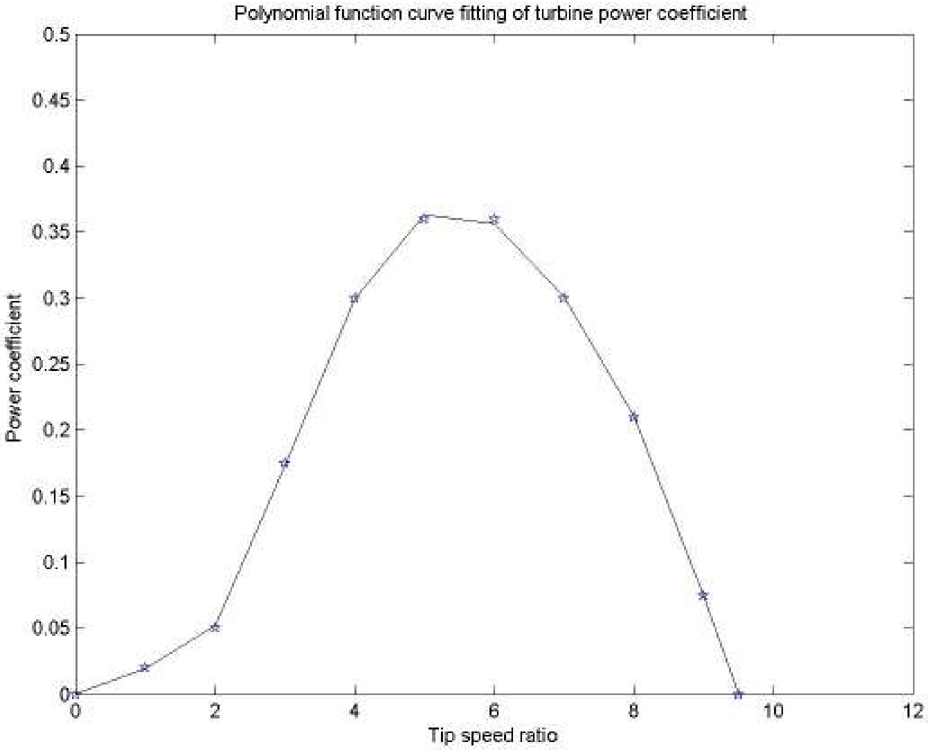

Fig. 7.1 Polynomial function curve fitting of turbine power coefficient

Turbine Characteristics

Both horizontal and vertical axis wind turbines are used in wind generation systems. The vertical Darrieus (egg beater) type has the advantages of being located on the ground and accepting wind from any direction without any special yaw mechanism. It is, therefore, preferred for high power output. The disadvantages are that the turbine is not self-starting and there is a large pulsating torque which depends on wind velocity, turbine speed, and other factors related to the design of the turbine. The aerodynamic torque of a vertical turbine is given by the equation

$$T_m = C_p(\lambda) \cdot \left[0.5 \frac{\rho \pi R_w^3}{\eta_{\mathrm{GEAR}}}\right] \cdot V_w^2$$

where

C_p	power coefficient;
λ	tip speed ratio (TSR) $\left(\frac{R_w w_w}{V_w}\right)$;
ρ	air density;
R_w	turbine radius;
η_{GEAR}	speed-up gear ratio;
V_w	wind velocity;
ω_w	turbine angular speed.

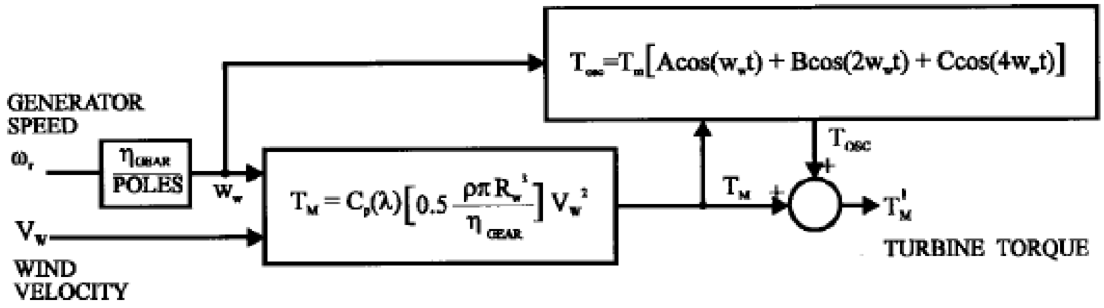

Fig. 7.2 Model of wind turbine with oscillatory torque.

The power coefficient (C_p) is the figure-of-merit and is defined as the ratio of actual power delivered to the free stream power flowing through a similar but uninterrupted area, and tip speed ratio (TSR) is the ratio of turbine speed at the tip of a blade to the free stream wind speed. The parameter C_p is a nonlinear function of λ and is shown in Fig. 7.1. The oscillatory torque of the turbine is more dominant at the first, second, and fourth harmonics of fundamental turbine angular velocity (ω_w) and is given by the expression

$$T_{OSC} = T_m \cdot [A\cos(\omega_w) + B\cos(2\omega_w) + C\cos(4\omega_w)]$$

Where A,B and C are constants. Fig. 7.2 shows the block diagram of the turbine model with oscillatory torque. A typical family of turbine torque/speed curves at different wind velocities is shown in Fig. 7.3. This shows that, for a particular wind speed, the turbine speed (or the TSR) is to be varied to get the maximum power output, and this point deviates from the maximum torque point, as indicated. Since the torque/speed characteristics of the wind generation system are analogous to those of a motor blower system (except the turbine runs in reverse direction), the torque follows the square-law characteristics$(T_e = K\omega_r^2)$ and the output power follows the cube-law $(P_0 = K\omega_r^3)$, as indicated in Fig. 7.3. This means that, at reduced speed light load steady state conditions, generator efficiency can be improved by programming the flux.

Torque Speed characteristic of Wind Turbine

```
Lambda=6;
Row=180;
Rw=20;
Gear=5;
Cp=0.36;
Vw=[6 6.15 6.2 6.36 6.4];
```

```
for i=1:5
    Tm(i)=Cp*((0.5*Row*pi*Rw^3)/(Gear))*Vw(i)^2;
end
A=0.015;
B=0.03;
C=0.015;
t=1;
Ww=linspace(-7,-5.34,100);
Tosc=Tm(1)*(A*cos(Ww*t)+B*cos(2*Ww*t)+C*cos(4*Ww*t));
Tm1=Tosc+Tm(1);
plot(Ww,Tm1,'k');
hold on;

Ww=linspace(-4.1,-2,100);
Tosc=Tm(2)*(A*cos(Ww*t)+B*cos(2*Ww*t)+C*cos(4*Ww*t));
Tm1=Tosc+Tm(2);
plot(Ww,Tm1,'k');
hold on;

Ww=linspace(-1,1,100);
Tosc=Tm(3)*(A*cos(Ww*t)+B*cos(2*Ww*t)+C*cos(4*Ww*t));
Tm1=Tosc+Tm(3);
plot(Ww,Tm1,'k');
hold on;

Ww=linspace(2.2,4.2,100);
Tosc=Tm(4)*(A*cos(Ww*t)+B*cos(2*Ww*t)+C*cos(4*Ww*t));
Tm1=Tosc+Tm(4);
plot(Ww,Tm1,'k');
hold on;
```

```
Ww=linspace(5.3,7.2,100);
Tosc=Tm(5)*(A*cos(Ww*t)+B*cos(2*Ww*t)+C*cos(4*Ww*t));
Tm1=Tosc+Tm(5);
plot(Ww,Tm1,'k');

xlabel('Turbine angular  velocity')
ylabel('Turbine torque')
title('Torque-Speed characteristic of Wind Turbine')
```

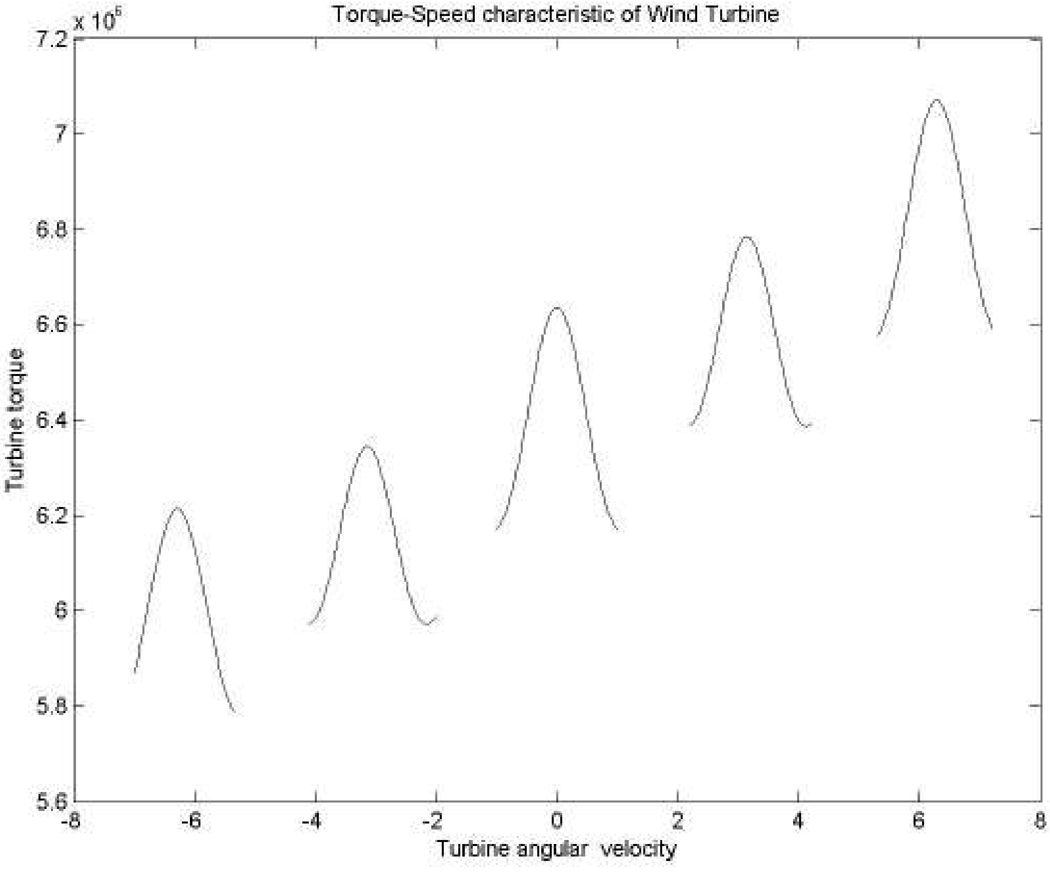

Fig. 7.3 Torque-speed characteristics of wind turbine

Control System

It appears that fuzzy logic based intelligent control is most appropriate for performance improvement of wind generation systems. The machine and inverter output currents are sinusoidal, as shown. The machine absorbs lagging reactive current, but it is always zero on the line side; i.e., the line power factor is unity. The rectifier uses indirect vector control in the inner current control loop, whereas the direct vector control method is used for the inverter current controller. Vector control permits fast transient response of the system. The fuzzy controllers indicated in the figure will be described in detail in the next section. For a particular wind velocity(V_w), there will be an optimum setting of generator speed (ω_r^*). The speed loop will generate the torque component of machine current so as to balance the developed torque with the load torque. The variable voltage variable frequency power from the supersynchronous induction generator will be rectified and pumped to the dc link. The dc link voltage controller will regulate the line powerP_0 (i.e., the line active current) so that the link voltage always remains constant. A feedforward power signal from the machine output to the dc voltage loop (not shown) prevents transient fluctuation of link voltage. Evidently, the system can be satisfactorily controlled for start-up and regenerative braking shutdown modes besides the usual generating mode of operation.

The model of the direct grid-connection mode is given in this article, and Fig 7.4 shows the sketch.

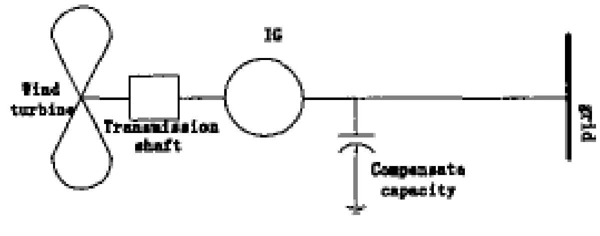

Fig.7.4 Sketch of the grid-connected wind turbine

On condition that the input wind velocity is step change and nature wind, the simulation results is given.

A. Simulation of step wind speed

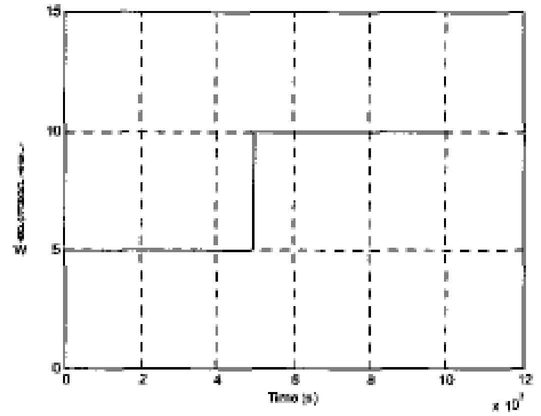

Fig 7.5 Input wind speed of wind turbine

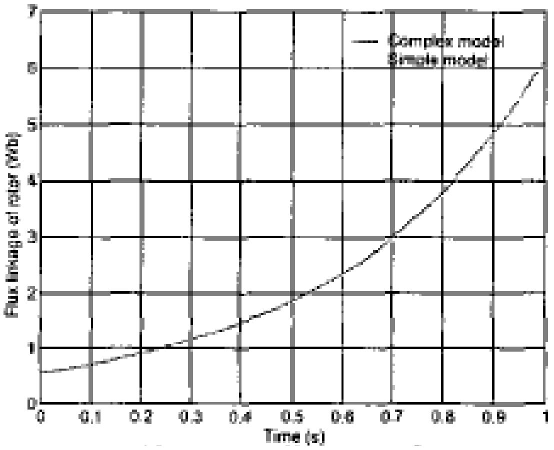

Fig 7.6 Flux linkage of rotor

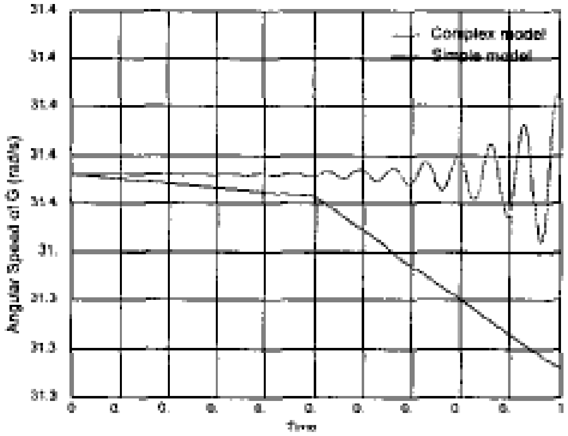

Fig. 7.8 Mechanical angular speed of generator

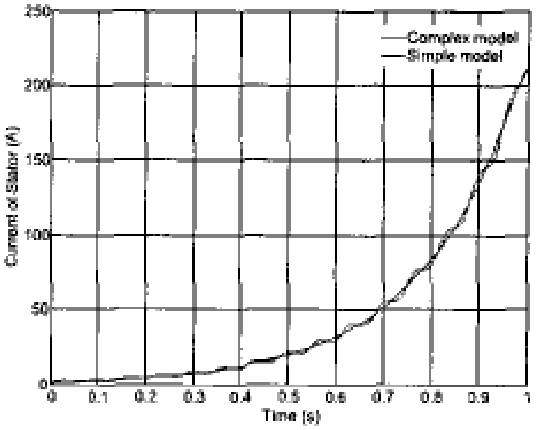

Fig. 7.9 Current of the stator

B. Simulation of natural wind speed

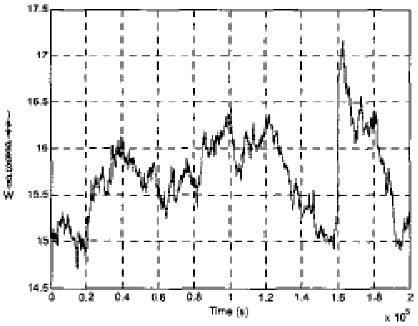

Fig. 7.10 Input wind speed of wind turbine

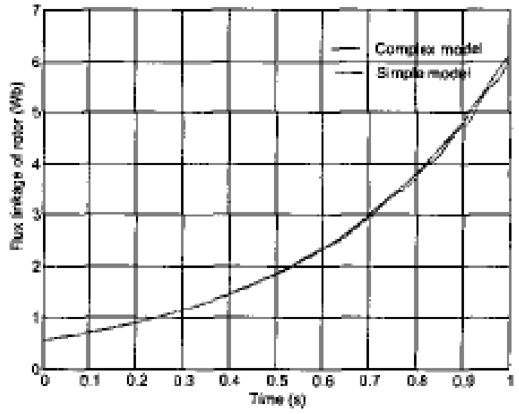

Fig. 7.11 Flux linkage of rotor

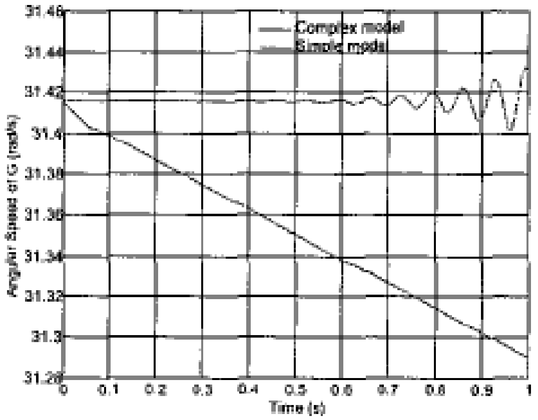

Fig. 7.12 Mechanical angular speed of generator

Chapter 8

CONCLUSION AND REFERENCES

CONCLUSION

In this paper ,the various parameters that regulate the performance of a wind turbine driven generator system were studied in details .In addition, simulation procedure was carried out to vary the characteristics of the asynchronous generator within specified limits and modeling of the asynchronous generator connected to the grid was studied The first part of the project dealt with the basic scope of wind turbine driven generator system The subsequent chapters zeroed upon torque speed characteristics along with the proposed rectifier inverter system using IGBT PWM . The concluding part of the project deals with the simulation results of the directly connected wind turbine generator system.

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