IMPROVEMENT OF POWER FACTOR IN RENEWABLE ENERGY SYSTEM

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ABSTRACT

Fuzzy logic (FL) controller that will manipulate an AC synchronous motor to produce reactive power to bring the entire system to the optimum operating point is presented. The FL controller performs adequately both rapid and slow changing load condition.The FL controller performance was highly satisfactory in tracking and improving the plant PF to achieve the set point. The FL controller in conjunction with a synchronous motor represents a new practical method to take advantage of Renewable Energy Sources by dynamically monitoring plant eletrical parameters and automatically bringing the system to the optimum operating point, and could some day be implemented in an industrial plant environment that may require PF improvement with a high degree of accuracy.

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CHAPTER I

INTRODUCTION

1.1 Project Background

Renewable energy sources (RES) revolution has already commenced in many countries, as evidenced by the growth of RES in response to the climate change challenge and need to enhance fuel diversity. Renewable energy currently provides more than 14% of the world's energy supply [13].

The power system is currently undergoing fundamental changes in its structure. These changes are associated not just with the deregulation issue and the use of competitive policies, but also with the use of new types of power production, new technologies, and rapidly increasing amounts of RES.

The increasing need for electrical energy, as well as limited fossil fuel reserves, and the increasing concerns with the environmental issues call for fast development in the area of RES. RES is derived from natural sources such as the sun, wind, hydropower, biomass, geothermal, and oceans. These changes imply a requirement for better control schemes in modern power systems. Recent studies have found that the renewable integration impacts on system frequency and power fluctuation are non zero and become more significant at higher sizes of penetrations.

Integration of RES into power system grids has impacts on optimum power flow, power quality, voltage and frequency control, system economics, and load dispatch [1]. The RES have different operational characteristics relative to the traditional forms of generating electric energy, and they affect the dynamic behavior in the power system in a way that might be different from conventional generators. This is due to the fact that the primary energy source in the most RES types (such as wind, sunlight, and moving water) cannot presently be controlled or stored.

Increasing awareness of power quality problems in highly sensitive industry like continuous process industry, complex machine part producing industry and large plant is an important aspect. Currently the growth of RES is very fast throughout the world. Power factor is one of the most important power quality aspects that should be reduced. A high power factor is generally desirable in a transmission system to reduce transmission losses and improve voltage regulation at the load. It is often desirable to adjust the power factor of a system to near 1.0. When reactive elements supply or absorb reactive power near the load, the apparent power is reduced. Power factor correction may be applied by an electric power transmission utility to improve the stability and efficiency of the transmission network. Individual electrical customers who are charged by their utility for low power factor may install correction equipment to reduce those costs.

Power factor (PF) correction brings the power factor of an AC power circuit closer to 1 by supplying reactive power of opposite sign, adding capacitors or inductors that act to cancel the inductive or capacitive effects of the load, respectively. For example, the inductive effect of motor loads may be offset by locally connected capacitors. If a load had a capacitive value, inductors (also known as *reactors* in this context) are connected to correct the power factor. In the electricity industry, inductors are said to *consume* reactive power and capacitors are said to *supply* it, even though the energy is just moving back and forth on each AC cycle.

The reactive elements can create voltage fluctuations and harmonic noise when switched on or off. They will supply or sink reactive power regardless of whether there is a corresponding load operating nearby, increasing the system's no-load losses. In the worst case, reactive elements can interact with the system and with each other to create resonant conditions, resulting in system instability and severe overvoltage fluctuations. As such, reactive elements cannot simply be applied without engineering analysis [14].

In electricity generation, an electric generator is a device that converts mechanical energy to electrical energy. A generator forces electric current to flow through an external circuit. The source of mechanical energy may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, compressed air, or any other source of mechanical energy. Generators provide nearly all of the power for electric power grids [15]. Generators are normally operated in the overexcited mode since the generators are the main source of reactive power for inductive load throughout the system [16]. The improvement of power factory can be achieved by controlling the generator excitation system.

Nowadays, because of simplicity, robustness, and reliability, fuzzy logic is used in almost all fields of science and technology, including solving a wide range of control problems in power system control and operation. Unlike the traditional control theorems, which are essentially based on linearized mathematical models of the controlled systems, the fuzzy control method tries to establish the controller directly based on measurements, long term experiences, and knowledge of domain experts/operators [13].

In sum, this project is to improve PF by implementing the technique of excitation of an RES synchronous generator to provide the reactive power by applying Fuzzy Logic as a tool to control the purpose system.

1.2 Problem Statement

The predominant usage of induction motors in industrial plants poses the problem of heavy inductive loading and therefore, causes poor power factor. Poor PF has been costly for both utility and industrial companies. With the utility companies being forced to deliver excess power to satisfy demand, and the industrial companies being penalized for low PF, there are emerged a number of solutions and taking advantage of renewable energy sources the poor PF issues could be tackle. To achieve the objective of this project, *MATLAB/SIMULINK* software is used to analysis the system.

1.3 Objectives and Scopes

The primary objective of this project is to formulate a paradigm that will use Fuzzy Logic as a tool to control the synchronous motor execute by Renewable Energy sources that will track and correct PF of the system. In addition, this project has various objectives, which comprise of:

1. To design a controller by simulation for the power factor improvement using generator excitation technique.

2. To analyze simulations result of the power factor correction.

1.4 Scope of Work

To complete this project, the scope are consider take into account. The limitations of this project are described as below:

1. The controllers have been design using Fuzzy Logic controller and in the defuzzificatin step the Takagi Sugeno Kang (TSK) weighted average is employed.

2. The optimum controller will be evaluating based on some criteria for I instance, the intelligible of finding the field current as the output , the faster responds (speed) and the accuracy when the system due to power factor value.

3. The analysis by simulation of this project is to determine the optimum controller can produce the power factor correction using *MATLAB/SIMULINK*.

1.5 Thesis Overview

This thesis contains 5 chapters with appendices at the end. Each of the chapters represents of enough information for better understanding due on this project.

Chapter 1

Briefly explain the scope and objective for this project to achieve and a general view of renewable energy system and power factor issues in renewable energy system.

Chapter 2

There is a brief discussion about a general overview of the measurement and correction power factor and excitation of machines. The relationship between load and real power i.e frequency is described.

Chapter 3

Represent excitation modeling by using Fuzzy Logic Controller. In this chapter, generator model, load model, governor model, turbine model are described in detail.

Chapter 4

Illustrate the simulation results and the defuzzification method.

Chapter 5

A brief conclusion, discussed and calculate the result obtain from *MATLAB Simulink* and testing.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter has assembled to summarize information of relevant on power improvement method for renewable energy system. Furthermore, this chapter are also discussing about a study on the previous research based on journals and conferences. The information that studied during research will be recorded and discussed in the following subchapters. The sources of the literature reviewed are journals, conferences and books.

2.2 Case Studies

There are several journal have been analysed which are Power Factor Improvement using Fuzzy Logic Control of an AC Synchronous Motor by Audley D. Grey, Improvement of Power Factor Voltage for Renewable Energy Systems using PLC`s New Fuzzy Module by Li Wang and Kuo- Hua Liu, A Fuzzy Logic Controller based on Power Factor Correction for LED Lighting Application by Hariprasath S and Dr Balamurugen R, Grid Connected PV`s and Wind Turbine with a Wide Range of Reactive Power Control and Active Filter Capability by E.K Hussain and Electrical Energy Conservation in Automatic Power Factor Correction and Embedded System by M. Ravindran and V. Kirubakaren.

2.2.1 Power Factor Improvement using Fuzzy Logic Control of an AC Synchronous Motor.

This research is to formulate a paradigm that will use Fuzzy Logic as a tool to control the synchronous motor that will track and correct Power Factor of a plant. in the United States, Power Factor correction is commonly done at the local (equipment) level or through the use of a large capacitor bank, but this work will address the solution using and appropriately sized AC synchronous motor to match the plant in question. Many plant use synchronous motors in different areas of operation, hence eliminating the cost of purchasingb extra hardware. The synchronous motor will provide a smooth transient and more precise correctional value compared to capacitor bank when correcting the Power Factor.

2.2.2 Improvement of Power Factor Voltage for Renewable Energy Systems using PLC`s New Fuzzy Module.

This paper presents a novel control scheme using an industrial programming logic controller (PLC) withn a new fuzzy module to enhance power factor and voltage of a hybrid wind/PV power generation system. The purposed scheme can automatically regulate both power factor and voltage of a wind induction generator under various wind speeds. From the experimental results, it shows that the purposed control scheme can effectively provide better power factor and voltage profile for the studied renewable energy system.

2.2.3 A Fuzzy Logic Controller based on Power Factor Correction for LED Lighting Application.

A Power factor Correction (PFC) topology with fuzzy logic controller(FLC) for light emitting diode(LED) lighting applications is presents in this paper. Nowadays, high brightness white LEDs become feasible in residential, industrial and commercial aplications to replace the incandescent bulbs, halogen bulbs and even compact fluorescent light (CFL) bulbs. since LED lighting represents a green technology, the issue of power factor is very important.A valley-filled circuitis combined with a single-ended primary inductance converter (SEPIC) to achieve power factor nearerto unity. The fuzzy logic controller is implemented to drive the SEPIC- PFC topology. The performance of the purposed design will be analyzed in terms of power factor using the Matlab/Simulink simulation results.

2.2.4 Grid Connected PV`s and Wind Turbine with a Wide Range of Reactive Power Control and Active Filter Capability.

This paper presents a two-stage, single-phase power converter system fed from PV and wind Turbine Energy sources, and a new control methodology for transferring the output power to the grid, leading to reduce the harmonics in the grid current, and controlled power factor. The purposed control depends on comparing the total power from the renewable energy sources with the power required to supply the non linear load, leading to a controlled distribution of power requirement from the sources. Key outcome of the paper is that excellent power factor and good harmonics reduction is obtained from the perspective of the grid, with no requirement for an intermediate battery due to inherent ability to provide leading reactive power to the grid when necessary. Simulation and experimental results are used to support the purposed control methodology.

2.2.5 Electrical Energy Conservation in Automatic Power Factor Correction and Embedded System.

This paper presents a new method for power factor correction with low cost drives. Power factor control is a major role in the improvement of power system stability. Many of the existing systems are expensive and difficult to manufacturer. Nowadays, many of the converters have no input power factor corrections circuit. The effect of power factor correction circuit is used to eliminate the harmonics present in the system. This type of power factor corrections circuit is mostly used in Switched Reluctance Motor Controller device. Fixed capacitor systems are always leading power factor under at any load conditions. This is unhealthy for installations of power systems. The proposed embedded systems drive is used to reduce the cost of the equipment and increase the efficiency of the systems. Experimental results of the purposed systems are included. It is better choice for effective cost process and energy savings.

2.3 Introduction of the Renewable Energy System

Renewable energy is generally defined as energy that comes from resources which are naturally; generation, hot/space heating, motor fuels, and rural (off-grid) energy replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas services.

About 16% of global final energy consumption presently comes from renewable resources, with 10% of all energy from traditional biomass, mainly used for heating, and 3.4% from hydroelectricity. New renewable (small hydro, modern biomass, wind, solar, geothermal, and bio fuel) account for another 3% and are growing rapidly. At the national level, at least 30 nations around the world already have renewable energy contributing more than 20% of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond. Wind power, for example, is growing at the rate of 30% annually, with a worldwide installed capacity of 282,482 megawatts (MW) at the end of 2012 [17].

Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits. In international public opinion surveys there is strong support for promoting renewable sources such as solar power and wind power.

While many renewable energy projects are large-scale, renewable technologies are also suited to rural and remote areas and developing countries, where energy is often crucial in human development United Nations' Secretary-General Ban Ki-moon has said that renewable energy has the ability to lift the poorest nations to new levels of prosperity

2.3.1 Wind Power

Airflows can be used to run wind turbines. Modern utility-scale wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5–3 MW have become the most common for commercial use; the power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases dramatically up to the maximum output for the particular turbine. Areas where winds are stronger and more constant, such as offshore and high altitude sites, are preferred locations for wind farms. Typical capacity factors are 20-40%, with values at the upper end of the range in particularly favorable sites.

Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand, assuming all practical barriers needed were overcome. This would require wind turbines to be installed over large areas, particularly in areas of higher wind resources, such as offshore. As offshore wind speeds average ~90% greater than that of land, so offshore resources can contribute substantially more energy than land stationed turbines.

2.3.2 Hydro Energy

Energy in water can be harnessed and used. Since water is about 800 times denser than air, even a slow flowing stream of water, or moderate sea swell, can yield considerable amounts of energy. There are many forms of water energy:

- Hydroelectric energy is a term usually reserved for large-scale hydroelectric dams. The largest of which is the Three Gorges Dam in China and a smaller example is the Akosombo Dam in Ghana.
- Micro hydro systems are hydroelectric power installations that typically produce up to 100 kW of power. They are often used in water rich areas as a remote-area power supply (RAPS). Run-of-the-river hydroelectricity systems derive kinetic energy from rivers and oceans without the creation of a large reservoir.
- Hydropower is produced in 150 countries, with the Asia-Pacific region generating 32 percent of global hydropower in 2010. China is the largest hydroelectricity producer, with 721 terawatt-hours of production in 2010, representing around 17 percent of domestic electricity use. There are now three hydroelectricity plants larger than 10 GW: the Three Gorges Dam in China, Itaipu Dam across the Brazil/Paraguay border, and Guri Dam in Venezuela.

2.3.3 Solar Energy

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever-evolving technologies such as solar heating, solar photovoltaic, solar thermal electricity, solar architecture and artificial photosynthesis.

Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

Solar power is the conversion of sunlight into electricity, either directly using photovoltaic (PV), or indirectly using concentrated solar power (CSP). Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Commercial concentrated solar power plants were first developed in the 1980s. Photovoltaic convert light into electric current using the photoelectric effect. Photovoltaic are an important and relatively inexpensive source of electrical energy where grid power is inconvenient, unreasonably expensive to connect, or simply unavailable.

However, as the cost of solar electricity is falling, solar power is also increasingly being used even in grid-connected situations as a way to feed low-carbon energy into the grid.

2.3.4 Biomass

Biomass is biological material derived from living, or recently living organisms. It most often refers to plants or plant-derived materials which are specifically called lignocelluloses biomass. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of bio fuel. Conversion of biomass to bio fuel can be achieved by different methods which are broadly classified into: *thermal*, *chemical*, and *biochemical* methods.

Wood remains the largest biomass energy source today; examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants including miscanthus, switch grass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo, and a variety of tree species, ranging from eucalyptus to oil palm (palm oil).

2.3.5 Biofuel

Biofuel include a wide range of fuels which are derived from biomass. The term covers solid bio fuels, liquid biofuels, and gaseous bio fuels. Liquid biofuel include bio alcohols, such as bio ethanol, and oils, such as biodiesel. Gaseous biofuel include biogas, landfill gas and synthetic gas.

Bioethanol is an alcohol made by fermenting the sugar components of plant materials and it is made mostly from sugar and starch crops. These include maize, sugar cane and, more recently, sweet sorghum.

With advanced technology being developed, cellulosic biomass, such as trees and grasses, are also used as feedstock for ethanol production. Ethanol can be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bio ethanol is widely used in the USA and in Brazil. The energy costs for producing bio-ethanol are almost equal to, the energy yields from bioethanol. However, according to the European Environment Agency, bio fuels do not address global warming concerns.

Biodiesel is made from vegetable oils, animal fats or recycled greases. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe. Biofuel provided 2.7% of the world's transport fuel in 2010.

2.3.6 Geothermal

Geothermal energy is from thermal energy generated and stored in the Earth. Thermal energy is the energy that determines the temperature of matter. Earth's geothermal energy originates from the original formation of the planet (20%) and from radioactive decay of minerals (80%). The geothermal gradient, which is the difference in temperature between the core of the planet and its surface, drives a continuous conduction of thermal energy in the form of heat from the core to the surface. The adjective *geothermal* originates from the Greek roots *geo*, meaning earth, and *thermos*, meaning heat.

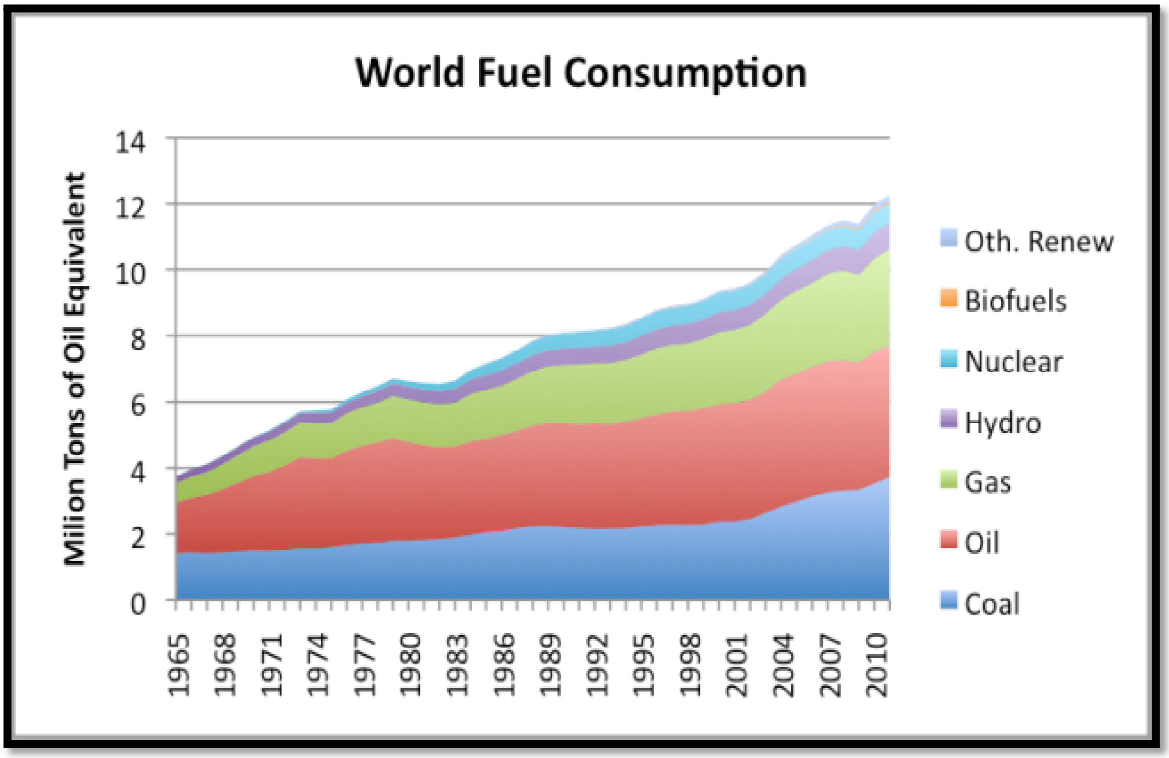

Figure 1 : World fuel consumption from year 1965-2010

2.4 Smart Microgrid

Global warming and the environmental impact of coal-based power generation are changing the design and operation of the power grid. The industry is experiencing a gradual transformation that will have long term effect on the development of the infrastructure for generating, transmitting, and distributing power. This fundamental change will incorporate renewable green enrgy sources in new distributed generation program based on increased levels of distributed monitoring, automation, and control as well as new sensors. Power grid control will rely on data and information collected on each microgrid for decentralized control. In return, the microgrids and interconnected power grid will be able to operate as a more reliable, efficient, and secure energy supplier.

A smart grid is a modernized electrical grid that uses analog or digital information and communications technology to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.[2]

Smart grid policy is organized in Europe as Smart Grid European Technology Platform. Policy in the United States is described in 42 U.S.C. ch. 152, subch. IX § 17381.Roll-out of smart grid technology also implies a fundamental re-engineering of the electricity services industry, although typical usage of the term is focused on the technical infrastructure.

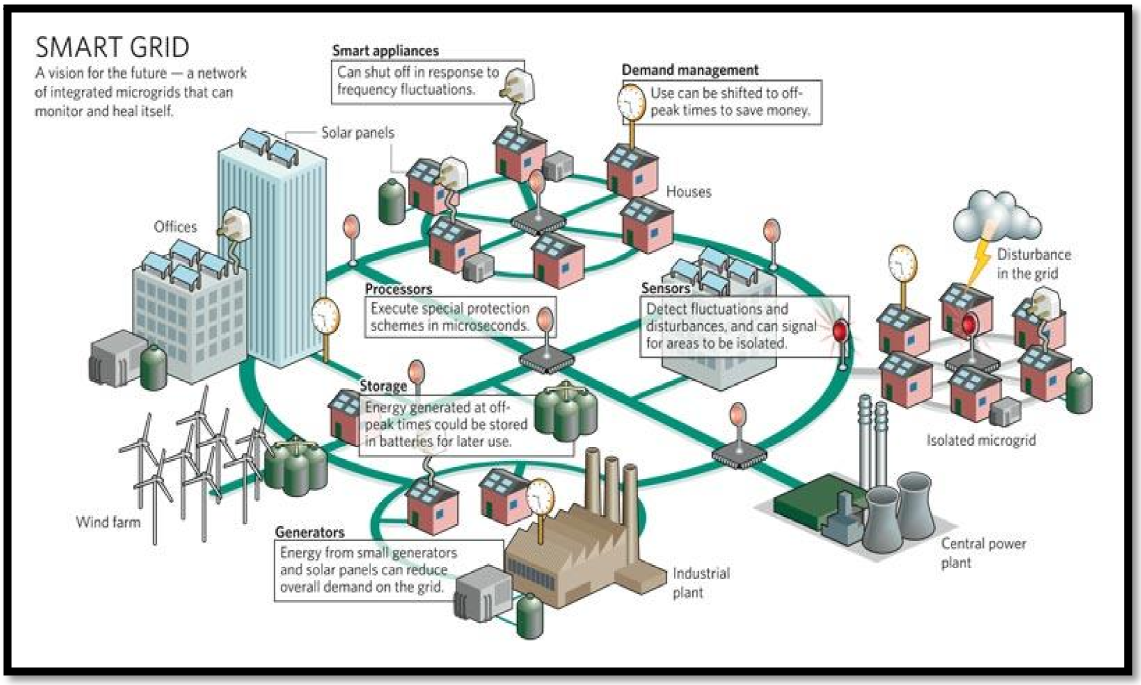

Figure 2 : Smart Grid concept

2.4.1 Renewable Energy : Analysis of Power Factor Problems

For RE generation in distribution grid, photovoltaic and wind power are already in service at many installations. Basically, these types of energy generation are very favorable for the environment but do have several issues regarding power quality. Wind energy continues to be the first contributor to such development because of the enormous potential that exists and which could be extracted from such renewable source, and that that is also harnessed at a reasonable cost per kWhr, in comparison to other possible renewable sources. This is confirmed by the statistics given by WEA (Wind Energy Association) that suggest the total power capacity that has been produced from wind farms reached 152GW in 2009 [6]. As for solar, its resources has no limitation and becomes one of the most important electrical energy in many countries, and even becomes the most important electrical energy in some European country, such as Germany and Spain. The solar photovoltaic market in the US could grow more than 30% per year over the next 20 years, from 340 MW of installed capacity to 9600MW [8].

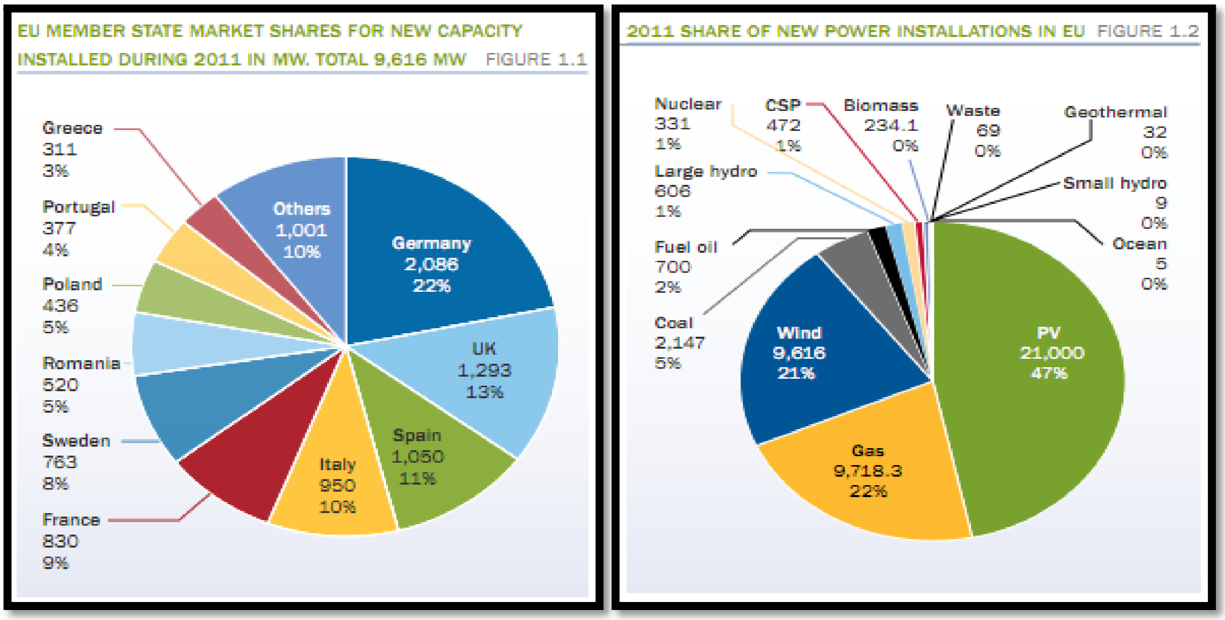

Figure 3: 70% of New EU Power from Renewable Energy in 2011 (47% Solar, 21% Wind)

Kamal Al-Haddad [5] presents a comprehensive review of power quality challenges under high penetration rate, fluctuation and imprecise prediction of incoming energy provided from different types of renewable sources. The predicted power fluctuation are mostly coming from wind energy generators that are gaining much importance nowadays. Therefore, fast increase in penetration rate of such renewable , pollution-free, sources into the network would result in a serious problem threatening the reliability of the network and would have to be solved. Generated active-and reactive power should be used to support voltage stability and faults. Voltage stabilization and reactive power control are mandatory especially in transient mode where network stability requirement for reactive power is more critical than carrying active power; because in wind turbine application, reactive power consumed during their normal operating condition and this contribute to low power factor.

As stated in [7] wind powered generators are self excited induction generators. The main characteristic of induction generators is the considerable reactive power absorb during their operation. This reactive power problem may create dynamic voltage instability in the system. There are two major types of wind generators, which widely used in wind farms. The first one is the squirrel cage induction generator while the second one is doubly fed induction generator. In this, squirrel cage induction generator is used due to the low cost, low maintenance rate and possible utilization under wind gusting condition. The required reactive power of induction generator c n be supplied by the grid or self capacitor bank in parallel with the generator stator terminal.

Along with worldwide demands for constantly growing electric energy, there has been a great interest in exploring photovoltaic (PV) resource. Research in [9] state that PV inverter is the most important part for energy conversion. Regulation of VDE-AR-N 4105[9-7] requires the capability of the inverters to feed in the displacement power factors up to 0.95 lagging/leading from apparent plant power of 3.68kVA. If the plant power exceed 13.8kVA, even displacement power factor up to 0.9 must be supported.

Meanwhile study in [10] propose that high penetration levels of distributed PV generation on an electrical distribution circuit may degrade power quality due to voltage sags and swells caused by rapidly varying PV generation during cloud transient coupled with the slow response of existing utility compensation and regulation equipment. Fast reacting, VAR-capable PV inverters may provide the necessary reactive power injection or consumption to maintain voltage regulation under difficult transient condition. As side benefit, the control reactive power injection at each PV inverters provide a new tool for distribution utilities to minimize thermal losses in circuit. A local control scheme that dispatches reactive power from each PV inverter based on local instantaneous measurements of the real and reactive components of the consumed power and the real and power generated by PVs.

Maryam H. N [11] recommend an idea controlling the PV inverter to not to inject specific current but to control the magnitude of voltage at point of common coupling and make it stable. For voltage controlling process, it is necessary to have the possibility of reactive power injection, supposing inductive coupling between network and inverter. Means that the reference values for voltage are calculated due to amount of reactive power is needed to save the power factor.

Li Wang and Kuo-Hua Liu [1] propose a control scheme using an industrial programmable logic controller (PLC) with a new fuzzy module to enhance power factor and voltage of a hybrid wind/PV power generation system. The propose scheme can automatically regulate both power factor and voltage of a wind induction generator under various wind speeds. The fuzzy theory inferences with number to get explicit conclusions and completes the power factor and voltage control of a renewable energy system. The PLC has the following advantages over other control schemes ; specific design for sequential logical decisions, computer implementation of Boolean logic is feasible, relatively simple microprocessor based devices, low cost & good flexibility and restricted to simple control algorithms involving logical decisions.

Apparently in [11] among the power quality problems (sags, swells, harmonics) reactive power uncompensation is the most severe disturbance. Reactive power consumption in a wind farm is mainly due to the use of induction generators of energy conversion. The basic principle of induction generators is that they consume reactive power (to set up the excitation/magnetic field) in order to generate real power. The magnetizing currents drawn by step up transformers also contribute to reactive power consumption to some extent. Reactive power (vArs) is required to maintain the voltage to deliver active power (watts) through transmission lines. Motor loads and other loads require reactive power to convert the flow of electrons into useful work. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines. This reactive power consumption leads to increased transmission and distribution losses, poor voltage profile (voltage stability reduced) over loading of transmission and distribution equipment and blocked capacity and over loading and reduction in life of transmission and distribution equipment.

2.5 Power factor

In electrical engineering, the power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit, and is adimensionless number between -1 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power. A negative power factor occurs when the device which is normally the load generates power which then flows back towards the device which is normally considered the generator.

Power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts). This increases generation and transmission costs. For example, if the load power factor were as low as 0.7, the apparent power would be 1.4 times the real power used by the load. Line current in the circuit would also be 1.4 times the current required at 1.0 power factor, so the losses in the circuit would be doubled (since they are proportional to the square of the current). Alternatively all components of the system such as generators, conductors, transformers, and switchgear would be increased in size (and cost) to carry the extra current.

Utilities typically charge additional costs to commercial customers who have a power factor below some limit, which is typically 0.9 to 0.95. Engineers are often interested in the power factor of a load as one of the factors that affect the efficiency of power transmission.

With the rising cost of energy and concerns over the efficient delivery of power, active PFC has become more common in consumer electronics. Current Energy Star guidelines for computers call for a power factor of ≥ 0.9 at 100% of rated output in the PC's power supply. According to a white paper authored by Intel and the U.S. Environmental Protection Agency, PCs with internal power supplies will require the use of active power factor correction to meet the ENERGY STAR 5.0 Program Requirements for Computers. In Europe, IEC 555-2 requires power factor correction be incorporated into consumer products [8].

2.5.1 Power factor measurement

Loads such as induction motors draw significant reactive power from the supply system, and a poor overall power factor may result. The flow of reactive power increases the voltage-drops through series reactances such as transformers and reactors, it uses up some of the current carrying capacity of power system plant and it increases the resistive losses in the power system.

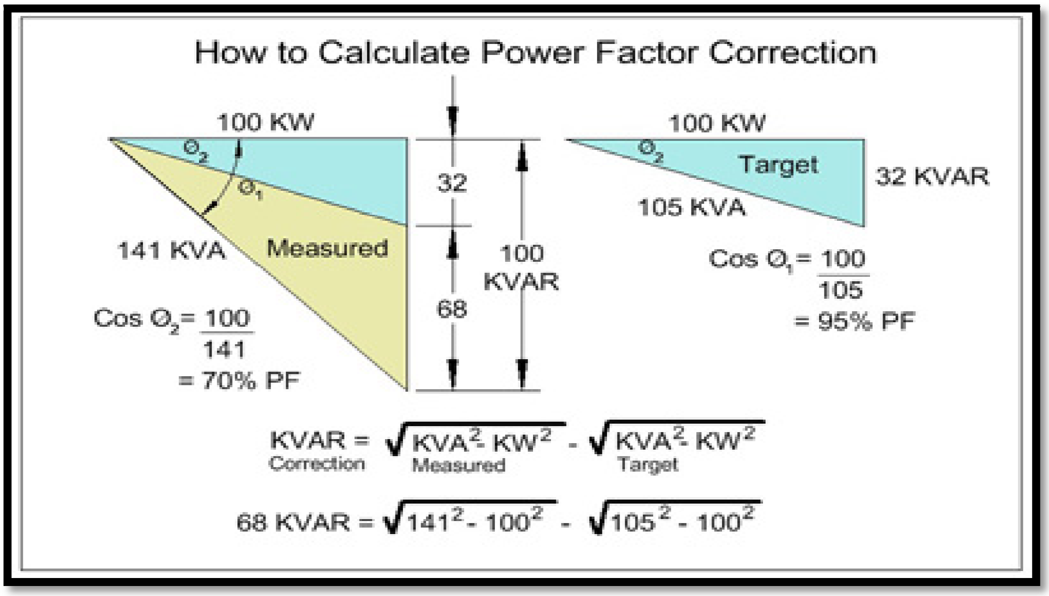

Figure 4 : Power Factor correction

2.5.2 Controller correction technique

There are number of known techniques used in improving Power Factor, namely:

- Fixed shunt capacitor banks.
- Correction circuits at the equipment level (buck-boost).
- Alternating current (AC) synchronous motors.

2.5.3 Reactive power and voltage control

The generation excitation system maintains generator voltage and controls the reactive power flow. The generator excitation of older systems may be provided through slip rings and brushes by means of dc generators mounted on the same shaft as the rotor of the synchronous machine [14]. However, modern excitation systems usually use ac generators with rotating rectifiers, and are known as *brushless excitation.*

A change in the real power demand affects essentially the frequency, whereas a change in the reactive power affects mainly the voltage magnitude. The interaction between voltage and frequency controls is generally weak enough to justify their analysis separately.

The sources of reactive power are generators, capacitors and reactors. The generator reactive powers are controlled by field excitation. Other supplementary methods of improving the voltage profile on electric transmission systems are transformers load-tap changers, switched capacitors, step-voltage regulators, and static Var control equipment.

2.5.3 Basic generator control loops

In an interconnected power system, load frequency controls (LFC) and automatic voltage regulator (AVR) equipment are installed for each generator. Figure 5 represents the schematic diagram of the load frequency control (LFC) loop and the automatic voltage regulator (AVR) loop. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependant on changes in rotor angle δ and thus, the frequency. The reactive power is mainly dependant on the voltage magnitude (i.e on the generator excitation). The excitation system time constant is much smaller than prime mover time constant and its transient decay much faster and does not affect the LFC dynamic. Thus, the cross-coupling between the LFC loop and the AVR loop is negligible, and the load frequency and excitation voltage control are analyzed independently.

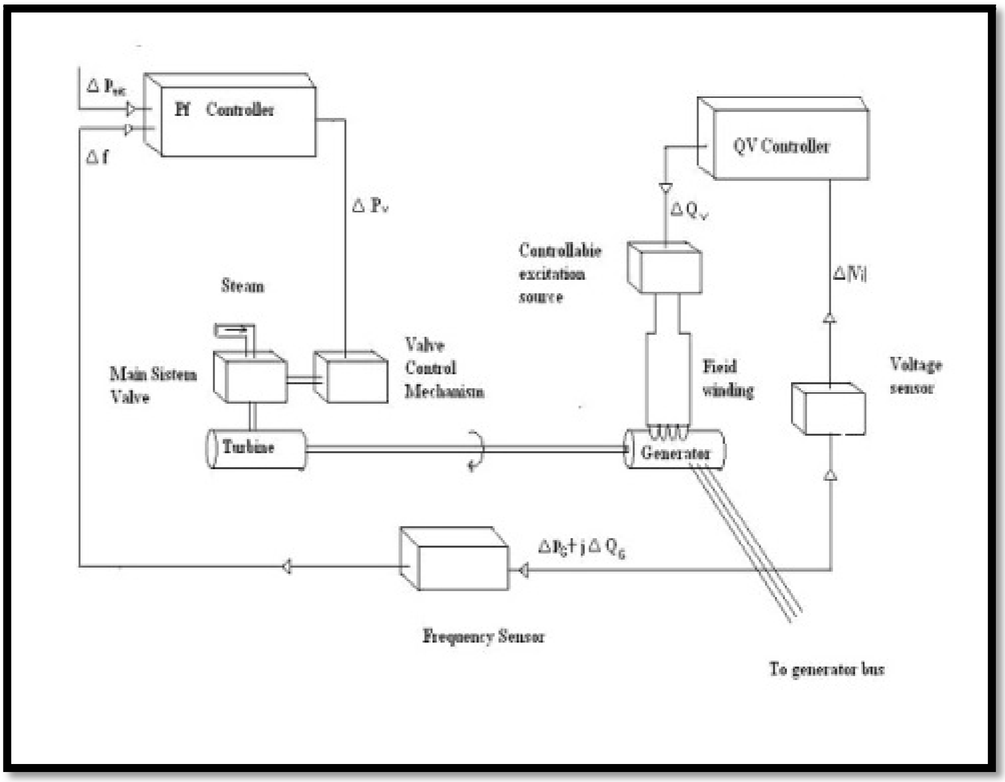

Figure 5 : Schematic diagram of the load frequency control (LFC) loop and the automatic voltage regulator (AVR) loop.

2.5.4 Load frequency control

The operation objectives of the LFC are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie line interchange schedules. The change in frequency and tie-line real power are sensed, which is a measure of the change in rotor angle δ, i.e, the error Δδ to be corrected. The error signal, i.e, Δf and ΔP_{tie}, are implified, mixed and transformed into real power command signal ΔP_V, which is sent to the prime mover to call for increment in the torque.

The prime mover, therefore, brings change in the change in the generator output by an amount ΔPg which will change the values of Δf and ΔP_{tie} within the specified tolerance.

The first step in the analysis and design of a control system is mathematical modelling of the system. The two most common methods are the transfer function method and the state variable approach. The state variable approach can be applied to portray linear as well as non linear systems. in order to use the transfer function and linear state equations, the system must be linearized. Proper assumptions and approximations are made to linearize the mathematical equations describing the system, and a transfer function model is obtained for the following components.

2.5.4.1 Generator model

Applying the swing equation of a synchronous machine given by 2.1 to small perturbation, we have

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta Pm - \Delta P_e \quad (2.1)$$

or in terms of small deviation in speed.

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H} \quad (\Delta Pm - \Delta P_e) \qquad (2.2)$$

with speed expressed in per unit, without explicit per unit notation, we have

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H} \quad (\Delta Pm - \Delta P_e) \qquad (2.3)$$

taking Laplace transform (2.3), we obtain

$$\Delta\Omega(s) = \frac{1}{2H}\,[\Delta Pm(s) - \Delta P_e(s)] \qquad (2.4)$$

The above relation is shown in block diagram form in Figure 6:

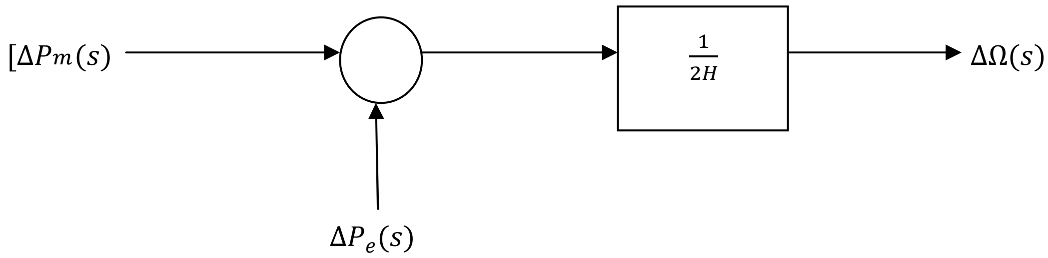

Figure 6: Generator block diagram

2.5.4.2 Load model

The load on a power system consists of a variety of electrical devices. For resistive loads, such as lighting and heating loads, the electrical power is independents of frequency. Motor loads are sensitive to changes in frequency. How sensitive it is to frequency depends on the composite of the speed load characteristics of all the driven devices. The speed load characteristics of a composite load is approximated by

$$\Delta P_e = \Delta P_L - D\Delta\omega \qquad (2.5)$$

where ΔP_L is the nonfrequency-sensitive load change, and $D\Delta\omega$ is the frequency-sensitive load change. D is expressed as percent change in load divided by percent change in frequency. For example, if load is changed by 1.6 percent for a 1 percent change in frequency, the D=1.6. Including the load model in the generator block diagram, reslts in the block diagram of Figure

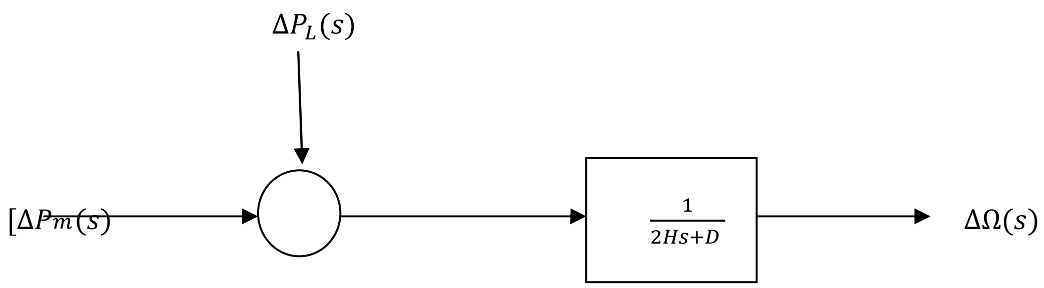

Figure 7 : Generator and load block diagram.

2.5.4.3 Prime mover model

The source of mechanical power, commonly known as the prime mover, may be hydraulic turbines at waterfalls, steam turbines whose energy comes from the burning of coal, gas, nuclear fuel, and gas turbines. The model for the turbine relates changes in mechanical power output ΔP_m to changes in steam valve position ΔP_v. Different types of turbines vary widely in characterstics. The simplest prime mover model for the nonreheat steam turbine can be approximated with a single time constant τ_T , resulting in the following transfer function

$$G_{T(s)} = \frac{\Delta P_{m(s)}}{\Delta P_{V(s)}} = \frac{1}{1+\tau_{T\,s}} \text{Type equation here.}$$

The block diagram for a simple turbine is shown in Figure 8:

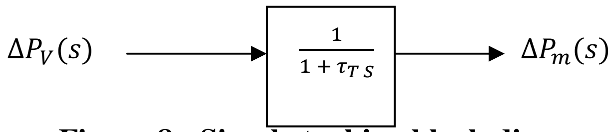

Figure 8 : Simple turbine block diagram

2.5.4.4 Governer model

When the generator electrical load is suddenly increased, the electrical power exceeds the mechanical power input. The power deficiency is supplied by the konetic energy stored in the rotating system. The reduction in kinetic energy causes the turbine speed and, consequently, the generator frequency to fall. The change in speed is sensed by the turbine governer which acts to adjust the turbine input valve to change the mechanical power output to bring the speed to a new steady state. The earliest governer were Watt governers which sense the speed by means of rotating flyballs and provides mechanical motion in response to speed changes. However, most modern governers use electronic means to sense speed changes. Figure shows:

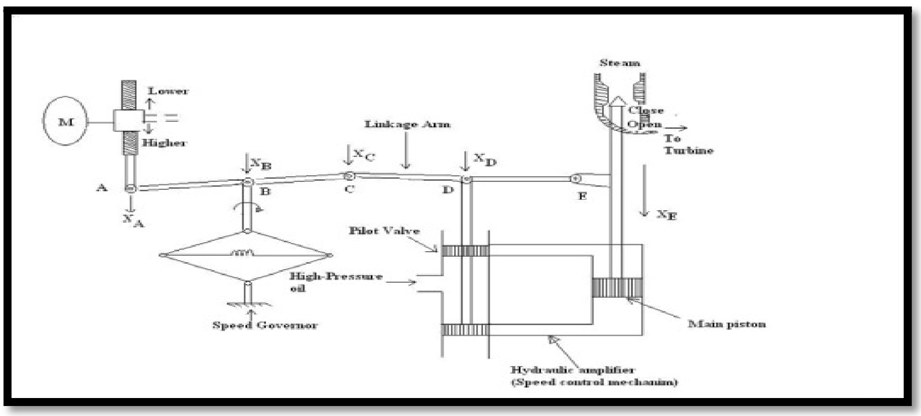

Figure 9 : Speed governing system

- Speed Governor: The essential parts are centrifugal fly balls driven directly or through gearing by the turbine shaft. The mechanism provides upward and downward vertical movement proportional to the change in speed.
- Linkage Mechanism: These are links for transforming the fly balls movement to the turbine valve through a hydraulic amplifier and providing a feedback from the turbine valve movement.
- Hydraulic Amplifier: Very linkage mechanical forces are needed to operate the system valve. Therefore, the governor movements are transformed into high power factor via several stages hydraulic amplifiers.
- Speed Changer: The speed changer consists of servomotor that can be operated manually or automatically for scheduling load nominal frequency. By adjusting this set point, a desired load dispatch can be scheduled at nominal frequency.

2.6 Fuzzy Logic Controller

Nowadays, because of simplicity, robustness, and reliability, fuzzy logic is used in almost all fields of science and technology, including solving a wide range of control problems in power system control and operation. Unlike the traditional control theorems, which are essentially based on linearized mathematical models of the controlled systems, the fuzzy control methodology tries to establish the controller directly based on the measurements, long term experiences, and knowledge of domain experts/operators.[13]

Generally, a controller design based on fuzzy logic for a dynamical system involves the following four steps:

1. Understanding of the system dynamic behaviour and characteristics. Define the states and input/output control variables and their variation ranges.
2. Indentify appropriate fuzzy sets and membership functions. Create the degree of fuzzy membership function for each input/output variable and complete fuzzification.
3. Define a suitable inference engine. Construct the fuzzy rule base, using the control rules that the system will operate under. Decide how the action will be executed by assigning strengths to the rules.
4. Determine defuzzification method. Combine the rules and defuzzify the output.

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