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Fuzzy Model Predictive Control for Grid Tied Inverter with Multiport Renewable Energy Systems

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Abstract*: The paper presence a Fuzzy Model Predictive Control (FMPC) for grid tied inverter with multiport DC-DC converter. Three phase grid tied inverter with multiple renewable energy sources are widely used to connect the distributive generating systems to the utility grid. Compare with the conventional control schemes, FMPC scheme is suitable for distributed generation system for its unique advantages likes reliable, fast and more accurate. In this proposed system, different sources having nonlinear parameters and it's controlled by Fuzzy system. All linear states of three phase grid connected inverters are tested to attain the control objectives. FMPC is proposed to reduce the Total Harmonic Distortion (THD) of the output power. In the proposed system, the inverter control algorithm is developed using some essential vectors. The aim is to monitor the three phase grid current stability and improve the constancy function of the grid-tied inverter during variation of grid voltage. The grid tied converter is designed in two phase standing vector (αβ)model, and the FMPC of grid tied inverter is realized during variation of grid voltage. The simulation results show the superiority of the FMPC in control strategy.

Keywords: Fuzzy model predictive controller, grid connected converter, multiport DC-DC converter.

I. INTRODUCTION

Advancement of the world civilisation, usages of electrical power increasing day by days. Usages of fossil fuels to generate electrical energy leads the society for many harmful effects like global warming and etc., now, we are in position to find alternate energy sources for fossil fuels.Photovoltic and Fuel Cell technologies are leads to alternate energy solution for conventional system because of its advantages. Most of the renewable energy system generates electrical energy in the farm of Direct Current (DC). High efficiency DC-DC converter with Multiport is designed for handling energy management between different energy sources [1-2].DC supply system is not used in domestic and commercial applications, because of its undesirable factors in transmission, distribution and utilisation. Electrical system in the farm of Alternating Current (AC) is used in domestic and commercial applications. Grid connected system is used to interconnect all the electric source and load in common system. Grid connected Inverter (GCI) is used to interface DC Sources to Grid.

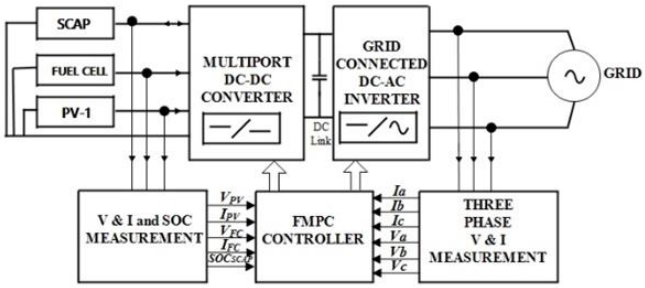

Fig.1 Block Diagram of Proposed Control System

The power grid voltage, current and power requirements are not continuously stable and balanced, and the GCI is frequently disturbed by voltage and current faults, harmonics and etc., hence to compensate the inverters used in grid connected system from grid balance on the converters. Once the voltage of the grid is asymmetrical, the destructive sequence components are showed in the current and voltage of the grid system, Caused by negative sequence components, generated twice the fundamental frequency of ripples of active and reactive power, Consequncely generates undesirable 3rdharmonic [3], the current control loop is preferred from voltage source inverters. The converter performance is improved by the current loop control strategy [4]. Paper [5] projected a proportional–integral (PI) regulator based on the positive sequence current controller to switch the current in both of the direct and quadratic axis (dq axis) in the same time the Synchronously Rotating Reference (SRF) frame. Paper [6] proposed a dual current control method using PI controller under positive and negative phase sequence, and SFR frame is considered to control the positive and negative sequence module respectively. However, the control system with the two-phase (d-axis and q-axis) synchronous rotating manage system is based on complex coordinate transformation system, same time, the current and voltage direction decomposition of negative and positive sequence components produces delay, bringing a few poor management execution in positive and negative arrangement of twin synchronous rotation. Additionally, it's laborious to switch the parameters of the PI controller, which may simply result in unpredictability of the system. Furthermore Fuzzy based system to control nonlinear parameter variation is considered for PV fed grid connected system [7]. Classical method and other control techniques are very fit for linear parameter variations system.

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Model predictive control (MPC) method is proposed in this paper [8].

The Proposed method can gross all the connectivity and smooth operation issues in grid connected system is solved with good dynamic performance, it's been broadly speaking used and accepted methodology in power electronic converters management technology. The diagram of FMPC is shown in Figure-1.FmPC theme conjointly significantly cut back switch frequency, switch losses and considerably increasing potency of the convertor systems, during which it's chiefly utilized in high power electronic converters. MPC will be divided into 2 classes, they're Finite management Set MPC (FCS-MPC) and Continuous management Set MPC (CCS-MPC),FCS-MPC method has advantages of CCS-MPC , FCS-MPC is directly consider the discrete characteristics of the system and improve the system intuitively and suitably, and also decomposing the positive and negative sequence the complicated coordinate transformation is based on its two-phase stationary (αβ), which has easy to control system and make simple and advanced in this proposed system, a control strategy of Grid tied inverter is under unpredictable and unbalanced grid parameters likes voltage and current condition, FCS-MPC control method is considered. The proposed FCS-MPC is used in this paper having good dynamic characteristics, Reduce switching frequency, Increase the efficiency of the converter and hold the system in stable region during transient grid parameter circumstances.

To start with, the Mathematical model of the Grid tied Inverter is developed in this paper, and the mathematical model of the multiport converter is concluded throughthe target of supervisory of the matrix associated present. In every examining historical, the present blunder the following point is evaluated by the esteem work, then the exchanging state that limit the present mistake is chosen straightforwardly, so as to dispense with the impact of deferral, a two-advance expectation technique is embraced.

II. MODELLING OF THE GRID CONNECTED INVERTER

In figure 2, a pair of is that the topology graph of the Grid Connected electrical Inverter (GCI), Udc is that the dc side bus voltage, C is that the dc side capacitor, ua, ub, uc, are the inverter grid side voltages, ia, ib, ic, are the inverter grid side current or feeding current flows, L is that the smoothing inductor , R is that the current limiting resisterand ea, eb, ec, are matrix voltages

$$u_{abc} = \frac{di_{abc}}{dt} + Ri_{abc} + e_{ab} \qquad (1)$$

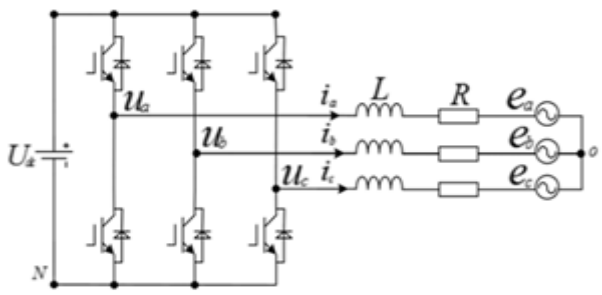

Fig.2 Grid Connected Inverter

In equations

$$e_{abc} = [e_a e_b e_c]^T, u_{abc} = [u_a u_b u_c]^T, i_{abc} = [i_a i_b i_c]^T$$

The output side voltage of three-stage GCI can be communicated as

$$u_k = S_k U_{dc} + u_{No} (k = a, b, c) \qquad (2)$$

where the sk is to the transmission condition of the relating span legmodification, when the greaterleg is open sk = 1, when the lower leg arm is open sk = 0.The voltage across the grid tied phase and neutral is expresses in following equation (3)

$$u_{No} = -\frac{(S_a + S_b + S_c)U_{dc}}{3} \qquad (3)$$

The recipe (3) is relieved to (2)

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2s_a & -s_b & -s_c \\ 2s_b & -s_a & -s_c \\ 2s_c & -s_a & -s_b \end{bmatrix} U_{dc} \qquad (4)$$

The numerical model of three-phase and six active vector voltage Grid tied inverter from a three phase stationary vector (abc) to a two-stage stationary vector (αβ)model is derived, and the three vector and two vector model is shown in Figure. 3.Θ is the angle between quadrature axis and direct axis voltage.

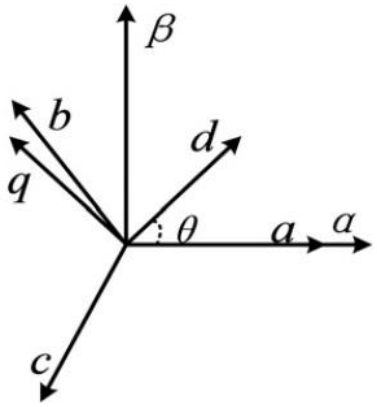

Fig.3The Vector relationship between Main three phase Vector (abc), Decomposed two vector (αβ) and direct and quadratic axis synchronous reference frame (dq).

Also, the θ represented in Figure. 2 is the angle betweentwo vector and three vector model.Among the an axis in three-stage static organize system and d-pivot in two-stage synchronous turning manage framework. In this paper, a proportionate facilitate alterationis utilized, the change grid Tαβ is communicated as pursues:

$$T_{\alpha\beta} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \qquad (5)$$

The scientific model of the grid tied inverter in the two vector stationary model and the equation is represented in equation (6) is gotten by increasing (1) together the privilege and contribute the reduction of THD the organize change network Tαβ

$$T\alpha\beta.u_{abc} = T\alpha\beta.e_{abc} + T\alpha\beta.L\frac{di_{abc}}{dt} + T\alpha\beta.Ri_{abc} \quad (6)$$

$$u_{\alpha\beta} = e_{\alpha\beta} + L\frac{di_{\alpha\beta}}{dt} + Ri_{\alpha\beta}$$

In this equations eαβ = [eα eβ]T is the two vector stationary frame voltage ,uαβ = [uα u β]T is the three phase grid tied inverter two vector stationary frame grid side inverter output voltage, iαβ = [iα I β]T is the three phase grid tied inverter two vector stationary frame grid side inverter output current.

During unbalanced grid parameters likes voltage and current, the inverter produces a negative sequence components, the vector form of produced negative sequence can be writting as

$$e_{\alpha\beta} = e_{\alpha\beta+} + e_{\alpha\beta-} = e^{+}_{dq+}e^{j\omega 1t} + e^{-}_{dq-}e^{-j\omega_1 t}$$
$$u_{\alpha\beta} = u_{\alpha\beta+} + u_{\alpha\beta-} = u^{+}_{dq+}u^{j\omega 1t} + u^{-}_{dq-}e^{-j\omega_1 t}$$
$$i_{\alpha\beta} = i_{\alpha\beta+} + i_{\alpha\beta-} = i^{+}_{dq+}i^{j\omega 1t} + i^{-}_{dq-}e^{-j\omega_1 t}$$

During symmetrical grid voltage , inverter grid side voltage and feeding current is produces -ve sequence components, the output 3 phase output current will be unbalanced, the active power, reactive power and input dc link voltages are generates harmonics frequency. The frequency of generated harmonics frequency is twice the fundamental frequency.Unfortunately third harmonics is generated and its affect the performance of grid tied inverter. During unbalanced grid voltage, Need proper control strategies to eliminate third harmonics presented in inverter output power.

III. FMPCCONTROLLER FOR GCI

Unbalanced grid voltage and currents are affect the stable performance of the grid connected inverter. Model predictive controller is used for linear variation of system parameters. The output voltage is varying linear form and its controlled by model predictive controller. The Magnitude of DC link voltage is depends on the environmental conditions, State of Charge (SOC) of battery and super capacitor. The parameters fixed the DC Link voltages are Non-linear and suitable control techniques are needed to solve the unfavourable issues in input side. Fuzzy system is preferred to enhance the system performance in input side. The control strategies of the grid connected inverter can be performed as step by step instructions to choose the suitable sampling signal s(t) with the controller reach the system tuning variable x(t) of the controller framework is as close as achievable to the reference variable x*(t). FMPC is considering every linear and nonlinear parameters of the system. FMPC is forecasting and select the likely values for the following period structure variable x(t) and concluded the founding the estimated system equation, Uses of a value functions of the system, compared the forecast value x(t) and reference value x*(t) for choose the grid tied inverter switching sequences to eliminate the undesirable parameters variation in system outputs.

Grid connected inverter mathematical model with two phase coordinates system with single inductor L and filter are represented in equation (6).To effective implementation of controller with digital processor discrete mathematical model is derived and its shown in equation (7).

$$u_{\alpha\beta}(k) = u_{\alpha\beta}(k) + \frac{L}{T_s}\left(i_{\alpha\beta}(k+1) - i_{\alpha\beta}(k)\right) + Ri_{\alpha\beta}(k) \quad (7)$$

Whenevera current forecasted data is

$$i_{\alpha\beta}(k+1) = \left(1 - \frac{T_s}{L}R\right)i_{\alpha\beta}(K) + \frac{T_s}{L}\left(u_{\alpha\beta}(k) - e_{\alpha\beta}(k)\right) \quad (8)$$

In the recipe, Ts is the discrete testing time frame, iαβ(k) is the conveter yield current vector at k snapshot of two-stage stationary co-ordinate, eαβ(k) is lattice voltage vector at k snapshot of two-stage stationary organize, uαβ(k) is converter yield voltage vector at k snapshot of two-stage stationary organize. eαβ(k) and iαβ(k) can be acquired from the testing signals through arrange trans-development, and the uαβ(k) should be determined by the converter adjustment state and dc voltage.

By equation (4), uαβ can be signified as

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = T_{\alpha\beta}\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2s_a & -s_b & -s_c \\ \sqrt{3} & (s_b - s_c) & . \end{bmatrix} U_{dc} \quad (9)$$

The articuation can be called

$$u_{\alpha\beta} = s_k u_{dc} \quad (10)$$

In conditions, Sk = [sa sb sc].

There are 8 converting vectors for the 2-level GCC: S∈{000… 111}, each changing state relates near a yield voltage vector of GCC. At the beat of k, the dc side voltage is udc(k). what's more, the lattice voltage is e(k). By methods for (8), the 8 sorts of yield current i(k + 1) at the k + 1 beat of the GCC can be gotten comparing to the 8 exchanging conditions. Next, an improvement work is expected to choose the ideal exchanging vector state.

The improvement capacity of current following for GCI is

$$J = \left|i^{*}_{\alpha}(k+1) - i_{\alpha}(k+1)\right| + \left|i^{*}_{\beta}(k+1) - i_{\beta}(k+1)\right| \quad (11)$$

In the recipe, J is the present blunder, i∗a (k + 1) and i∗b (k + 1) are the present place an incentive for k + 1 beat,

With ascertaining the eight sorts of yield current at the k + 1 beat comparing to the eight exchanging states, the relating current blunder in individuallychange state is gotten through utilizing the improvement capacity, after that the ideal switch vector which brands the present mistake J least is chosen to produce the wave. For each examining period, the 8 changing states need to parchment after to choose the ideal exchanging vector Sk.

Because of the attributes of computerized signal processor (DSP) advanced usage, when the previously declared single step prescient control figures the k time exchanging vector, it can't be performed promptly at the k minute, and it requirements to hold up until the k + 1 beat to be performed, along these lines producing a beat postponement, and influencing the framework control execution. So as to wipe out the postponement, two-advance prescient control can be embraced, that is, the exchanging vector at the k + 1 minute is anticipated at the k minute.

In the first place, the forecast current for k + 1 weary is gotten from the pre-lingual authority condition (8)

$$i_{\alpha\beta}(k+1) = \left(1 - \frac{T_s}{L}R\right)i_{\alpha\beta}(k) + \frac{T_s}{L}\left(s_k u_{dc}(k) - e_{\alpha\beta}(k)\right) \quad (12)$$

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In conditions, Sk is the exchanging vector at the k minute. The current prescient incentive for k + 2 beat is additionally gotten by the present expectation condition of equation (12)

$$i_{\alpha\beta}(k+2) = \left(1 - \frac{T_s}{L}R\right) i_{\alpha\beta}(k+1) + \frac{T_s}{L}\left(s_k v_{dc}(k+1) - e_{\alpha\beta}(k+1)\right) \quad (13)$$

As the dc side voltage is enduring steady amount, this varieties Udc(k + 1)≈Udc(k), the matrix voltage amid the testing time frame can be viewed as direct alteration [8], so lattice voltage at k + 1 minute can be communicated as pursues:

$$e_{\alpha\beta}(k+1) = e_{\alpha\beta}(k) + \left(e_{\alpha\beta}(k) - e_{\alpha\beta}(k-1)\right)$$
$$= 2e_{\alpha\beta}(k) - e_{\alpha\beta}(k-1) \quad (14)$$

At last, the current prescient incentive for the k + 2 beat is conveyed into the enhancement work appeared in the accompanying model, and the ideal exchanging vector esteem is gotten by moving improvement

$$J = \left|i_\alpha^*(k+2) - i_\alpha(k+2)\right| + \left|i_\beta^*(k+2) - i_\beta(k+2)\right| \quad (15)$$

It will be multiple epochs expectation in the upstairs anticipated current procedure amid every retro, so it increment the computation of prescient control as well as increment the converter exchanging misfortune. One of the real preferences of MPC is that the exchanging recurrence is low and this preferred position is utilized at whatever point conceivable, in this manuscript, an improved vector choice plan dependent on report [9] is utilized, as appeared in Fig. 3, that is, the point at which the exchanging vector of the past period is zero, the switch can be changed to any non-zero vector; when the last time of the exchanging vector is non-zero, the change must be changed to its adjoining vector. Along these lines, in the exchanging procedure of non-zero vectors, there is just a single exchanging state all things considered in each cycle, and the other two exchanging states are clasped to accomplish the motivation behind lessening the exchanging recurrence.

The current prescient control technique of GCC is presented in feature, and after that we will disclose how to decide the present reference esteem. So as to have the option to brand free dynamic and re-dynamic power decoupling control, we straightforwardly compute the dynamic present and receptive current reference an incentive on the synchronous indication outline situated to framework voltage, which can separately, control the dynamic power and responsive power by dynamic and receptive current. We realize that under lopsided network voltage circumstances, the current can be deteriorated into the +ve grouping part i*dq+ in the +ve succession synchronous turning co-ordinate framework and negative arrangement segment i*dq− in the negative arrangement synchronous pivoting coordinate framework, so the information estimation of the enhancement work in the two-stage stationary facilitate framework ought to be for the control unprejudiced is to wipe out the negative arrangement segment of the yield existing, that implies i*dq− = 0, so it just ought to compute the obligatory positive grouping present as per the estimation of the dynamic as well as the responsive power required.

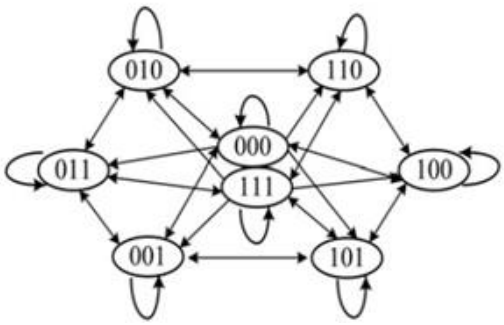

Fig.3 Switching Function Optimization

$$\begin{cases} i_\alpha = i_{\alpha^+} + i_{\alpha^-} = \left(i_{d^+}\cos\theta - i_{q^+}\sin\theta\right) + \left(i_{d^-}\cos\theta + i_{q^-}\sin\theta\right) \\ i_\beta = i_{\beta^+} + i_{\beta^-} = \left(i_{d^+}\sin\theta + i_{q^+}\cos\theta\right) + \left(-i_{d^-}\sin\theta + i_{q^-}\cos\theta\right). \end{cases} \quad (16)$$

Amid the DSP computerized discrete acknowledgment function, the model dynamic and receptive present qualities i*d(k) and i*q(k) are mentioned as an incentive for k beat, yet the current necessary in the advance expectation are k + 2 beat existing. In this article, the principal request straight expectation strategy is utilized to acquire the present reference an incentive for k + 2 beat

$$\begin{cases} i_d^*(k+2) = 3i_d^*(k) - 2i_d^*(k-1) \\ i_q^*(k+2) = 3i_q^*(k) - 2i_q^*(k-1) \end{cases} \quad (17)$$

The real reference an incentive in the two-stage stationary arrange framework ought to be

$$\begin{cases} i_\alpha^*(k+2) = i_{d+}^*(k+2)\cos(\theta) - i_{q+}^*(k+2)\sin(\theta) \\ i_\beta^*(k+2) = i_{d+}^*(k+2)\sin(\theta) + i_{q+}^*(k+2)\cos(\theta) \end{cases} \quad (18)$$

when the negative benchmarked current esteem is zero.

In conditions, θ is the point among the a-pivot in three-stage static facilitate framework and d-hub in two-stage synchronous turning co-ordinate framework as appeared in Fig. 2.

Finally, the present reference esteem is contrasted and the current prescient incentive in streamlining capacity design to discover the converter yield voltage vector which can limit the present mistake, with the goal that the following of the reference current esteem can be accomplished.

IV. PROPOSED PARTIALLY DISCONNECTED MULTIPORT CONVERTER

Proposed somewhat disconnected staggered converter appeared in Fig.- 2. Sources and capacity gadgets are associated in essential of high recurrence transformer. Burden is associated auxiliary of transformer through DC connection and three stage inverter. Transformers center is made by ferrite centre. The turns radio of transformer is characterized by n=Ns/Np, where Ns is number of optional turns and Np is number of essential turns. Essential side of transformer having cushion capacitor (CB is much of the time charged and released for make bi directional current stream in essential of the transformer. Decoupling capacitor (Cs) is associated over the capacity gadgets to dodge voltage variance. Sources and Super capacitor are associated with essential of transformer through inductor (L1,L2 and L3),

Reverse blocking diode (D1,D2 and D3) are associated arrangement with sources and Supercacitor to limit turn around power stream to sourses and capacity gadgets. The switch Ss and Sf and Ssd are control sources and super capacitor. The switch Ssc is utilized to charge the super capacitor. It is shown in figure 4.

Table 1 Source and heap of every mode

Mode	Source	Load
Mode-1	Photovoltaic	Grid
Mode-2	Photovoltaic and Fuel Cell	Grid
Mode-3	Photovoltaic, Fuel Cell and Super capacitor	Grid
Mode-4	Photovoltaic, Fuel Cell	Super capacitor and Grid

The proposed converter has five working modes. Source and heap of every mode is recorded in table-1.Each mode having two phase of activities, During Stage-I source

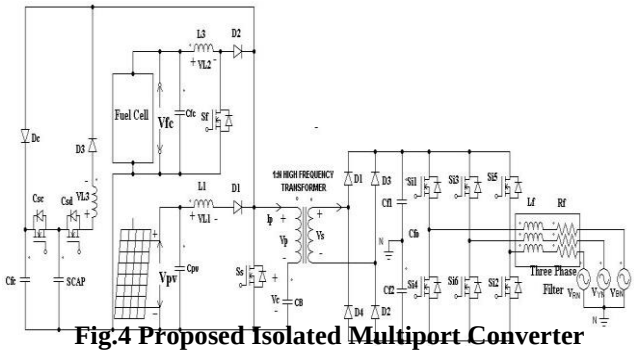

Fig.4 Proposed Isolated Multiport Converter

(PV, Battery and SCAP) vitality is put away in separate inductor and support capacitor CB is released through essential of the transformer. VP is negative and equivalent to VCB, Energy put away in CB is exchanged to stack. At the point when the converter in Stage-II tasks, sources are associated with essential of transformer through lift inductor and support capacitor CB. Voltage crosswise over transformer essential (VP) and optional (VS) are certain. One segment of vitality is exchanged to stack and remaining vitality is put away in cradle capacitor CB. Figure 3 shows exchanging examples of every mode with various states.

V. RESULT AND DISCUSSION

Matlab simulation is carried out to validate performance of the proposed system.The developed Matlab model is shown in Figure 5.

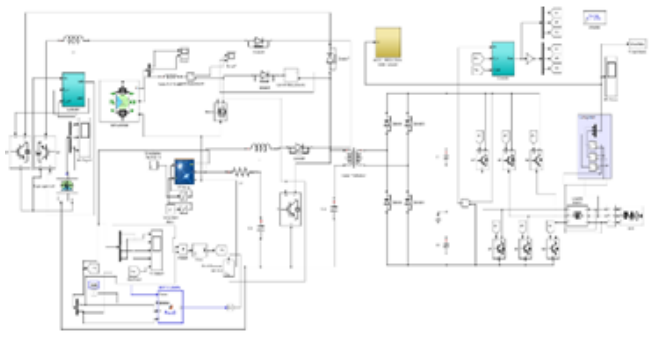

Fig.5 Matlab Simulation diagram of Proposed System

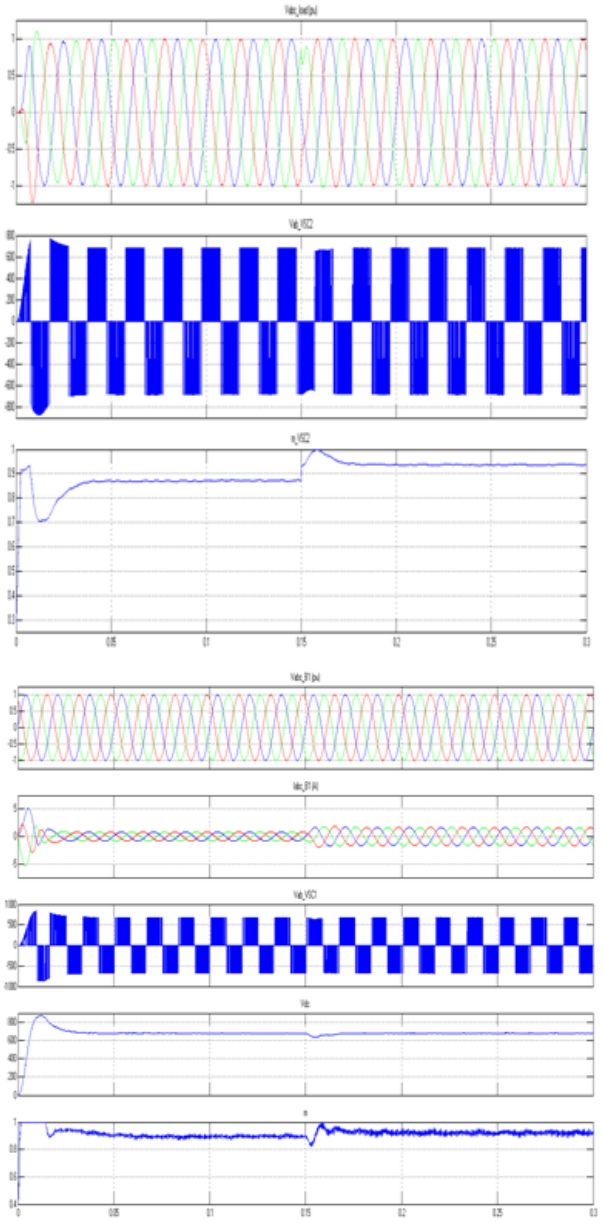

Fig.6 Simulation Result of Grid Connected System

The proposed control method is Implemented using Atmega328 processor. Reduced rated system is developed to validate the system. So as to approve the practicality of the suggested methodology and plot the system. A recreation design of three stage network associated PWM voltage supply converter manage framework is based on Matlab/Simulink. The Grid tied inverter is evaluated at 1kW for circuit considerations utilized in the reproduction are shown in Table 1, in re-enactment the time period dc interface voltage of the converter was placed at 650 V, the framework region line voltage is appraised at 380 V and frequency 50 Hz, the voltage is following of the A stage is settle onto 1.2 p.u. at the point when the matrix is uneven, and the asymmetry of the network voltage. The Total Harmonics Distortion (THD) of the system is less than 6%.

VI. CONCLUSION

This paper suggested a current forecasting monitor methodology for three-stage two-level grid connected inverter with multiport DC-DC converter. The control method developed based on Fuzzy Model Predictive Controller (FMPC), in order to reduce the undesirable factors due to harmonics and load variations of the grid unbalance of the system, the proposed control method is ensure the three phase grid tied inverter and grid current is sinusoidal and balanced. The Matlab simulation results show the superiority of the future controller method. The performance of the developed control method is certify the good tracking ability of the grid current variations and also reach fast dynamic response with good steady state operating performance.

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