

Fuzzy Control Based Micro-grid System with a Back to Back Converter

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Abstract: This concept proposes to use a back-to-back converter as the inter link between a utility grid and a micro grid. To justify this proposal, two modes of operation are explained and the benefits of the back-to-back converter over conventional static switches are shown. In mode-I, the inter-link converter injects pre specified amounts of active and reactive power to the micro grid. This mode is identified as Fuzzy control mode. Mode-2 is the voltage control mode in which, the back to back converter controls the voltage of the micro grid and maintains the power quality of the current drawn from the utility grid in spite of nonlinear and unbalanced loads in the micro grid. Abstract- This paper proposes to use a back-to-back converter as the interlink between a utility grid and a micro grid To justify this proposal, two modes of operation are explained and the benefits of the back-to-back converter over conventional static switches are shown. In mode-I, the inter-link converter injects pre specified amounts of active and reactive power to the micro-grid. This mode is identified as Fuzzy control mode. Mode-2 is the voltage control mode in which, the back to back converter controls the voltage of the micro-grid and maintains the power quality of the current drawn from the utility grid in spite of nonlinear and unbalanced loads in the micro-grid.

Keywords-microgrid; back-to-back; inter-link converter; voltage control mode; PQ control mode

I INTRODUCTION

Micro grids have been introduced as alternatives to conventional centralized grids. These systems will play an important role in the future of smart grids. A Microgrid can usually operate either in grid-connected or island mode. Electro-static switches are normally used to make an AC microgrid completely separated from the utility in an island mode of operation. Therefore, the critical loads can survive from the disturbances in frequency/voltage of the utility grid. In this condition, the utility grid has been lost as a stiff resource.

The static switches can be replaced with an ac-dc-ac converter. This back-to-back (b-to-b)

converter as an interlink converter can offer the following benefits:

- Isolating the microgrid from the utility while keeping the flow of power between them.
- Removing the necessity of the resynchronization, when the microgrid is intended to reconnect to the utility grid.
- Facilitating power flow control between the microgrid and the utility.

In recent years, the idea of using ac-dc-ac converter as the interlink between microgrid and utility grid has been proposed, but its application limits to power flow control [1]. In this work, it is intended to extend this application to another voltage control mode of operation. The b-to-b converter also has been used to interlink two or more independent micro grids operating at different voltage and frequency [2].

In this paper, the microgrid is intended to work in two different modes with the b-to-b converter. In mode-I, the active and reactive power flow from the utility to the microgrid is controlled. In this mode, the grid has no contribution to the voltage control of the microgrid and the microgrid is seamed as a PQ load from the grid view. This mode will be called as PQ control mode. This operation of contributing to the active/reactive power can only be achieved by the use of a b-to-b converter. The other operation is when the b-to-b converter works in mode-2, in which the voltage of the microgrid is controlled with the interlink converter. In this mode, the idea is to maintain the utility current in-phase with its voltage without any unbalances or harmonics, in the presence of nonlinear and unbalanced loads in the microgrid. This is one of the most important benefits of the proposed interlink converter which will remove the necessity of using a DG active filter and a power factor correction device.

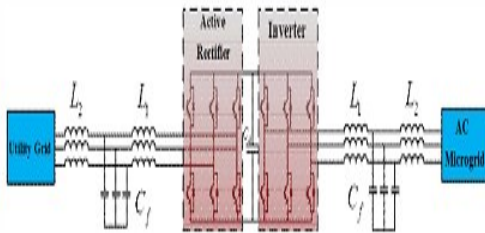


Fig.1. Power circuit of the back to back converter

As shown in Fig.1, the b-to-b converter is used with an LCL filter on both sides to attenuate the converter switching ripples. In the stationary frame used in this paper, the proportional resonant (PR) controller must be used for tracking sinusoidal references. The PR controller is recently used for several purposes such as, reactive power control in island microgrid [8] and harmonic sharing in the microgrid [9]. In the next sections, the approaches used for designing the control loops in the voltage and the PQ control modes, are explained using the methods introduced in [3]. Several approaches have been used for parameter tuning of the multi-loop controllers in the literature, such as the iterative process [4] and pole-zero cancellation [5].

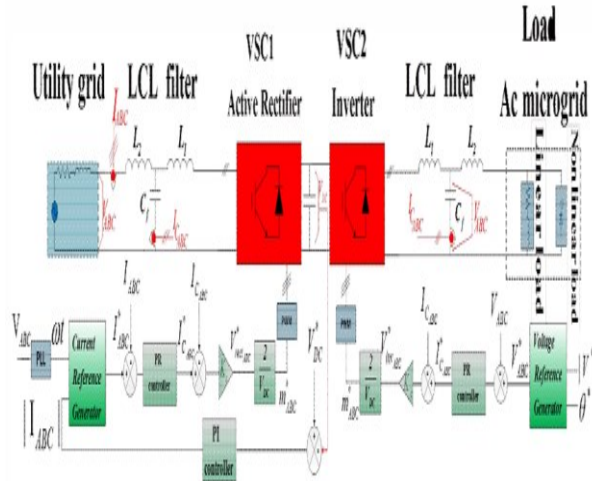


Fig.2. Back to back converter operated in the PQ control mode (mode-1) or voltage control mode (mode-2)

II POWER CIRCUIT STRUCTURE

A Schematic diagram of the system under study. It consists of an active rectifier with an LCL filter, a DC-link capacitor and an inverter with another LCL filter. The parameters of the LCL-filters are determined according to some factors such as current ripple, resonant frequency, the permissible reactive power injected by the filter capacitor, voltage attenuation caused by the filter and passive

and active damping that must be added in series with the capacitor of the filter.

In this work, active damping is used and introduced as the inner loop of the controllers. The configuration and parameters of the filters of the rectifier and inverter used in the proposed inter-link converter are the same. These parameters have been designed according to the characteristics of the power circuit and the aforementioned factors. The electrical characteristics of the power circuit and parameter values are listed in Table 1.

TABLE .1: Electrical and Physical Characteristics of the System

Parameter	Description	Value
P_{nom}	Nominal active power flow through the converter	100 kW
V_{grid}	Line to line voltage of the microgrid and the utility grid	380 V
f_{net}	Frequency of the microgrid and the utility grid.	50 Hz
L_1	Converter-side inductor	290 μH
L_2	grid-side inductor	170 μH
C_f	Filter capacitance	76.7 μF
V_{dc}	DC-link voltage	750 V
C_{dc}	DC-link capacitor	2.7 mF
f_{sw}	Switching frequency	10 kHz

III CONTROL SYSTEM STRUCTURE

The b-to-b converter can be used in two different modes depending on the structure of the microgrid. In Mode-1, the proposed inter-link converter is used in a condition in which the voltage of the AC microgrid is set by its own resources and the converter has no contribution to it. As shown in Fig.2, in this mode, the b-to-b converter is controlled to inject or absorb pre-specific amount of active and reactive power to or from the microgrid depending on the operator decisions. In another control mode, the b-to-b converter controls the voltage of the microgrid or contributes to it in conjunction with the resources in the microgrid.

As illustrated in Fig.2, the control loop of the utility side converter is unique in both modes of operation. In this converter, a current controller is used in which the magnitude and the phase of the current reference are determined respectively, to control the DC-link voltage and to not draw any reactive power from the utility. However the microgrid side converter uses different control loops. In Mode-1, a current controller is applied to inject the desired active and reactive power to the microgrid but in Mode-2, a voltage control loop is used to control the voltage of the microgrid system. The inner loop in both voltage and

current control loops is used for active damping and fast dynamic response.

In this paper, the basic ABC frame is chosen for the controller strategy. In this frame, each phase can be controlled separately, while it would still work properly in unbalanced conditions. For better tracking and rejecting of sinusoidal signals resonant controllers are used. This controller has an infinite gain at a certain frequency called resonant frequency and almost zero gain at other frequencies. The theory beyond this kind of controller is discussed in more details in [6]. To avoid stability problems associated with an infinite gain at the resonant frequency, some damping can be added to have a quasi-resonant integrator as follows:

$$G_c(s) = \frac{2k_f \omega_c s}{s^2 + 2\omega_c s + \omega_0^2}, \quad (1)$$

Where ω_c is the resonant frequency.

The controller gain is now finite but still relatively high to have a small steady state error. The controller bandwidth is widened by setting larger values for ω_c . This could help the controller work properly in spite of variations in the frequency. If the resonant integrator is accompanied by a proportional term, the result will be a proportional resonant (PR) controller as expressed in (2).

$$G_c(s) = k_p + \frac{2k_f \omega_c s}{s^2 + 2\omega_c s + \omega_0^2}, \quad (2)$$

Where K_p is the proportional gain.

As in the PI controller, the dynamic response of the system such as bandwidth, phase and gain margins is dominantly tuned by K_p and the steady state behavior of the system can be tuned by choosing an appropriate value for K_i .

1 Voltage Control Loop

In voltage control mode the magnitude and frequency of the grid are controlled under load current variations. In this mode, the voltage of the capacitor of the filter is measured and compared with the reference voltage, and the output is given to the controller. In this scheme, an inner current loop is introduced not only for damping the LC-resonance introduced by the filter but also for improving the overall system stability. For this reason, the capacitor current of the output filter is fed back into the current control

loop so as to provide both active damping and disturbance rejection enhancement.

The inner controller is a gain (K_c) that is selected such that its effect on the outer loop is considered. The system is modeled in Fig.3.3. The load is modeled as two parts, a linear part and a non-linear part. The linear current load is modeled as a function of the output voltage, however the non-linear part is considered as a disturbance in the model.

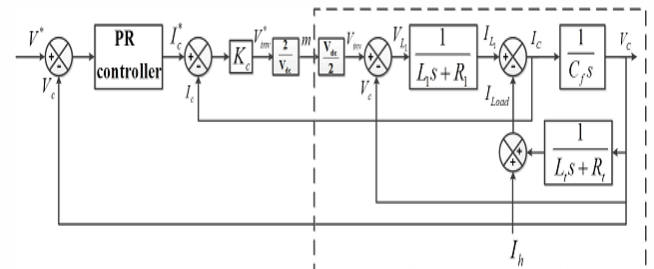


Fig.3. Modeling of an inverter operated as a voltage controller

In the design process, the value of K_c is set to a very low value for damping the resonant frequency. Larger values of K_c result in higher gains at lower frequencies that could amplify low-frequency noises [3]. Additionally, larger values of K_c produce larger phase lag at the operating frequency that could deteriorate both reference tracking and disturbance rejection.

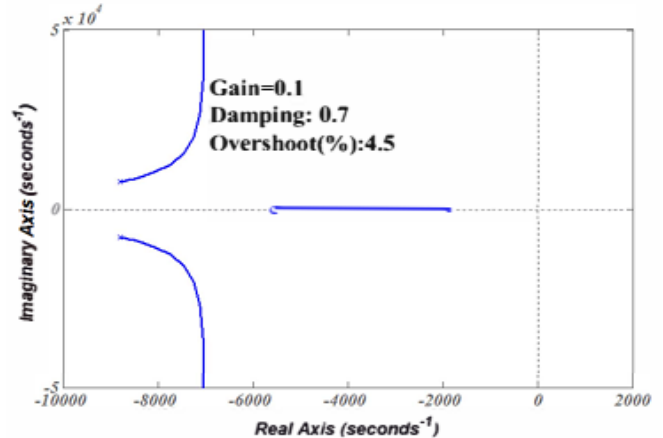


Fig.4. Root locus of the open loop system in voltage control mode

Then, the value of K_p must be determined considering the system dynamic performance. As depicted in Fig 5, the root locus of the system is optimized for the damping ratio of 0.7 with the controller parameters of $K_c=4$ and $K_p= 0.1$. In addition to the resonant controller at the operating frequency, harmonic resonant controllers must be added for the rejection of load harmonic currents as given in (3).

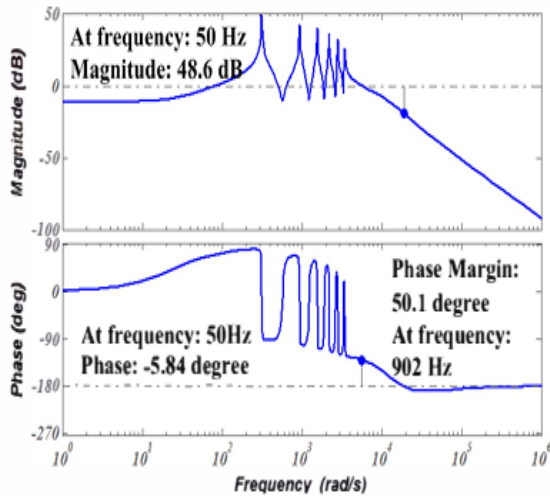


Fig.5. Bode diagram of the open loop system with voltage controller designed

$$G_c(s) = k_p + \sum_{k=0}^5 \frac{2k_{ih}(h\omega_c)s}{s^2 + 2(h\omega_c)s + (h\omega_0)^2} \quad (3)$$

The integral term for each frequency is determined according to its desired magnitude. Assuming that ω_c is equal to 1.5rad/s, the integral terms are tuned to have the desired bandwidth and provide maximum possible magnitude at the operating frequency and its harmonics. Here the bandwidth is set to 5500 rad/s. The bode diagram of the final open-loop system is illustrated in Fig.5.

2 PQ control Loop

Another operation mode of the inverter is the PQ control mode. In this mode the microgrid includes voltage sources as well. In this condition, the reference of the current is determined based on the desirable active and reactive powers and the load voltage. The inner current loop is the same as that in the voltage control mode, and the inverter must inject a particular amount of active and reactive powers which determines the magnitude and phase of the reference current. Fig. 6 shows a block diagram of the inverter working in this mode of operation.

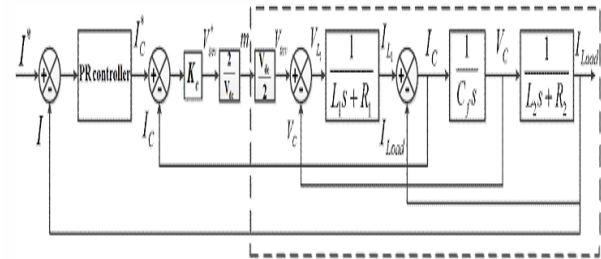


Fig.6. Modeling of an inverter operated as a PQ controller

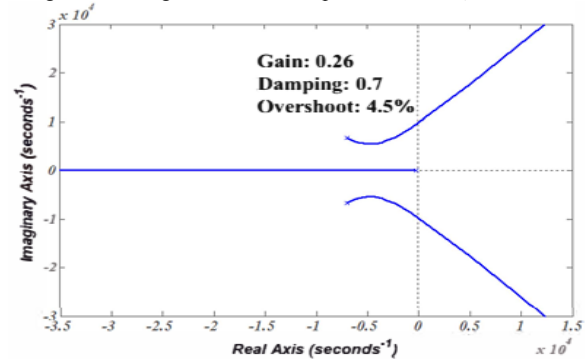


Fig.7. Root locus of the open loop system in the PQ control mode

The design process of the outer and inner controller in this mode is the same as the process described for the voltage control loop, i.e. $K_c=4$. To determine a proper value for K_p , the root locus of the system is plotted in Fig.7. As it can be seen from this figure, a suitable value for K_p to have an optimum dynamic behavior is 0.26.

Now, the integral term and the cutoff frequency are specified according to the desired bandwidth and tracking at the operating frequency. In the PQ control mode, there is no need to add a harmonic resonant controller. Within the previous assumption for ω_c , the value of the integral term is tuned at 100 to have a bandwidth equal to 2840rad/s, which is small enough as compared to the resonant frequency. To achieve this bandwidth the value of K_p must be increased, such that the damping ratio will be decreased enough. For this reason, a phase lead compensator is added to increase the phase at the cross over frequency. The bode diagram of the final open loop system is illustrated in Fig.8.

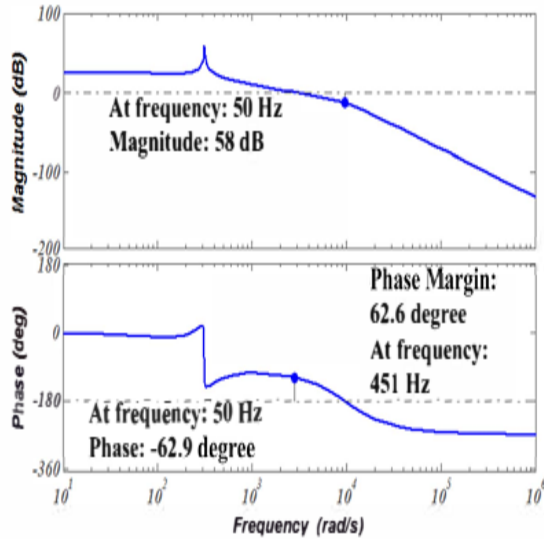


Fig.8. Bode diagram of the open loop system with current controller

3 DC-link Voltage Control Loop

To maintain the voltage of the DC-link in a back to back converter at a constant value, the active power that flows into the DC-link must be equal to the active power absorbed by the load. For this purpose, the voltage of the capacitor must be measured and compared to the reference one. The error is given to a PI controller to produce the amplitude of the current reference of the grid-side converter. It is worth mentioning that this current reference must be in-phase with the utility grid voltage in order not to draw any reactive power from the utility. The model of the DC-bus voltage control loop is shown in fig.9. In this figure, T_1 is the time constant of the current control loop of the grid-side converter which is equal to:

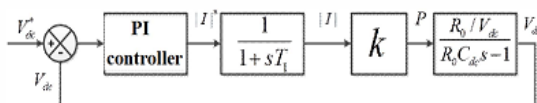


Fig.9. Modeling of the system used for controlling of the DC-link voltage

$$T_1 = \frac{1}{BW_{\text{current loop}}} = \frac{1}{2840} = 3.5 \times 10^{-4} \quad (4)$$

Where R_0 and K are the steady-state equivalent resistance and the transfer function from the current amplitude to the active power, respectively, which can be found as:

$$R_0 = \frac{V_{dc}}{I_{dc}} = \frac{V_{dc}^2}{P} = \frac{750^2}{10^5} = 5.625 \Omega \quad (5)$$

$$k = \frac{P}{|I|} = \frac{3 \times V_{grid}}{\sqrt{2}} = 466.7 \quad (6)$$

As shown in Fig.9, the system has a right-hand pole. Therefore the phase and gain margin criteria could not be used for stability of the closed loop system. Thus the design procedure must be done using the zero/pole placement in the Z-plane [7]. The PI controller is designed as:

$$G_c = -(P + \frac{I}{S}), \quad (7)$$

Where $P=1.1$ and $I=52$.

The performance of the designed controller is investigated in the next section.

IV INTRODUCTION TO FUZZY LOGIC CONTROLLER

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig 5 and consists of four principal components such as: a fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

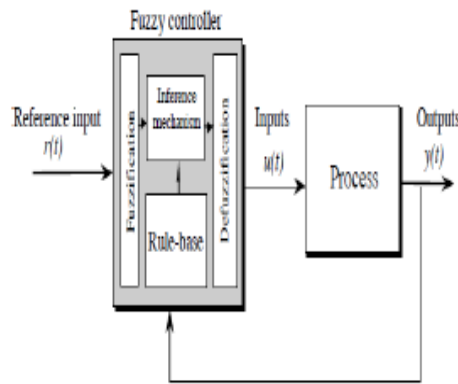


Fig.10 General Structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

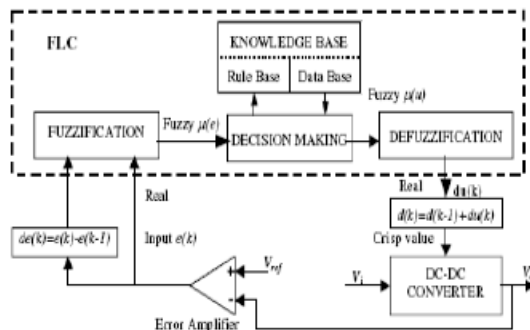
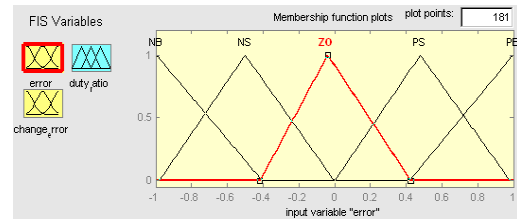


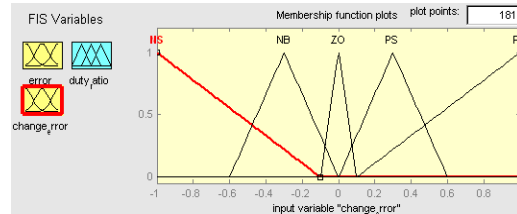
Fig.11. Block diagram of the Fuzzy Logic Controller (FLC) for dc converters

A. Fuzzy Logic Membership Functions:

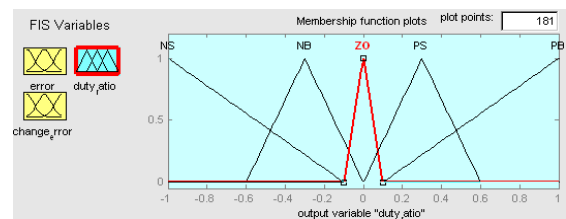
The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.



The Membership Function plots of error



The Membership Function plots of change error



the Membership Function plots of duty ratio

B. Fuzzy Logic Rules:

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table I as per below:

V.MATLAB/SIMULINK RESULTS

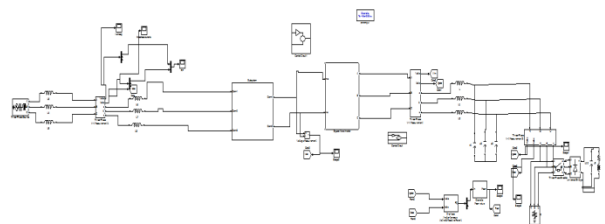


Fig 12 Matlab/simulation circuit of back to back converter operated in the PQ control mode or voltage control mode

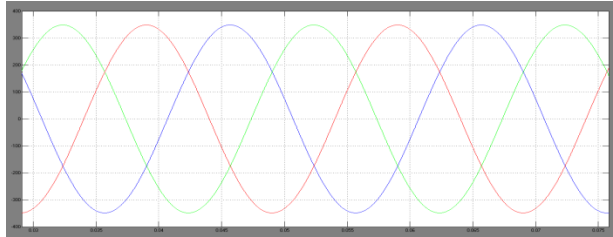


Fig 13 Three phase voltage of the microgrid in the voltage control mode with adding six-pulse rectifier to load at 0.08

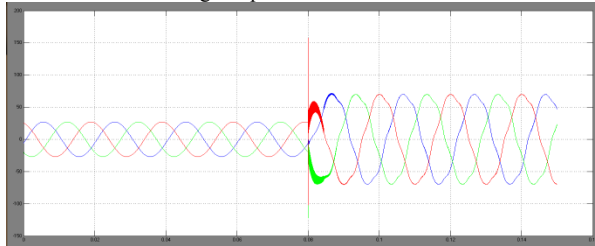


Fig 14 Three phase current of the microgrid(top figure) and utility grid(lower figure) in the voltage mode control with add mg six-pulse rectifier to load at t=0.08

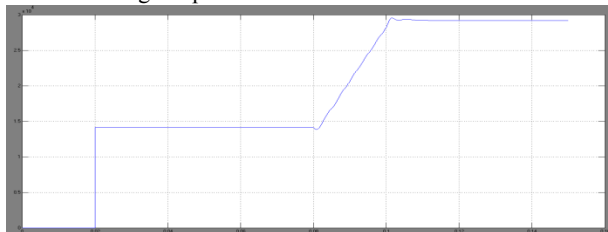


Fig 15 DC-bus voltage in the voltage mode control with adding six pulse rectifier at t=0.08.

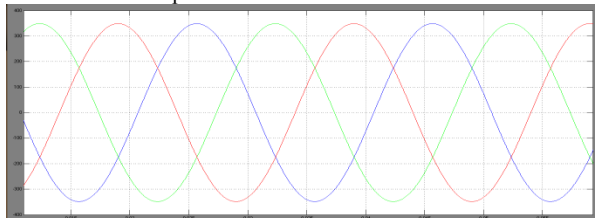


Fig 16 Three phase voltage of the microgrid in the voltage control mode with adding single phase load at t=0.08.

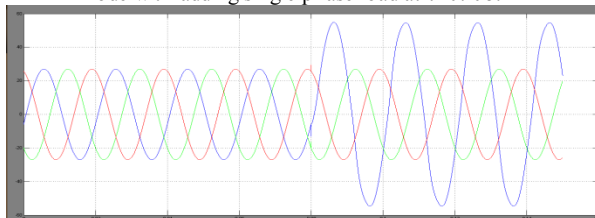


Fig 17 Three phase current of the microgrid (top figure) and utility grid (lower figure) in the voltage mode control with adding single phase load at t=0.08.

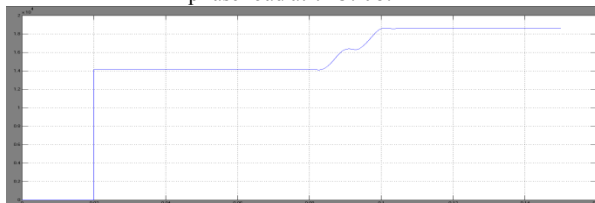


Fig 18 DC-bus voltage in the voltage mode control with adding six pulse rectifier at t=0.08.

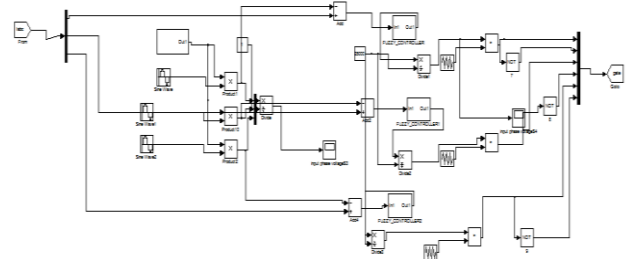


Fig 19 Modeling of the system used for controlling of the DC-link voltage with fuzzy logic

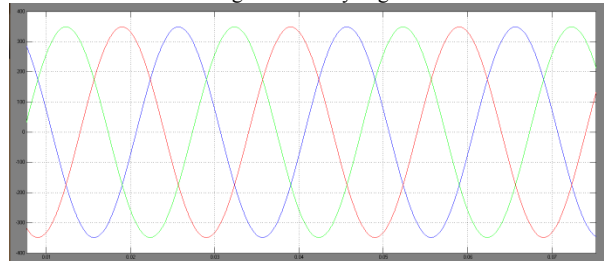


Fig 20 simulation wave form of three phase voltage of the microgrid in the voltage control mode with adding single phase load at t=0.08 with fuzzy logic controller

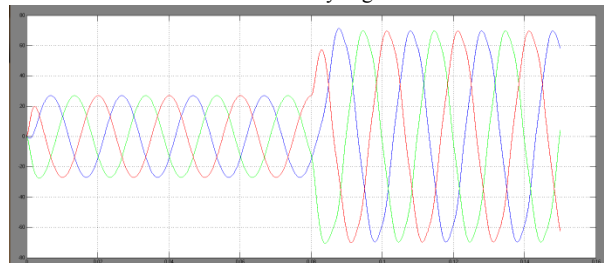


Fig 21 Three phase current of the microgrid (top figure) and utility grid (lower figure) in the voltage mode control with adding single phase load at t=0.08 with fuzzy logic controller

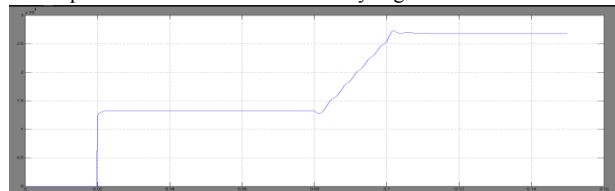


Fig 22 DC-bus voltage in the voltage mode control with adding six pulse rectifier at t=0.08 with fuzzy logic controller

CONCLUSION

This paper presents the application of the b-to-b converter and its advantages in power/voltage control of a grid-connected microgrid system. By changing the pi with fuzzy logic controller two modes of operation are studied. In the first one, i.e. the PQ control mode, the proposed system offers precise active/reactive power control from the grid side. The grid has no contribution to the control of the microgrid voltage. In the second control

mode, i.e. Voltage control with fuzzy logic controller mode although the grid has a role in the control of both the power flow and voltage of the microgrid, it is slightly affected by the disturbances in the microgrid system.

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