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IJIEMR Transactions, online available on 3rd Nov 2017. Link :http://www.ijiemr.org/downloads.php?vol=Volume-6&issue=ISSUE-10

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Volume 06, Issue 10, Pages: 15 – 26.

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GRID-CONNECTED BACK-TO-BACK CONVERTER FOR POWER AND VOLTAGE CONTROL BY USING FUZZY LOGIC CONTROLLER

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ABSTRACT- The proposed system presents power and voltage control strategies of a grid-connected Micro grid generation system with fuzzy controller. Fuzzy logic controller and controlling converters are proposed for smooth power transfer between ac and dc links and for stable system operation under various generation and load conditions. The back-to-back converters also provide total frequency isolation between the utility and the microgrid. It is shown that the voltage or frequency fluctuation in the utility side has no impact on voltage or power in microgrid side. Proper relay-breaker operation coordination is proposed during fault along with the blocking of the back-to-back converters for seamless resynchronization. Both impedance and motor type loads are considered to verify the system stability. The impact of dc side voltage fluctuation of the DGs and DG tripping on power sharing is also investigated. The switching strategy of the grid side converter is designed to improve voltage caused by the fault in the grid while maximum available active power of system is injected to the grid and the DC link voltage in the converter is regulated. The Power balancing and voltage Control simulation results are presented to illustrate the operating principle, feasibility and reliability of Micro grid proposed system by using MATLAB/SIMULINK software.

KEYWORDS-microgrid; back-to-back; inter-link converter; voltage control mode; PQ control mode, PI and Fuzzy logic controller.

I. INTRODUCTION

Along with environmental benefits of renewable energies, the advent of new technologies in the operation and control of renewable energy sources and the increasing demand for high quality and consistent supply result in more attentions to this type of energy sources [1]. Besides optimal operation of a power system in normal condition, controlling the system in faulty condition is one of the most challenging concerns. Power quality is one of the most significant subjects in utilizing the distributed generation (DG). In addition to frequency and active power, voltage and reactive power must be bounded and controlled in predefined ranges [2-3]. To achieve the goal, the generators must be controlled in a properly, so that the voltage drop and voltage rising are avoided at peak time or low demand, respectively. One of the most important advantages of DGs, other than active power injection and local load supply, is reactive power injection at the point of common coupling (PCC) [4-5]. By controlling the reactive power of a DG, voltage profile and power quality can be improved in different operational modes of the grid especially during faults. Wind turbine generation is one of the most common sources used in distributed generation systems for this purpose.The necessity of an AC or DC microgrid is governed by available micro sources and connected loads. A hybrid structure can ensure a sustainable configuration blending both the forms. In this paper, a hybrid microgrid structure or a grid connected microgrid with DC connection at back to back (B2B) converters is proposed [6-7]. An assessment and mitigation strategies for system level dynamic interaction (to achieve tight regulation of load requirement) with control power converters is investigated in a hybrid microgrid. An effective control method to reshape the DC side admittance is proposed to improve the system stability. In [8], a real-time circulating current reduction method, for parallel harmonic-elimination pulse width modulation (HEPWM) inverters used to employ power transfer between AC and DC buses in hybrid microgrid, is proposed. The proposed method can provide an extra15% modulation index range which is a great benefit for power converter applications in this area. The stability issues in a hybrid microgrid are very well addressed in [9]. The proposed control schemes improve the voltage stability in the DC bus and the efficacy of the controller is verified considering the uncertainty of the generators and loads existed in microgrid. In [10], different effective and simple control strategies for hybrid AC-DC microgrid (both grid-connected and islanded operations) are described. The proposed control can keep the power balance and ensures stable AC/DC bus. A decoupled control framework is developed for the hybrid microgrid and the performances are evaluated. The power electronics interfaces and controls for a microgrid with both DC and AC links are investigated in [11]. The presence of AC and DC sources requires detail investigation of the control aspects in such systems. The coordination control algorithms are proposed to balance the power flow between the AC and the DC grids and to maintain both the DC and the AC voltages. Another efficient AC/DC microgrid structure is presented in [12]; where the hybrid grid is consist of AC and DC network connected through multi bidirectional converters. The coordination control algorithms are proposed for smooth power transfer between AC and DC links and for stable system operation under various generation and load conditions. 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 [13] and harmonic sharing in the microgrid [14]. 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

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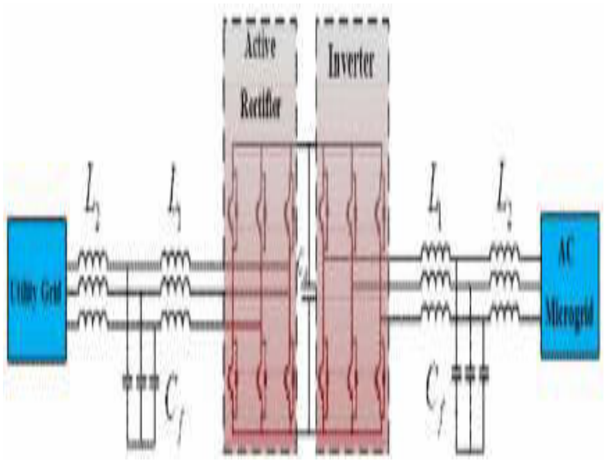

Fig.1. Power circuit of the back to back converter

It is assumed that only VSC interfaced micro sources are present in the AC microgrid. However, the proposed method can also accommodate inertial DGs. It must be noted that the DGs in AC microgrid are VSC interfaced and they are represented by ideal DC sources. In the AC Microgrid the power set points and measured powers are used to calculate the limited power reference [15]. The power errors are fed to the power controller to derive the current references. The voltage reference is then calculated based on the measured current, measured voltage and current reference values. The frequency and voltage regulation are achieved with measured output powers.

II. POWER CIRCUIT STRUCTURE

Fig.2 shows 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.

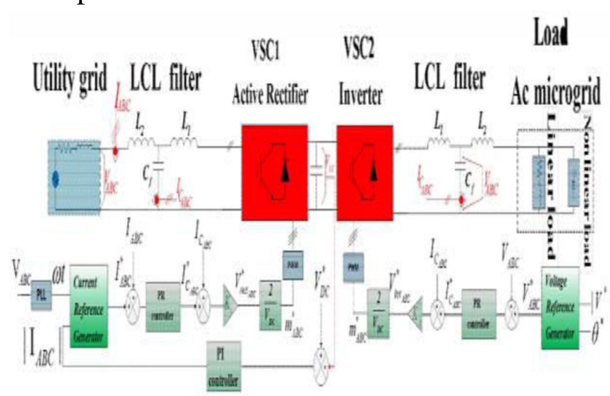

Fig.2. Back to back converter operated in the PQ control mode (mode-1) or voltage control mode (mode-2)

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

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

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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 microgid 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:

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

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 We. 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).

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

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 Ki•

a) 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

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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.

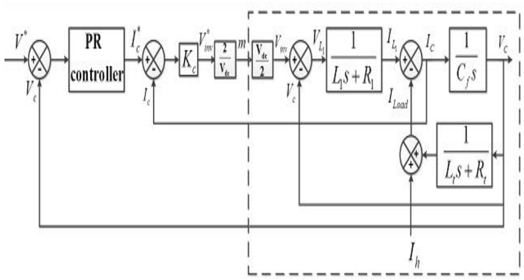

Fig.3. Modeling of an inverter operated as a voltage controller

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.

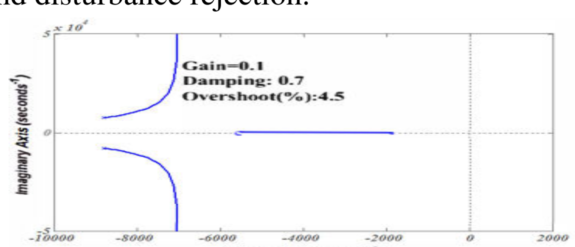

Fig.4. Root locus of the open loop system in voltage control mode

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= O.l. 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).

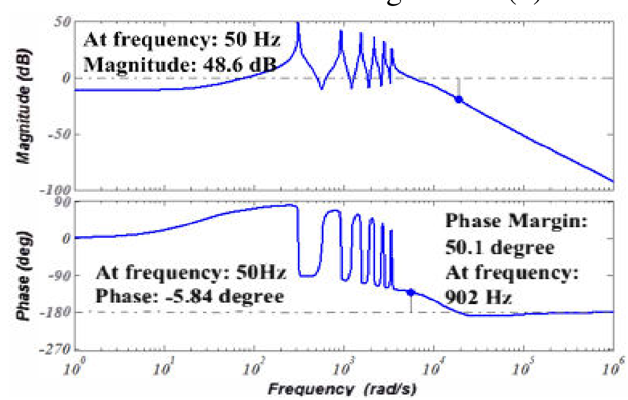

Fig.5. Bode diagram of the open loop system with voltage controller designed

$$G_c(s) = k_p + \sum_{\substack{k=0 \\ h=2k+1}}^{5} \frac{2k_{ih}(h\omega_c)s}{s^2 + 2(h\omega_c)s + (h\omega_0)^2} \quad (3)$$

The integral term for each frequency is determined according to its desired magnitude. Assuming that We 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.

b) 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

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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.

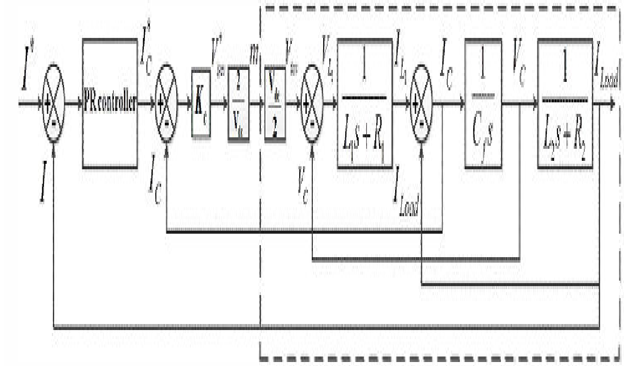

Fig.6. Modeling of an inverter operated as a PQ controller

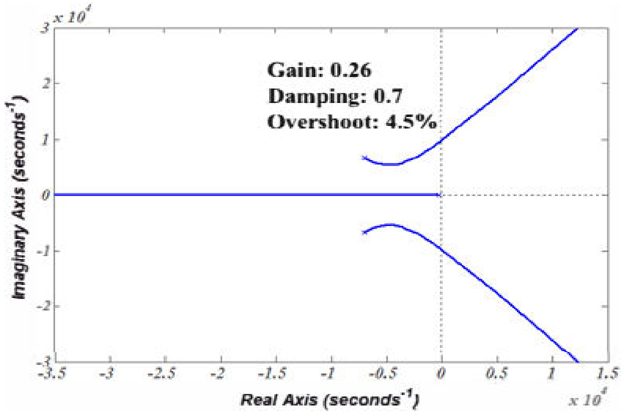

Fig.7. Root locus of the open loop system in the PQ control mode

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,,, 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 We, the value of the integral term is tuned at 100 to have a bandwidth equal to 2840radls, 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.

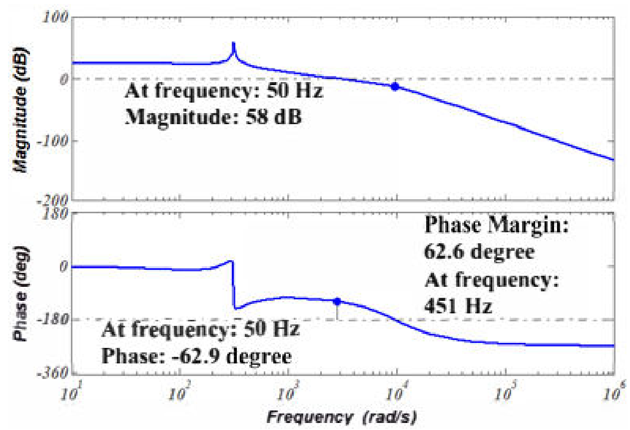

Fig.8. Bode diagram of the open loop system with current controller

c) 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

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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, is the time constant of the current control loop of the grid-side converter which is equal to:

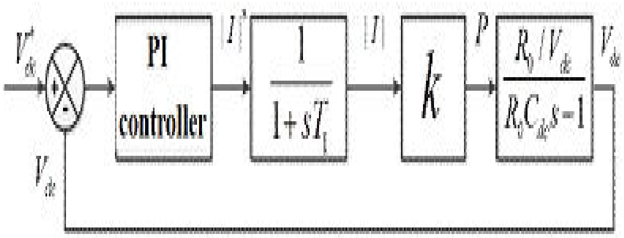

Fig.9. Modeling of the system used for controlling of the DC-link voltage

$$T_1 = \frac{1}{BW_{current\ loop}} = \frac{1}{2840} = 3.5\times10^{-4} \quad (4)$$

Where R_o 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 1=52.

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

IV. FUZZY LOGIC CONTROLLER

The Fuzzy control is a methodology to represent and implement a (smart) human's knowledge about how to control a system. A fuzzy controller is shown in Figure.6. The fuzzy controller has several components:

- A rule base that determines on how to perform control
- Fuzzification that transforms the numeric inputs so that the inference mechanisms can understand.
- The inference mechanism uses information about the current inputs and decides the rules that are suitable in the current situation and can form conclusion about system input.
- Defuzzification is opposite of Fuzzification which converts the conclusions reached by inference mechanism into numeric input for the plant.

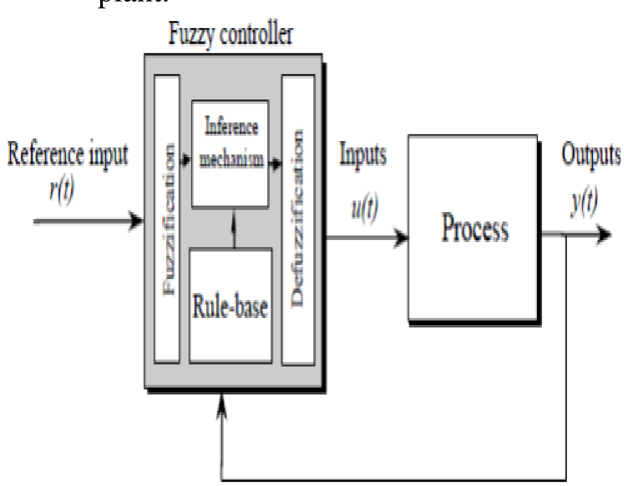

Fig.10 Fuzzy Control System

Fuzzy logic is a form of logic that is the extension of boolean logic, which incorporates partial values of truth. Instead of sentences being "completely true" or "completely false," they are assigned a value that represents their degree of truth. In fuzzy systems, values are

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indicated by a number (called a truth value) in the range from 0 to 1, where 0.0 represents absolute false and 1.0 represents absolute truth. Fuzzification is the generalization of any theory from discrete to continuous. Fuzzy logic is important to artificial intelligence because they allow computers to answer 'to a certain degree' as opposed to in one extreme or the other. In this sense, computers are allowed to think more 'human-like' since almost nothing in our perception is extreme, but is true only to a certain degree.

Table 2: IF-THEN rules for fuzzy inference system

u(t)		e(t)						
		NB	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	NS	PS	PS
Δe(t)	**ZO**	NB	NM	NS	ZO	ZO	PM	PM
	PS	NM	NS	ZO	PS	PS	PB	PB
	PM	NS	ZO	PS	PM	PM	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

The fuzzy rule base can be read as follows

IF e(t) is NB and Δe(t) is NB **THEN** u(t) is NB

IF e(t) is <negative big> and Δe(t) is <negative big>**THEN** u(t) is <negative big>.

V. MATLAB/SIMULINK RESULTS

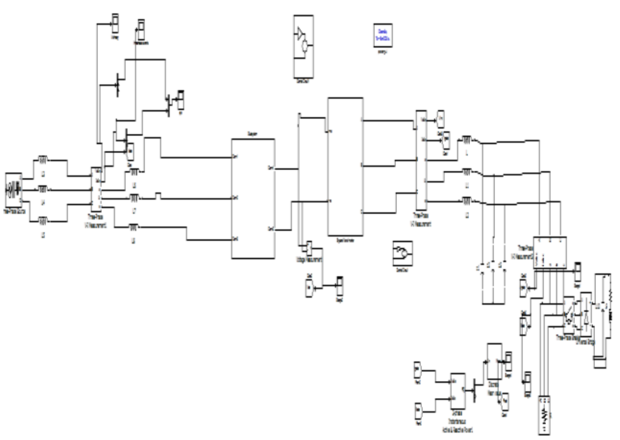

Fig.11 MATLAB/SIMULINK circuit for Power circuit of the back to back converter

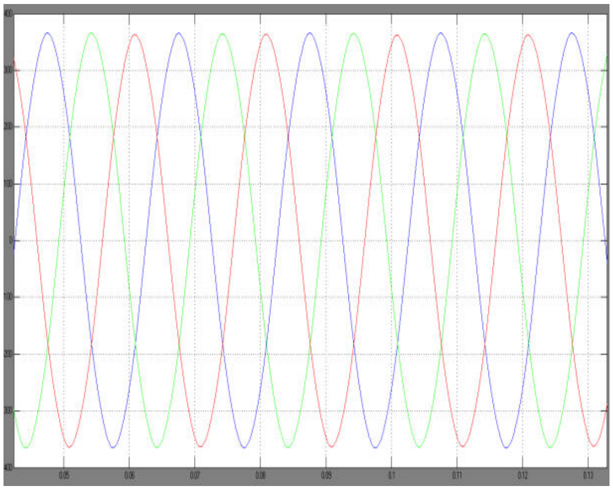

Fig.12. Three phase voltage of the microgrid in the voltage control mode with adding six-pulse rectifier to load at t=0.08.

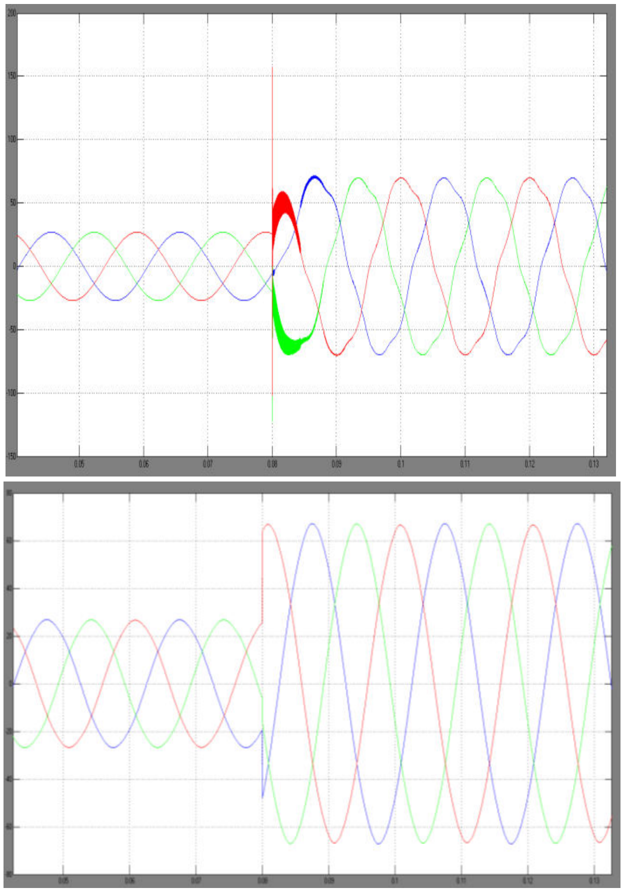

Fig.13. Three phase current of the microgrid (top figure) and utility grid (lower figure) in the voltage mode control with adding six-pulse rectifier to load at t=0. 08

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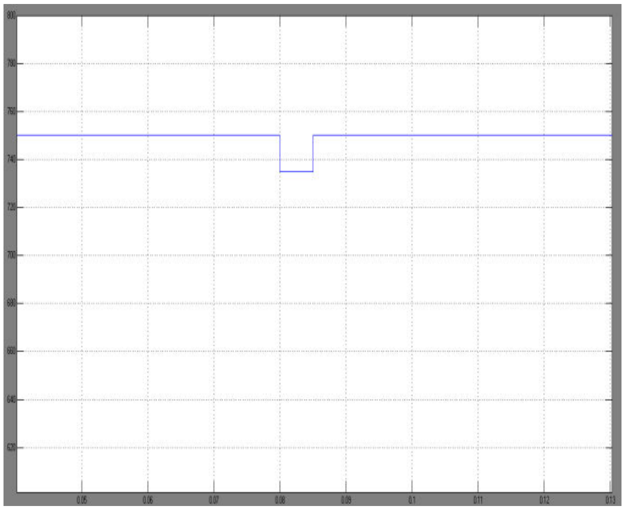


Fig.14. DC-bus voltage in the voltage mode control with adding six- pulse rectifier at t=0 08.

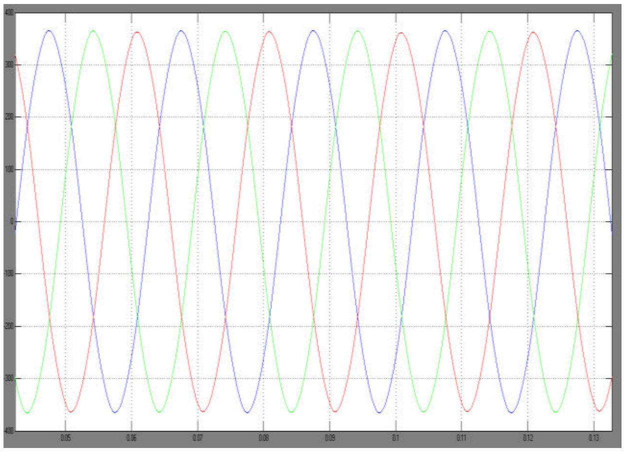
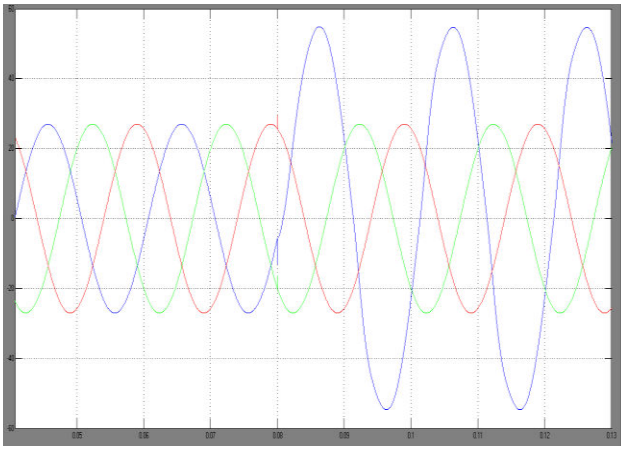


Fig.15. Three phase voltage of the microgrid in the voltage control mode with adding single phase load at t=0.08.



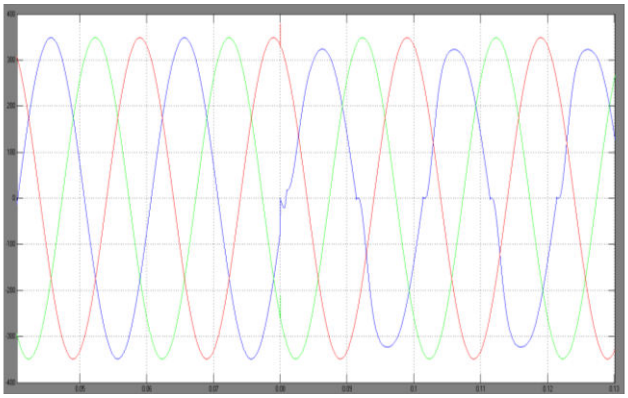


Fig.16. Three phase current of the microgrid (top figure) and utility grid (lower figure) in the voltage mode control with adding single phase load at t=0.08.

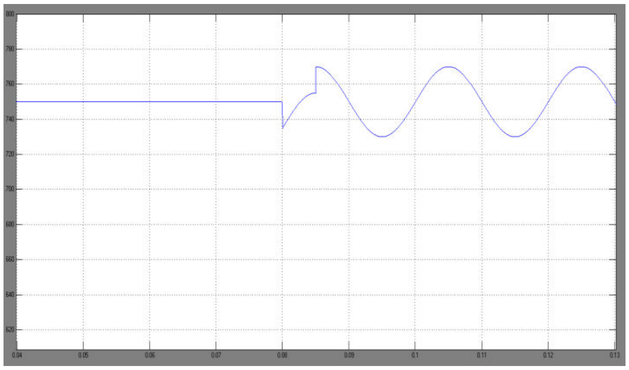


Fig.17. DC-bus voltage in the voltage mode control with adding six pulse rectifier at t=0. 08.

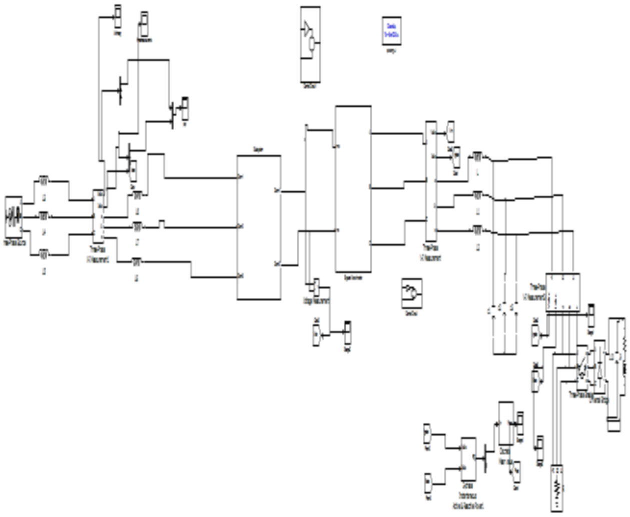


Fig.18 MATLAB/SIMULINK circuit for Power circuit of the back to back converter with PI controller

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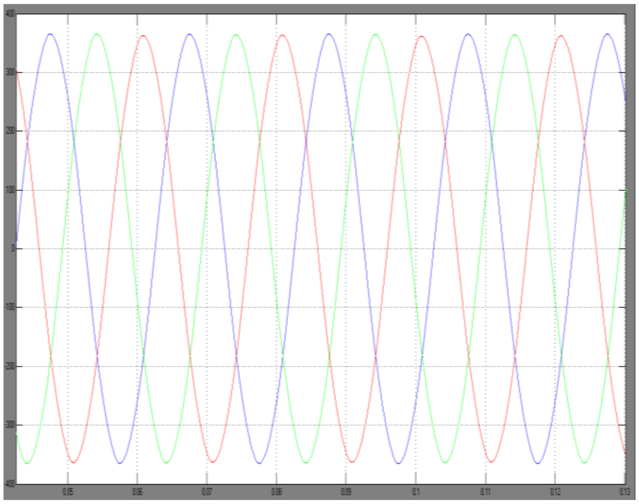


Fig.19. Three phase voltage of the microgrid in the voltage control mode with adding single phase load at t=0.08.

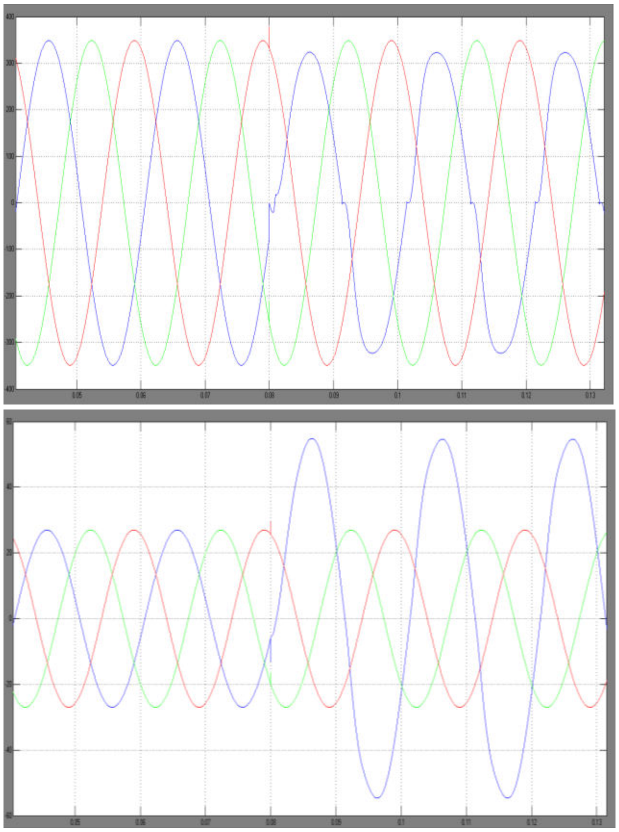


Fig.20. Three phase current of the microgrid (top figure) and utility grid (lower figure) in the voltage mode control with adding six-pulse rectifier to load at t=0. 08

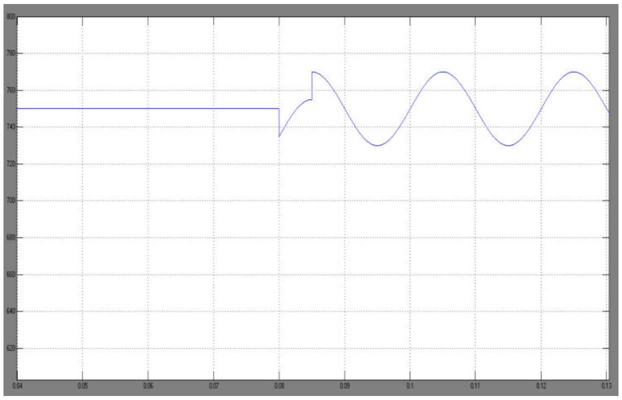


Fig.21. DC-bus voltage in the voltage mode control with adding six- pulse rectifier at t=0. 08.

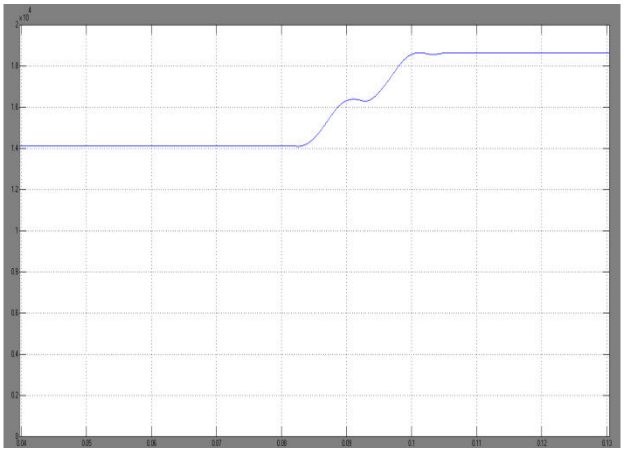
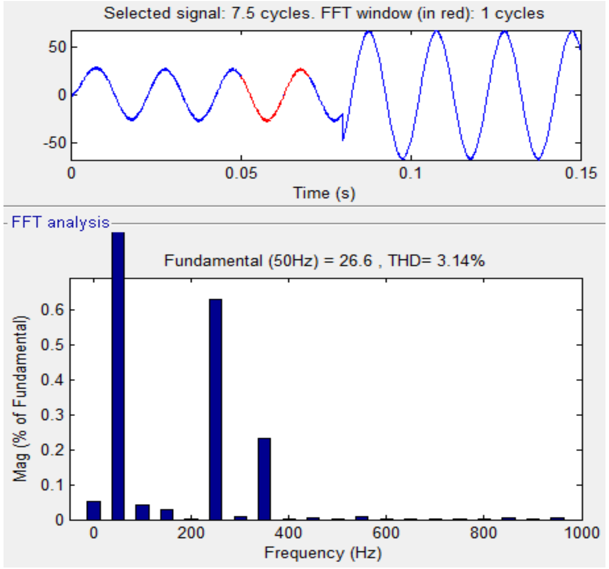


Fig.22. Active power tracking injected to the microgrid in PQ control mode.



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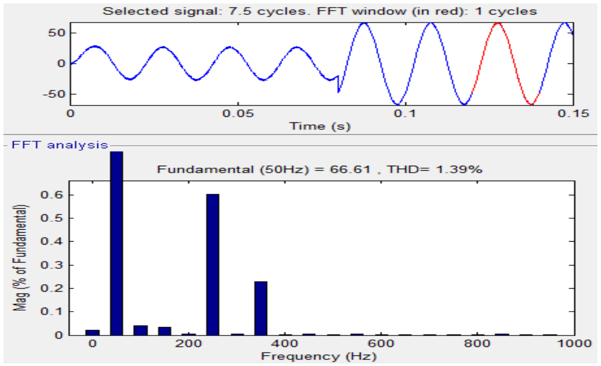

Fig.23 Source current THD waveform of before and after adding the rectifier by using PI controller

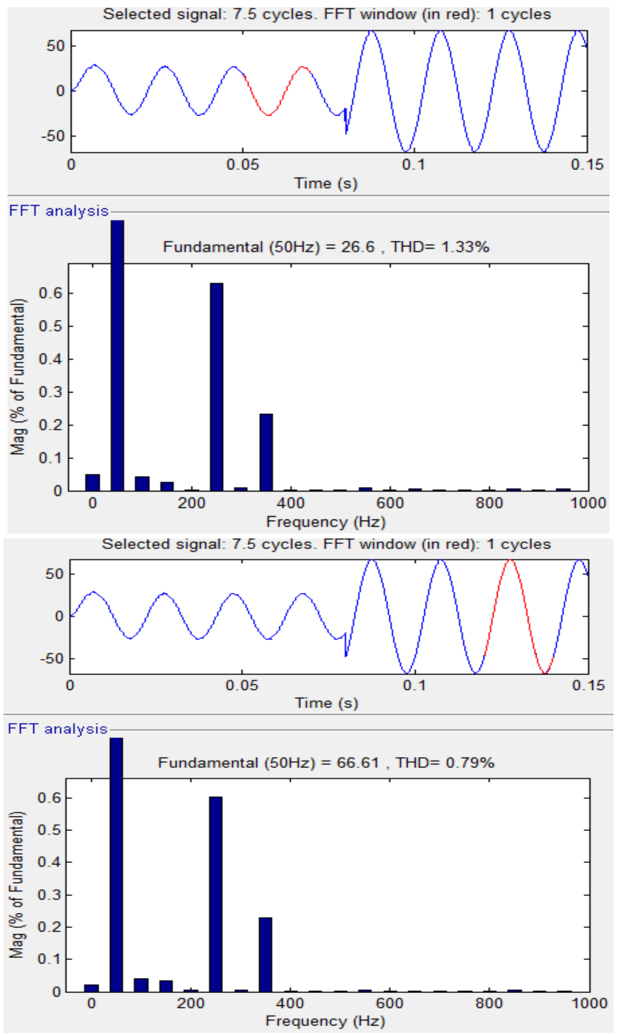

Fig.24 Source current THD waveform of before and after adding the rectifier by using Fuzzy controller

VI. CONCLUSION

The coordinated control strategies are verified with Matlab/Simulink. In the proposed system control methods have been incorporated to harness the maximum power from dc and ac sources and to coordinate the power exchange between dc and ac grid. Different resource conditions and load capacities are tested to validate the control methods. The simulation results show that the grid can operate stably in the grid mode. But PI controllers are not a reliable controller compared to fuzzy logic controller. This is proved by comparing the output response of these systems. Although the grid can reduce the processes of dc/ac and ac/dc conversions in an individual ac or dc grid, there are many practical problems for implementing the hybrid rid based on the current ac dominated infrastructure. The total system efficiency depends on the reduction of conversion losses and the increase for an extra dc link. By using fuzzy logic controller we can reduce those conversion losses

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