Power Quality Improvement in Grid Connected Wind Energy System

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Abstract:- The renewable energy sources which are expected to be promising alternative energy sources ,can bring new challenges when it is connected to power grid. Injection of the wind power into anelectric grid affects the power quality. The concerned power quality measurements are: active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behaviour of switching operation. The performance of the wind turbine and thereby power quality are determined on the basis of measurements and the norms followed according to the guideline specified in International Electro-technical Commission standard, IEC-61400.Thecompensator is designed to inject reactive power to overcome power quality problems and also for better grid operation. The addition of STATCOM into the system supports to maintain the active power, reactive power and terminal voltage as constant. The wind turbinegenerators have power electronic based converters canbe effectively utilized for efficient control of power, but they generate harmonics. The modified STATCOM as shunt active filter which is used forreducing system harmonics and to improve the systemPerformance. In this proposed scheme a FACTS deviceSTATIC COMPENSATOR (STATCOM) is connected at a point of common coupling. The STATCOM will reduce the harmonics inthe grid current by injecting superior reactive power in to the grid. This is because of reactive power drops off STATCOM is linearwith voltage. Here a bang-bang control scheme has beenimplemented with the STATCOM to achieve fast dynamic responsefor the reduction of harmonics in grid current. Bang-bangcontroller is simple and reliable. A STATCOM can improve powersystemperformance in such areas as the following: the dynamicvoltage control in transmission and distribution systems, thepower-oscillation damping in power transmission systems, thetransient stability, the voltage flicker control and the control of notonly reactive power but also (if needed) active power in the connected line.

Keywords- Power Quality, Wind Turbine, STATCOM, SVC, Bang-Bang controller.

I. INTRODUCTION

The interest for renewable energy sources has increased significantly due to environmental issues and fossil fuels elevated cost. With most of the developing countries looking forward to renewable energy sources as a sustainable option, it is imperative that the issues associated with large scale integration of these renewable energy sources with grid be studied in detail and better understood.. The generated power from renewable energy sources is always fluctuating due to environmental condition. In the same way wind power injection into an electric grid affects the power quality due to the fluctuating nature of the wind and the comparatively new types of its generators. However, due to the uncertain behaviour of wind speed it is difficult to obtain good quality power, since wind speed fluctuations reflect on the voltage and active power output of the electric machine connected to the wind turbine.The power arising out of the wind turbine when it connected to grid system concerning the power quality measurements are-the active power, reactive power, voltage sag, voltage swell, flicker, harmonics, and electrical behaviour of switching operation and these are measured according to national/international guidelines. Soby utilization of FACTS devicesin order to deal with harmonic current injection, reactive power compensation and voltage variation,the grid function can be maintained and even improved, enabling increased power transmission capacity over existing lines.The computer simulation using MATLAB shows that the effect of power quality issues is mitigated by application of FACTS devices mentioned above.

II. POWER QUALITY

A power quality problem can be defined as any deviation of magnitude, frequency, or purity from the ideal sinusoidal voltage waveform. It can also be defined as any problem manifested in voltage,current or frequency deviations that result in failure or misoperation of customer equipment. Power quality has become a buzzword in therecent past due to the increase in sensitive loads, proliferation of non-linear loads and switching devices and increasing awareness of the implications of poor power quality. Though poorquality of power affects all consumers of power, this article specifically deals with the wind farms.Like in most loads, wind farms are not only affected by poor power quality (of the grid), but also affects the quality of power. Based on this the power quality aspects can be broadly classified into two, those from the grid that affects the WEG and those from the WEG that affects the grid. Good power quality enables the equipment to work properly and is benefit to the operation of electrical equipment, whereas poor power quality will produce great harm to the power system. The generated power from wind energy conversion system is always fluctuating due to the fluctuating nature of the wind. Therefore injection of the wind power into an electric grid affects the power quality. The increasing number of renewable energy sources and distributed generator requires new strategies for operation andmanagement of electric grid, in order to improve the power quality norms. International standards are developed by the working groups of Technical Committee-88 of the International Electro Technical Commission (1EC); IEC 61400-21 describes the procedure of determining the power quality characteristics of wind turbine.

III. GENERALPOWER QUALITY ISSUES

Power Quality is defined as power that enables the equipment to work properly. A power quality problem can be defined as any deviation of magnitude, frequency, or purity from the ideal sinusoidal voltage waveform The following are the various power quality issues related to wind turbine:-

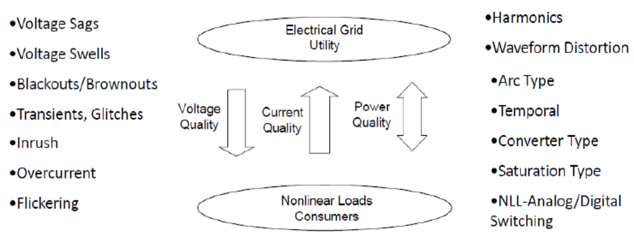

Figure1.1 Power Quality Issues

IV SHORT-DURATION VOLTAGE VARIATIONS

The deviation in the voltage magnitude for a period of time less than one minute. Short-duration voltage variations are caused by fault conditions, the energization of large loads which require high starting currents, or intermittent loose connections in power wiring. Depending on the fault location and the system conditions, the fault can cause either temporary voltage drops (sags), voltage rises (swells), or a complete loss of voltage(interruptions). The fault condition can be close to or remote from the point of interest. In either case, the impact on the voltage during the actual fault condition is of the short-duration variation until protective devices operate to clear the fault.

Short Duration voltage Variations includes the following –

a) Voltage sag
b) Voltage swell
c) Brief interruptions

A) Voltage sag :-

A *sag* is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.

B) Voltage swell : -

A swellis defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min. swells are usually associated with system fault conditions, but they are not as common as voltage sags.

C) Interruption: **-**An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min. Interruptions can be the result of power system faults, equipment failures, and control malfunctions. The interruptions are measured by their duration since the voltage magnitude is always less than 10 percent of nominal.

V. LONG-DURATION VOLTAGE VARIATIONS

The deviation in the voltage magnitude for a period of more than 1 – minute can be considered as long duration voltage disturbance.

A) Overvoltage: -

An overvoltageis an increase in the rms ac voltage greater than 110 percent at the power frequency for a duration longer than 1 min. Overvoltages are usually the result of load switching (e.g., switchingoff a large load or energizing a capacitor bank).

B)Undervoltage : -

An undervoltageis a decrease in the rms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min. Undervoltages are the result of switching events that are the opposite of the events that cause overvoltages.

C)Sustained interruptions : -

When the supply voltage has been zero for a period of time in excess of 1 min, the long-duration voltage variation is considered a *sustained interruption.* Voltage interruptions longer than 1 min are often permanent and require human intervention to repair the system for restoration. This could be as little as one-half of a cycle.

D) Voltage transients : -

"That part of the change in a variable that disappears during transition from one steady state operating condition to another."Voltage disturbances shorter than sags or swells ($\Delta T < 0.5T$) are classified as transients. The transients refer to abrupt changes in voltage or current waveform. The transients are classified as unidirectional (Impulsive) and oscillatory. The typical impulsive and oscillatory transients are shown in the figure – 2.1.

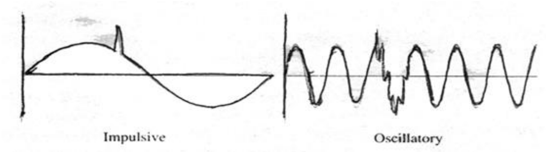

Figure 1.2Impulsive and oscillatory transient

VI. POWER QUALITY ISSUES RELATED TO WIND POWER SYSTEM

The power fluctuation from wind turbine during continuous operation causes voltage fluctuation on grid. The amplitude of this fluctuation depends on grid strength, network impedance, and phase angle and power factor. The voltage fluctuation and flicker are caused due to switching operation, pitch error, yaw error, fluctuation of wind speed. Today, the measurement and assessment of power quality on grid connected wind turbine is defined by IEC 61400-21 and stated that the 10 minute average of voltage fluctuation should be within +/- 5% of nominal value. The voltage fluctuations due to wind speed variations are not only a stability issue but can also cause flicker. Flicker takes place when voltage fluctuates in a range of frequency between 10-35Hz, it may produce light disturbances to the human eye through incandescent lamps, which can trigger epileptic attacks of photosensitive persons and also damage sensitive equipment. Energy storage techniques that can be used in order to avoid flicker due to wind speed variations. Flicker is induced by voltage fluctuations, which are caused by load flow change in the grid. The flicker emission produced by grid connected wind turbines during continuous operation is mainly caused by fluctuations in the output power due to wind speed variation, the wind shear and tower shadow effect. The wind shear and tower shadow effect are normally referred to as the 3p oscillation. As a consequence, output power drop will appear three times per revolution for a three bladed wind turbine. There are many factors that affect flicker emission of grid connected wind turbine during continuous operation such as wind characteristics and grid conditions. Variable speed wind turbines have shown better performance related to flicker emission in comparison with fixed speed wind turbine.

VII. FLEXIBLE AC TRAMSMISSION SYSTEM (FACTS)

FACTS solutions are particularly justifiable in applications requiring rapid dynamic response, ability for frequent variations in output, and/or smoothly adjustable output. Under such conditions, FACTS is a highly useful option for enabling or improving the utilization of power systems. FACTS devices can basically be sub-divided into three categories:

1) Shunt devices such as SVC (Static Var Compensator) and STATCOM1

2) Series devices such as Series Capacitors and Thyristor Controlled Series Capacitors (TCSC)

3) Dynamic Energy Storage device

4) Some other FACTS devices are Dynamic voltage restorer and TCSC

The STATCOM is a 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. It is a solid-state switching device capable of independently generating and absorbing real and reactive power at its output terminals. The STATCOM's output is highly controllable; it produces a set of 3-phase ac-output voltages each in phase with the corresponding ac system voltage. A schematic representation of the one-phase STATCOM is shown in Fig. 1.12. It is composed by a voltage source converter (VSC), and its associated shunt connected transformer. The transformer is used as a link between the VSC and the system

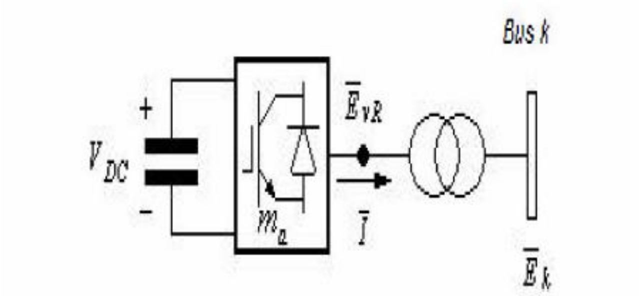

Figure 1.3 STATCOM's Schematic Representation

To explain the basic STATCOM' s operation principles, it is considered that the coupling transformer is lossless, Fig1.13 and Fig1.14, shows the phasor diagram of STATCOM under lagging and leading power factor where EvR represents the voltage in the STATCOM' s terminals and Ek is the voltage in the power system bus.

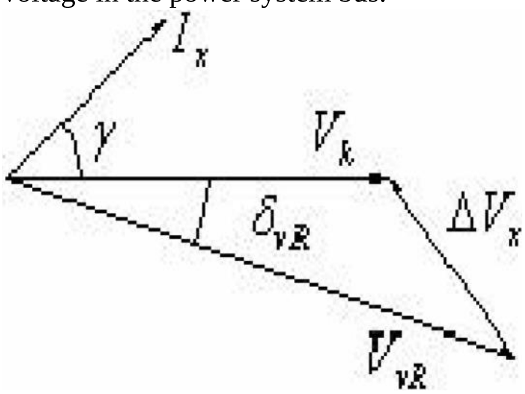

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Figure 1.4 leading current

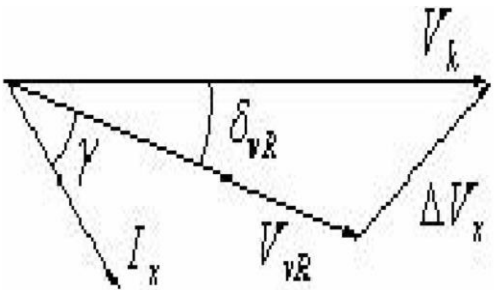

Figure 1.5 lagging current.

Where VvR>Vk, with a lagging power factor, in such circumstances, the STATCOM is absorbing active power from the system and giving reactive power to the same one. On the other hand, Fig 1.14 represents a operation condition where (VVR<Vk), with leading power factor; now, the STATCOM absorbs active and reactive power from the system.

VIII. POWER QUALITY IMPROVEMENT TOPOLOGY

The STATCOM based current control voltage source inverter injects the current into the grid in such a way that the source current are harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized in generating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC), as shown in Figure 1.15 below

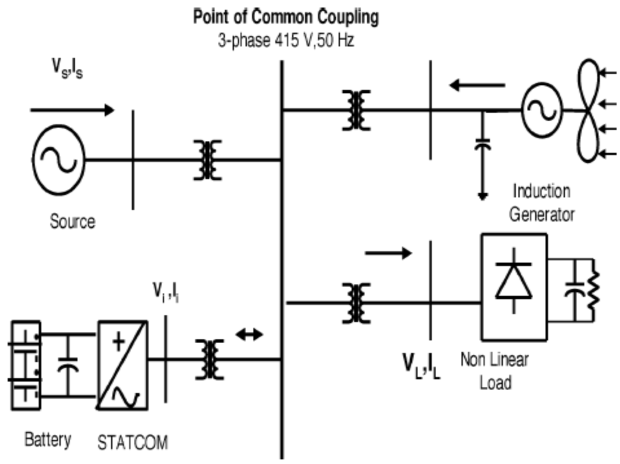

Figure 1.6 Grid connected system for power quality improvement

The grid connected system consists of wind energy generation system and battery energy storage system with STATCOM.

Wind Energy Generating System-

In this configuration, wind generations are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented as under in equation

$$P_{mech} = \frac{1}{2} \rho A V^3_{wind}$$

where (kg/m) is the air density and A (m) is the area swept out by turbine blade, V_{wind} is the wind speed in mtr/s. It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient *Cp*of the wind turbine, and is given in equation 2 as

$$P_{mech} = C_P P_{wind}$$

Where *Cp*is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be express as a function of tip speed ratio and pitch angle. The mechanical power produce by wind turbine is given in equation 3 as

$$P_{mech} = \frac{1}{2}\rho\Pi R^2 V^3_{wind} C_P \quad (8)$$

Where R is the radius of the blade (m).

BESS-STATCOM

The battery energy storage system (BESS) is used as an energy storage element for the purpose of voltage regulation. The BESS will naturally maintain dc capacitor voltage constant and is best suited in STATCOM since it rapidly injects or absorbed reactive power to stabilize the grid system. It also control the distribution and transmission system in a very fast rate. When power fluctuation occurs in the system, the BESS can be used to level the power fluctuation by charging and discharging operation.The battery is connected in parallel to the dc capacitor of STATCOM.The STATCOM is a three-phase voltage source inverter having the capacitance on its DC link and connected at the point of common coupling. The STATCOM injects a compensating current of variable magnitude and frequency component at the bus of common coupling.Figure 1.16

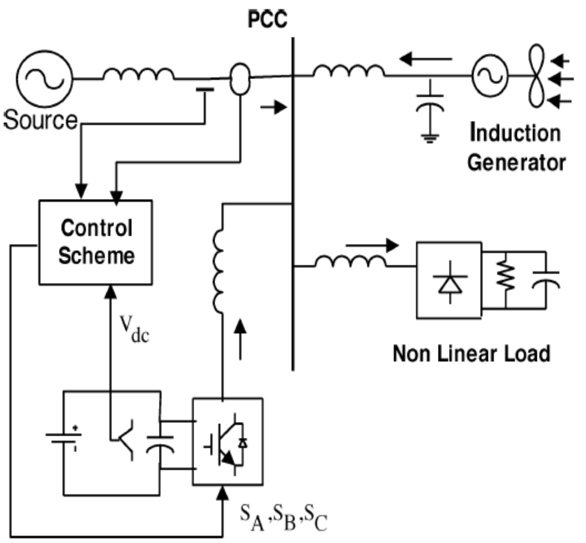

Figure 1.16 system operational schemes in grid system

System Operation

The shunt connected STATCOM with battery energy storage is connected with the interface of the induction generator and non-linear load at the PCC in the grid system. The STATCOM compensator output is varied according to the controlled strategy, so as to maintain the power quality norms in the grid system. The current control strategy is included in the control scheme that defines the functional operation of the STATCOMcompensator in the power system. A single STATCOM using insulated gate bipolar transistor is proposed to have a reactive power support, to the induction generator and to the nonlinear load in the grid system. The main block diagram of the system operational scheme is shown in Fig.1.16

IX.CONTROL SCHEME

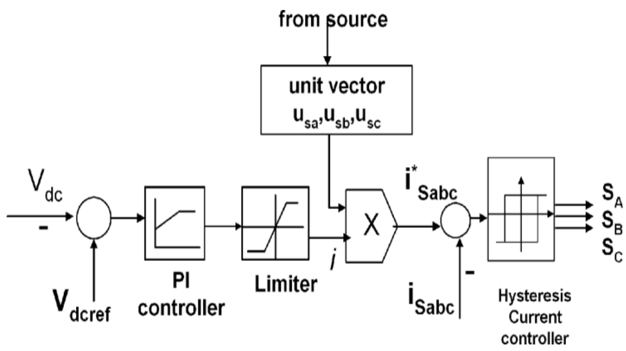

Figure 1.17 Control circuit for switching inverter circuit

The control scheme approach is based on injecting the currents into the grid using "bang-bang controller." The controller uses a hysteresis current controlled technique. Using such technique, the controller keeps the control system variable between boundaries of hysteresis area and gives correct switching signals for STATCOM operation.The control system scheme for generating the switching signals to the STATCOM is shown in Fig.1.17.The control algorithm needs the measurements of several variables such as three-phase source current i_{sabc}DC voltage V_{dc} inverter current i_{iabc} with the help of sensor.the current control block, receives an input of reference current $i^*_{sabc}$and actual current i_{sabc} are subtracted so as to activate the operation of STATCOM in current control mode.

X.GRID SYNCHRONIZATION

In three-phase balance system, the RMS voltage source amplitude is calculated at the sampling frequency from the source phase voltage (V_{sa},

V_{sb}, V_{sc}) and is expressed, as sample template *Vsm*, sampled peak voltage, as in (11).

$$V_{sm} = \text{sqrt}\{\tfrac{2}{3}\,(V^2_{sa} + V^2_{sb} + V^2_{sc})$$

The in-phase unit vectors are obtained from AC source—phase voltage and the RMS value of unit vector U_{sa}, U_{sb}, U_{sc}, as shown in (12).

$$U_{sa} = \frac{V_{sa}}{V_{sm}},\ U_{sb} = \frac{V_{sb}}{V_{sm}}\ ,\ U_{sc} = \frac{V_{sc}}{V_{sm}}$$

The in-phase reference currents generated are derived using in-phase unit voltage template as shown below.

isa*=I* Usa, isb*=I*Usb, isc*= I* Usc

Where 'I' is proportional to magnitude of filtered source voltage for respective phases. This ensures that the source current is controlled to be sinusoidal.

Bang-Bang Current Controller-

It is implemented in the current control scheme. The reference current is generated as in equation (12) and actual current are detected by current sensors and are subtracted for obtaining a current error for a hysteresis based bang-bang controller. Thus the ON/OFF switching signals for IGBTs of STATCOM are derived from hysteresis controller.The switching function SA for phase 'a' is expressed as :

(isa-i*sa**)** <HB = SA = 1
(isa-i*sa**)** >HB = SA = 0

This is same for phases 'b' and 'c'.

Fuzzy Logic Controller

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does notrequire a mathematical model of the system.
The objectives include excellent rejection of input supply variations both in utility and in wind generating system and load transients. Expert knowledge can also be participated with ease that is significant when the rules developed are intuitively inappropriate [7]. The rule base developed is reliable since it is complete and generated sophistically without using extrapolation.In this paper, fuzzy control is used to control thefiring angle for the switches of the VSI of STATCOM. In this design, the fuzzy logic based STATCOM has two inputs'change in voltage(ΔV)' and 'change in current(ΔI)' and one control output(ΔU).

Firstly the input values will be converting to fuzzyvariables. This is called fuzzification. After this, fuzzy inputs enter to rule base or interface engine and the outputs are sentto defuzzification to calculate the final outputs. These processes are demonstrated in Fig. 3.

Here seven fuzzy subsets have been used for two inputs. These are: PB (positive big), PM (positive medium), PS(positive small), ZE (zero), NS (negative small), NM (negative medium) and NB (negative big).We use Gaussian membership functions [8] and 49 control rules are developed, which are shown in table 1.

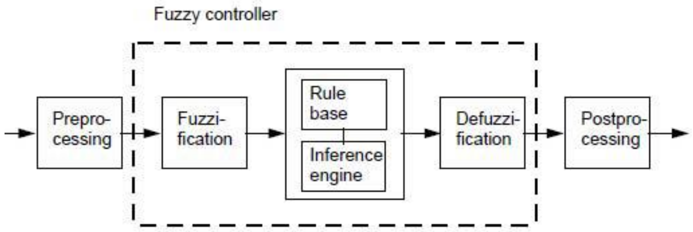

Fig1.18 Fuzzy control block diagram

ΔI / ΔV	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Fig1.19 Table I Control Rule

Fuzzification: It is the process of representing theinputs as suitable linguistic variables .It is first block of controller and it converts each piece of input data to a degree of membership function. It matches the input data with conditions of rules and determines how well the particular input matches the conditions of each rule.

The membership functions for the inputs (for ΔV and ΔI) are shown in Fig.4 and Fig.5.

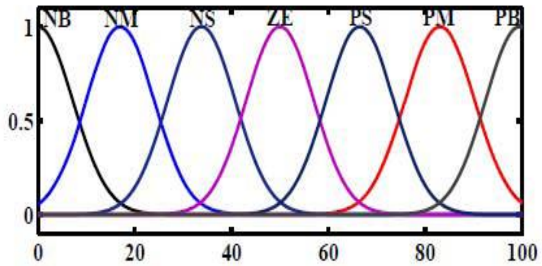

Fig1.20. Membership function for ΔI

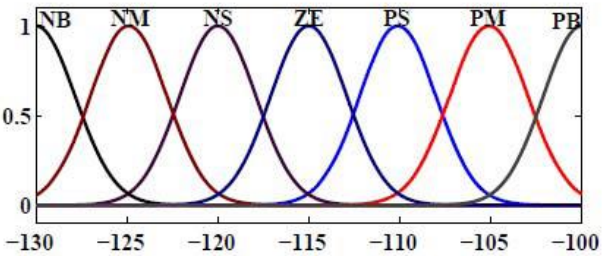

Fig.1.21. Membership function for ΔV

Defuzzification: It is the Process of converting fuzzified output into a crisp value. In the defuzzification operation a logical sum of the results from each of the rules performed.This logical sum is the fuzzy representation of the change in firing angle (output). A crisp value for the change in firing angle is calculated. Correspondingly the grid current changes and improves the power quality.

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