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Novel Control Scheme for Renewable Energy SourcesIntegrated with the Three Phase Grid System

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ABSTRACT-This work is composed of PV, battery and wind hybrid system integrated with three phase ac grid system through a three-phase inverter which is controlled by a combined deadbeat PI controller and switched pulse width modulation (SPWM) switching. The controller is used to pure sinusoidal output voltage in the light of low harmonic distortion even if variation occurs in the input of PV and wind hybrid system-the output voltage remains constant.Controller regulates voltageby keeping constant 415 line to line and 239 phase to ground rms voltage along with less than 2% hormonic distortions with constant 50 hertz frequency even if the load is changing. The proposed controller attributed of stiffness and robustness characteristic to maintain output voltage at desired value and low harmonics.

KEYWORDS: Photovoltaic, Wind turbine, Battery, three- phase inverter, Deadbeat based PI controller

I. INTRODUCTION

Constant growth in the world population requires more energy for consumption. Conventional sources of energy like coal, fuel and gas are environmentally hazardous with limited sources, to counter these drawbacks, replacing of them with eco-friendly and available in abundant sources of energy like solar and wind are highly recommended. Intermittent nature of each, solar and wind energy is considered as a great disadvantage of mentioned sources to compensate this effect a hybrid system of PV and wind is modeled. IEEE Standard 519- 1992 recommends total harmonic distortion (THD) should not cross 5% in industry, harmonic control, interconnection setup and safety standards are suggested by IEEE 1547 along with efficient work of inverter[1].

There are many methods for decreasing voltage distortion in the output. Fixed LC compensator is one of them which the design is used for minimizing total harmonic distortion, an optimized way for maintaining power factor (PF) at desired value.For removing harmonics from the system due to connecting nonlinear load in the output of inverter the hybrid of active power filter in series or series and shunt compensation is employed. Somehow using filters and shunt reactive compensation cause distortion in voltage and intensify current harmonic in the input side of the system. Overload in the tools and power factor degradation are the greatest disadvantages of using combined source harmonics and capacitive compensators. Due to commutation in higher frequency increase in losses of extra switching and higher order harmonics noise are the main drawbacks of pulse modulation of two level in series active filter. Repetitive control strategy requires precise value in designing otherwise downgraded fast dynamic response and narrow operating stability will be the outcome of this method. The repetitive control of odd harmonic also has disadvantages-the event harmonic residues spike in the tracking error. Meanwhile, uncertainty issue can be solved by control of sliding mode but the problem with this strategy is that when the hardware is implemented it causes chattering problem in turn causes of high wear of mechanical moving parts[1]. Memory accessibility of microcontroller is a great challenge when PWM harmonics elimination and fuzzy system control is lunched. Robust optimization is used to model load uncertainty while stochastic method is used to model other uncertainties [2].

Pulse width modulation based on state

space vector has been used for current control of interface circuit three-phase inverter system. The controller technique integrates tracking constant voltage of variable power in PV and PI current controller of SVPWM in the AC grid, the limitation with this technique is that it needs complicated mathematics modeling for bulk system[3].Prediction abilities and teaching mechanism of predication engine which is formed of multi-stage neural network is achieved using intelligent algorithm. Techniques in hybrid system predication is composed of novel feature selection strategy and engine based sophisticated method prediction as explained in [4]. Characteristics of precision and capability boosting which obtained by new intelligent algorithm are considered during parameters selection of prediction engine [5].In order to minimize emission and operation cost for load profile, management of load during peak time is employed [6]. To handle the pool market price uncertainty, it is suggested to use the information gap decision theory [7].

Time response is slow when four numbers of PI controller are used in a p-q control scheme[8]. Phase locked loop (PLL) output is not correct and invalid for three-phase with neutral and single-phase system[9]. If the loads are nonlinear, harmonics suppression is not obtained fully. The current spikes in a transient condition[10]. A great number of filters inductance in nature is necessary to filter out the harmonics in the converter, the compensator reactive power capability will be decreased[11]. The unique characteristic of Deadbeat based PI controller is providing fast dynamic response in digital implementation and capability of minimizing variable error in a defined number of sampling steps[12].

Producing pure sinusoidal output voltage with limited low THD and control technique for fast dynamic response are the motivation of this work. So, for the hybrid system dead-based PI controller with SPWM switching control scheme is modelled and used to regulate output voltage in the ac grid. Hybrid of Solar and wind system each with capacity of (1 kw) are combined with integrated battery and VI controller fed the dc bus, from the dc bus through a three-phase inverter the ac grid is fed. The controller regulates output voltage and frequency as of three-phase grid system if there are any changes in input (i.e., wind speed, irradiation, temperature) or in the load. The controller proves its robustness and excellent dynamic and static characteristics.

In previous research work, the inverter is used inthe distributed generation system is for single phase grid-connectedapplicationbut,theinvestigation of the three-phase grid-connected application is lacking. This work investigates the behavior of a deadbeat PI controller for a three-phase inverter system which is connected to a three-phase ac grid system.Producing pure sinusoidal output voltage with limited low THD and control technique for fast dynamic response are the main objective of this work. In the current work the SPWM along with deadbeat PI controller is designed for hybrid wind system(1kw) and PV system (1kw) is integrated with a battery to feed a dc bus and connected to three phase ac grid through a three-phase inverter system. The controller regulates voltage and frequency if any variation occurs in temperature of wind speed. The control technique also has robustness and excellent static and dynamic characteristics.

II. PROPOSED SYSTEM

In the proposed system PV array through a dc-to-dc converter and the wind turbine via ac-dc rectifier connected to a dc bus in hybrid with VI battery through a bidirectional converter connected to dc bus. DC bus feed AC bus through a three-phase inverter which is controlled by combination of SPWM switching and deadbeat PI controller to make output voltage pure with low harmonic distortion even if there is change in sun irradiance or temperature and variation in the speed of wind, the output remains constant. Figure1 shows the schematic diagram for proposed system which is connected to the three phase AC grid.

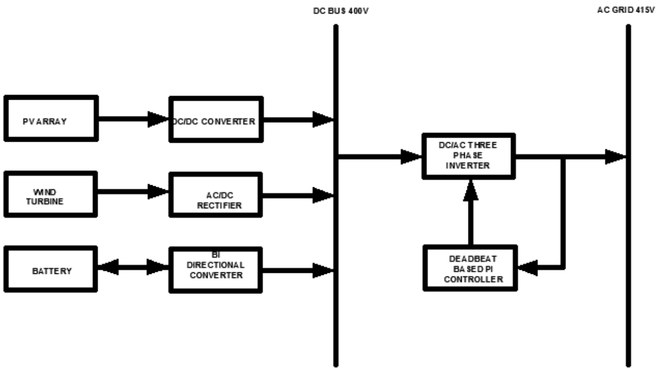

Fig 1. Proposed system block diagram

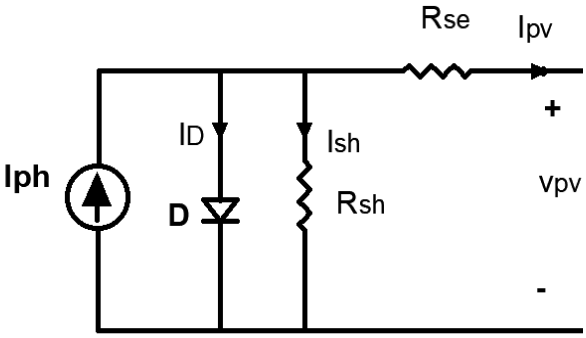

Fig 2.PV cell equivalent circuit model

III. SYSTEM DESIGN AND SIMULATION

A. PHOTOVOLTAIC SYSTEM (PVS)

A PV cell equivalent circuit is shown in figure 2, which contains a current source, diode, shunt resistance and series resistance in order, the complete system is called "four parameters model.", in the equivalent circuit Ip represents the cell current source, Rse and Rsh indicate series resistance and shunt resistance in order.

Ns is arrays comprising cells in series, where k is Boltzmann's constant $1.38065 \times 10^{-23}\, {}^{J}/_{K}$ and q is elementary charge 1.6022×10^{-19}C where a is the ideal factor, and I_D is the current through diode, I_{ph} and V_{ph} are the current and voltage of PV cell in order.

To achieve maximum output power out of PV panel Perturb and Observing algorithm is used [13]. Using Kirchoff's current law for current I,

$I = I_p - d - I_{sh}$(1)

The current is gained from the light varies by changing in temperature and irradiance as indicated below,

$$I_D = I_0\left[\exp\left(\frac{V+IR_S}{nV_T}\right) - 1\right]$$

(2)

$$V_T = \frac{kT_C}{q}$$

(3)

$$I = I_{ph} - I_0\left[\exp^{\left(\frac{V+IR_S}{nV_T}\right)}\right] - \frac{V+IR_S}{R_{sh}} \quad (4)$$

$$I_{ph} = I_r \frac{I_{sh}}{I_{r_0}}$$

(5)

$$I_0 = {}^{I_{sc}}\Big/\left[\exp^{\left(\frac{V_{oc}}{aV_t}\right)} - 1\right] \quad (6)$$

$$I_{sh} = \frac{V+IR_S}{R_{sh}} \quad (7)$$

$$V_t = \frac{kTN_s}{q}$$

(8)

Table 1.PV array specification

Name	Value
PV parallel string	1
PV series string	5

Open circuit voltage (in V)	36.31
Short circuit current (in A)	7.840
Cell per module	60
Vmp (in V)	29
Imp (in Amp)	7.351
Ideality factor of diode	0.98170
Shunt resistance (in ohm)	314
Series resistance (in ohm)	0.394
Power of output (in kw)	1

B. Wind System

To extract efficient power from wind power plant system it is required to have a proper model of wind speed [14] the power which is extracted from wind [21]is

$$P_w = \frac{dW_w}{dt} \quad (9)$$

The energy is extracted by wind turbine,

$$W_w = V_a \frac{1}{2}\rho({V_1}^2 - {V_3}^2) \quad (10)$$

$V_a$is the volume of air passing through a disc, $V_1$is the velocity of air unaffected by rotor interference, $V_3$is the velocity of air away from the disc and ρis the air density.

The maximum out power extracted by wind turbine is shown as follow

$$P_{max} = \frac{16}{27} P_0 (11)$$

$$P_0 = \frac{1}{2}\rho A {V_1}^3 \quad (12)$$

$P_0$is the power contained in wind.

Table 2. Wind system parameters rating

Name	**Value**
Wind speed startup (mph)	4.50
Wind nominal speed (in mph)	20.0
Torque (Nm)	30
Wind base speed (m/s)	12.0
Base rotational speed (per unit of the base generator)	1.2
Stator phase resistanceR_s in (ohm)	0.18
Inductance of Armature (H)	0.8351
Electrical generator base power (VA)	200/0.90
Rated output power P_0 (in W)	1000

Table 2 represents rating of wind system. It is composed of startup speed, nominal speed, torque, phase resistance, armature inductance base power and rated power of electrical generator [15].

C. BOOST CONVERTER

The boost converter is used to set up a fluctuating PV panel voltage to a higher constant dc voltage [16]. The gained output voltage is fed the dc bus of 400 volts. The following equation is used for a DC-DC boost converter designing[13].

$$\frac{V_0}{V_i} = \frac{1}{1-k} (13)$$

$$C = \frac{I_s kT}{\Delta V_s} \quad (14)$$

$$L = \frac{kV_e}{F\Delta I} \quad (15)$$

$$R_c = \frac{V_0}{I_0} (16)$$

It the above relations V_0 or V_s: voltage in the output (in volt), V_i(or)V_e is the input voltage (in volt), k is duty cycle, I_s is the current in the output (in amp), T is the time period (in sec) and F is frequency (in Hz).

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Table 3. Specification of Boost Converter

Name	**Value**
Input voltage (in V)	200
Duty cycle	0.5
Output voltage (in V)	400
Inductance (in H)	$870e^{-6}$
Capacitance (in F)	$5.085e^{-4}$
Resistance (in R)	170

D. AC-DC CONVERTER

The rectifier is connected to wind turbine in order to convert ac to dc power. As it is being seen in the figure 3 the circuit is made up of 6 diodes which direct current in one direction through inductor and resistor to dc bus of 400 volt.

Table 4.indicates the specification of AC-DC converter

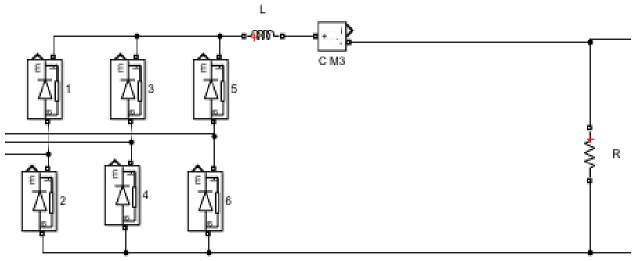

Fig 3. AC-DC Rectifier circuit model

Table 4. Design characteristicof AC-DC rectifier

Name	**Value**
Input voltage (in V)	185.0
Voltage in the output (in V)	400.0
Inductance (in H)	80.0
Resistance (in Ω)	3.5*10^3
Diode resistance (in Ω)	10
Diode inductance (in H)	e^{-3}
Forward voltage in the diode (in V)	0.80
Initial current of the diode (in A)	0
Snubber resistance of diode (in Ω)	10^3
Diode snubber capacitance (in Ω)	$250e^{-9}$

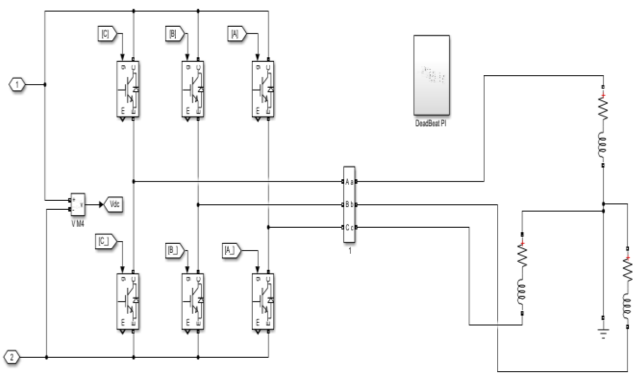

Fig 4. Three-phase inverter

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E. THREE PHASE INVERTER

In power electronic systems applications three phase invertersarethe basic part, including dc and ac gridsystems, dc energy storage system, as well as three phase inverters forrenewable energy applications linked to the low voltagegrids[17].The three-phase inverter is the main part of this work, it is integrated with 400 V DC grid and AC grid. The function of inverter is to invert the DC voltage to a pure, constant sinusoidal voltage along with constant 50 Hertz frequency- it is being done through controlling the gates of inverter by deadbeat PI controller.

Table 5. Design value for three phase inverter

Name	Value
Input voltage (in V)	400.0
Voltage of the output (in rmsV)	415.3
Inductance (in H)	0.2
Resistance (in Ω)	18.5
Inductance (in H)	$2e^{-4}$
Internal resistance IGBT (in Ω)	$1e^{-4}$
Snubber resistanceIGBT (in Ω)	$1e^{-4}$

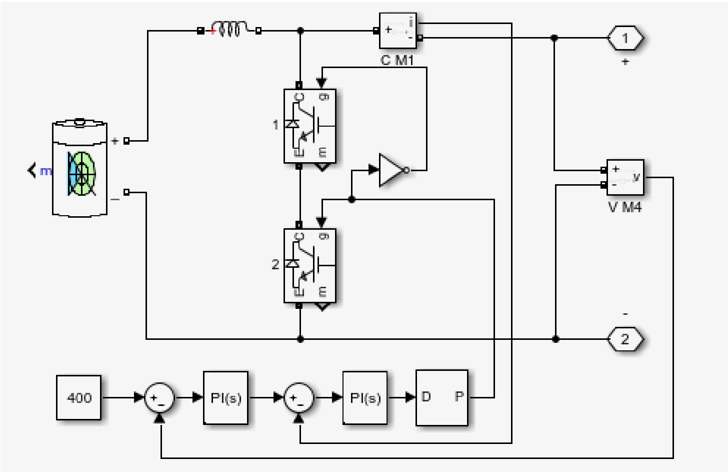

Fig 5. Battery and vi controller

F. BATTERY

The battery main function is to store excess energy from the 400 DC voltage bus. PV and wind turbine is directly tied to dc bus through converters to generate power[18]. When there is no use of energy in the load the battery will be charged and in case there is shortage ofenergy in the connected load power will be supplied to the load through a bidirectional converter from the battery [19]. Main function of the bidirectional converter is to manage power between dc source from battery and the load [20]. VI controller is used to adjust 400 volts constant at dc bus. Figure 5 represents the circuitry for battery and VI controller.

Table 6. Battery design values

Name	Value
Battery Type	Lead Acid
Battery nominal voltage (in V)	0.3*10^3
Battery rated capacity (in AH)	24
Initial state of charge of battery (in %)	60
Timeresponse of thebattery (in sec)	30
Maximum capacity of the battery (in Ah)	25
Cut-off voltage of the battery	225

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(in V)	
Battery Fully charged battery voltage (in V)	327
Dischargecurrent of the battery (in A)	4.810
Internal resistance of the battery (in ohms)	0.125
Capacity of battery at nominal voltage(in Ah)	7.43

Table 6 represent battery design value.
The designed battery has the capacity to supply power to the grid continuously for 5 hours.

$$\text{Battery rated capacity} = \text{discharge current} \times \text{discharge time}$$

Hence, the battery discharge time $= \text{battery rated} \frac{\text{capacity}}{\text{discharge current}}$

$$= \frac{24}{4.8}$$

$$= 5\text{hrs}$$

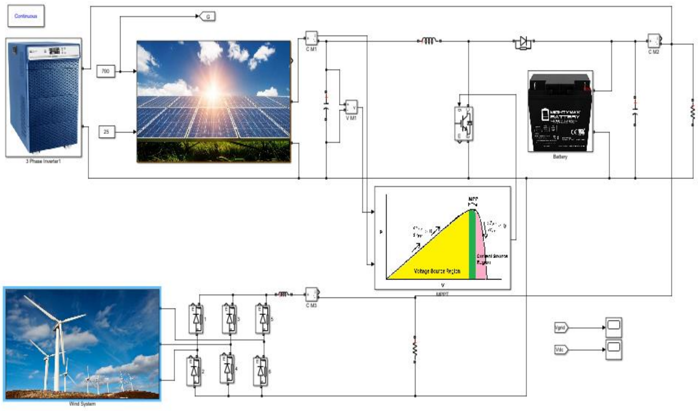

Fig 6.MATLAB simulation of pv and wind turbine connected to a three-phase grid system.

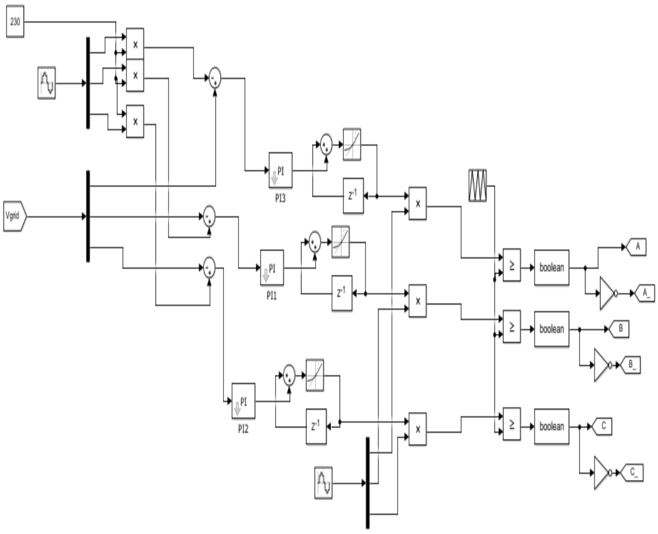

Fig 7. Deadbeat-based PI controller

F. DEADBEAT-BASED PI CONTROLLER WITH SWITCHING CONTROL SCHEME OF SPWM

As shown in figure 7 For a PV and wind hybrid power generation sourcescombined with a battery integrated to a three-phase grid through a

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three-phase inverter a deadbeat-based PI controller with SPWM switching control scheme is proposed and employed to maintain, regulate phase to ground and phase to phase rms voltage at 239 and 415.3 consecutively along with 50 hertz frequency constant.

Vgrid fundamental rms value of each phase output voltage will be fed back to the deadbeat PI controller and each phase compared with product of 230 reference rms voltage and sinusoidal signal. The difference between each phase and reference signal is the input to the PI controller to get a proper modulation index. The correct proportional gain Kp and integrator gain Ki calculated using a heuristic tuning method.

The modulation index is accumulated from time after time delay. The product of output of three modulation indices and sinusoidal reference signals will be compared with a triangular waveform to provide switching pulse signal to a three-phase inverter in order to trigger three pairs of IGBTs of a three-phase inverter. Refence sinusoidal wave form is 50 hz frequency and the switching frequency of triangular wave form is 5 kHz. The three-phase pure sinusoidal, 0, 120, 240-degree phase angleoutput voltage with 50 hertz frequency has been shown in figure 10. The proposed design method proves robustness of deadbeat PI controller against parameter mismatches.

Table 7 shows constants value for proportional and integrator gains

Table 7. Proportional and integrator gains (Kp, Ki)

Parameters	Chosen values
Integral gain constant (Ki)	0.6501
Proportional gain constant (Kp)	56.021

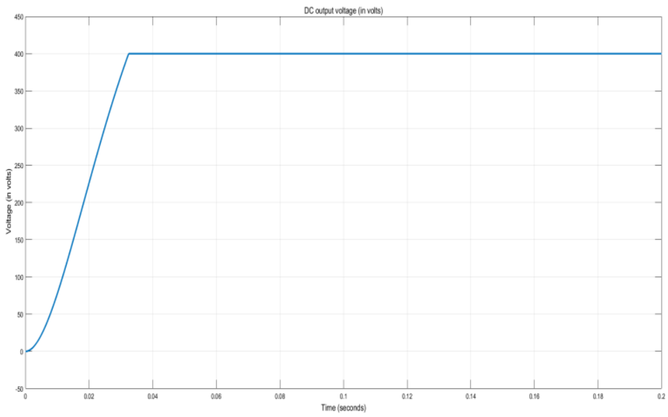

Fig 8. DC bus voltage

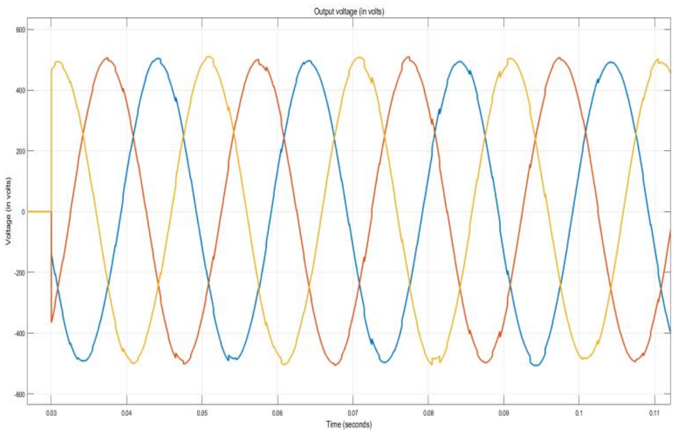

Fig 9. Threephaseinverteroutput voltage when controller is not connected to the system.

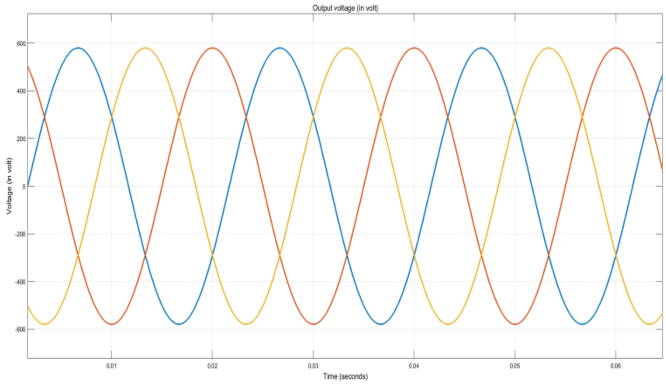

Fig10. Three-phase InverterOutput Voltageafter Controller Operation

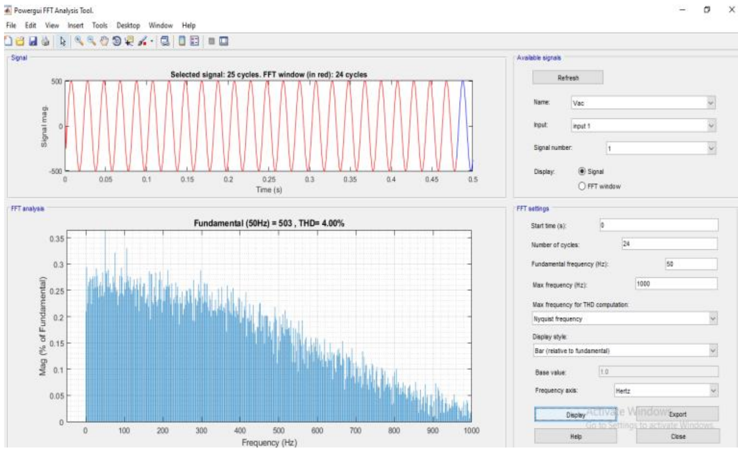

Fig 11. Total Harmonic Output When Deadbeat PI Controller is out of Operation

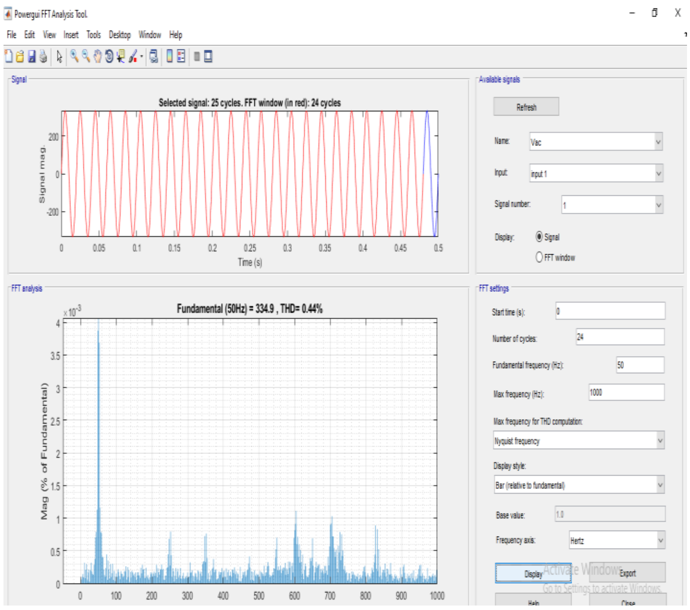

Fig 12. Total Harmonic Output When Deadbeat PI Controller Operates

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IV. RESULTS AND MATLAB SIMULATION

Figure 6 shows PV and wind hybrid system integrated to a three-phase grid system through a three-phase inverter along MPPT and battery are modulated in MATLAB/Simulink.

Figure 8 represents the 400-dc bus output voltagewaveform. DC is fed by a hybrid of PV and wind turbine generator along with the battery. The simulation is runed for 0.2 sec and reaches at steady state in less than 0.04 sec.

Figure 9 shows the three-phase output voltage in the three-phase grid system before the inverter gating pulse is controlled by deadbeat-based PI controller. Waveform is enriched in harmonics.

Figure 10 indicates three-phase output voltages which are 120 degrees out of phase with each other after pulses in inverter are controlled by deadbeat-based PI controller. The simulation is runed for 0.26 sec. The output waveforms reach at steady state in less than 0.05 sec, THD 0.44%, 239 volts phase to ground and 415.3 phase to phase voltages.

Figure 11 and 12 Show the results of FFT analysis of fundamental signal for THD analyzing before and after deadbeat-based PI controller is operational. Figure 11 shows FFT analysis for THD computation before controller starts functioning. Simulation time is 0.5 sec total harmonic distortion for odd signal is 4% and rms phase to phase voltage is 353.7. figure 12 shows the result of FFT analysis when controller starts functioning. The simulation time is 0.5 sec, total harmonic distortion is 0.44% and rms voltage regulates at 415.3 volts.

V. CONCLUSION

A three-phase voltage source inverter using PV and wind hybrid system integrated with battery as a primary source of energy and being controlled by a deadbeat-based PI controller hasbeen modeled in MATLAB/Simulink software. The renewable energy of 1kw capacity is utilized to supply three phase grid system. To regulate and maintain output as phase to ground voltage 239 rms, phase to phase 415 voltage rms and 50 hertz frequency constantat different load, the control scheme SPWM switching with the deadbeat-based PI controller for a three-phase inverter integrated with the grid is proposed, in results. The output showsa pure sinusoidal voltage rms 239 phase to ground, 415.3 phase to phase voltages with total harmonic distortions of three phase less than 2%, even if there are variations in the input of PV and wind turbine system. Hence controller proves a very good performance and robust characteristic with fast dynamic response. For the future scope controller can be replaced with a fuzzy system to get better results.

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