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Impact of GCIs Performance on Power Quality of Smart Grid using Fuzzy Logic

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ABSTRACT
The operating performance of the Grid Connected Inverters (GCIs) in windmill is highly important related to stable and safety operation of a "Smart Grid" (SG). These inverters control features not only cover the renewable energy conversion and active power feeding into the utility grid but also they cover the grid voltage stabilization, supporting with reactive power of the grid in case of voltage dips. The GCIs support to meet the power quality standards by means of their fast acting of control abilities. Decentralized suppliers must contribute to the control of the grid by delivering active and reactive power. This paper gives an overview on the necessary features of GCIs, the importance of GCI on power quality and introduces some simulation results using fuzzy logic controller to avoid the over current problem during voltage dip under short circuit fault condition.

Keywords- **Smart Grid, Power Quality, Grid Connected Inverter, Windmill, Fuzzy logic controller.**

I. INTRODUCTION
As we know very well the common power quality problems occurs generally in grids are below:

- Magnitude of the supply voltage
- Voltage fluctuations
- Voltage dips and short supply interruptions
- Voltage and current distortion

The SGs' standardization is recently running in Technical Committees of IEC, IEEE and EN.

The power quality problems should be notable not only in Centralized Generation systems but also in Smart Grid systems as well.

The main reason for the changes in RMS voltage value in a power network is the load variations. It is common that the utility network voltage level is strongly influenced by local power flows. The reactive power flows are highly important in this case. Since they have very strong influence on the voltage stability. The voltage fluctuations are caused mainly by industrial high power consumption as arc furnaces, cold and hot iron mills, etc.

Voltage dips are short time reductions of the voltage level which is normally longer than 10 ms and typically caused by short circuits at the distribution network or at large industrial consumer side and last as long as the protection acting time.

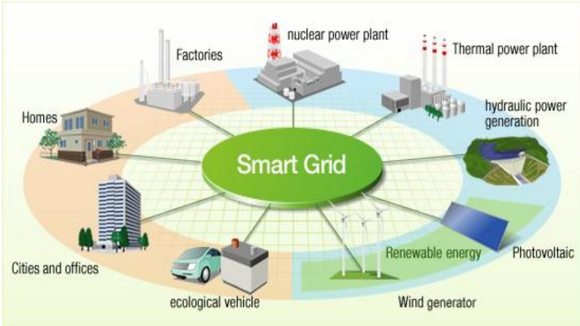

Fig 1. Typical Smart Grid arrangement

The distorted (not fully sinusoidal) current and voltage have been occurred in normal operating condition. The utility networks are used by various power electronics devices (old type among them). The conventional thyristor and diode converters produce mostly integer multiples of the fundamental harmonics [1]. The total harmonic distortion THD calculation is typically required up to 50th order harmonics. The relevant standards define the limit of the maximum current and voltage THD value.

The voltage dip due to short circuit in the distribution network and the slight over current is shown and discussed in [2]. The rise of reactive power to compensate the active power because of the effect of capacitor voltage also discussed.

Classical PI controllers can be used for current control in Grid Connected Inverters. A reasonable performance can be obtained with a constant gain PI controller, designed for certain operating point. However, when the working point changes due to the variations in system parameters, transient response cannot be quick enough and inverter current quality cannot reach the required level. That's why the Fuzzy logic controller is implemented here.

Here our main objective is to avoid voltage dip, over current effect and also to improve the response time by using fuzzy logic controller.

II.PERFORMANCE REQUIREMENTS OF GCI
The Grid connected inverter can be adapted to the above mentioned operating conditions and also it contribute to maintain the grid power quality too [3]. GCIs shall provide voltage control in grid and keeping the defined slope in the actual Grid Code or Site Specific Connection Agreement (SSCA).

As an example the German Grid Codes have been amongst the most important driving documents regulating the connection of large wind farms to the conventional (not DG) grid [4].

The most recent Grid Codes require the wind farm among other things to contribute the

- Reactive power exchange and voltage control
- Fault-ride through support in the case of balanced faults
- Defined behaviour in case of unbalanced faults
- Post Fault Active Power Recovery

2.1.Reactive power exchange and voltage control:

The Grid Codes specify the power factor at nominal active wind park power output over a defined connection voltage range.

Some grid codes needs of the implementation of voltage control functionality as it is well known for other generators [4]. The reactive power generation that may be leading or lagging and active filtering capability is highly depend on the inverter limits and the converted actual active power.

Reactive power has to be provided depending on the system voltage following a droop characteristic. Thereby, the provided reactive power is a linear function of the system voltage. Parameters such as target voltage and droop slope have to be altered remotely by the overriding controller.

The nature of faults with various fault currents and voltage dips has occurred not only in a centralized generation system but also in a Smartgrid (where is a distributed generation (DG) concept) and there are cases when have to “ride through” or switch off the grid connected inverter. The fault ride through (FRT) capability of GCIs improves the reliability of the Smart grid operation. This is the main advantage of the GCI.

During a dip the GCI shall provide reactive current as high as possible to boost the local voltage. Fig 2 introduce this requirement. A typical requirement is that after the recovery of grid voltage to 90%, the GCIs shall restore the injected active power at least 90% of their pre-fault values. The restoration time of the injected active power shall be less than 1 second if the fault time is longer than 140 msec (unless plant input power has reduced).

The local voltage could contain fluctuations and specific harmonics generated by consumers [3] (e.g. old type of thyristor converters). Some local active power fluctuation has occurred due to load rejections somewhere on the network.

GCIs can provide an active power filtering functions (with limited power range).

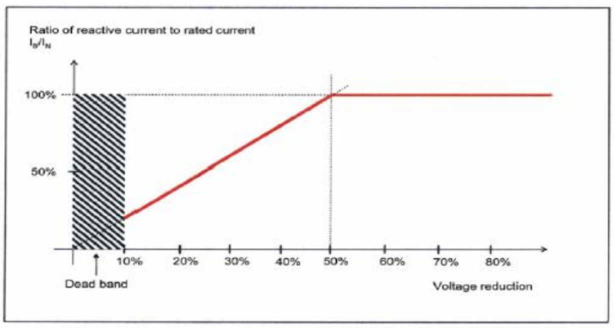

Fig 2. Reactive current requirement during faults

In a SG where is a distributed power generation, Grid connected inverter contribute in connection with the frequency control by means of modification of the output power moreover it can be equipped with power system stabilizer(PSS) to increase the system damping. During a power as well as frequency oscillation on the grid the PSS should provide an artificial damping effect to help suppression of the grid oscillation.

III.STRUCTURE OF GCIs

The grid connected windmill system with back to back voltage source inverter is shown in fig 3. The grid connected inverter output generally connected with an LCL third level harmonic filter [6] plus an EMC filter [7] while the machine side converter output contains only a du/dt filter circuit. The grid side inverter output contains a step up transformer which is used to connect to the medium voltage network.

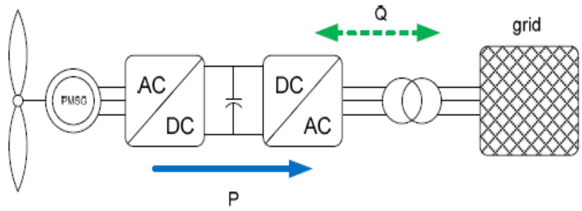

Fig 3. Grid connected windmill system

The grid side converter which is of the type of two or multilevel IGBT inverters make possible to control the reactive power according to the actual demand of the Active power. The inverters apply modulation frequency (3-5 kHz) providing a good dynamic behaviour and it makes the possibility to eliminate some current harmonics with low order numbers [8], [9] coming from the medium voltage side of the grid. This is the main advantage of the grid connected inverter.

IV.STRUCTURE OF CONTROLLER

The generator side converter controller algorithm is based on the rotor flux oriented reference frame for calculations. The active power is controlled by the I_q current component and the reactive power is by the I_d current component. It is shown in fig 4.

The torque controller feedback signal is calculated from the (i_q x ψ_{pm}) [2]. In case of high speed and stator voltage range the field weakening controller sets the I_d component.

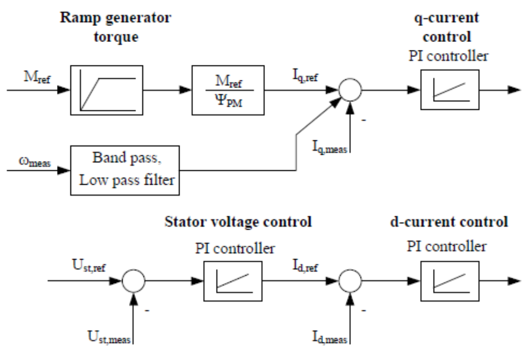

Fig 4. Generator side controllers

The controller algorithm of grid side controllers is carried out in grid voltage-oriented d-q reference frame.

The fuzzy controller which is responsible for both d-current and q-current component which is shown in fig.5.

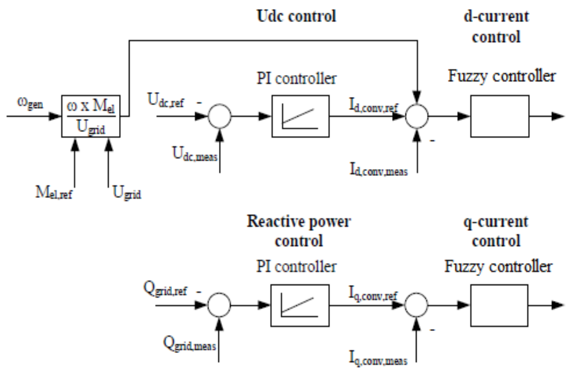

Fig 5. Grid side controller using Fuzzy logic.

V. FUZZY LOGIC CONTROLLER

As we know the Fuzzy logic controller (FLC) is used to improve the response time, here it is implemented in grid side controller. Here the fuzzy controller is used instead of the PI controller which is used in [2], for the purpose to reduce the over current effect during the voltage dip period and also to improve the response time. For the d- current control, the measured value and reference value of d component current is compared and the error value is given as one of the input to the fuzzy controller.

Similarly, for q-current control the measured, reference value of q component current is compared and the error value is given as one of the input. The change in error value is another input for fuzzy controller in both cases d and q, and it is given by introducing the delay circuit to the error value.

In FLC the error and the change of error are scaled and quantised. During the tuning of the controller, the values of scaling factor are obtained by trial and error. The scaling factor for the error is denoted as SFe and for the change of error is denoted as SFce. And then the fuzzified values are kept within a certain range.

In Fuzzy logic controller, there are three membership functions are used as positive, negative and zero. It is shown with respective rules in table below. The operating points of each membership function is selected in order to get the effective output with better response time for all output parameters. Similarly for both inputs, the limits of three membership functions are selected to obtain better outputs. The simulations mainly focused on to verify the converter operation when voltage dips [10], [11] have occurred by short circuit at the high voltage grid. The main target was to avoid over current what would trip the system and to feed the required reactive current into the grid. There was also very important to keep a stable intermediate DC voltage level avoiding over-voltage and to provide smooth operation conditions in the smart grid.

TABLE 1
FUZZY-RULE-BASED MATRIX

Change in Error / Error	NS	Z	PS
NS	NS	NS	Z
Z	NS	Z	PS
PS	Z	PS	PS

VI.SIMULATION DIAGRAM

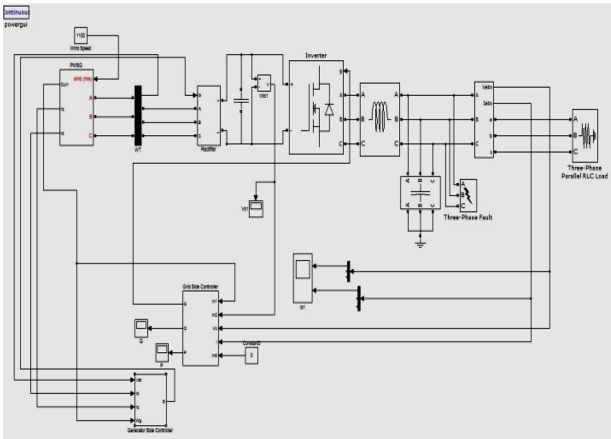

Fig 6.MATLAB model for GCI influence on power quality improvement using Fuzzy controller.

VII. SIMULATION RESULTS

The simulated system was a windmill equipped with the full converter (back to back). The simulations made in MATLAB/Simulink. The power circuit blocks were made from the SimPowerSystem toolbox blocks and control system blocks were made using basic Simulink blocks. And the main advantage of using SimPowerSyatems is that the power system is similar to the schematic diagrams made in Pspice. The windmill consists of full converter which is of 4.8kW.

The important data of the system is:

Table-2
Data of the system

Parameter	Values
Nominal Power	4.8 kW
Nominal DC link voltage	200 V
Wind speed	1100 rpm
PMSG pole pairs	2
PMSG no load voltage	300 V

The simulation was performed during the period of 100ms and 50% voltage dip at the grid voltage. Fig 7.a shows the grid voltage at the frequency of 60Hz and grid current verses time during voltage dip.

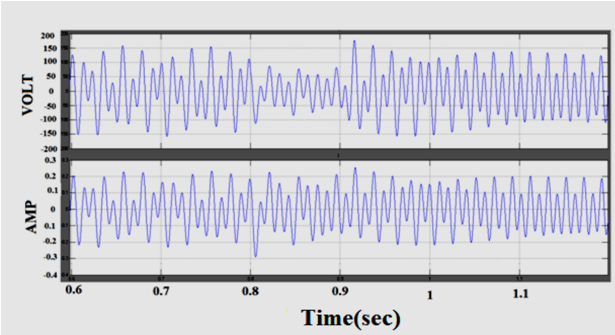

Fig 7.a Grid Voltage and Current with voltage dip from 0.8 to 0.9 time period

Fig 7.b shows the Active power drop during the period of voltage dip and correspondingly fig 7.c shows the reactive power rise to compensate the active power drop. The intermediate DC voltage can be followed on the fig 7.d

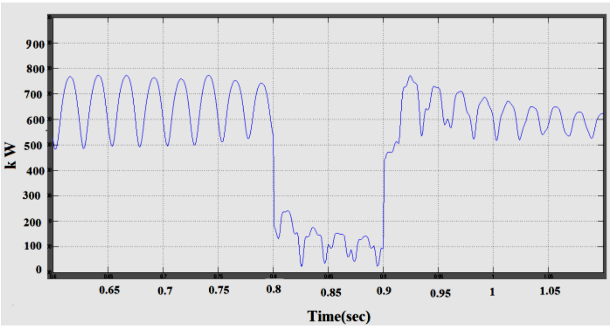

Fig 7.b Active Power

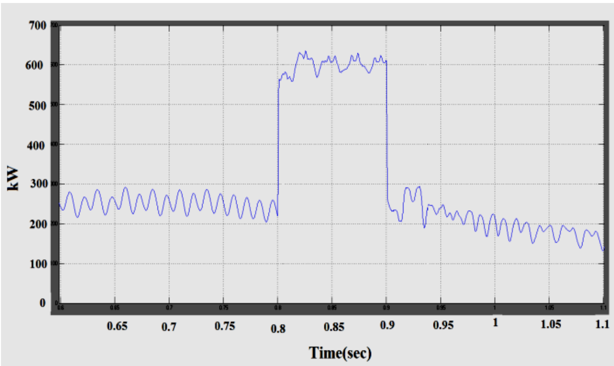

Fig 7.c Reactive Power

The capacitor voltage rise boost up the reactive power to compensate the active power. The magnitude of capacitor voltage and reactive power shows the statement above. During the period of voltage dip on the grid voltage the fed power of the generator increases the intermediate DC voltage level on the capacitor bank and it stabilizes the voltage without any overshooting.

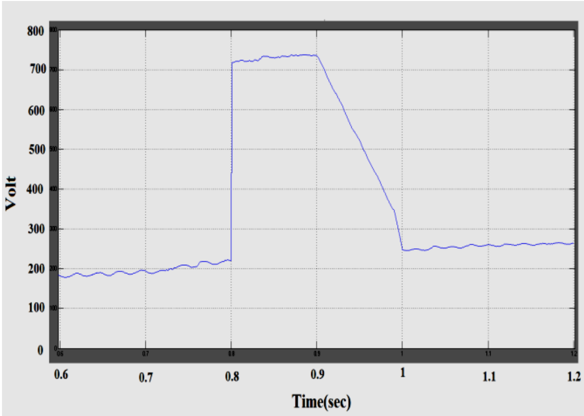

Fig 7.d Capacitor Voltage

VIII.CONCLUSION

This paper has focussed on the performance of the grid connected inverter and the effect of Smart grid operating conditions. The simulations includes the voltage dip due to short circuit on the distribution network and the results highly concentrated on the Over current elimination, grid voltage stabilization and reactive power exchange by GCIs performance using fuzzy logic is shown above.

The presented simulation results is all about the safety and smooth operation of the consumers on the smart grid due to the partly decentralized voltage control in whiles the GCI operation parameters have not exceeded the adjusted limits. The presented simulation results have been obtained by using MATLAB Sim power System tools.

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