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Inertia for Smart Grid Utility with Existing Grid Energy in Tropical (Indian)Power Systems

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ABSTRACT

The power outages in the recent past shows the extent of power consumption by the nations as a whole. Addition of renewable energy resources to the grid is expected to solve the power problem whereas its volatile nature is a threat to the stability of power system.. This paper presents a brief study of the Indian power system which belongs to the tropical climatic zone where the availability of solar energy is very high which could be utilized for grid enhancement. The challenges faced during grid integration of renewable energy sources with some possible solutions for the encountered problems are briefly discussed.

KEYWORDS: *black out, inertia of power system, synchronization, power system stability, renewable enery*

1. INTRODUCTION

Energy is a nation's primary concern. Moving apart from conventional system with the aim of developing a pollution free solution for global energy demand, the global power system today has adhered to the renewables supporting the go green notion to reduce carbon emission as well as to improve the energy efficiency considering the climate and energy security objectives.[1] Renewable energy sources such as wind, solar, biomass etc. are getting greater recognition in meeting the day-to-day energy requirements for captive power of domestic, commercial and industrial sectors [2]. Almost all of the renewable energy resources are connected to the grid through power electronic interfaces. These are done either for DC to AC conversion or to improve the quality of injected power. This also helps in conditioning the power input to the commercial loads. The most commonly used renewable energy sources are the photovoltaic systems, wind energy systems, tidal energy systems and fuel cells [3][4]. These are efficient sources of energy which are green, clean and in effect the promise for a smart and pollution free era of energy generation. The climate in the tropical region is dominated by very high stable temperatures and high humidity and lacks the moderate climate's seasonality. India is a country which lie in the tropical as well as temperate zone of Earth in almost equal proportion, Though it shares its land mass equally between both the zones, the great Himalayas in the north helps the region to maintain itself in a tropical climatic region.

2. INDIAN POWER SYSTEM –CITATION OF BLACK OUT

Renewable energy in India comes under the purview of the Ministry of New and Renewable Energy (MNRE). A large number of decentralized renewable energy systems such as biogas plants, solar photo voltaic systems, wind energy etc have been promoted under various schemes of the the MNRE. Previously, Indian power system was divided in to five grids namely Northern, Eastern, Southern, Western and North Eastern grids.The North and North Eastern grids were synchronized and interconnected to run in one frequency on October 1991.The Western, Eastern and North Eastern Grids were connected to run as in synchronism on March 2003. Similarly Northern grid was connected to Eastern grid on August 2006 and finally the Southern grid which is known as the energy efficient grid was connected to the Central grid (comprising the rest of the four) on December 31 2013,after the great north Indian blackout of 2012.[5]

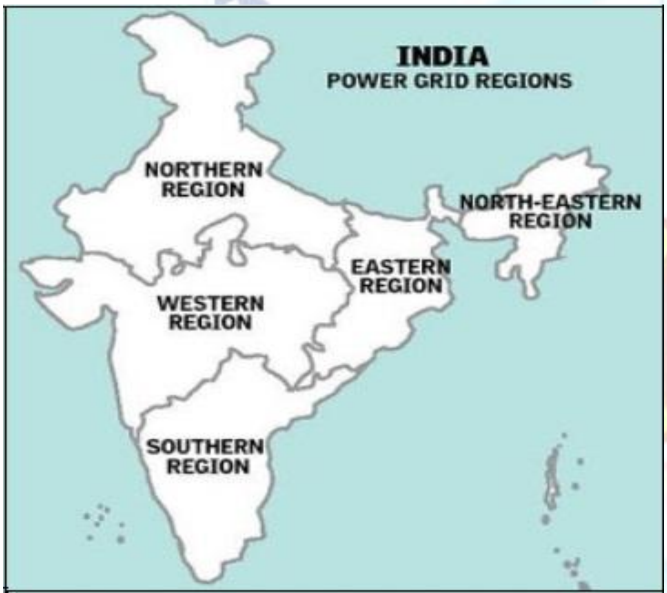

FIG.1 POWER GRID REGIONS OF INDIA

Fig 1 shows the classification of regions under Indian power Grid,The great North Indian black out of 30-31 July 2012 marked the largest power outage in India. The reason for such an enormous power outage was the collapse of northern grid that connects the states of Punjab, Haryana, Rajasthan, Delhi, Uttar Pradesh, Uttarakhand, Himachal Pradesh ,Jammu Kashmir and Chandigarh. The root causes that resulted in the collapse of the northern grid and hence the black out were the late arrival of monsoons (This made farmers of Punjab & neighbouring states to draw more power from grid to water paddy fields) and the intense weather of summer(The intense heat made people consume increased level of power for conditioning systems).The lack of monsoon at the expected time decreased outputs of hydro power stations. Analysis of the event by the three member panel appointed by the power minister Sushil Kumar Shinde came up with the ample reasons for the outage as weak inter-regional power transmission corridors due to multiple existing outages (both scheduled and forced),high loading on 400 kV Bina-Gwalior-Agra link, inadequate response by State Load Despatch Centers (SLDCs) to the instructions of Regional Load Despatch Centres (RLDCs) to reduce over-drawal by the Northern Region utilities and under-drawal/excess generation by the Western Region utilities and loss of 400 kV Bina-Gwalior link due to maloperation of its protection system.[3][5]. The contingencies such as tripping of a large generating unit, tripping of HVDC back-to-back stations (or inter-regional HVDC links) and loss of a large block of load have been frequently recorded both for Northern Regional Grid and the Southern Regional Grid over a wide period of time.[6].These kind of incidents are a threat to the grid as a whole as they degrade the stability of the grid.

3. FREQUENCY RESPONSE CHARACTERISTICS

Demand-generation balance is globally indicated by frequency. The type of machines usd for generation of power are rotating machines and the inertia constant 'H' for rotating machines is denoted by

$$H = (J\omega 0m\ 2\ )/2VAbase \quad (1)$$

J = combined inertia of the generator and turbine

$\omega 0m$ = rated angular velocity in mechanical rad/second

VA= the volt ampere rating of the machine .

The reduction in load following a decline in frequency is characterized by the load reduction factor "d", which is defined as the percentage change in load for a percentage reduction in frequency. The general rule of the thumb is that a 1% change in frequency causes a 2% change in the load. The simplest way to calculate the frequency response of a control area is to use the "1% of load criteria"[8]

4. GRID ENHANCEMENT WITH RENEWABLES

One or all of the conventional energy resources is said to be the back bone of the power Grid. The power deficit in the grid creates an imbalance in demand-generation pattern of the country.This can be avoided by integrating more and more renewable energy resources to the grid.. India's proximity to equator has made it a country rich in solar as well as wind power and the peninsular geographic nature has contributed a bulk amount of tidal and ocean energy reserve to the power sector of the Indian mainland. So integration of renewable energy to the grid is expected to possibly clear the power deficit in electrical power system. Renewable energy integration has created mutations to the existing grid in a wide manner. The main downside of renewable energy is the volatile supply of power and also its low rotational inertia.[9] The integration of renewable energy and its interconnection to the grid may cause the instability of grid which is often addressed as system's problem.

5. BEHAVIOUR ANALYSIS OF INDIAN POWER GRID

India's cumulative grid interactive or grid tied renewable energy capacity (excluding large hydro) has reached 33.8 GW, of which 66% comes from wind, while solar PV contributed nearly 4.59% along with biomass and small hydro power of the renewable energy installed capacity in India.[10]The integration of renewable energy resources to the grid creates system's problem as follows. Most of the renewable energy sources contain variable frequency or high frequency ac or sources and hence result in the wide use of inverters and converters in the grid and they eventually dominate power generation. Addition of renewables to grid is highly beneficial for the power system provided, they are constituting a lower share compared to their counter part-the conventionals. This is because of the reason that they are more prone to power fluctuations.To a minimum extent these fluctuations can be handled by the controllers of the existing grid connected large conventional generators. If the renewable integration is done in plenty ,the system as a whole finds it hard to meet the fluctuations of the grid.

The key element to be noted that is the inertia offered by conventional generators which help them handle the power swings easily. As we move on to renewable energy source integration, we could easily find that they lack the feature called inertia.This ends up in a system problem affecting the stability of the system /grid taken in to consideration. This causes the misbehavior of the system, production of unwanted spurious controls signals or even drastic variation in the output. It needs to be resolved for the proper functioning of the system.

From Newton's first law or law of inertia it is clear that inertia is the key element that makes a system stay in that particular state similar to its predecessor state. Newton's first law of motion can be stated as -when viewed in an inertial reference frame, an object either remains at rest or continues to move at a constant velocity, unless acted upon by an external force. As far as rotating machines are considered they have enormous mass and hence synchronous generators stores a huge amount of kinetic energy on rotation and in case of a sudden collapse, it tries to release the stored energy to oppose the abrupt halt to the rotation that it experiences i.e, by the release of energy, the machine is attempting to maintain its nominal speed. Fig 2 shows the frequency response of the power system corresponding to its inertial aspect.

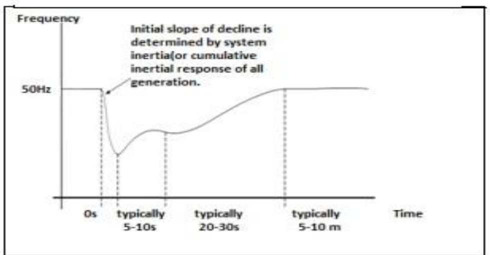

FIG.2 FREQUENCY RESPONSE OF THE SYSTEM FOR A FAULT ON INERTIAL ASPECT

Distributed energy resources lack whole of the inertia component hence the slope of decline of frequency is very steep. The frequency control reserve of power system shown in fig.3 clearly depicts the response of power systems to a fault wherein the power systems are powered by variant sources. The curve in green represents the nominal power system characteristics if the system could work with high inertia. The curve in blue indicates the power system employing only synchronous generators The curve in red depicts the frequency drop of a power system employed with renewable energy resources like solar and wind up to 50% of its capacity(very low inertia)

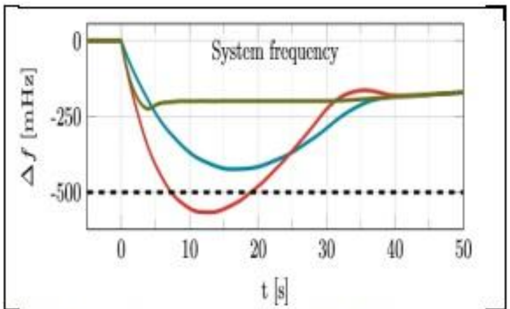

FIG.3 FREQUENCY CONTROL RESERVE OF POWER SYSTEM

6. POSSIBLE SOLUTIONS FOR PROBLEMS DUE TO LACK OF INERTIA

A stable power system must be capable of withstanding sudden power fluctuations -either by the conventional machines only or with the help of controllers associated with the conventional machines or in particular say, the synchronous generator.The serious issue of lack of inertia for inverter connected systems can be solved by developing inverters that could possess the characteristics of synchronous generators [11], [12]. This could be done by developing a model of SG where the dynamic equations remain the same and the mechanical power exchanged with the prime mover(or mechanical load) is switched to exchange with the DC bus..Finally a system can be modelled such that it would look like an SG with a small capacitor bank connected to the stator terminals.This will be a non linear system,[15]

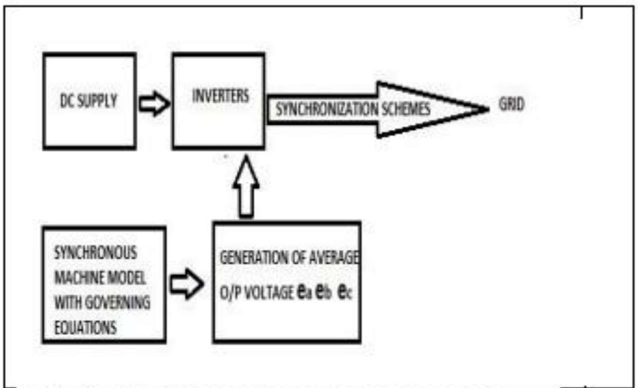

FIG.4 BASIC BLOCK DIAGRAM OF A SYNCHRONVERTER

This provides sufficient control and smooth integration of renewable energy to the grid. The typical conventional inverters are used in this system wherein the control circuit has underwent a suitable modification.ie, these could independently exchange the real and reactive power without depending on the mechanism of tracking the reference currents or voltages. Here the conventional inverter system is employed with frequency and voltage droop control as that of the classical synchronous machines. By using the torque, back emf, and active power equations of the synchronous generators a characteristic control is easily modeled where the generated voltage 'e' (average values of nodal voltages i.e, of ea, e b and ec over a switching period is equal to e.) is used to generate the PWM signals to drive the switches. This also helps to synchronize the distributed energy resources with the grid before connection as well as to deliver the desired real and reactive powers after connection.

7. CONNECTION OF INVERTERS TO THE GRID

When an electric power system is considered, synchronization aims at effectively co-ordinating the phase, frequency and voltage magnitude of the incoming and existing system. This could be made possible by using synchroscopes or conventional methods like bright lamp method, dark lamp method etc[6]where the parameters to be made same are the frequency, phase, phase sequence and voltage between the incoming machine and the existing machine/the grid as a whole.

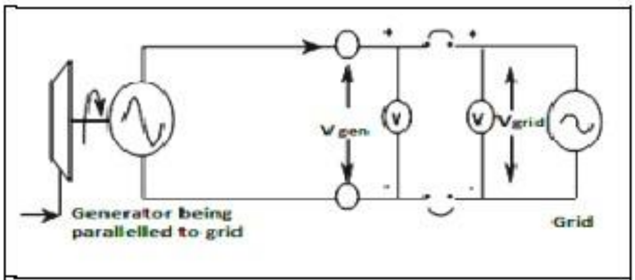

FIG:5 SYNCHRONIZING A GENERATOR TO THE GRID

The renewable energy sources which are considered alike generators can be effectively synchronized to the grid by use of effective mechanisms aided by electronic elements.Baic single line diagram is shown in fig 6.

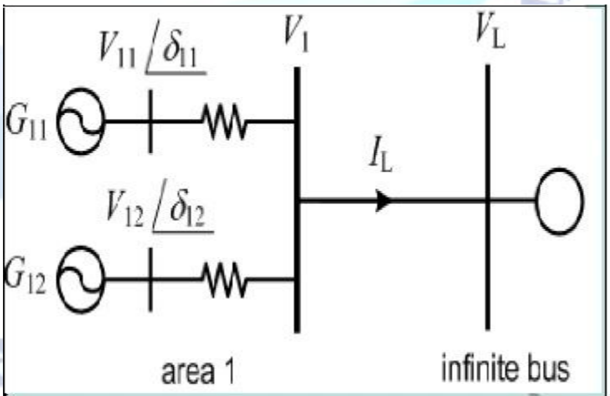

FIG.6 GENERATORS CONNECTED TO INFINITE BUS

The simplest and easiest solution for synchronization is the zero-crossing-detection (ZCD) but It can be only used where the input is a stable and sinusoidal signal due to its sensitivity to transient and noise. An ideal PLL can provide the fast and accurate synchronization information with a high degree of immunity and insensitivity to harmonics, unbalances, sags/swells, notches and other types of distortions in the input signal.

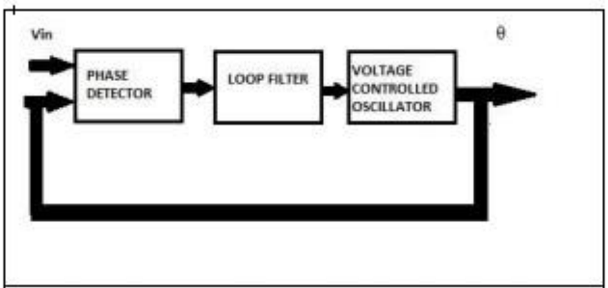

FIG:7 BASIC BLOCK DIAGRAM OF A PLL

As shown in Fig. 7, the difference between phase angle of the input and that of the output signal is measured by the phase detection (PD) and passed through the loop filter (LF). The LF output signal drives the voltage-controlled oscillator (VCO) to generate the output signal, which could follow the input signal. Synchronous Frame PLL (SF-PLL) is widely used in three-phase systems. Here the is detected byθinstantaneous phase angle synchronizing the PLL rotating reference frame to the utility voltage vector. The PI controller sets the direct or quadrature axis reference voltage Vd or Vq to zero, which results in the reference being locked to the utility voltage vector phase angle. In addition, the voltage frequency f and amplitude Vm can be obtained as the by-products. Under ideal utility conditions without any harmonic distortions or unbalance, SF-PLL with a high bandwidth can yield a fast and precise detection of the phase and amplitude of the utility voltage vector. Other types of PLLs that are commonly used are real and imaginary power PLL (PQ PLL) and Double Synchronous Frame PLL (DSF-PLL) where the former prevents the failure in tracking the system voltage during start up under some adverse conditions, and oscillations caused by the presence of sub harmonics and the latter which is based on transforming both the positive and negative sequence components of the utility voltage into the double synchronous frame completely eliminates the detection errors of the conventional SF-PLL.[13] [14] We know from the equation of power that

$P = VE \sin\delta X$ (2)

where , P is the active power of the system

V is the amplitude of the infinite bus voltage

E is the induced voltage amplitude of the synchronous generator

X is the synchronous reactance of synchronous generator and δ = θ − θg ,where θg and θ are the phases of the grid voltage and of the generator respectively. For better results like speed of response, accuracy, reduction of bulk circuitry etc, self synchronization mechanisms can be used where a virtual current signal is generated from the difference between E and V and a PI controller is employed to regulate the output of the frequency droop control as well as to generate reference frequency for the synchronverter so as to aid the purpose of synchronization[15].

8. SIMULATION RESULT

The problems asscociated with lack of inertia can can be avoided using synchronverters.The simulation results shows the performance analysis of synchronverters with Phase Locked Loop(PLL) and self synchronization technique for synchronization with grid.The simulations are done in the platform- MATLAB 2014a

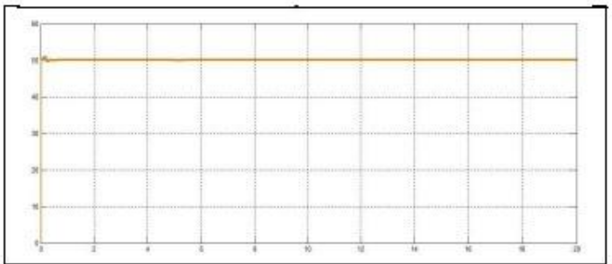

FIG:8 FREQUENCY TRACKING CAPABILITY OF SYNCHRONVERTERS USING PLL

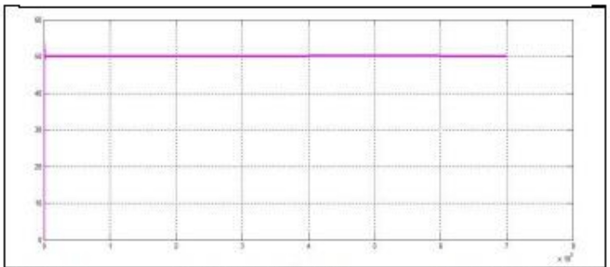

FIG:9 FREQUENCY TRACKING CAPABILITY OF SELF SYNCHRONIZED SYNCHRONVERTERS

The simulations shows that self synchronized synchronverters track the change in frequency far effectively than other synchronization techniques and that too comparitively negligible fluctuations at the initial state.Fig 8 shows the frequency characteristics of grid connectes renewable energy systems using PLL where an oscillatory transient is observed at the initial stage ie, before attaining the grid frequency.Use of PLL for grid synchronization(fig.8) is better compared to ZCD which is a primitive technique.The initial frequency transients are less and PLL has the capability of better frequency tracking.The use of additional synchronization schemes like PLL as well as ZCDs increase the bulkiness of the system as well as affect the system response to become slow. Fig 10 shows the self synchronization scheme applied to synchronverters where proper and transient free frequency tracking is done with a light system and that too with ease.

9. CONCLUSION

The paper discusses methods to impart inertia to the inverter systems used for grid connection of renewable energy resources.The need for synchronization schemes,types as well as the synchronization capabilities of different synchronization schemes for the interconnection of renewable to the grid are described and validated by simulations.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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