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# Power Quality Improvement of Hybrid Wind, Solar & Diesel Generator Energy Systems using Fuzzy Logic and Hysteresis Loss Current Control of D-Statcom, with Power System Planning

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## Abstract

Application with renewable energy sources such as solar cell array, wind turbines and diesel generator have increased significantly during the past decade. To obtain the clean energy, the hybrid solar–wind power generation is used. Consumers prefer quality of power from suppliers. The quality of power can be measured by using parameters such as voltage sag, harmonic and power factor. To obtain the quality of power different topologies are used. Due to diesel generator the harmonic disturbance in the transmission line will be increased. By implementing the D-STATCOM harmonics compensation technique, the harmonics are reduced. The several different aspects of the PV systems and the most widely addressed technical scope is on developing various PV models integrated with the maximum power-point tracking (MPPT) function. Maximum Power Point Tracking (MPPT) control is attained by intellectual controller. Intellectual controller is controlled by optimal utilization control. Wind power, solar power, diesel engine and an intellectual controller are used in existing method. The MPPT technique has a lot of limitation, so PQ theory with hysteresis loss current control algorithm is introduced to overcome this problem. In this work, D-STATCOM voltage source inverter (PWM-VSI) is connected between diesel generator and load which compensates harmonics in the AC grid. Implementation of the harmonics compensation by using D-STATCOM in the hybrid distribution system is used to attain the voltage stability. Here, Fuzzy logic algorithm with hysteresis loss current control method is used for harmonic reduction using D-STATCOM. The objective of this work is to show that with an adequate control, the converter not only can transfer the DC from hybrid solar wind energy system, but also can improve the power factor and quality power of electrical system. Whenever a disturbance occurs on load side, this disturbance can be minimized using open loop and closed loop control systems. Computer simulation results are presented to verify the performance of the proposed PWM-VSI by using MATLAB software

**Keywords**: Diesel Generator, D-STATCOM, MPPT, Power Quality, Solar Panel, Wind Generating System (WGS)..

## Introduction

Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Amongst the above mentioned sources of energy there has been a lot of development in the technology for harnessing energy from the wind. Wind is the motion of air masses produced by the irregular heating of the earth's surface by sun. These differences consequently create forces that push air masses around for balancing the global temperature or, on a much smaller scale, the temperature between land and sea or between mountains. Wind energy is not a constant source of energy[4].It varies continuously and gives energy in sudden bursts.

Recently, wind power generation has attracted special interest, and many wind power stations are in service throughout the world. In wind power stations, induction machines are often used as generators, but the development of new permanent magnet generators, the improvement of the AC-DC-AC conversion and its advantages for output power quality make other solutions possible [8].A recent solution is to use a permanent magnet synchronous generator with variable speed and a conversion stage, which is studied in this paper. A STATCOM or Static Synchronous Compensator is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-

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source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation [2].

There are a number of other uses for STATCOM devices including, wind energy voltage stabilization, and harmonic filtering. However, the most common use is for stability. In this paper complete wind farm is modeled with PWM based STATCOM converter to stabilize grid connected synchronous wind generator system[2].A theoretical and simulation study by matlab software of wind turbine generation is analyzed by this paper.

## Photo Voltaic Systems

A photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell.

Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and dc motors. [6] A photovoltaic cell is basically a semiconductor diode whose *p*–*n* junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

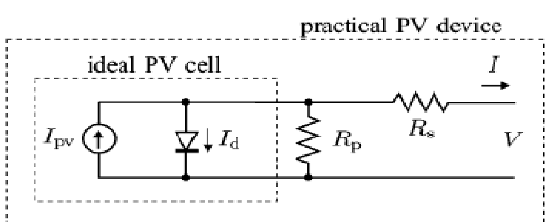


**Fig.1.Equivalent Circuit of a PV Device including the series and parallel Resistances.**

The equivalent circuit of PV cell is shown in Fig. 1. In the above diagram the PV cell is represented by a current source in parallel with diode. Rs and Rp represent series and parallel resistance respectively. The output current and voltage from PV cell are represented by I and V.

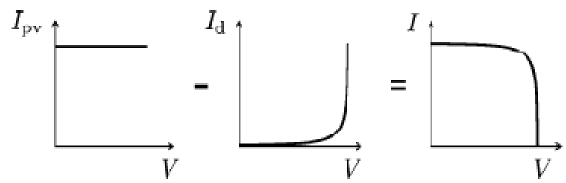


**Fig. 2. V-I Characteristic of PV Cell**

The I-V Characteristics of PV cell [7] is shown in Fig.2.

The net cell current I is composed of the light-generated
current Ipv and the diode current Id

$$I = Ipv - Id \qquad (1)$$

where

Id = Io exp(qV⁄akT)

Io = leakage current of the diode
q= electron charge
k = Boltzmann constant
T= temperature of pn junction
a= diode ideality constant

The basic equation (1) of the PV cell does not represent the
*I-V* characteristic of a practical PV array. Practical arrays are composed of several connected PV cells and the observation of the characteristic at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

$$I = Ipv - [\exp V + RsIVta - 1] - V + RsI/R\,p \qquad (2)$$

where

$$Vt = NskT/q$$

is the thermal voltage of the array with Ns cells connected in series. Cells connected in series provide greater output voltages. The I-V characteristic of a practical PV cell with maximum power point (MPP), Short circuit current (Isc) and Open circuit voltage (Voc) is shown in Fig.3.The MPP represents the point at which maximum power is obtained.

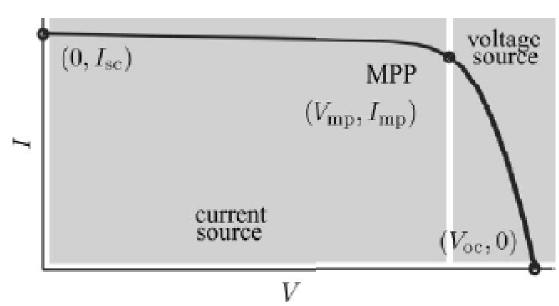


**Fig. 3. I-V Characteristic of Practical PV Module**

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Vmp and Imp are voltage and current at MPP respectively. The output from PV cell is not the same throughout the day, it varies with varying temperature and insulation (amount of radiation).Hence with varying temperature and insulation maximum power should be tracked so as to achieve the efficient operation of PV system.

## Statcom Overview

The STATCOM is shunt-connected reactive-power compensation device that is capable of generating and or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system[2].It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed

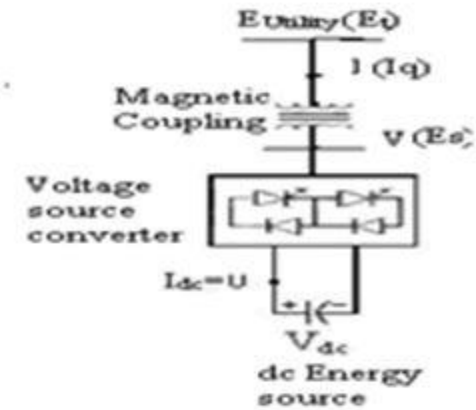


**Fig.4.Single Line STATCOM Power Circuit**

from an energy source or energy- storage device at its input terminals[6] as shown in fig.4.Specifically, the STATCOM considered as a voltage source converter that, from a given input of dc voltage produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor. The VSC has the same rated-current capability when it operates with the Capacitive- or inductive-reactive current. Therefore, a VSC having certain MVA rating gives the STATCOM twice the dynamic range in MVAR (this also contributes to a compact design)[6]. A dc capacitor bank is used to support (stabilize) the controlled dc voltage needed for the operation of the VSC. The reactive power of a STATCOM is produced by means of power-electronic equipment of the voltage-source-converter type. A number of VSCs are combined in a multi-pulse connection to form the STATCOM[10]. In the steady state, the VSCs operate with fundamental-frequency switching to minimize converter losses. However, during transient conditions caused by line faults, a pulse width-modulated (PWM) mode is used to prevent the fault current from entering the VSCs. In this way, the STATCOM is able to withstand transients on the ac side without blocking. A single-line STATCOM power circuit is shown in Fig.4 where a VSC is connected to a utility bus through magnetic coupling.

## Principle of D-Statcom

A D-STATCOM is a controlled reactive source, which includes a Voltage Source Converter and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of D-STATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.

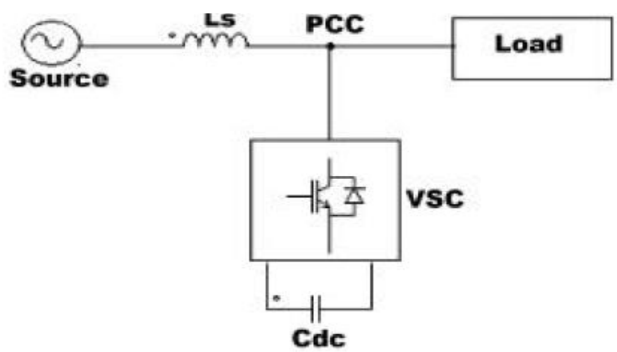


**Fig. 5 Circuit Diagram of D-STATCOM**

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Fig.5.The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages;

whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a D-STATCOM for power factor correction and harmonic mitigation.

## Fuzzy Logic Controller

The Fuzzy Logic Controller (FLC) is used as controller in the proposed model. The Fuzzy Logic tool was introduced in 1965, also by Lotfi Zadeh, and is a mathematical tool for dealing with uncertainty. It offers to a soft computing partnership ‗the important concept of computing with words,,. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic constructs such as „many" „low" „medium" „often" „few". In general, the fuzzy logic provides an inference structure that enables appropriate human reasoning capabilities. In fuzzy logic, basic control is determined by a set of linguistic rules which are determined by the system. Since numerical variables are converted into linguistic variables, mathematical modeling of the system is not required. The fuzzy logic control is being proposed for controlling the inverter action. FLC is a new addition to control theory and it incorporates a simple, rule based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically

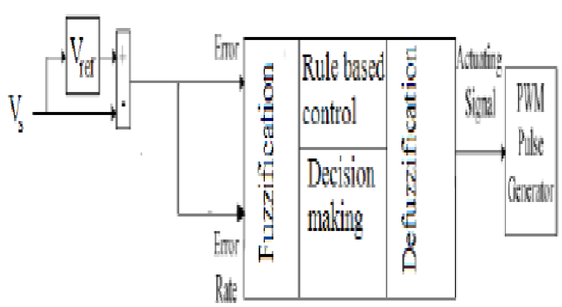


**Fig. 6: Block diagram of proposed control system.**

*A. Error Calculation*

The error is calculated from the difference between supply voltage data and the reference voltage data. The error rate is the rate of change of error.

*B. Fuzzification*

Fuzzification is an important concept in the fuzzy logic theory. Fuzzification is the process where the crisp quantities are converted to fuzzy. Thus Fuzzification process may involve assigning membership values for the given crisp quantities. This unit transforms the non-fuzzy (numeric) input variable measurements into the fuzzy set (linguistic) variable that is a clearly defined boundary, without a crisp (answer). In this simulation study, the error and error rate are defined by linguistic variables such as negative big (NB), negative medium (NM), negative small (NM), zero (Z), positive small (PS), positive medium (PM) and positive big (PB) characterized by membership functions given in Fig. 7.

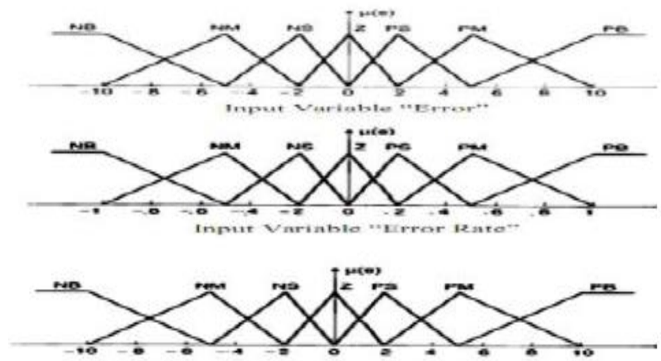

**Fig.7. Memembership function for input and output**

*C. Decision Making*

Fuzzy process is realized by Mamdani method. Mamdani inference method has been used because it can easily obtain the relationship between its inputs and output [11]. The set of rules for fuzzy controller are represented in Table II. There are 49 rules for fuzzy controller. The output membership function for each rule is given by the Min (minimum) operator. The Max operator is used to get the combined fuzzy output from the set of outputs of Min operator .The output is produced by the fuzzy sets and fuzzy logic operations by evaluating all the rules. A simple if-then rule is defined as follows: If error is Z and error rate is Z then output is Z.

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Table I

| Ce\e | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NM | NM | NS | Z |
| NM | NB | NB | NM | NM | NS | Z | PS |
| NS | NB | NM | NM | NS | Z | PS | PM |
| Z | NM | NM | NS | Z | PS | PM | PM |
| PS | NM | NS | Z | PS | PM | PM | PB |
| PM | NS | Z | PS | PM | PM | PB | PB |
| PB | Z | PS | PM | PM | PB | PB | PB |

## D-Statcom Applications

D-STATCOM (Distribution Static Compensator) is a shunt device used in distribution systems. D-STATCOM is a shunt device used in correcting the Power Factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network. D-STATCOM is used for Grid Connected Power System, for Voltage Fluctuation, for Wind Power Smoothening and Hydrogen Generation etc. This work D-STATCOM is used for harmonic reduction in Power Quality Improvement. Relevant solutions which applied now-a-days to improve Power Quality of electric network according to the five aspects of Power Quality – Harmonics, Fluctuation and Flick of Voltage, Voltage Deviation, Unbalance of 3 Phase Voltage, Voltage Deviation, Unbalance of 3 Phase Voltage and Current Frequency Deviation.

## System Modeling

*A.Hybrid System Simulation Model*

The overall simulation diagram of the proposed D-STATCOM with PQ theory with hysteresis loss current control method is shown in Fig.8.

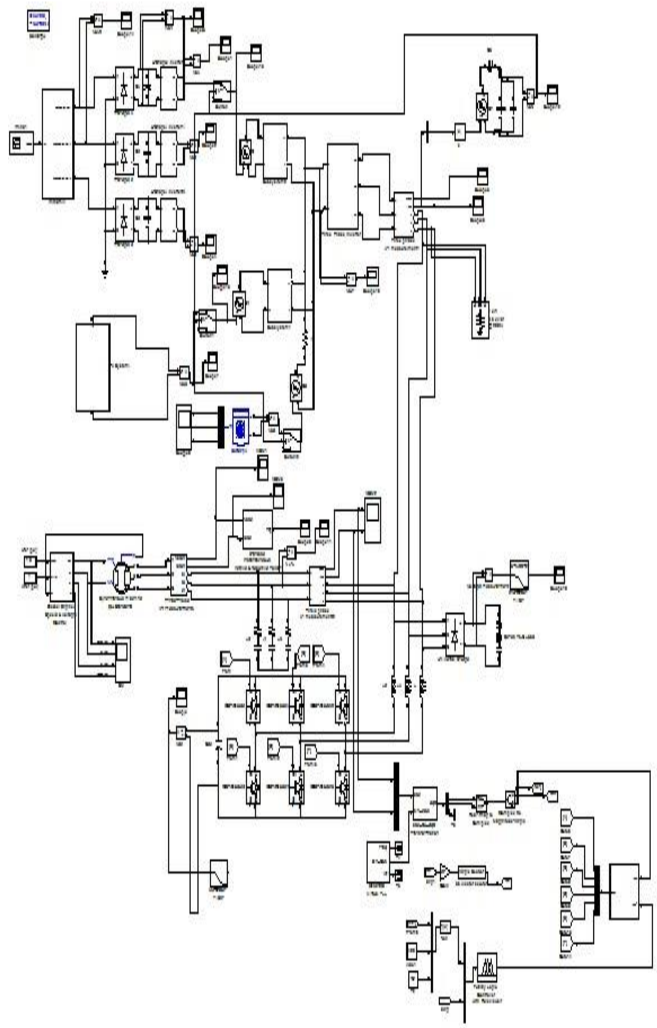

**Fig.8. Overall Simulation Block Diagram**

In this Simulink mode system contains three sources as wind, solar and diesel generator are shown Fig. 8.These three sources of supply is connected with the AC load and both loads are connected in parallel with the help of grid. In this work, D-STATCOM voltage source inverter (PWM-VSI) is connected between diesel generator and load which compensates harmonics in the AC grid. Implementation of the harmonics compensation by using D-STATCOM in the hybrid distribution system is used to attain the voltage stability. Here, Fuzzy logic controller with hysteresis loss current control method is used for harmonic reduction.

*C.Matlab Model for Hysteresis Loss Current Control*

The simulation diagram of the proposed D-STATCOM with hysteresis loss current control algorithm is shown in Fig.9.

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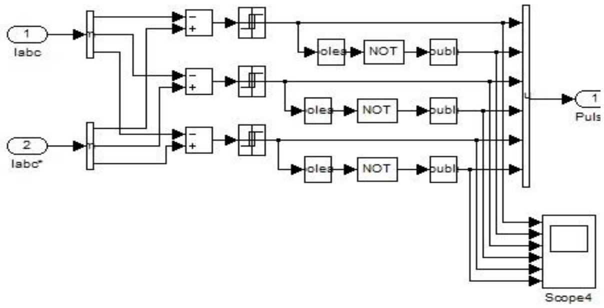


**Fig.9. Block Diagram for Hysteresis Loss Current Control**

The Hysteresis loss current control block Fig. 9. modulates using pulse modulation. The output is a pass band representation of the modulated signal. The output signal's frequency varies with the input signal's amplitude. Both the input and output signals are real scalar signals. Poles are used to convert the analog signal to digital signal. The modulating angle δ or delta is applied to the PWM generator in phase A, where as the angles for phase B and C are shifted by 240° or 120°and 120° respectively. Here Iabc is the reference current and Iabc* is the error current.

*D.Matlab Model for fuzzy logic controller*

The simulation diagram of the proposed D-STATCOM with Fuzzy Logic Controller is shown in Fig 10.

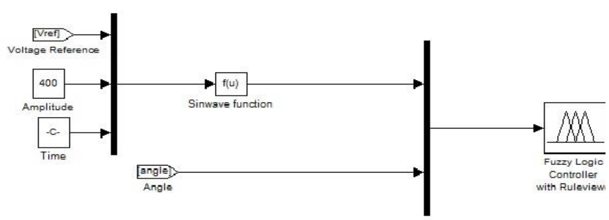


**Fig 10. Block Diagram for Fuzzy Logic Controller**

The Fuzzy logic controller is a controller used to calculate the error current Iabc* in Fig 10. The input that is given to this block is voltage reference, amplitude, time, sine wave function and reference sine wave angle. The output measured from this block is error current Iabc*.The Fuzzy Logic Controller (FLC) requires that each control variables which define the control surface be expressed in fuzzy set notations using linguistic labels. The fuzzy logic controller is appropriate for nonlinear control because it does not use complex mathematical equation. Fuzzy controller is a non-linear controller that does not require a precise mathematical model for its design. In essence, fuzzy controller is a linguistic-based controller that tries to emulate the way a human thinks in solving a particular problem. The basic fuzzy logic control system is composed of a set of input membership functions, a rule-based controller, and a defuzzification process.

The fuzzy logic input uses member functions to determine the fuzzy value of the input. There can be any number of inputs to a fuzzy system and each one of these inputs can have several membership functions. The set of membership functions for each input can be manipulated to add weight to different inputs. The output is also has a set of membership functions. These membership functions define the possible responses and outputs of the system. The fuzzy inference engine is the heart of the fuzzy logic control system. It is a rule based controller that uses If-Then statements to relate the input to the desired output.

## Simulation Results

The input data of hybrid Wind, Solar, Diesel Generator generation system are given in Table I, Table II, Table III.

**TABLE I Wind Generation System Operating Limit**

| Simulation Parameters for Wind | Values |
|---|---|
| Rotor speed | 1800 (RPM) |
| PF correction factor | 75 (KVAR) |
| Snubber Resistance (Converter) | 1 Ω |
| Snubber Capacitance (Converter) | 1 F |
| Diode Resistance | 1000 Ω |

**TABLE II Solar Generation System Operating Limit**

| Simulation Parameter for Solar(PV) | Values |
|---|---|
| Battery Nominal Voltage | 220 V |
| Battery Nominal Current | 2 A |
| Rated Current | 0.3 A |
| Temperature | 35°C |
| Hysteresis Band | 0.7 |
| Inductance | 1 mH |
| Capacitance | 1 µF |

**TABLE III Diesel Generator Generation System Operating Limit**

| Simulation Parameter | Values |
|---|---|
| Terminal voltage | 1 V |
| Field voltage | 1.427 V |
| Resistance | 8 Ω |
| Capacitance | 10 µF |
| Power | 1 p.u |

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| | |
|---|---|
| Vtref | 1 p.u |

*A.Wind Energy System Voltage Output*

The output voltage waveform of wind energy system is shown in Fig.11.

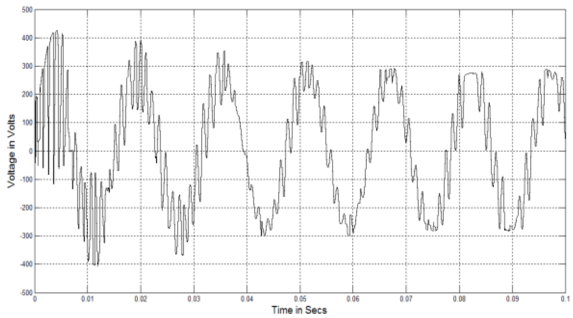


**Fig.11. Voltage Waveform for Wind Energy System**

The proposed D-STATCOM responds to the harmonic reduction, the voltage is as shown in Fig. 11. The output voltage waveform of wind energy system is carried out by using D-STATCOM with Fuzzy logic controller with Hysteresis loss current control algorithm. The voltage range of wind energy system is 420 volts.

*B.Solar Energy System Voltage Output*

The output waveform of solar energy system is shown in Fig.12.

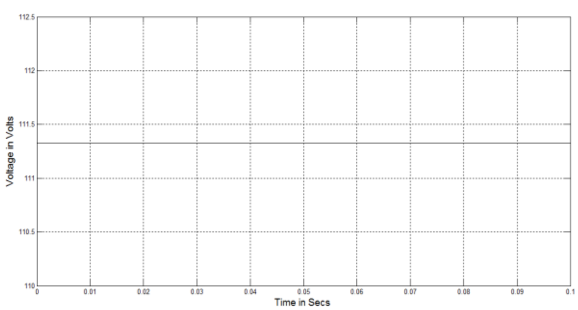


**Fig. 12.Voltage Waveform for Solar Energy System**

The proposed D-STATCOM responds to the harmonic reduction, the voltage is as shown in Fig. 12.The output voltage waveform of solar energy system is carried out by using D-STATCOM with PQ theory with Hysteresis loss current control algorithm. The voltage range of solar energy system is 111.4 volts.

*C.Diesel Generator Energy System Voltage and Current Output*

The voltage and current output waveform of diesel generator energy system is shown in Fig.13 and 14.

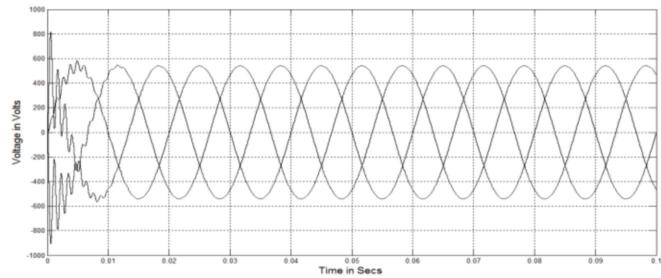


**Fig.13. Voltage Waveform for Diesel Generator Energy System**

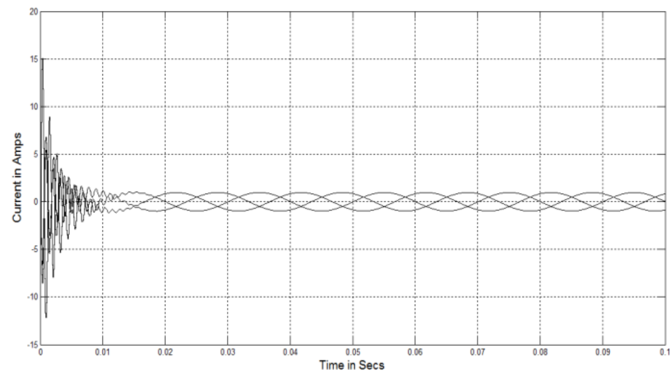


**Fig.14. Current Waveform for Diesel Generator Energy System**

The proposed D-STATCOM responds to the harmonic reduction, the voltage and current is as shown in Fig. 13 and 14. The output voltage and current waveform of diesel generator energy system is carried out by using D-STATCOM with PQ theory with Hysteresis loss current control algorithm. The voltage and current range of diesel generator system is 800 volts and 15 amps.

*D.Hybrid Energy System Voltage and Current Output*

The voltage and current output waveform of hybrid energy system is shown in Fig.15.

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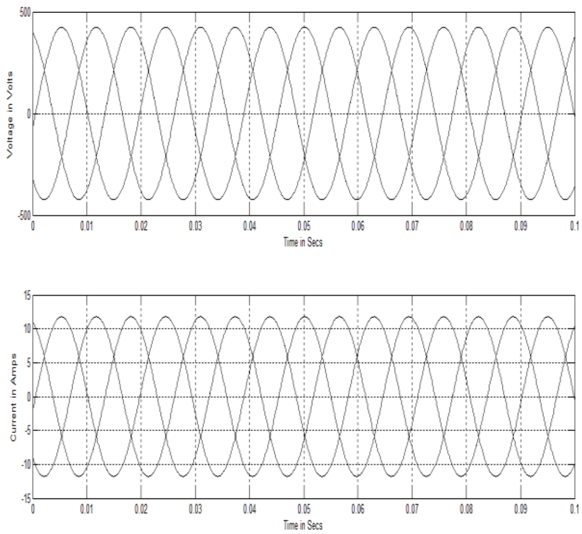


**Fig.15. Voltage and Current Waveform for Hybrid System**

The proposed D-STATCOM responds to the harmonic reduction, the voltage and current is as shown in Fig. 15. The simulation is carried out by using D-STATCOM of fuzzy logic controller with Hysteresis loss current control algorithm. After the harmonic reduction the voltage and current flowing in the three phase supply is 440 volts and 12 amps.

*E.Hybrid System Real and Reactive Power Output*

The real and reactive power output waveform of the proposed D-STATCOM with fuzzy logic controller with hysteresis loss current control method is shown in Fig.16.

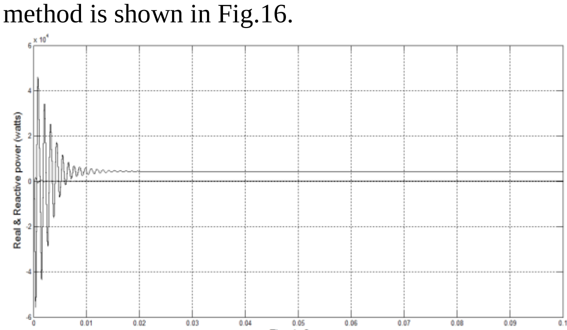


**Fig.16. Real and Reactive Power Waveform by using D-STATCOM**

From Fig.16. the first line shows real power that is total utilized power and second line shows the reactive power that is totally lost power after harmonic reduction. The range of real power is 1000 watts and the reactive power is 0 watts.

*F.Total Harmonic Reduction Output*

The waveform of total harmonic reduction of the proposed D-STATCOM of fuzzy logic controller with hysteresis loss current control method is shown in Fig. 17.

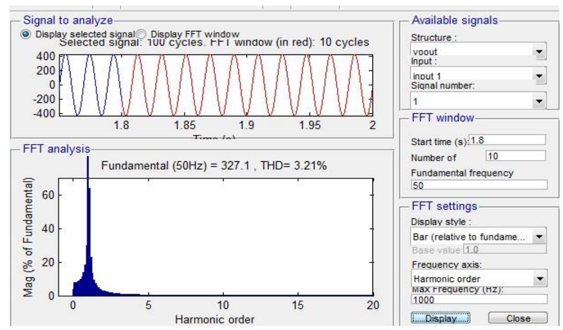


**Fig. 17. Total Harmonic Reduction Waveform**

According to the IEEE standard total harmonic reduction should be less than 10%. From Fig .17. the THD is reduced up to 3.21% by using D-STATCOM of fuzzy logic controller with hysteresis loss current control algorithm.

## Conclusion

To carry out any investigation in the power quality improvement it needs a thorough knowledge of nature of the power quality issues over the particular location of transmission lines and complete understanding of FACTS devices and controllers. In this work, a fast and cost effective D-STATCOM is proposed for reducing the problem of harmonics in industrial distribution systems. Hysteresis loss current control algorithm utilizes the error signal which is the difference between the reference voltage and actual measured load voltage to trigger the switches of an inverter using a Pulse Width Modulation (PWM) scheme. The D-STATCOM handled the situation without any difficulties and injected the appropriate voltage component to correct rapidly any changes in the supply voltage there by keeping the load voltage balanced and constant at the nominal value. In this study, the D-STATCOM has shown the ability to reduce the harmonics problem, total harmonic reduction has been proved through simulation implementation. The effectiveness of Fuzzy logic with hysteresis loss current control of D-STATCOM is established for RLC load. Through analysis, simulation and experimental measurements, it is shown that the proposed scheme is superior compared to the other conventional controller technique in terms of energy saving and dynamic performance. The Fuzzy logic control with hysteresis

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loss current control of D-STATCOM has the ability for good compensation characteristics. By using this compensation strategy the THD (Total Harmonics Distortion) is reduced up to 3.21%.

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