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A PV Based Autonomous HBCC Microgrid Performance Analysis Using Adaptive PI And PI Controller

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Abstract : A methodology based on MCPV (Microgrid connected Photovoltaic source) is presented in this paper. A DC-DC boost converter has been implemented which helps in maintaining the DC-link voltage constant and is fed to the VSC's input. This paper work imparts a regiment strategy for the autonomous operation of Microgrid. An adaptive control approach is designed to procure maximal control of parameters. This adaption feature is oriented in the proposed controller by constantly varying the 'Kp' and 'Ki' values through the fuzzy controller. Disregarding the variation of load and its unpredictability the proposed controller is used to monopolize the parameters of the islanded network. Along with the fuzzy controller an additional Hysteresis Band Current Control (HBCC) is used which assists towards the accuracy. The demonstration of the controller is legitimated through simulation studies, which offsets the proposed controller to provide a desired control of system parameters.

Keywords : Photovoltaics(PV), Voltage Source Converter (VSC), Hysteresis Band Current Controller(HBCC), PI Controller, Adaptive PI Controller, Distributed Generation(DG), Renewable Energy Sources(RES).

1. INTRODUCTION

Renewable energy is procuring emphasis on the area of power system and trying to fulfill the demand for supplying sustainable clean power. Various Renewable Energy Resources (RES) like fuel cells, solar cells, and wind turbines are signed as distributed energy resources in microgrid. With the eruption in the RES, photovoltaic power generation is being inked in much pertinence since they are more assuring and are extensively used as efficient source. In past days PV system were mainly used in remote off Grid areas. However due to up gradation in factors like efficiency, solar installation price reduction, feed in tariff are bricking integration of PV system in grid as well as islanded Microgrid. In this work we have connected the PV to a boost converter which helps in maintaining the DC-link capacitor voltage to supply constant DC to the VSC.

The rigorous growth in usage of renewable generating sources has contributed towards the increased use of microgrids, as they have been proved to be a useful instrument in controlling the power supply by Distribution Generators which are in a location close to the consumption area. Also the production of clean energy with zero emission and minimal dependency on the fossil fuels for producing energy which proves the renewable energy sources an ideal choice. Microgrid is a reticulum with two or more DGs assembled technically which either in parallel with each other or independently from a conventional authorized power supply. Microgrid renders a more reliable and efficient operation in comparison to canonical technologies such as energy networks which are centralized. An important subject to be think in this production scheme

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is that such units can produce or generate autonomously, if the system demands. Furthermore, in case if the distribution system fails, due to their autonomous generation, energy can directly be provided to the loads making the system more obsequious. when the units directly provide power to the load, the operation to be in islanded mode. However operation can be carried out in two modes- 1) grid connected mode, 2) Autonomous or islanded mode as stated above. The limitation in the flow of power between the source and load creates a challenge for maintaining the voltage stability in autonomous or islanded mode microgrids. Despite of the above narrated positive points of renewable due to their high uncertainties, fluctuations and lower power quality in microgrids it causes instability. This intimates the importance of a controller. Here in this work the essentiality of an ideal controller such as peak overshoot, faster settling time, fast response to any flaw are kept in mind while designing the proposed controller. This paper work contributes towards the operation in potentiating of the dynamic performance of islanded mode of Microgrid.

The autonomous operation of DG is envisioned in [1]. In [2] the modes of operation are being delineated. Investigation towards the fault analysis is figured through VSC modelling in [3]. In [4] it describes the effective mitigation of harmonics in the Microgrid. In [5][6] it confers about the robust controllers which are adaptive in nature. The control scheme for islanded operation of a microgrid under various control strategy are stultified in [7]. The working of HBCC for VSI is analyzed in [8]. The mathematical and dynamic modeling of PV is stated in [9][10]. The maximum power point tracking using several control schemes is analyzed in [11].

2. SYSTEM DESCRIPTION

Fig. 1 shows the microgrid architecture of the system, it consists of a PV array with DC/DC Boost converter, a Voltage Source Converter, a series LC filter and RL Load. It can be seen that the currents and voltages are sensed and fed to the control block which generates the gate pulses for the inverter.

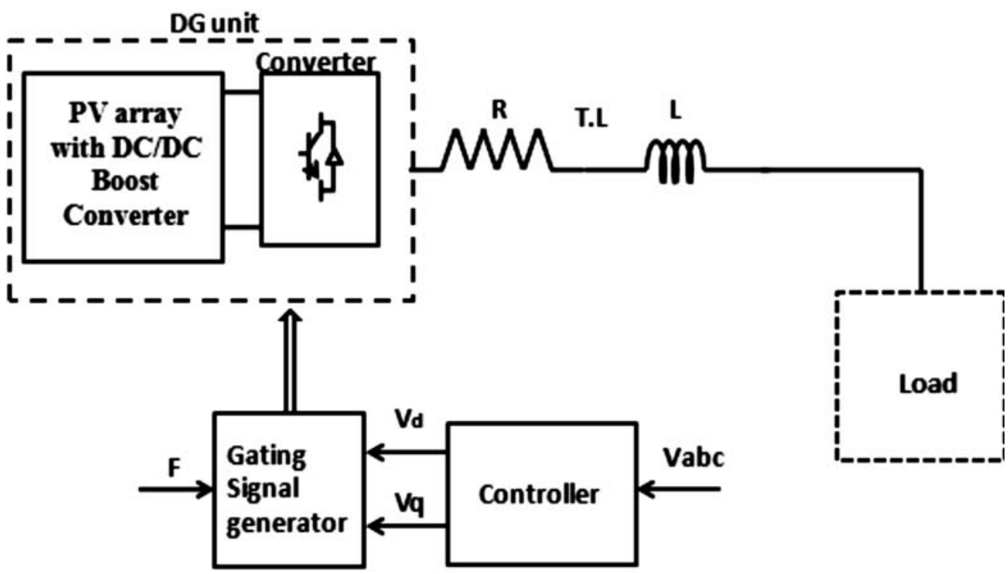

Figure 1: Model of Microgrid System

3. SYSTEM MODELLING

The above block diagram considered in this paper consists of some major parts as:

1. PV array with DC/DC Boost converter
2. Voltage Source Converter(VSC)
3. Filter
4. RL Load
5. Modeling of PV

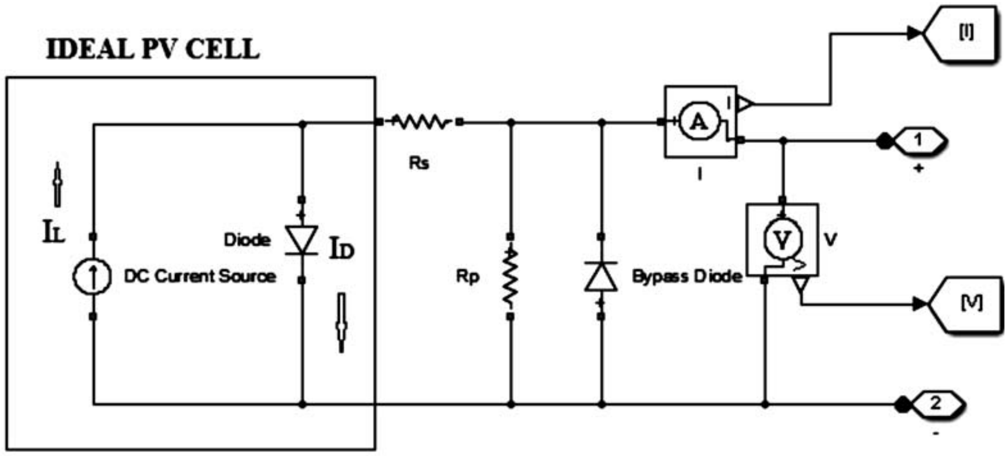

Figure 2: Equivalent electrical circuit of a PV cell with a bypass diode

An equivalent electrical circuit of a PV cell with bypass diode is shown in Fig.2. Here, the current generated due to exposure of p-n junction of the PV cell to solar irradiation is presented by a non-linear DC current source (I_L). A diode illustrates P-n junction in the above circuit. The bypass diode protects the PV cell from overheating during partial shading. The series resistance (R_S) represents the sheet resistance of the semiconductor body or surface. Parallel resistance (R_P) is considered to block the leakage current from the PV cell.

Applying Kirchhoff's current law to the equivalent electrical model of PV cell,

$$I = I_L - I_D \tag{1}$$

Where, I_L = Current generated by solar irradiance; I_D = Diode current; I = Terminal output current of PV module. The current generated by solar irradiance is expressed as

$$IL = (I_{L,ref} + K_i \Delta T)\frac{G}{G_{n,ref}} \tag{2}$$

Where, $I_{L,ref}$ = Reference current generated by solar irradiance at nominal condition; ΔT = Difference between actual temperature and nominal temperature; K_i = Temperature coefficient of maximum PV cell current (A/˚K); G = Irradiance incident on PV module surface; $G_{n,ref}$ = Nominal Irradiance, 1000W/m^2. Diode current is calculated as

$$I_D = I_O[e^{\left(\frac{V + R_S I}{\alpha V_t}\right)} - 1] \tag{3}$$

Where, I_o = Diode saturation current in the absence of solar light; V_t represents PV cell thermal voltage and is expressed as

$$V_t = \frac{N_S K T}{q} \tag{4}$$

Where, N_S = Number of PV cells in series; K = Boltzmann constant = 1.3806 × 10^{-23} J/K; q = Electron charge = 1.602 × 10^{-19}C; T = Actual temperature in Kelvin; α = Diode ideality constant (1< α <1.5).

Further, the saturation current of the diode depending on temperature is represented as:

$$I_0 = I_{0,ref}\left(\frac{T_{n,ref}}{T}\right)^3 e^{\left[\frac{qE_g}{\alpha K}\left(\frac{1}{T_{n,ref}} - \frac{1}{T}\right)\right]} \tag{5}$$

Where, $T_{n,ref}$ = Nominal temperature (*i.e*. 25˚C); $I_{0,ref}$ Saturation current of diode at nominal condition; E_g = Band gap energy. The saturation current is expressed as

$$I_{O,ref} = \frac{I_{SC,ref}}{e^{\left(\frac{V_{OC,ref}}{\alpha V_{t,ref}}\right)} - 1} \tag{6}$$

Where $V_{OC,\,ref}$; $I_{SC,ref}$ & $V_{t,ref}$ are open circuit voltage, short circuit current and thermal voltage nominal values of PV module respectively, the above evaluated parameters represent a single PV cell at nominal irradiance and temperature.

$$I_{L,Total} = N_P * {}_{I}L \tag{7}$$

$$I_{O,Total} = N_P * I_0 \tag{8}$$

$$R_{S,Total} = \frac{N_S}{N_P} * R_S \tag{9}$$

Where N_S and N_P are the number of PV cells in series and parallel respectively. Cells in series will contribute to the output voltage whereas cells in parallel will contribute to the output current. Therefore,

$$I_{Total} = N_P * I \tag{10}$$

$$V_{Total} = N_S * V \tag{11}$$

B. Modeling of Boost Converter

The DC-DC boost converter topology is shown in Fig.3. Basically it has two conduction modes, *i.e*. continuous conduction mode for efficient conversion of power and discontinuous conduction mode for low power operation or standby operation. The model can be mathematically expressed as:

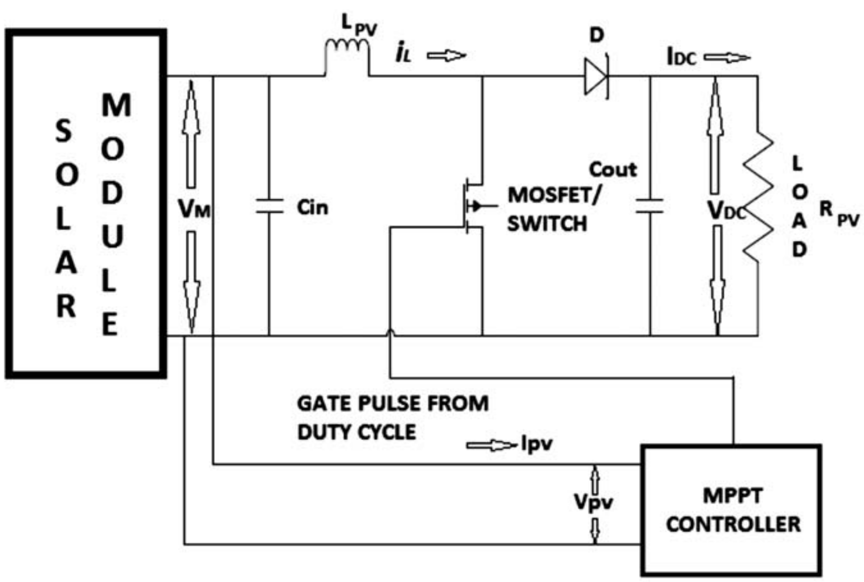

Figure 3: DC-DC boost converter topology

$$\begin{bmatrix} V_m \\ i_{dc} \end{bmatrix} = \begin{bmatrix} V_{dc} \\ i_L \end{bmatrix} \tag{12}$$

Where, $m = 1 - D$; D = duty cycle fed to the converter switch; i_L and i_{dc} are the instantaneous values of I_L and I_{dc} respectively. V_m is the voltage across the PV array and V_{dc} is the voltage across the capacitor of DC-DC boost converter. D is calculated as:

$$D = \frac{t_{on}}{T} = t_{on} * f_s \tag{13}$$

Where, f_s is the switching frequency of the MOSFET/Switch of the converter; T is the total time of one cycle; t_{on} is the turn on time of one cycle.

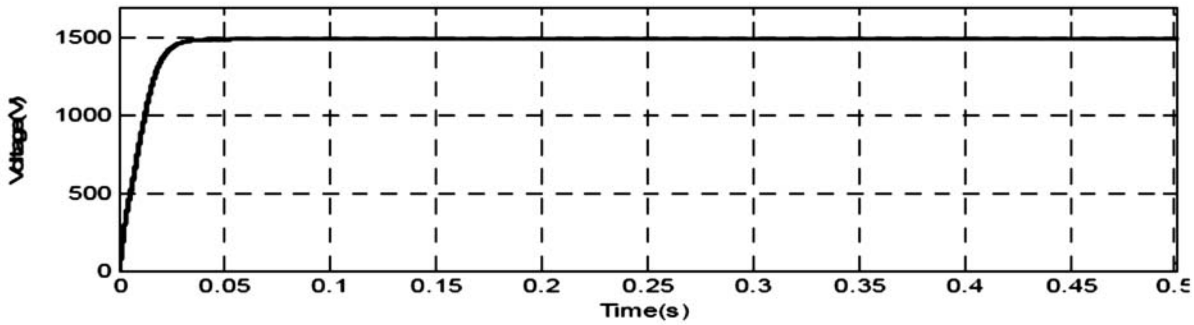

Figure 4: Boost converter output Voltage

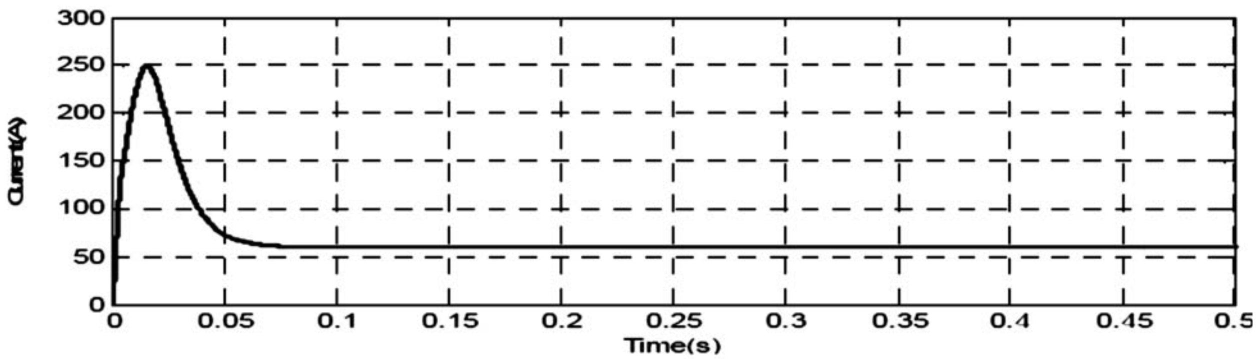

Figure 5: Boost converter output Current

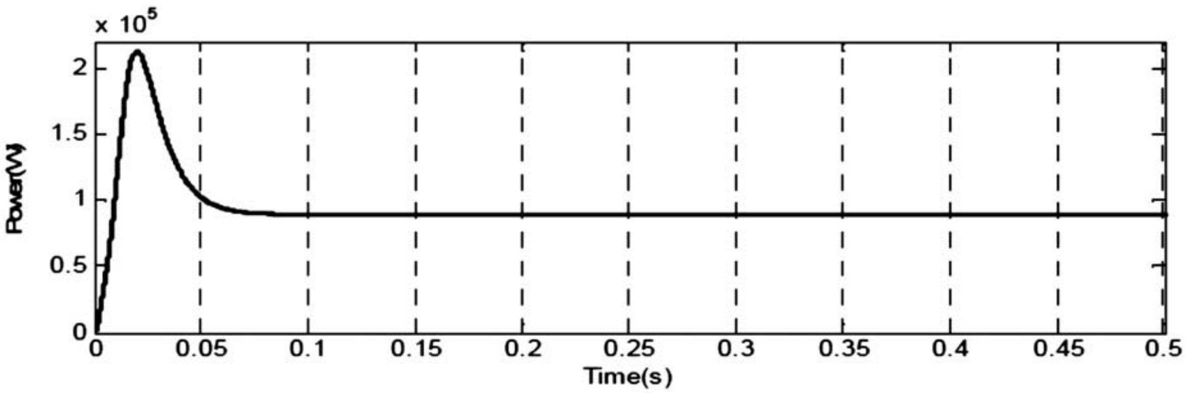

Figure 6: Boost converter output Power

C. Modelling of VSC

The modelling of Voltage Source Converter is done in natural (*abc*) reference frame. The modelling is done according to the given equations,

$$S_a = 2S_1 - 1 \tag{14}$$

$$S_b = 2S_3 - 1 \tag{15}$$

$$S_c = 2S_5 - 1 \tag{16}$$

$$V_{ai} = \frac{2}{3} * \frac{V_{dc}}{2} * S_a - \frac{1}{3} S_b - \frac{1}{3} S_c \tag{17}$$

$$V_{bi} = \frac{2}{3} * \frac{V_{dc}}{2} * S_b - \frac{1}{3} S_a - \frac{1}{3} S_c \tag{18}$$

$$V_{ci} = \frac{2}{3} * \frac{V_{dc}}{2} * S_c - \frac{1}{3} S_a - \frac{1}{3} S_b \tag{19}$$

Where S_1, S_4, S_5 are the switching states of the positive switches of the inverter. S_a, S_b, S_c are the three phase switches. V_{ai}, V_{bi}, V_{ci} are the inverter output voltage, V_{dc} is the inverter DC link voltage.

D. Modelling of Filter

Due to the harmonics present in the current due to the power electronics converter in the system a filtering unit is used which helps in reducing the harmonic components and improving the current waveform. The modelling of the filter is done using the synchronous rotating (*d-q*) frame.

$$V_{di} = R_f i_d + L_f \frac{di_d}{dt} - \omega_e L_f i_q \tag{20}$$

$$V_{qi} = R_f i_q + L_f \frac{di_q}{dt} - \omega_e L_f i_d \tag{21}$$

Where R_f is the Filter resistance, L_f is the Filter Inductance, i_d, i_q, V_{id} & V_{iq} are the d-axis and q-axis the inverter currents and voltages respectively, ω_e is the angular frequency.

E. Modeling of RL Load

The modelling of RL load is done using the natural (abc) reference frame

$$\frac{di_{la}}{dt} = \frac{V_{pcca}}{L_l} - \frac{R_l}{L_l} i_{la} \tag{22}$$

$$\frac{di_{lb}}{dt} = \frac{V_{pccb}}{L_l} - \frac{R_l}{L_l} i_{lb} \tag{23}$$

$$\frac{di_{lc}}{dt} = \frac{V_{pccc}}{L_l} - \frac{R_l}{L_l} i_{lc} \tag{24}$$

Where i_{la}, i_{lb}, i_{lc} are the load currents, V_{pcca}, V_{pccb}, $_{Vpcc}$ are the voltages at the Point of Common Coupling in three phases, R_l is the load resistance and L_l is the load inductance.

4. CONTROL STRUCTURE OF MICROGRID SYSTEM

In this work the microgrid is made to work in autonomous mode. In normal condition, without any variation the system is stable. But whenever there is any kind of disturbance in the system it behaves in a pervasive way. As system loads and it's conditions are changing continuously, with a constant k_p and k_i value so it is difficult to reach the desired response in the microgrid system.

System voltage, active & reactive power of the islanded system becomes unstable due to the load & voltage variation. A different control strategy along with the controllers has been proposed for maintaining the system voltage constant. So the control has to develop proficiency to self tune the k_p and k_i value dynamically irrespective of system variations. The reasoning capacity of fuzzy logic controller tunes the integral and proportional gains which makes the controller adaptive.

A. Hysteresis Band Current Controller

Hysteresis Band PWM is a current controller based on PWM techniques. This controller is basically a current control method where the real current of the system tracks the reference current continuously inside the Hysteresis Band. It is an instantaneous feedback current controller.

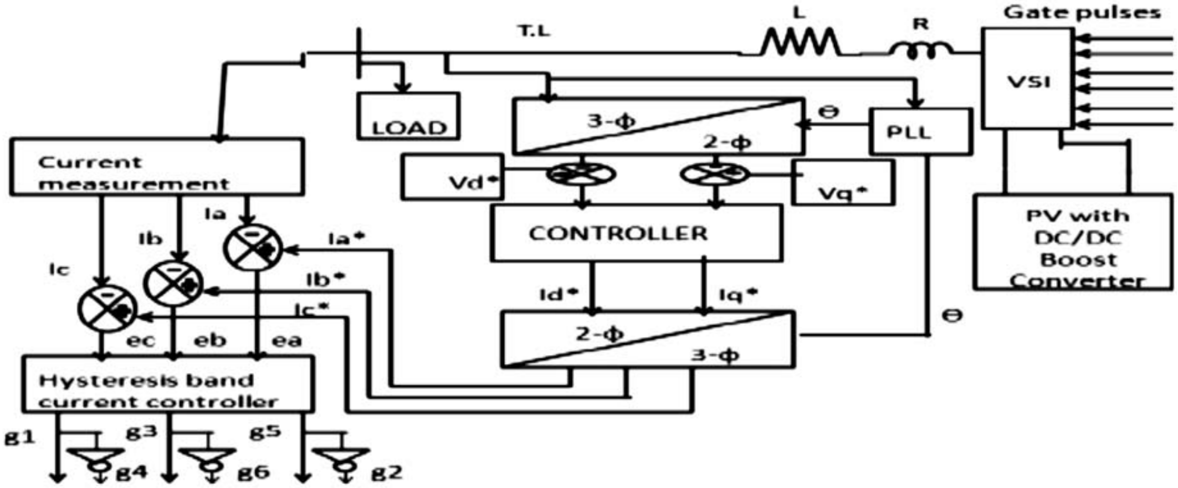

Figure 7: Control Structure of Islanded System

The control circuits (either PI or Fuzzy) generates reference current signals i_{dref} & I_{qref}, which are taken as the reference. This *d*–axis and *q*–axis currents are then converted to three phase currents, these are compared with the actual currents. The current errors are then fed to the Hysteresis band controller to generate the gate pulses for VSC

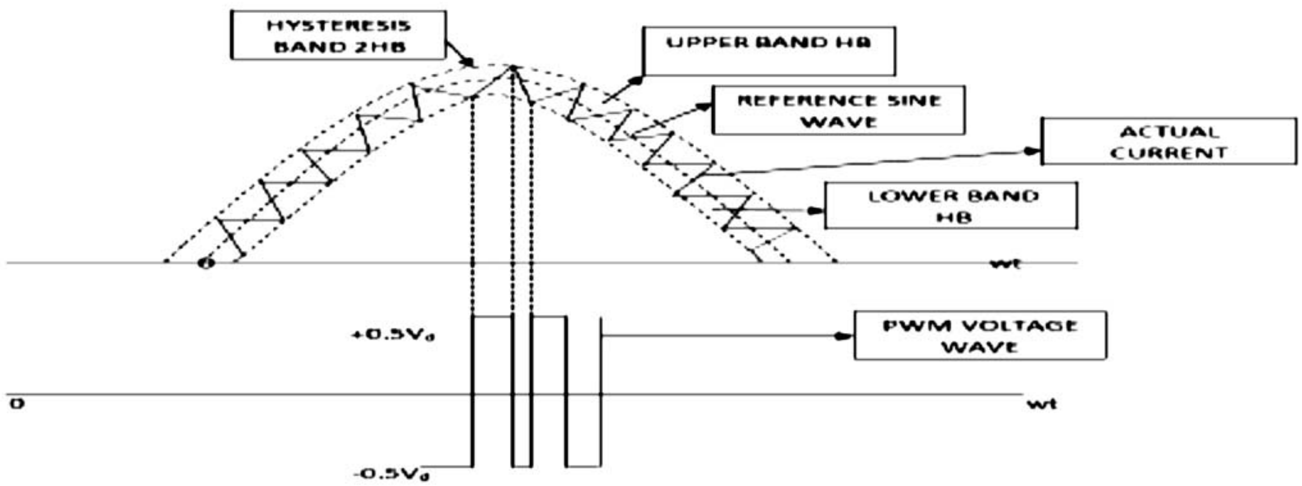

Figure 8: Principle of Hysteresis Band Current Controller

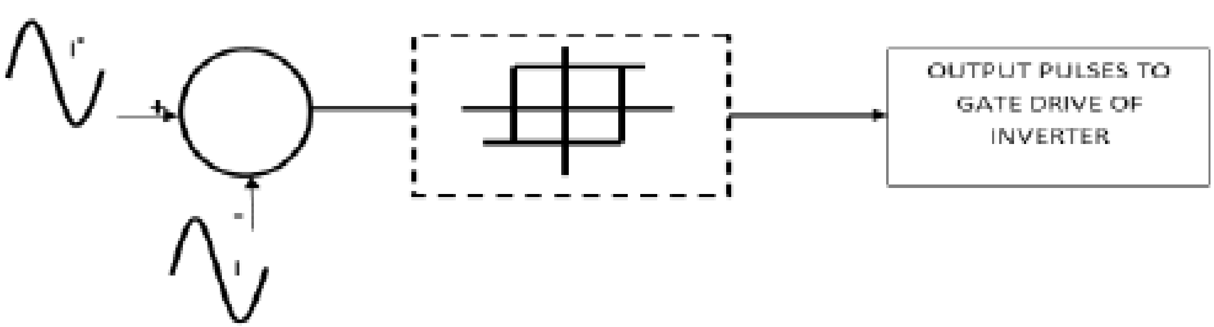

Figure 9: Control Block Diagram of HBCC

B. Structure 0f Pi Controller

The proportional integral controller has been extensively used for controlling the voltage of a three phase VSC based islanded micro grid. PI controllers are simple in structure and its performance is good for various disturbances. This controller wipes out the oscillation & steady state errors due to the frequent opening & closing of controller action and proportional controller action respectively. PI controllers are frequently used in industries where fast response of the system is not required and speed response is not a big issue. For complex systems & micro grids, controlling the system parameter the PI controller is not much efficient due to its manual tuning of Kp & Ki. Tuning of Kp & Ki takes much time and is a lengthy process. To avoid these manual tuning of PI controllers various techniques has been developed.

$$u = k_p e + k_i \int edt \tag{15}$$

Where k_p & k_i are non-negative constants, the input error signal is *e* and *u* is the output signal. The proportional controller accounts present value of the error. If error is positive & huge then control variable will be huge and negative. The k_p & k_i values has been set to get the best control action, by trial & error method.

C. Structure of Adaptive Pi Controller

The three phase voltage of the islanded system is controlled by using the fuzzy based adaptive PI controller. Fuzzy controller is a non-linear controller. It is based on the approximation of the human being. The structure of the fuzzy based adaptive pi controller is not much modified than the conventional PI controller. Here a fuzzy based PI controller is proposed for the voltage control of the autonomous micro grid. The error and change in error of each instance are the inputs to the fuzzy logic controller .The fuzzy logic controller gives an instantaneous K_{pa} and K_{io} which are added with the k_p & k_i value and are fed to the PI controller. As in this proposed controller the integral and proportional gains are continuously updated by the FLC so the controller action is changing in each instance according to the error and change in error.

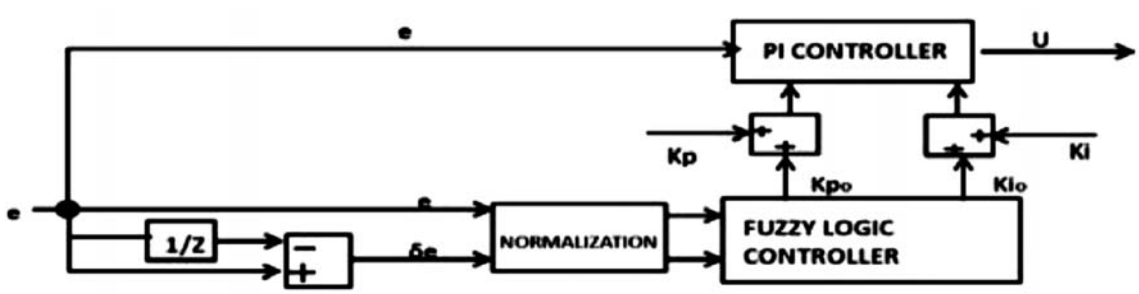

Figure 10: Structure of Adaptive PI Controller

The input error and change in error and the output of the Fuzzy logic controller are defined for the range of the universe of discourse *i.e* 0 to 1. There are 4 membership functions for The error and change in error of the system (zero(z), low(L),medium(M) and high(H)) . Hence the rule base is of 16 rules of 'If then', and it covers all states which are possible for the system. The output membership functions are (zero (Z), small (S), medium (M), high (H), very high (VH)). All the membership functions and rule base table are shown below,

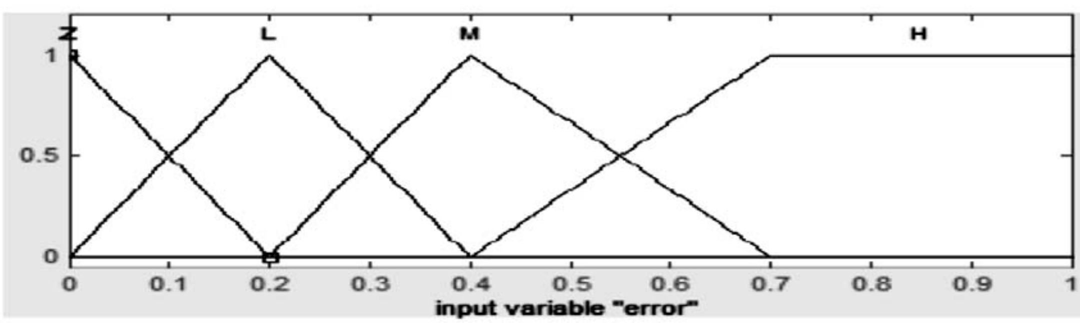

Figure 11: Membership Function of Error

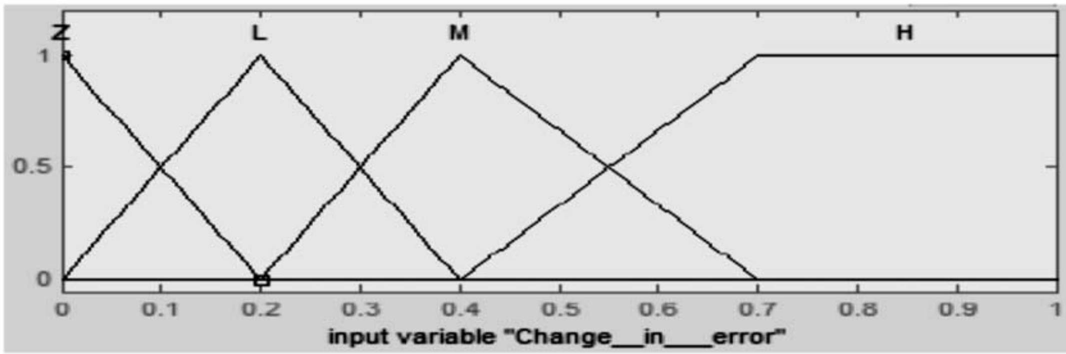

Figure 12: Membership Function of Change In Error

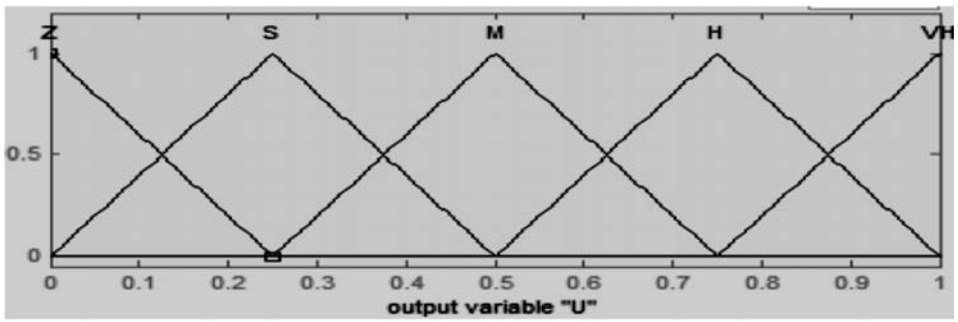

Figure 13: Membership Function of output function (U)

Table 1
Rule Base

e / *ce*	*Z*	*K*	*N*	*G*
Z	Z	S	M	VH
L	S	M	H	VH
M	M	H	H	VH
H	VH	VH	VH	VH

5. SIMULATION & RESULT ANALYSIS

Here in this work an adaptive PI controller is contemplated with PI controller under conditions as R load variation, Voltage variation & load unbalance in one phase. The microgrid system is in islanding mode and a change is applied in steps to vary the resistance R of RL load, voltage and a deviation of load resistance in any one of the three phases.

Case I. 'R' Load variation

Fig. 14-17. Shows the ***d***-axis voltage, active power, Kp and Ki during change in load resistance.

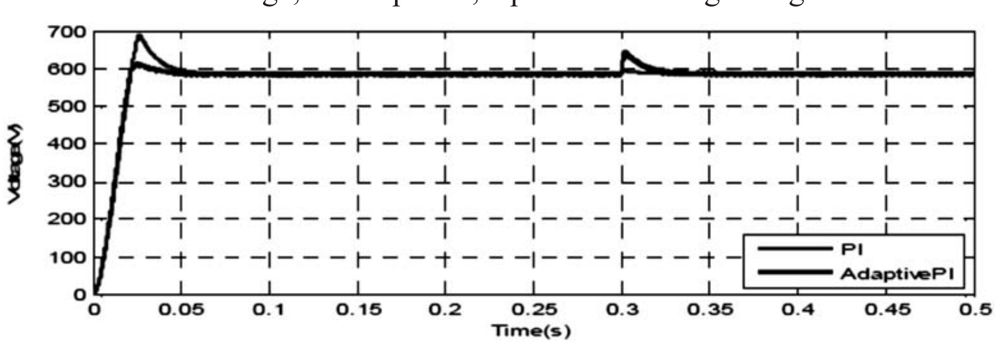

Figure 14: *d*-axis Voltage for 'R' Load Variation

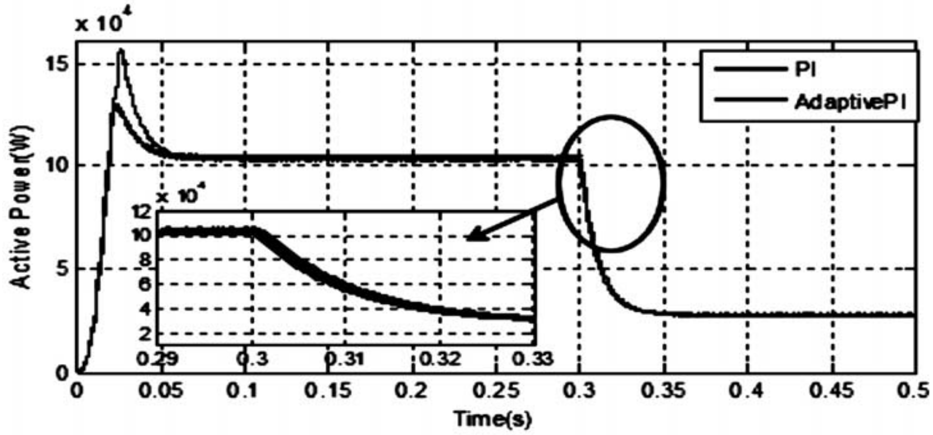

Figure 15: Active Power for 'R' Load Variation

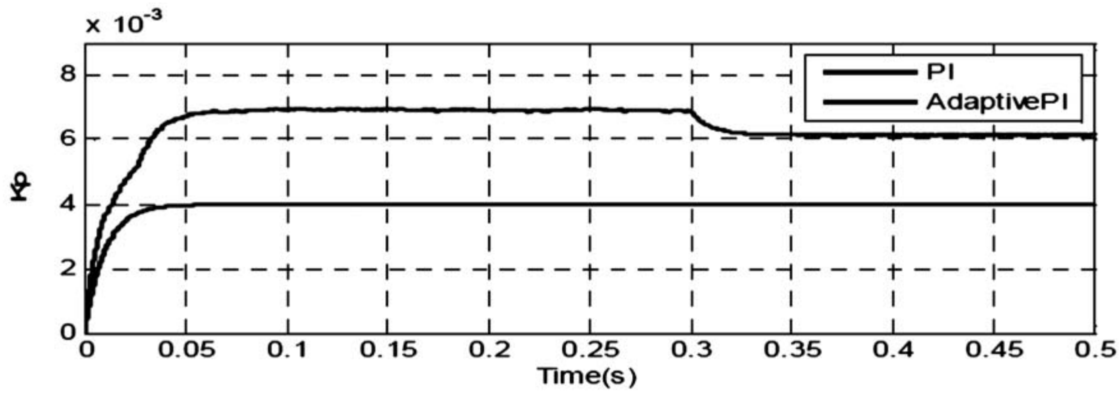

Figure 16: Kp for 'R' Load Variation

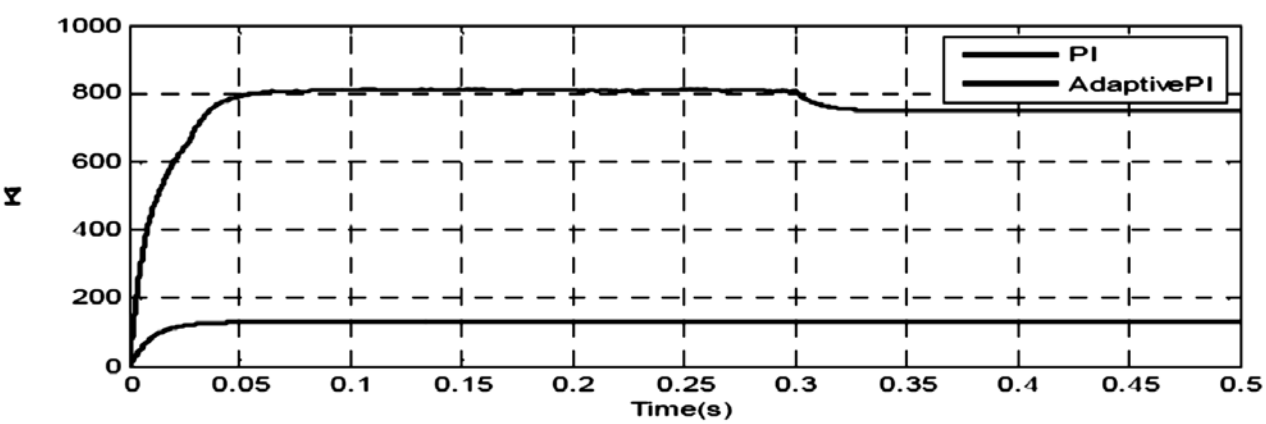

Figure 17: Ki for 'R' Load Variation

Here load resistance is varied from 5Ω to 20Ω at instant 0.3 sec. The conventional PI controller has a peak overshoot of 9.66% but it is only 1.5% in case of proposed controller as shown in Fig.14. In Fig.15. the active power is decreased as the load resistance is increased at 0.3s. In conventional PI controller Kp and Ki gain values depend only on error signal, these are set constant by hit and trial method . The gain values of the PI controller are changing in case of proposed controller, as Kp and Ki values depend on both error and change in error. It makes the controller adaptive due to these variable gains which are obtained from the Fuzzy controller. It is clearly observed from Fig.16.and Fig.17.that,from time 0.3sec the gains has been changed according to the system error and change in error. As depicted from the above figures 14 to 17 it has been noticed that the proposed controller in comparison to the conventional PI controller has better rise time, settling time and less damping and peak overshoot.

Case II. Voltage Variation

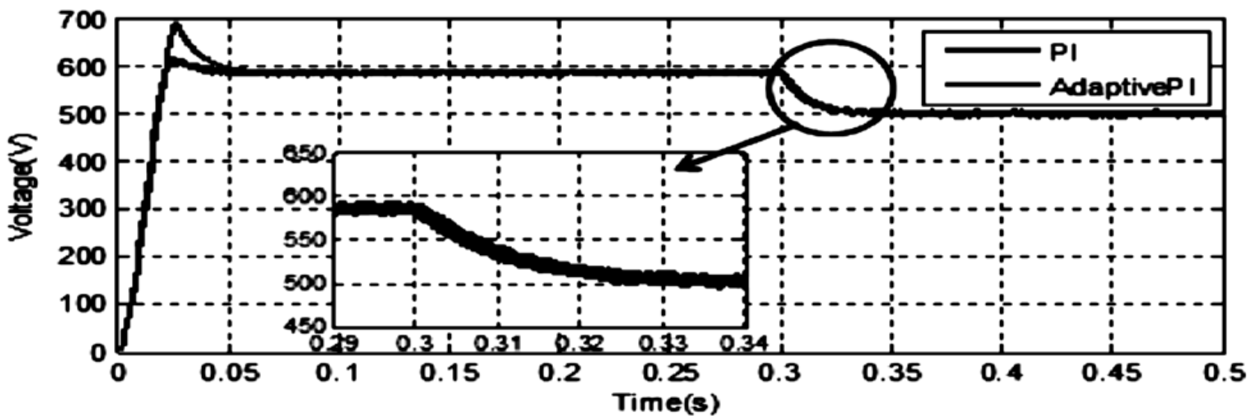

Figure 18: *d*-axis Voltage for Voltage Variation

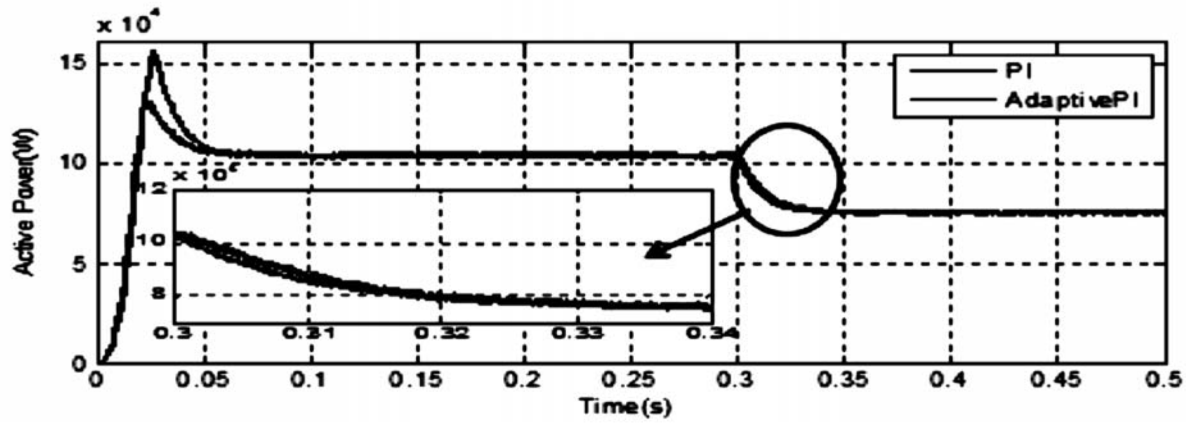

Figure 19: Active Power for Voltage Variation

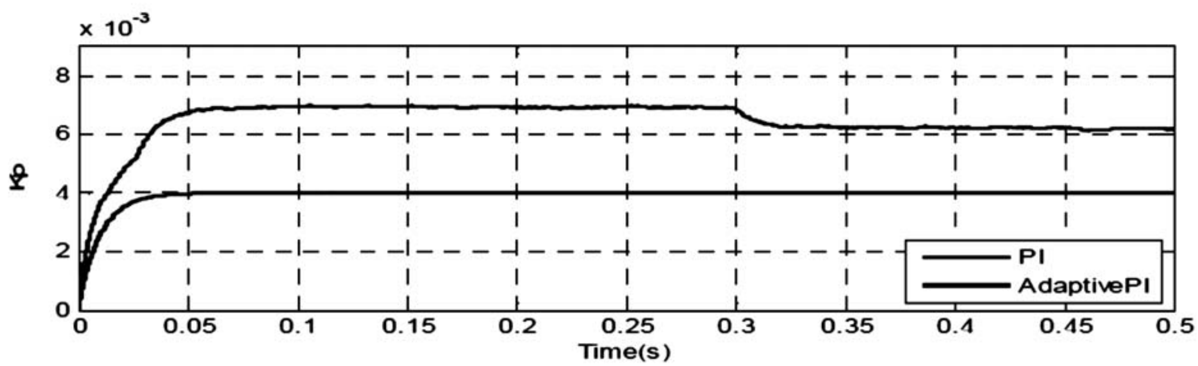

Figure 20: Kp for Voltage Variation

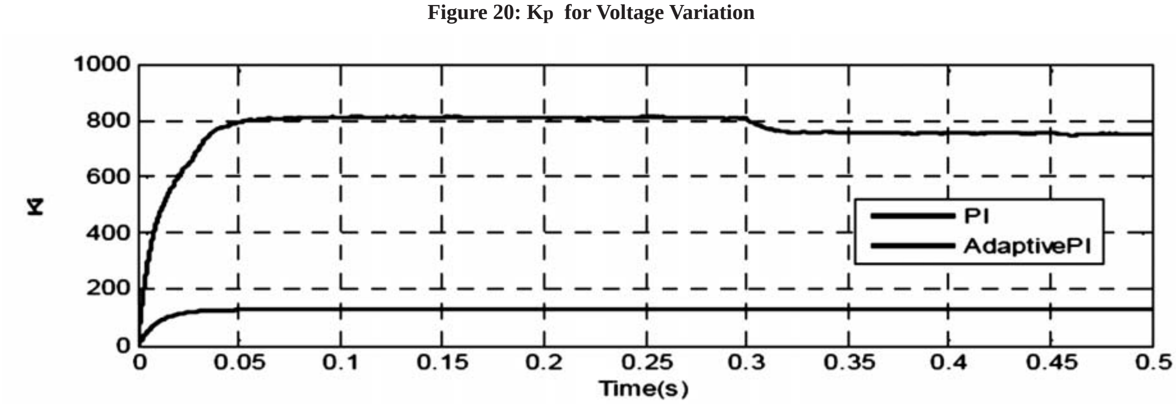

Figure 21: Ki for Voltage Variation

Fig.18-21 shows the d-axis voltage, active power, Reactive power, Kp and Ki during change in reference voltage. The d-axis voltage and active power has been decreased as the reference voltage goes down as shown in Fig.18 and Fig.19. According to the above stated point the Kp and Ki values depend on the error and the change in error. Here in the above Fig.20.and Fig.21. it has been clearly shown that the gain values are varying after 0.3sec. As verified from the above figures 18 to 21 it can be clearly noticed that the conventional PI controller has larger rise time, settling time and it also has more damping and peak overshoot than that of the proposed Adaptive PI controller.

Case III. Unsymmetrical Fault

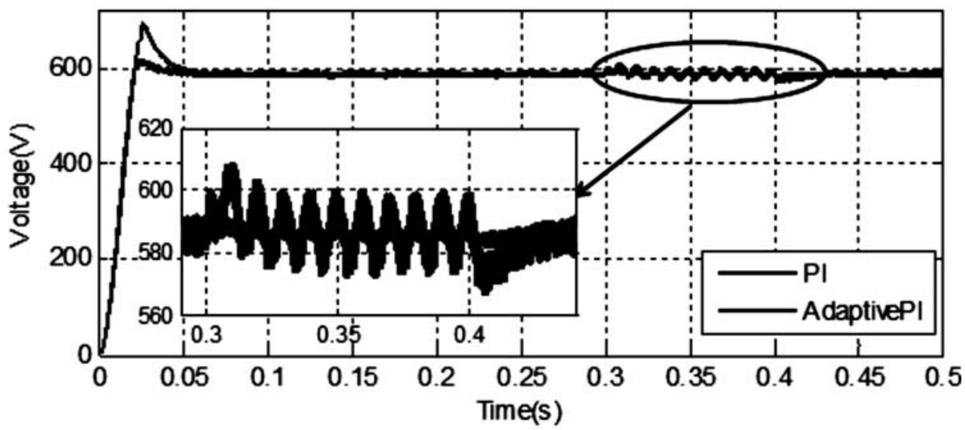

Figure 22: *d*-axis Voltage for Unsymmetrical Fault

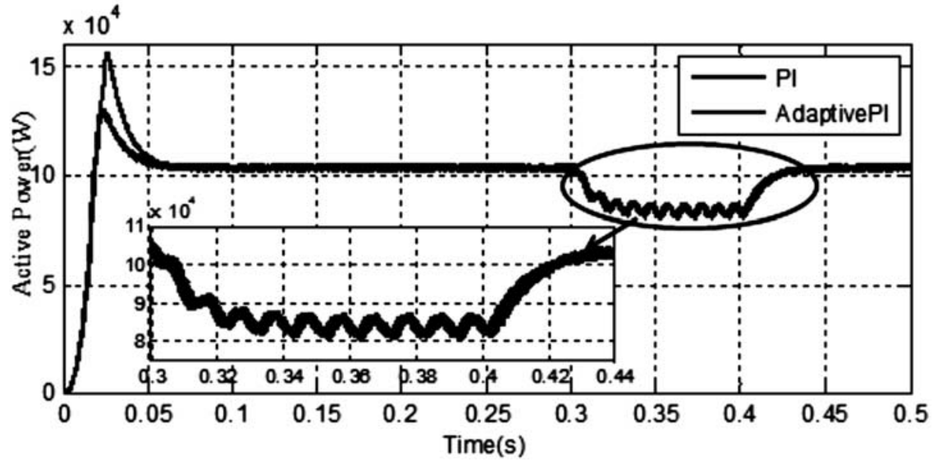

Figure 23: Active Power for Unsymmetrical Fault

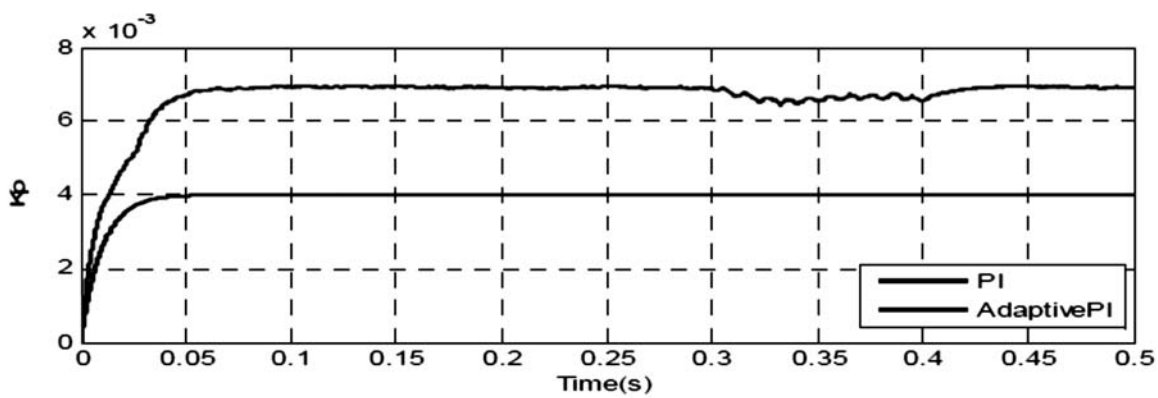

Figure 24: Kp for Unsymmetrical Fault

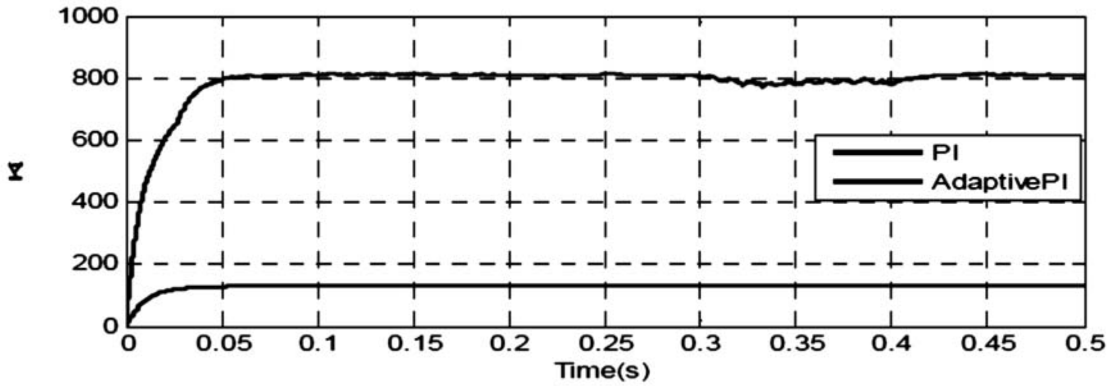

Figure 25: Ki for Unsymmetrical Fault

Fig.22-25shows the d-axis voltage, active power, Kp and Ki during change in resistance in any one of the three phase load. At the instant between 0.3 sec and 0.4 sec due to the unsymmetrical loading condition the system under goes large oscillations and by the usage of the controller the system parameters can be restored back. In comparison to conventional PI controller the proposed Adaptive controller proves to be robust. It restores back the parameters faster than that of the PI controller as shown in Fig.22 -Fig.25.

6. CONCLUSION

The paper has correlated an Adaptive PI and conventional PI controller with Hysteresis band current controller for control of an islanded microgrid. HBCC based PWM controller controls the current of the system instantaneously and provides the gate pulses along with the PV array boosted dc output are fed as the input to the VSC as the input power.

A detailed exploration of both PI & Adaptive PI has been taken for different cases. Proposed Adaptive PI controller shows better damping response, transient behavior, lower maximum overshoot, rise time, settling time in the faulted conditions. Adaptive PI controller shows less steady state error than PI. Simulation & results for load variation , voltage variation and unbalanced loading has been assessed .The proposed controller performs more steadily , it provides a robust control & better stability than traditional PI Controller irrespective of voltage & load variations.

7. REFERENCES

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