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Application of synchronous frame Controller for Grid Connected and Islanding operation of Distributed Power Generation

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Abstract-- **This paper investigates with the design of synchronous reference frame control strategy also called DQ control, uses a reference frame transformation module for inverter-based Distributed generation systems. The SRF based compensation is developed by sensing, load currents. Using Reference Frame Transformation, the current is transformed from a-b-c stationary frame to Rotating d-q frame. Using the PI controller, the current in the d-q frame is controlled to get the desired reference signal. By means of this, the control variable becomes dc values. Then filtering and controlling can be easily achieved. The essence of the proposed control strategy is to use an SRF-PI controller to regulate the output voltage, to improve the system robustness. A detailed design procedure for the proposed control strategy is presented using the hybrid DG system. The potency of this control technique is illustrated using MATLAB simulation.**

***Index Terms*—** **Distribution generation, Phase locked loop, Point of common coupling, Grid connected operation, Islanding operation, synchronization.**

I. INTRODUCTION

During the grid connected mode of operation the distributed generation system is operated to inject power to the grid, which is a current control mode in a stiff synchronization with grid. This paper describes a control technique which is used to operate a grid connected system with interface to distributed generator. In the past few decades, there has been a sudden increase in the demand for electricity so we're employing renewable energy sources. While these sources connected to local loads and during grid interconnection they will cause some problems. So in order to recur these problems in micro grid technologies we are employing some control techniques. The mandatory task in energy generation is a high efficiency, thus the inverter strategy control must inject only active grid current, i.e. a pure sinusoidal current in phase with the grid voltage [1]. The issue is to provide zero steady state error in grid frequency and to this aim many control architectures have been presented in literature with the aim to overcome the simple PI controller drawbacks. The poor performance of the integral action at a particular frequency different from zero leads to steady state error and to poor disturbance rejection making the PI controller not suitable to track a sinusoidal reference. This paper proposes distribution generation system which is interconnected to the utility grid at the point of common coupling. The proposed distributed Generation consists of a Photovoltaic array which acts as a main generation unit. During non sunny days proton Exchange Membrane fuel cell works as a main generation unit.

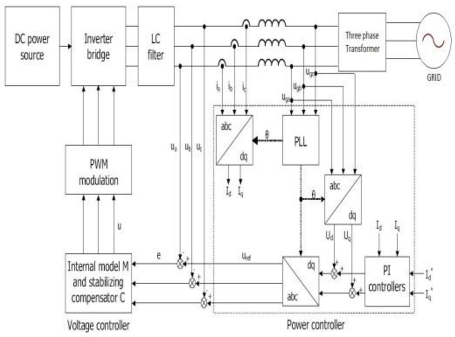

Fig.1. schematic diagram of grid-connected system

II.MATHEMATICAL MODELLING OF CONTROLLER CIRCUIT

The main circuit topology of the system contains a DG system that is represented with a DC source. The conversion circuit which is a transformation technique performs interfacing between DC bus and three phase AC system and filter which transfers and distributes power to the end user load. Thus, this control technique provides a constant DG power output and maintains stiff voltage at the point of common coupling (PCC).In grid connected operation the control technique [2] is intended to supply a constant current output .The angle difference of point of common coupling and frequency is

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determined by a phase locked loop (PLL).The PLL will carry out the grid synchronization.

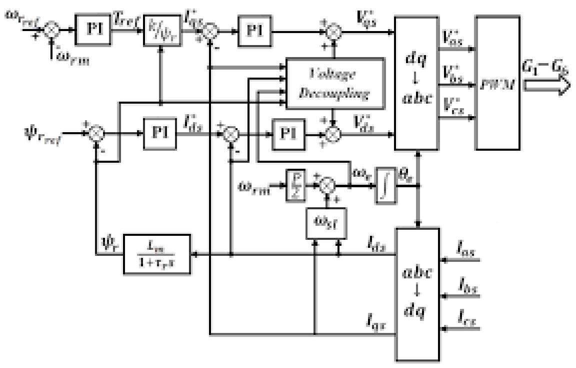

Fig.2. Block diagram of current controller for Grid connected mode

While using the current control the current output from the filter which is transformed into a synchronous frame by Park's transformation[3]. The DC quantity is regulated and feedback to compare reference current $I_{DQ\ ref}$.This particular process will generate an error in current signal and is passed to Integral controller [4] (PI controller). So that voltage references are generated by PI controller to the inverter. To get a dynamic response, V_{DQ} fed forward .This condition has to be occurring because the inverter terminal voltage is treated as a disturbance and in order to compensate this disturbance feed forward is used to compensate for input[5].

$$\begin{bmatrix} X_D \\ X_Q \\ X_0 \end{bmatrix} = \begin{pmatrix} -cos\theta & -\cos(\theta+2\pi/3) & -\cos(\theta-2\pi/3) \\ \sin\theta & \sin(\theta+2\pi/3) & \sin(\theta-2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{pmatrix} \times \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \quad (1)$$

Where θ= wt and w is the frequency of the electrical system.

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = \begin{pmatrix} -cos\theta & \sin\theta & 1/2 \\ -\cos(\theta-2\pi/3) & \sin(\theta-2\pi/3) & 1/2 \\ -\cos(\theta+2\pi/3) & \sin(\theta+2\pi/3) & 1/2 \end{pmatrix} \times \begin{bmatrix} X_D \\ X_Q \\ X_0 \end{bmatrix} \quad (2)$$

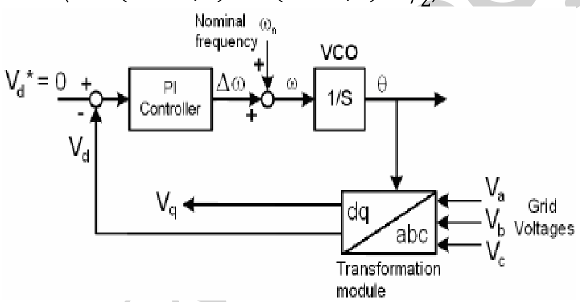

Fig.3. DQ-PLL Structure

The schematic of the DQ-PLL is shown in above fig.3.The DC quantities of $V_{DQ\ ref}$ are transformed into stationary frame by Inverse Park's Transformation (2) and are used as voltages for generating high frequency PWM voltages.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} 2/3 & 1/3 \\ 0 & 1/\sqrt{3} \end{bmatrix} \begin{bmatrix} V_{ab} \\ V_{bc} \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} V_D \\ V_Q \end{bmatrix} = \begin{bmatrix} -\cos\theta & \sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (4)$$

The DQ-PLL which consists of Clarke's transformation, the Park's transformation, a PI regulator, and an Integrator[6].

III. PHOTOVOLTAIC CELL

The photo voltaic array manufacturing is increasing in recent few years because of growth and a rise in demand for renewable energy sources.

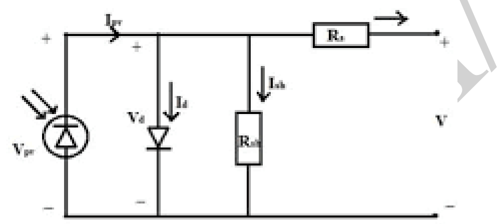

Fig 4: Single diode model of PV cell

Photo-voltaic is a term in which we can employ semiconductor materials, which has an in built capability i.e. photo voltaic effect. This concept is about the generation of electrical power by converting sunlight. In this Photo-voltaic system we incorporate solar panels which consist of no of solar cells to generate electricity [7]. The basic unit of photo voltaic array is the photovoltaic cell .The number of cells is connected in series and in parallel will form solar module. The group of module connected in series will form photo voltaic array. The photo voltaic cell single diode model is shown which consists of diode and current source. The current source is parallel to diode represents photo current and series resistance R_s and parallel resistance R_p .

$$I_{pv} = I_{ph}N_p - I_sN_p \left[\exp\left(\frac{q\left(V_{pv}+I_{pv}R_s\frac{N_s}{N_p}\right)}{aV_tN_s} \right) - 1 \right] - \left(\frac{q\left(V_{pv}+I_{pv}R_s\frac{N_s}{N_p}\right)}{R_P\frac{N_s}{N_p}} \right) \quad (5)$$

Where

I_0 is the diode's reverse saturation current

V_T is the diode's thermal voltage

a is the ideality factor of the diode

The equation of a PV current as a concomitant of changing environmental conditions, the temperature and irradiance can be written as

$$I_{ph} = [I_{sc} + K_1(T_c - T_{ref})]S/1000 \quad (6)$$

Where

I_{PV_STC} is the photocurrent under Standard Test Conditions (STC)

$\Delta T = T - T_{STC}$ (in Kelvin) and T_{STC}=25°C

G is the irradiance on the surface of the cell

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G_{STC} is the irradiance under STC (1000W/m²)

K_I is the short circuit current coefficient (generally provided by the manufacturer).

The equation for the saturation current of the diode is given as

$$I_s = I_{rs}(T_c/T_{ref})^3 \exp[qE_g(\frac{1}{T_{ref}} - \frac{1}{T_c})/KA \qquad (7)$$

Where

E_g is the energy gap of the semiconductor

I_{0_STC} is the nominal saturation current

The reverse saturation current equation can be further improved as a function of temperature as follows

$$I_0 = \frac{I_{sc}+K_I\Delta T}{\exp[(V_{oc}+K_V\Delta T)aV_T]-1} \qquad (8)$$

Where

K_V is the temperature coefficient of open circuit voltage

I_{SC_STC} is the nominal short circuit current

V_{OC_STC} is the nominal open circuit voltage

Modeling of photo voltaic array:-

The photo voltaic array is modeled from the above described expressions which are applicable for a single photo voltaic cell [8]. While interfacing photo voltaic system, photo voltaic cells are connected in series and parallel to rise current in the entire module interface.

In this condition the output equation is mentioned as

$$I_{pv} = I_{ph}N_p - I_sN_p\left[\exp\left(\frac{q\left(V_{pv}+I_{pv}R_s\frac{N_s}{N_p}\right)}{aV_tN_s}\right)-1\right]-\left(\frac{q\left(V_{pv}+I_{pv}R_s\frac{N_s}{N_p}\right)}{R_P\frac{N_s}{N_p}}\right) \qquad (9)$$

IV. PROTON EXCHANGE MEMBRANE FUEL CELL

Proton Exchange membrane fuel cell is familiarly called as polymer exchange membrane fuel cell. The fuel cell is a device which generates electricity through a chemical reaction. The fuel cell consists of two electrodes, one is positive and the other is negative, which are called as anode and cathode respectively. The electricity is produced by the reactions undergone at the electrodes.

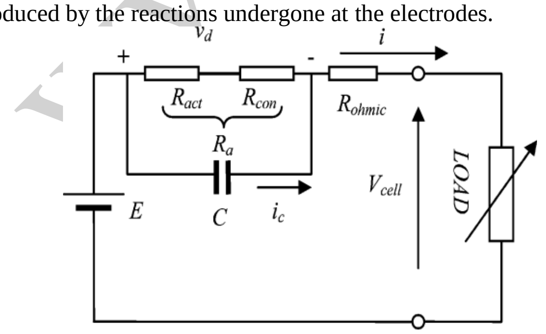

Fig 5: Equivalent circuit of PEMFC

When they combine anode or cathode together hydrogen and oxygen from water which drains from the cell as long as fuel cell is supplied with hydrogen and water it will generate electricity,

The single cell output voltage is expressed as

$$V_{cell}=E_{Nernst}-V_{act}-V_{ohmic}-V_{con} \qquad (10)$$

$$E_{Nernst}=\frac{1}{2F}\left(\Delta G - \Delta S(T-T_{ref}) + RT\left(lnP_{H_2}+\frac{lnP_{O_2}}{2}\right)\right) \qquad (11)$$

In proton exchange membrane fuel cell the activation loss is occurring due to the kinetic reaction takes place in surface electrodes and is explained as

$$co_2=\frac{po_2}{5.08*10^6 exp^{(-\frac{498}{T})}} \qquad (12)$$

In this specific model proton exchange membrane fuel cell. The Ohmic loss contains a voltage drop which is caused by Rm. i.e. the equivalent impedance[9]. The additional voltage drop caused by Rc both the contact resistances (Rm and Rc)of the membrane impedances and the additional voltage drop caused by Rc, both the constant resistances of membrane electrodes and as bipolar plate electrodes meanwhile the cell is fabricated the resistance is constant it is shown as

$$V_{ohmic}=iR_{ohmic}=i(R_m+R_C) \qquad (13)$$

The Rm equivalent membrane impedance is calculated with reference to ohm law

$$R_M=\frac{r_{ml}}{A} \qquad (14)$$

The NAF ion series Proton exchange membrane resistivity r_m is expressed as

$$r_m=\frac{181.6[1+0.03(i/A)+0.062(T/303)2(i/A)2.5]}{[\lambda-0.634-3(\frac{i}{A})]\exp[4.18\{\frac{T-303}{T}\}]} \qquad (15)$$

Table-1 Parameters of the Pemfc Dynamic model

parameters	value	parameters	value
N	20	ξ_1	-0.9514
T(K)	323	ξ_2	0.00312
P_{H_2}	0.5	ξ_3	7.4*10^-5
P_{O_2}	0.5	ξ_4	-1.87*10
ΔG	237180	$l(\mu m)$	51
A(cm²)	150	λ	20
$\Delta S(mol)$	-163.15	B(V)	0.016
T_{ref}	298.15	C(F)	2.5
F(C/mol)	96486.7	J_{max}(A/cm²)	1.5
R(J/mol K)	8.314	Rcm²)	3*10^-4

Where λ water content of membrane this parameter can be adjusted and a function of relative humidity of gas in anode and has a stoichiometric value.In this model, the concentration loss effect is also mentioned. This concentration loss is occurred due to mass transportation,which turns out and this effect will be held on concentration of H2 and O2 at a particular high current density. The

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particular concept is ignored or missed in some specific fuel cell modules. If the fuel cell stack is instructed to operate at the full end of high current density. This concept has to be subjected to,be subjected as concentration loss and is calculated as

$$V_{con}=B \ln (1-\frac{J}{Jmax}) \quad (16)$$

$$V_{act}=\xi_1+\xi_2 T+\xi_3 T[\ln(C_{O_2})]+ \xi_4 T[\ln(i)] \quad (17)$$

The charge double layer at the surface of the PEM fuel cell cathode and a simple equivalent circuit model of PEMFC which has an electrical capacitor which is considered as layer of charge which is used to store energy.

V. RESULTS of SIMULINK CIRCUITS

The Grid connected system is simulated in MATLAB/SIMULINK using Simpower system tool kits. The overall simulated circuit for grid connected operation of distributed generation is mentioned in Fig 6.

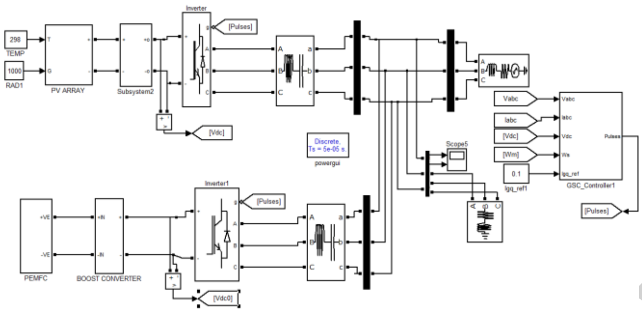


Fig 6. Grid connected Distributed generation system

The synchronous frame controller performance of grid connected system is described below in Fig 7.

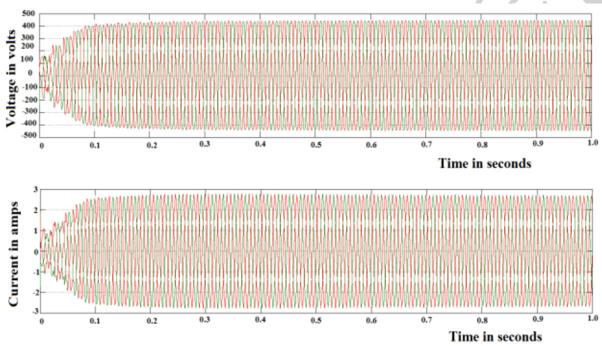


Fig 7. Grid voltage and current waveform

The synchronous frame controller performance is observed under grid connected mode and islanding mode of operation. The simulated circuit for Islanding mode of operation is described below in Fig 8.

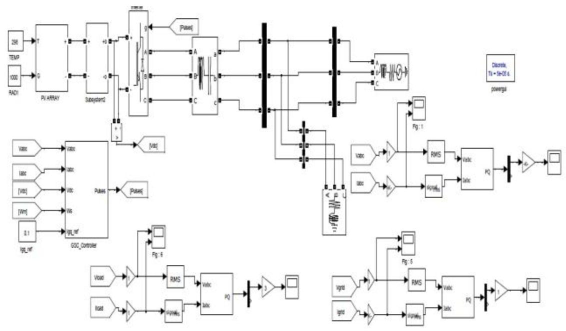
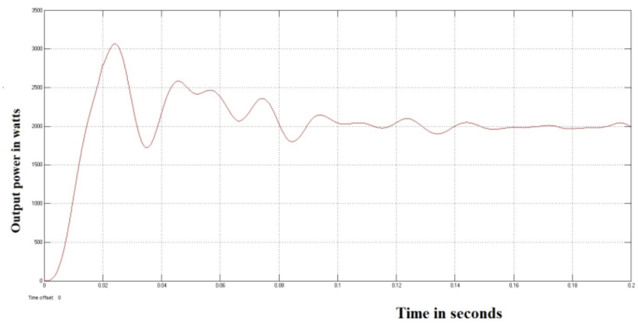
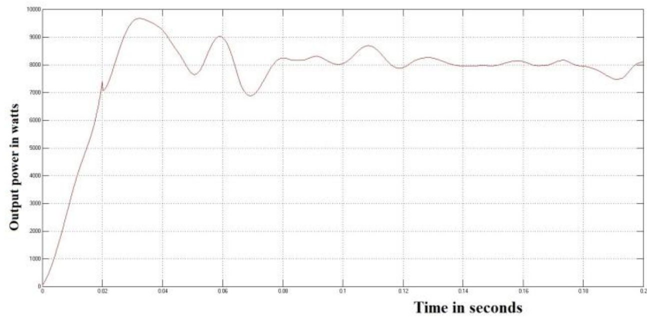


Fig 8. Islanding operation of Distributed generation

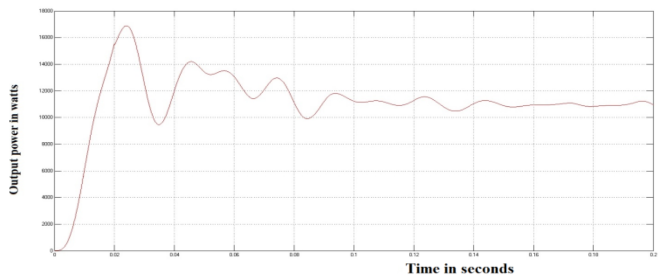
The Islanding operation performance with the synchronous frame controller is described in the below characteristics. The behavior of active and reactive power in the line, load side and grid connected side of the Distributed generation shown in Fig 9.



(a)



(b)



(c)

Fig 9. Synchronous frame controller performance during islanding operation (a) line side (b) load side(c) Grid side output power waveforms.

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VI. CONCLUSIONS

In the present paper, the performance of synchronous frame controller for grid connected operation and Islanding mode of operation has been analyzed for the distributed generation system. In the future use of this specific model, multi agent applications can be used developed such that it can provide intelligence to the model. The control of distributed generation system in a simulated environment for various fault conditions can be developed with multi agent systems.

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