"Enhancing Power Quality through Distributed Generation Based on Renewable Energy"

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ABSTRACT

The importance of renewable energy is rising because it is environmentally benign. Due to concept of avariable-speed wind turbine (WT), which is more controllable, efficient, & has good power quality, research into modelling for wind turbine-generator systems (WTGS) that are capable of accurately simulating behaviour of each component in WTGS is important & necessary as demand for controllability of variable speed WTs increases. Power quality improvement for efficient power transmission in a grid-integrated solar photovoltaic (PV)-wind energy hybrid system is the focus of this research. The hybrid system, which is based on a photovoltaic energy generation system & a wind energy conversion system (WECS), represents a renewable energy farm. The system frequently suffers issues with AC loads as well as power generated by renewable farm. Reactive power imbalance results from this, which also causes voltage instability and power quality problems. An adjustable reactive power source, such as a static synchronous compensator (STATCOM), can be used to close this gap. A wind energy conversion system of 2 MW and a solar PV system of 5 MW are taken into account in this dissertation work, and their output is used to investigate and analyse the dynamic performance of the system.

The turbine uses a PMSG type generator with 2 back-to-back coupled low capacity converters. The stator terminals of the PMSG end are connected to grid by converters. Machine Side Converter (MSC) refers to one of these that is connected to the stator terminals, and Grid Side Converter (GSC) refers to one that is connected to grid terminals. An integrated grid inverter, inverter controller, and PV array make up a PV system. Between the PV array and the grid, there is a connection for the inverter.

Since inverters are switching devices, they cannot be connected directly to grid. This is because inverter generates harmonics, which reduce quality of the power. Voltage variations, faults, and varied loading all affect the system. In this situation, a STATCOM is one of best candidates for dynamic reactive power compensation when voltage is lower than the typical voltage range or during grid or renewable system fault conditions. This dissertation work analyses dynamic performance of renewable systems using STATCOM.

Keywords: windenergy conversionsystem (WECS), solarphotovoltaic (PV), STATCOM, Machine Side Converter (MSC), Grid Side Converter (GSC).

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INTRODUCTION

The utilities are struggling to meet growing demand for power as a result ofurbanisation, industry, & an increase in living standards. Modern powerdemand cannot be met by power supply from conventional sources alone, increasing concerns about electricity security and dependability while massive amount of pollutants pose major environmental risks [1]. The burning of fossil fuels meets 7.5 percent of the world's total energy demand. However, rising air pollution, worries about global warming, the depletion of fossil resources, and the rising expense of those fuels have made it vital to look to renewable sources as a future energy alternative.

Renewable & distributed energy sources have been more prevalent over the past 2 decades as a complement to traditional energy sources, and utility experts anticipate that they will be a powerful tool in meeting load demand and successfully resolving the power difficulties [2].

Distributed generation (DG) based on hybrid renewable energy systems (HRES) is newest trend in renewable energy system, and it has been shown to increase overall performance & dependability. Many options for properly utilizing a range of renewable energy sources for power generation have been suggested. Wind & solar energy combined have been efficiently used in a number of hybrid systems, out of all the common renewable energy sources.Utility firms all across the globe have recently focused on hybrid solar PV-wind facilities [3]. Solar and wind energy systems acknowledge one another throughout day. Strong winds often occur at night, while solar energy is accessible all day and may satisfy up to four times world's total energy demand in one area in North Africa. Strong winds are more prevalent at night and on gloomy days, as opposed to moderate breezes on bright days. Wind-PV hybrid energy systems, despite their inconsistency and inherent limits, are employed to provide energy to loads with improved dependability and continuity of supply. Despite their potential to provide electricity with improved continuity and reliability, the variable character of such intermittent energy sources has a direct influence on the vital stability between renewable energy supply and associated load. The development of flexible ac technology and associated power electronics technologies has resulted in anomalies in the bus voltage and system frequency, system oscillations, and undesirable reactive power output, endangering the system's integrity and electrical dependability.

The devices might be utilized to reduce power quality difficulties caused by the integration of such Renewable Energy Sources (RES). STATCOM is one of the devices being used and studied that produce good results. Our current power producing system is built on huge, centralized power plants. Renewable energy, on the other hand, is irregular, scattered, and self-regulated. As a result, changing the power grid to allow renewable energy sources to operate efficiently may be quite difficult. Given the potential for substantial expenditures in sustaining and growing the power grid to deal with renewable energy production in the coming decades, it is critical to figure out how to boost flexibility and reliability, improve energy efficiency, and improve power quality for tomorrow's smart grid. It was recognised that grid-connected renewable energy production would impair the grid's capacity to supply clean power.

Renewable energy generation is non-dispatchable, intermittent, and vulnerable to considerable fluctuations due to the fluctuating nature of renewable energy supply. As the penetration of renewable energy grows, such huge oscillations present substantial power quality problems.

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The networked renewable energy sources would interact with grid side disturbances such as voltage drops produced by short circuit failures and frequency variations induced by changes in demand and generation, resulting in more challenging and unpredictable operation circumstances. Power quality is one of the most critical factors that may impact the overall stability and dependability of tomorrow's power system, among other things. [4]

OBJECTIVES OF THE STUDY

The research work is based on the conventional energy sources are running out quickly. Additionally when energy prices rise then solar and other renewable energy sources offer a promising option. They are plentiful, free of pollution, dispersed all across the world, and recyclable. Its high installation costs, poor conversion efficiency, and power quality issues are deterrents. Therefore, improving efficiency, power output, and power quality is our goal. Additionally, the load must get consistent voltage regardless of changes in temperature, wind speed, or sun irradiation. Solar power plants are made up of three parallel and series arrangements of PV cells that generate energy based on environmental circumstances (such as solar irradiation and temperature). As a result, the PV array must be coupled with a boost converter. In addition, our system is designed so that when the load changes, the change in input voltage and power given to the converter matches the PV array's open circuit characteristics. As a result, the d-q reference frame design is presented for integration with grid inverters. A wind turbine is coupled to a permanent magnet synchronized generator in a wind energy system to convert mechanical wind power energy to a current of electricity.

LITERATURE REVIEW

Emad Jamil [8] pushed for improved power quality in a grid-integrated solar photovoltaic-wind energy hybrid system for effective power transfer. A hybrid system is a renewable energy farm comprised of a solar energy generation system and a wind energy conversion system. This results in reactive power imbalance, exacerbating voltage instability and power quality concerns. An changeable reactive power source, such as a static asynchronously communicating compensator, can be used to bridge this gap.

Basaran et al. [9] introduced a new energy management technique for Wind-PV hybrid systems that has been demonstrated to be practical for both independent and grid-connected operation, boosting system efficiency by 10%.

In order to use the fewest components possible without requiring battery storage, Jamil et al. [10] built and simulated an 18 kW isolated Wind-PV hybrid system suitable for stand-alone small power applications in rural areas. Despite changing output, the hybrid system can continually provide varying DC loads, according to the simulation results.

Vasile-Simion[13] modeled a wind turbine system based on a permanent magnet synchronousgenerator (PMSG). The main objective is to design a comprehensive wind turbine system for a smart residential building by integrating a wind 8 turbine, a PMSG, a power converter, and a control system. Engineers may use this model to develop novel power converter topologies or control techniques that are more effective and controllable, as well as to simulate and test their performance.

Dipesh has a FACTS device called "STATIC COMPENSATOR (STATCOM)" linked to a common point. M. Patel's[14] design suggestion. The FACTS Device - Static Compensator (STATCOM) control strategy for the grid-connected wind energy

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generating system is simulated using MATLAB/SIMULINK. The primary power source is intended to be free of the reactive power requirements of the load and the induction generator. Based on the data, he validated the approach's feasibility and practicability for the applications under consideration.

An SPV, WEC, and micro-hydro hybrid system that Chichi and Gao [16] developed and simulated totally relied on renewable energy sources and did away with the need for diesel generators. Additionally, systemwas coupled with aSTATCOM to improve system's viability & performance due to sources' sporadic outputs and to account for changing reactive load requirements.

Bhatti et al. [17] investigated effect of STATCOM on managing bus voltage in an autonomous Wind-Diesel hybrid by balancing reactivepower requirements of IG & variable load in order to maintain system stability when responsive load and wind speed were changed in a step-wise manner.

WIND ENERGY CONVERSION SYSTEM

The kinetic energy of entering air stream is convertedinto electrical energy using a device known as a windenergy conversion system (WECS). This conversion takes place in 2 phases. The wind forces the extraction device, the wind turbine rotor, to revolve, creating mechanical power. The generator, which generates electricity, is powered by a revolving electrical device known as the rotor.

There are two types of wind turbines: horizontal direction and vertical axis. The whirling blades of an axis that is horizontal machine are parallel to the ground. The blades of a device having a vertical axis rotate parallel to its horizontal axis. The vast majority of wind turbines manufactured today have vertical axes, two or three blades, and may operate either upwind or downwind.

Traditional asynchronous power plants, such as induction generators and doubly-fed induction power plants, require several step gearboxes, whichare unstable, expensive to operate, & loud in low-speed winds. PMSGs are robust and compact.

Permanent magnetic materials have lately evolved, enhancing the performance of PMSG-based wind turbine systems, which are currently widely used. In this configuration, neither slip rings nor a separate power supply are required for magnetic field excitation. Furthermore, it can operate in a wide variety of wind speeds. As a result, it is known to be more efficient than any of the previous wind turbine technologies.

A wind turbine can be configured to operate at a fixed or variable speed.

Notwithstanding the fact that wind turbines with variable speed require power electronic converters to provide a set frequency and voltage to their loads, they may produce 8% to 15% more energy than constant speed wind turbines. The majority of turbine manufacturers have elected to use reduction gears between the high-speed three-phase generators and the low-speed turbine rotor. The advantages of direct drive design, which directly connects a generator to a wind turbine's rotor, include high reliability, minor upkeep, and perhaps low cost.

The following is a simple explanation of how wind turbine systemgenerates power.

When the wind blows over the blades, they revolve with low-speed shaft.

The kinetic energy is transmitted from a low-speed rotating shaft to a high-speed rotating shaft via gearbox, which determines rotational speed.

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Because of high-speed shaft, generator rotates at a high speed that is closer to the rated speed.
1.Mechanical energy is converted to electrical energy by the spinning generator.
Additionally, there are numerous on-board controllers that can control the yaw system, drive system, and power control components in addition to changing the pitch angle of the rotor blades. Additionally, these on-board controls have the ability to stop the rotor in scenarios where it may otherwise run away, such severe wind speeds and power interruptions. The wind vane, cooling fan, & other sensors are further components of a wind turbine-generator system. The anemometer,speed or position sensors, aswell as voltage and current sensors, are some of these sensors.
The yaw control system's operation is determined after the wind vane has measured the wind directions.
Electric cooling fans are needed to keep the gearbox, power converters, and onboard controls cool. The anemometer monitors wind speed in order to track the maximal energy of the wind for defensive purposes. Forexample, when wind speed 12 experiences gusts, anemometer signal is communicated to the onboard controllers, prompting wind turbine to shut down break for safety reasons. In line with the control schemes, other sensors used in wind turbine systems, such as speed sensors and sensors for current, should be provided.

Wind Turbine Operation:
Figure 1 depicts the four distinct zones of a wind turbine's power speed characteristics.

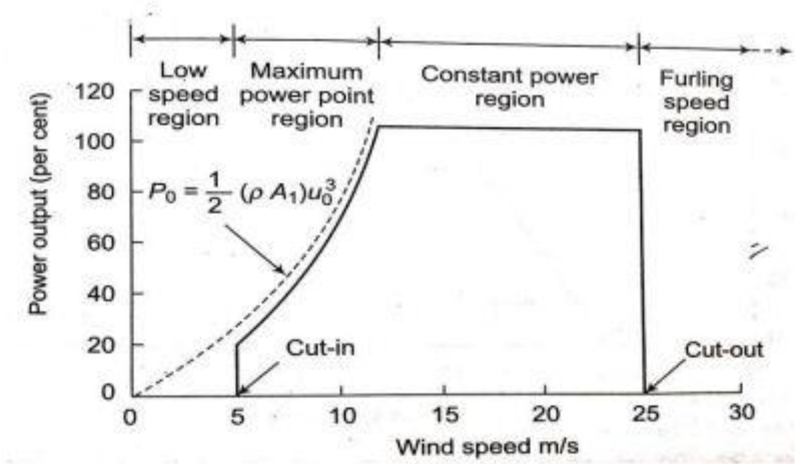

Fig.1: Power versus windspeed characteristics

Low Speed zone (Zero to Cut-in Speed): The turbine is held in the braked position during this zone until the minimum speed of 3.5 m/s, or cut-in speed, becomes available. Below this speed, turbine's is inefficient.
MaximumPower Coefficient zone: In this zone, the rotor speed is adjusted in accordance with the wind speed to maintain the maximum power coefficient Cpmax. The features of this area are very similar to those of the wind's peak power. Pitch control is used to operate the turbine at its highest power output point.
Constant Power Region (Constant Turbine Speed Region): The rotor speed is restricted to the top permitted value during high speed over 13m/s based on design limits of the system components .The power coefficient is therefore less than Cp max. To keep the

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turbine speed constant, large machines use pitches control. Pitch-regulated is the name given to such a device. In order to crudely maintain speed as constant, traditional European machines use fixed blades (constant pitch), blade twist, and blade thickness. Such a machine is 15 referred to as stall controlled. As there are no moving blade surfaces or intricate technology, this is a straightforward device that simply requires passive technique.

Control of Grid side converters

Because vector control is based on a concurrently moving, stator flux oriented d-q referencing frame, the d-axis coincides with grid voltage vectors, and the q part is zero. For this method of running the inverter linked to the network, we proceed as follows:

1. A PI controller was established to regulate DC bus voltage to its reference. The direct current reference is the result of this.
2. The inverter converts the current measured at its output into its dq components. We derive 2 components voltage to be imposed
3. By setting quadrature portion of the reference voltage to zero & then regulating the direct & convolution components of network side converter's output voltage.
4. Following decoupling and compensation methods, transformation into Cartesian coordinates, and simple modulation based onlevel comparators, control signals of converter are created.

   A simplifieddiagram in MATLAB/Simulink environment ofthis control is given below.

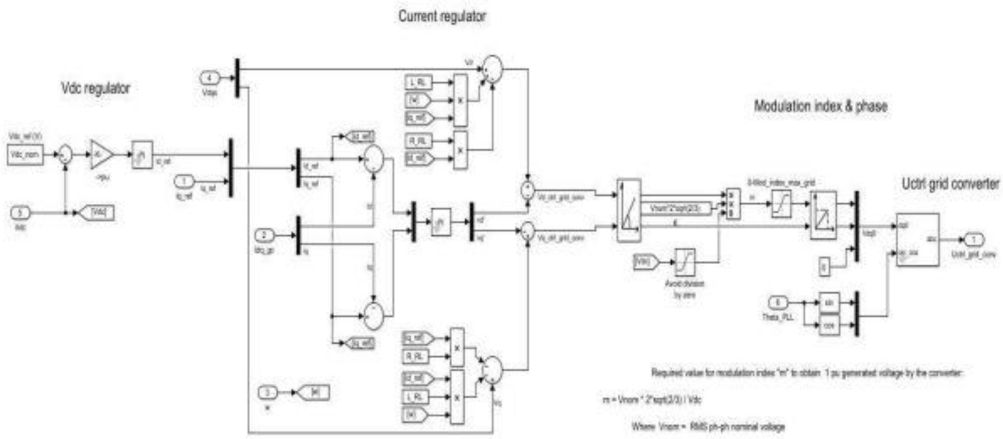

Fig.2: Voltage Oriented Control ofGrid side converter

WTGS Modeling and Simulation:

For research and analysis of the wind energy producing system's dynamic performance, a system of wind turbines with a combined output of 2 MW is used. The turbine uses a PMSG type generator with 2 back-to-back coupled low capacity converters. The stator terminals of the PMSG end are connected to the grid by the converters.Machine SideConverter (MSC) refers to one of these that is connected to the stator terminals, and Grid Side Converter (GSC) refers to one that is connected to grid terminals. A 2km

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transmission line connected the wind farm, which is a wind energy producing facility comprising wind turbines, to the grid. The grid has a 25 kV voltage level. Three different loads are employed to dynamically load wind farm. Base load is one of them and it is resistive in nature. Inductive is the second, and capacitive is third. For the purpose of simulation, these are dynamically turned on and off. Apart from voltage swells and sag at the grid side, an LG fault is made, and dynamic performance is examined.

The WTG model comprises of a permanent magnet synchronousgenerator, or PMSG. The grid terminals are connected to stator windings, and wind turbine is connected to rotor. Through a two-level PWM generator and a machine side converter, the gate pulses are supplied by controller for machine side converter. The DC link with a capacitor C is where its DC side is attached. The grid sideconverter maintains voltage of the DClink at desired level. Due to its direct connection to the grid, grid side converter supplies grid with activepower and maintains grid's dc voltage. The grid sideconverter controller supplies gate pulses to grid side converter.

Simulation Results and Waveforms

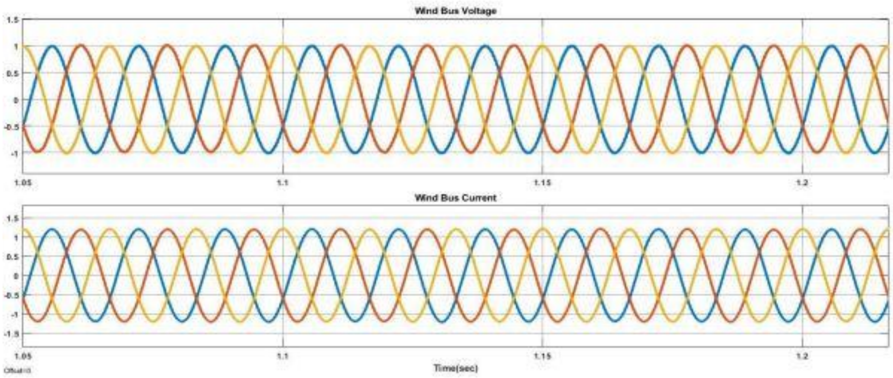

Fig.4: Wind Bus Voltage & Current

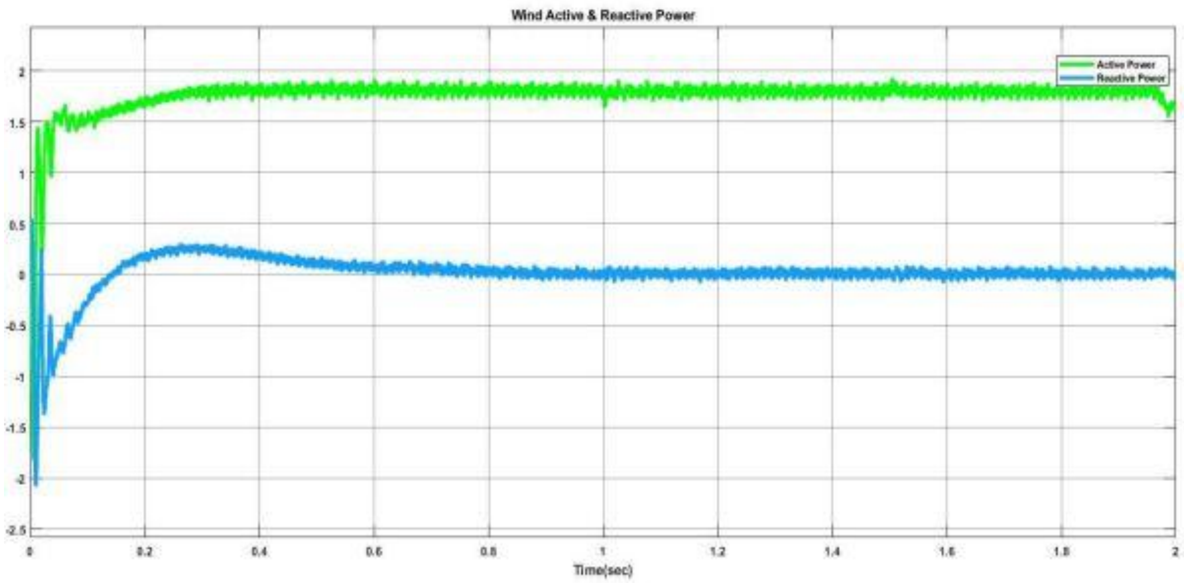

Fig.5: Active and reactive power supplied by WTG

Operation at variable load

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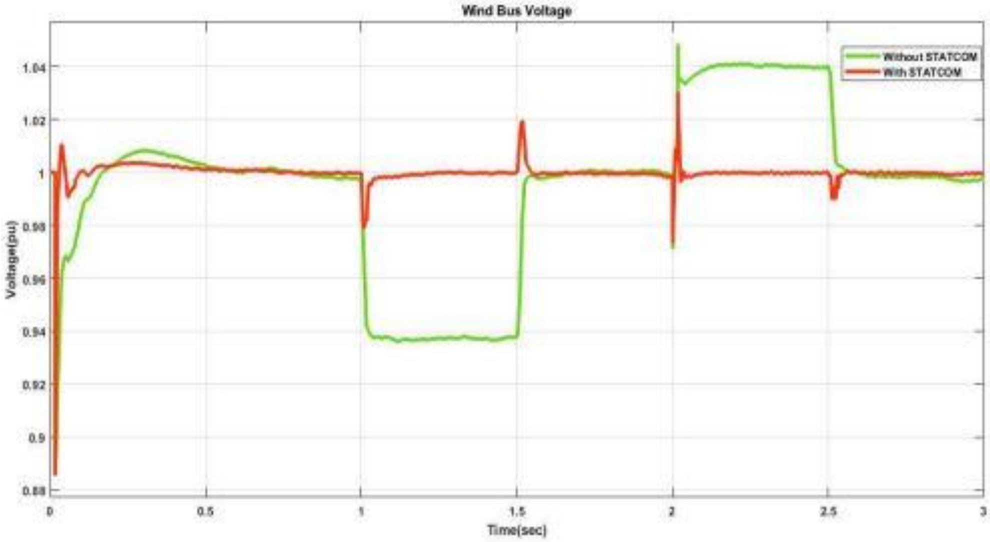

Fig.6: Voltage at wind bus during variable loading

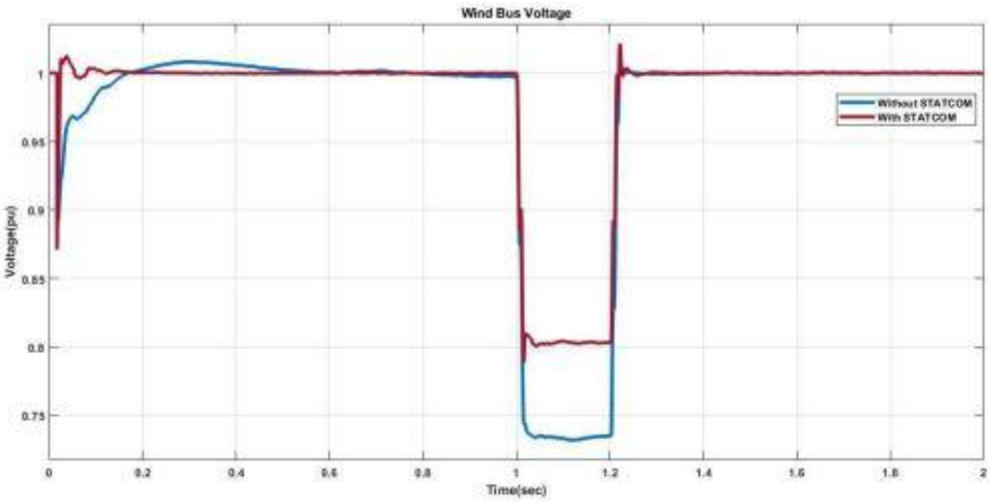

Fig.7: Voltage at windbus during fault

Photovoltaic System

Our daily activities rely greatly on energy. People's energy consumption is an excellent predictor of a country's degree of development and civilisation. Energy consumption is increasing on a daily basis as a result of population increase, urbanization, and industry. As a result, world's supply offossil fuels, such as coal, petroleum, & natural gas,will be depleted in a few hundred years. Rising energy consumption rates and dwindling energy supply cause energy shortages and inflation. This is known as an energy crisis. Alternative or renewable energy sources must be developed in order to meet future energy demands.
Because they are not unduly complicated, small-scale solar power systems are becoming increasingly popular. Backup PV systems withbatteries can also provide power at night when there is no sunshine in regions where a grid connection is not viable. Some of the current research concerns for solar power systems include inverter design, module material, and system reliability.

Stand-alone & Grid connected PVsystems

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A storage device is required if the PV array cannot directly supply a load. The majority of this is made up of batteries, although other technologies such as flywheels, compressed air, superconducting coils, double-layer capacitors, redox-flow batteries, and hydrogen are also being researched or used. These individual systems are not interconnected with the mains. Combining PV with other power producers, such as a diesel generator set, a small gas turbine, or a wind energy converter, can increase supply reliability without the need for extra storage. These are referred to as hybrid systems. A micro-grid is a large hybrid system composed of multiple geographically dispersed loads and generating units.

The focus of this research is on grid-connected solar systems with rated outputs of up to 100kW. The systems are typically interconnected with the low voltage distributing grid. In contrast to huge PV power plants, they are often employed on structures such as buildings. Grid-connected PV systems now always provide the most electricity possible, with the mains controlling voltage and frequency. Because they do not require storage, they are less expensive than standalone computers and easier to run. The entire new PV capacity deployed globally in 2002 was 525MW peak power.More over half of these systems were grid-connected. Only 23% of the 126MW of newly constructed capacity was linked to the grid in 1997. The proportion of systems connected to the grid is growing. These systems are characterized as distributed or embedded generating units in the context of power system engineering. This study presents an overview of solar system technology, with an emphasis on low-voltage grid-connected systems. The most critical system components, as well as the key words for analyzing solar radiation, are discussed. A electrically linked PV system's energy use is measured.

STATCOM Operation AND Modelling

The limits of the AC gearbox system can be divided intostatic limits & dynamic limits. Due to the restrictions imposed by these built-in power system limitations, the available gearbox resources are not fully utilized. Shunt and series capacitors, reactors, and synchronous generators were traditionally employed to address a large portion of the issue. There are limitations on how these traditional gadgets can be used, though. Unable to attain effectively was desired performance. The main issues were poor responsiveness and wear and tear on the mechanical part
s. The demand for alternative solid state technologies with quick reaction capabilities grew stronger.

The FACTS controllers' advantages and operational expenditures are offset by capital investment and running costs, which are effectively the cost of power losses and maintenance. Payback period is commonly used as an indication in planning. The three main challenges with FACTS controller deployment are the location, continuous and short-term ratings, and control techniques necessary for effective utilization. In this scenario, it is critical to examine both steady-state and dynamic operating conditions. To determine the requirements, several system investigations including power flow, stability, and short circuit analysis are necessary.It should be noted that a FACTS controller linked in series (such as the TCSC) may govern power flow throughout the whole line.

Results And Discussion

Through a 23 km, 25 kV transmission line, power from a 5 MW solar PV farm and a 2 MW windfarm that are connected to a25 kV distribution system through atransformer is exported to loads and the 25 kV grid. Two IGBT-based PWM converters and PMSG are

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used in wind turbines. For practical reasons, a wind turbine uses a changing wind speed. A PV farm has a PV array that receives constant temperature and varied irradiation. Utilising an inverter, DC output is transformed to AC.A reference system is used for simulation purposes and is depicted in the accompanying figure. It comprises of a 5 MW solar farm, a 2 MW wind farm, and a 25 kV transmission line that transmits electricity to loads. The farm for renewable energy is 23 km from the grid. Additionally, the bus B2 (the one that runs between the grid and the wind farm) has three loads linked to it.

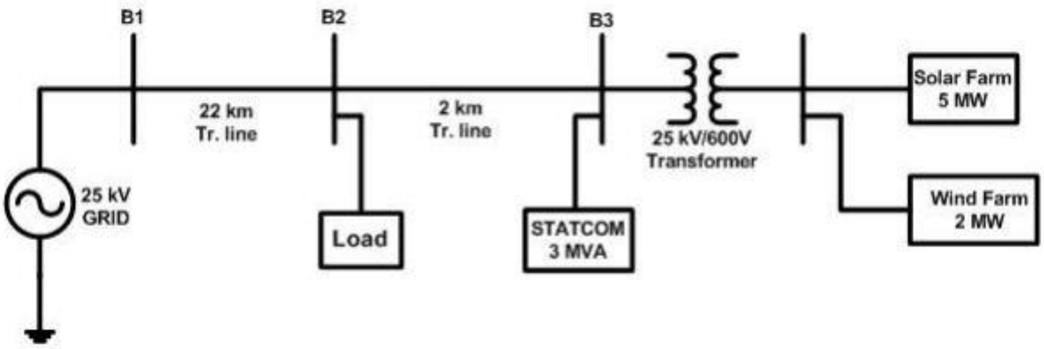

Fig.8: Block diagram of system configuration

Effect of variable loading

The dynamic performance is analyzed by observing following parameters in different cases which are going to be discussed later on:
Voltage at load bus.
Active and reactive power at gridbus.
Voltage and current at grid bus.
STATCOM bus voltage, current and power.
By observing these parameters variations during simulation we can easily analyze the performance of the DG based renewable energysystem in normal and abnormal conditions, with or without STATCOM.
The analysis of variable loading functioning of the system is of vital relevance since the loading on the power system has an unpredictable nature. Specifically, there are three loads that are wired into the system via the B2 bus. L1 is an inductiveload, L2 a resistive load, and L3 a capacitiveload. The table below provides the load value. The process of switching a load is done first without using STATCOM and subsequently with it turned on. Below, results are contrasted and given for examination.

S.no.	Load	Specification	Nature	Start time	Stop time
1	L1	3 MVAR	Inductive	1 sec	1.5 sec
2	L2	10 MW	Resistive	0 sec	3 sec
3	L3	2 MW – 1.5 MVAR	Capacitive	2 sec	2.5 sec

Table: 1 Specification of loads

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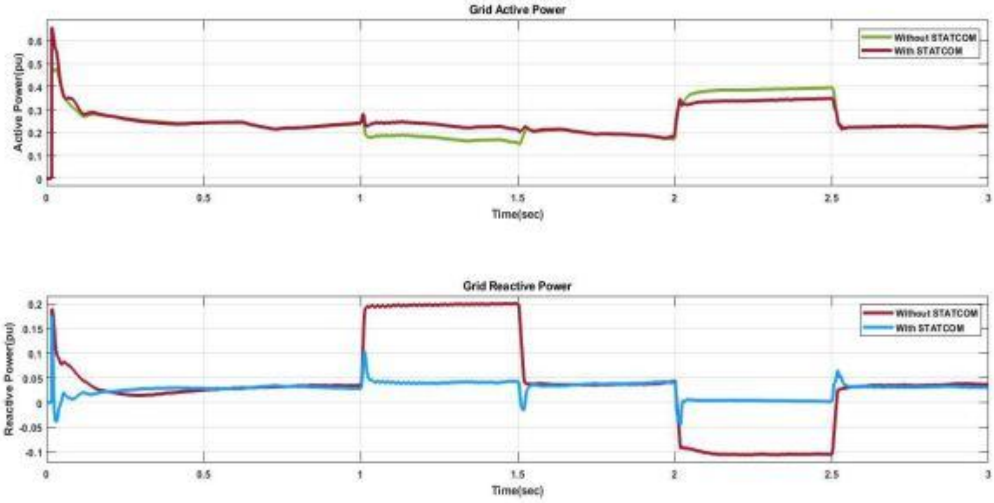

Fig.9: Active and reactive power at grid bus

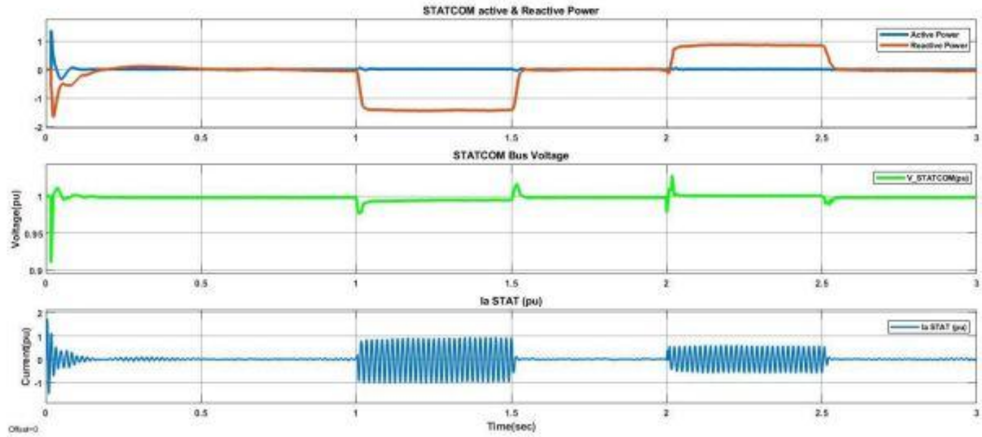

Fig.10:
Active & reactive power, voltage and current at STATCOM bus

Loading is done on 25 kV feeder, as normally load is going to be connected to it rather than at renewable energy farm bus. Variable loading at 25 kV bus effects both 25 kV bus and renewable energy farm bus voltages. But the effect is somewhat lesser at renewable energy farm bus as most demand of the load is being fed through the Grid. As observed in waveforms shown in figures 6.7-6.9, voltage at 25 kV bus falls to 0.93 pu when all the three loads are connected at this bus when STATCOM is not in service. With STATCOM in service voltage fall is reduced to 0.994 pu. Similarly, at grid bus voltage falls to 0.99 pu without STATCOM, but with STATCOM it is reduced to around 1.017 pu. As the STATCOM is connected at B3 bus it is able to maintain voltages at 25 kV bus more effectively than at grid bus.

Effect of LG fault at grid side

The wind speed and irradiance are both variable in this situation. as depicted in fig. 6.21 kilometres from the grid and 2 kilometres from a renewable energy farm, a fault is formed on the B2 bus. For this situation, LG's most frequent issues are taken into consideration. For a performance analysis of the system with and without STATCOM, many parameters stated above are tracked. The most frequent power system malfunction is the LG fault. Analysis of this fault's impact on the system is crucial, for that reason. At t=1 sec, for 0.2

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sec, a fault is inserted into the system at a transmission line 21 kilometres from the grid side. Without STATCOM 59 in use, waveforms of different parameters, includingvoltage, active power, reactivepower, etc., are recorded. At renewable energy farm bus, the STATCOM is put through the same test once more. Then, for analysis, recorded data is compared and shown below.

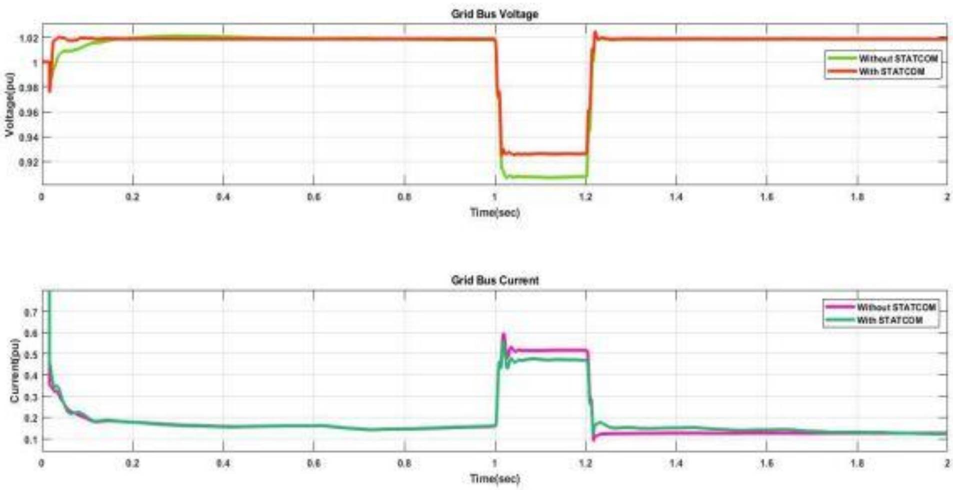

Fig.10: Voltage and current at grid bus

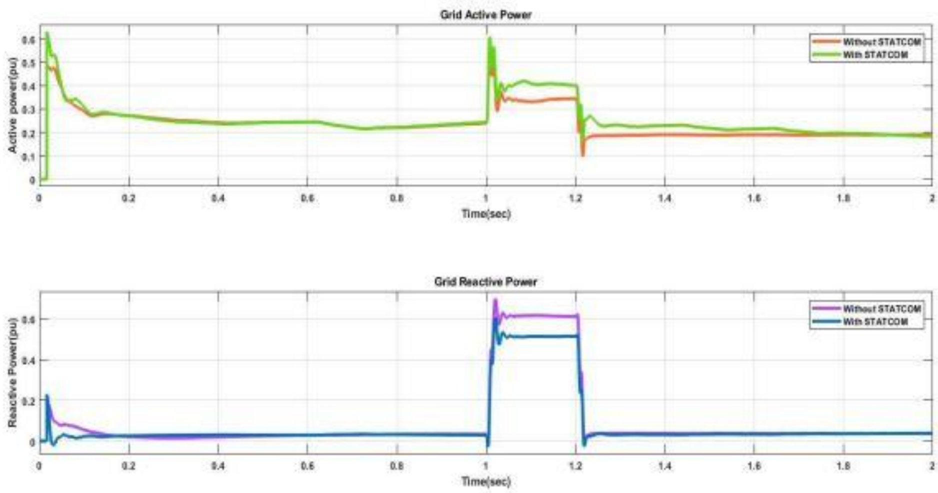

Fig.11: Active & reactive power at grid bus

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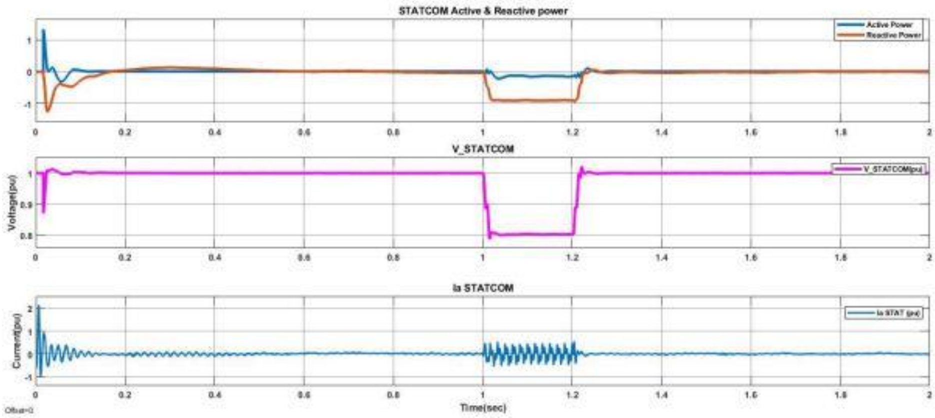

Fig.12:

Active & reactive power, voltage and current at STATCOM bus

As seen in the simulation results, the voltage at the grid bus decreases to 0.90 pu without STATCOM and 0.93 pu with STATCOM. The current waveform also improves, going from 0.47 to 0.52 pu. The usage of STATCOM also results in decreased intensity transients for Active and Reactive power. Consequently, STATCOM adoption improves dynamic performance under fault scenarios.

CONCLUSIONS

A thorough simulation model of a STATCOM, PMSG-based wind energy system & solarPV system is described in this dissertation study. Both STATCOM, PMSG-based wind farms and solar PV farms' modelling and control were researched, put into practise, and evaluated. A STATCOM-based renewable energy system is then simulated in the Simulink/MATLAB environment employing all of these models. With and without STATCOM, this model replicates the dynamics of a wind and solar farm. The advantages of employing a STATCOM are well demonstrated by the analysis and comparison of the impact of using a STATCOM in conjunction with a renewable energy farm and grid.

In the face of varying loading situations, faults, and voltage fluctuations, STATCOM is able to maintain stable grid and renewable energy farm operation. The WECS and PV system are really able to assist the grid in fault recovery thanks to its capacity to provide voltage ride through capabilities, which allows it to stay connected to the grid even during disturbances. Additionally, STATCOM can be used with different WES types to enhance dynamic performance. To improve STATCOM's performance in the distribution network, other cutting-edge controllers can be used, such as fuzzy and adaptive fuzzy controllers.

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