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Design and Implementation of Photovoltaic Based Islanded Microgrid with Inverter Control

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ABSTRACT

Microgrids are formed by integrating many small scale energy sources like solar energy, wind energy, fuel cells, etc. therefore a microgrid comprises of many inverters connected in parallel to supply common loads. This paper presents a control methodology to control and synchronize the system of parallel inverters in order to produce a stable power system, even though there are disturbances both in load as well as source side. Apart from being operated as an islanded microgrid, the developed control can also work efficiently in case of grid instabilities. The experimental results presents the validity of the designed controller and the results demonstrate that the system of inverters share the power equally consequently maintaining synchronization and stability.

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INTRODUCTION

The ever increasing energy demand of future can be met by the extensive use of renewable energy. Power from one renewable source may not be sufficient to meet the load demand, hence microgrids are formed by paralleling a number of inverters (Brian, B., 2014; Mohd, D., 2010) with many different energy sources like solar, wind, fuel cell, battery storage etc. (Guerrero, J.M., 2013; Aamadeh, A., 2010; Josep, M., 2004). By using a microgrid, the reliability of the system is improved with less transmission losses as there are localized generation. Moreover, there won't be any grid disturbances or outage affecting the system since the system is islanded. In this paper, the system is formed by paralleling three voltage source inverters with two inverters supplied via battery and one via a photovoltaic system thus forming a microgrid delivering a common load (Rithika, S. and R. Ramaprabha, 2014; Ritwik Majumder, 2013). Fig.1 shows the single line diagram of the designed microgrid.

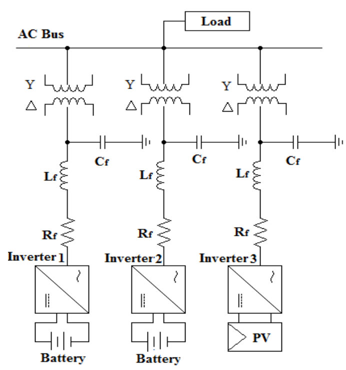

Fig. 1: Single line diagram of the designed microgrid.

The main aim of this microgrid is to make the most of the energy obtainable from the photovoltaic panel even during ambiguous energy availability. This is achieved by applying maximum power point tracking algorithm (Holmes, D. and T. Lipo, 2003; De Brito, M., 2013) for the photovoltaic system.There are already many control techniques for microgrid based on droop control (Maryam

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Babazadeh and Houshang Karimi, 2011; Brian, B., 2014) to share linear load but the increase in nonlinear loads has led to the development of control techniques that balances both real and reactive power and as well as share the harmonic current.

In this paper, control is based on the dynamics of an oscillator (virtual oscillator based control) is used. The system is simulated for integrating photovoltaic (PV) source and conventional DC supply. The controller performance is validated through experimentation and results are presented. The subsequent sections describe the methodology and implementation of the proposed work.

II. Description of the System with Virtual Oscillator Controller:

The system comprises of three inverters with a separate controller for each inverter. The controller is designed with the same concept of the oscillator hence named as dead zone oscillator based control. As each inverter is provided with individual identical controllers there is no communication among the inverters; therefore the system provides decentralized control (Mohd, D., 2010; Katiraei, F.M. and M Iravani, 2006) and tolerates failure in any number of inverters until the load is properly satisfied. The overall schematic of the designed microgrid is shown in Fig. 2(a), the model comprises of system of parallel inverters with output current from each inverter after filtering is given to their corresponding controller. The controller comprises of a dependent current source to withstand the oscillation, a damping element R and a resonant LC to establish the system frequency.

The synchronization of the oscillators has the leverage of intrinsic coupling of the inverters and hence dynamic load sharing can be achieved with trifling voltage and frequency deviations.

III. Simulation of Digital Controller and Microgrid:

The system shown in Fig. 2 (a) is simulated using MatLab-Simulink (Fig. 2 (b)).

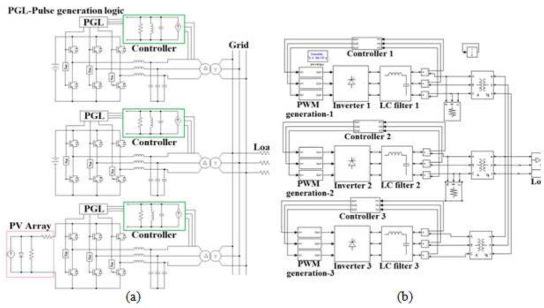

Fig. 2: (a) Overall schematic of the designed microgrid system (b) Simulation model of microgrid with three inverters.

The parameters are selected as per procedure given in (Rithika, S. and R. Ramaprabha, 2015). The simulation parameters are listed in Table I.

Table 1: Simulation parameters.

Parameter	Values
Input Voltage, V_{in}	415 V
Frequency, f_s	50 Hz
Oscillator parameters	
Resistance, R	10 Ω
Inductance, L	250 μH
Capacitance, C	24 mF
Inverter output filter parameters	
Switching frequency, f_{SW}	10 kHz
Resistance, R_{in}	0.1 Ω
Filter inductance, L_f	1.5 mH
Filter capacitance,C_f	1mF
Sizing PV module:	
Open circuit voltage of one module, V_{oc}	21.24 V
Short circuit current of one module, I_{sc}	2.55 A
MPP voltage, current	16.56 V, 2.25 A
PV and MPPT parameters	
Open circuit voltage of array	552 V
MPP voltage of array	430 V
Step size of INC MPPT	0.02
PI controller parameters	
K_p	0.1
K_i	75

The system was initially designed with a constant load of 10 kW and constant input irradiance level of 1000 W/m^2. The power delivered by the solar panel changes with environmental conditions. In order to track the maximum power with changes in varying conditions, a maximum power point tracking (MPPT) is used. In this work, incremental conductance (INC) algorithm is used. The MPPT tracking characteristics for the change in irradiance level for 16×1 PV array is shown in Fig. 3(a).

The system is then subjected to load changes and irradiance changes. The load for the system is gradually varied from 100 W to 20 kW and the irradiance of the system is suddenly varied from 1000 W/m^2 to 500 W/m^2. The response of the system for the change in load and suddenly change in input is shown in the Fig. 3(b) and 3(c) respectively.

It is observed that the changes in irradiation level and load are adopted by MPPT algorithm with proposed controller. The main deliverable of the designed controller is to provide voltage regulation for change in loading conditions. As stated earlier the system is checked for varying loading conditions and voltage variation is found to be within ±5% and the validated results are shown in Fig. 3(d).

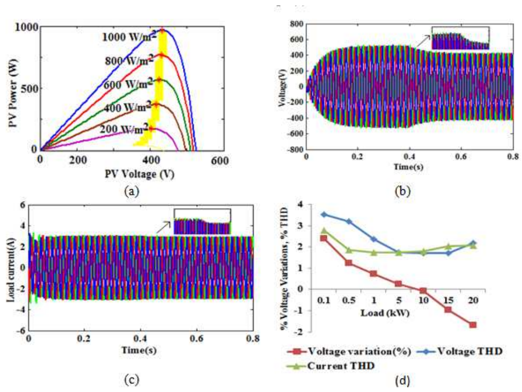

Fig. 3: (a) Maximum power point tracking for different irradiance values at temperature T=30^{o}C (b) Output voltage of the microgrid for step change in input (c) Load current of the microgrid for step change in input (d) Load changes versus % voltage variations.

According to IEEE standard 519, the voltage THD must be within 5 % for voltage rating less than 69 kV and for current rating less than 20 A. The graph shows that THD limits are satisfied for various loading conditions.

IV. Operation under Grid Instability:

Apart from being operated as an islanded microgrid the system can also work efficiently when connected to the grid and under grid instability. The converters connected to a non-ideal grid can become unstable by the presence of transmission line impedance separating the points of coupling. Thus by adding unequal impedance to the PCC artificial instability is introduced into the system. Fig. 4 (a) shows the system performance under unstable conditions in grid. From Fig. 4 (a) it is shown that the output remains synchronized even under grid disturbances, thus proving that the developed control can also be implemented for grid connected systems and the controller proves to be working efficiently even when connected to the grid.

V. Hardware Implementation and Results:

The output characteristics of the sized PV array was measured for various input irradiance conditions say G= 1000 W/m^2, 592 W/m^2, 486 W/m^2, where the standard irradiance is nearly 900 W/m^2. The practical voltage versus current and voltage versus power characteristics for different irradiance values are shown in Fig. 4 (b) and Fig. 4(c).

The hardware of the system of three parallel inverters with power supply, driver and protection circuits along with suitable filter design for the inverter has been implemented. The gate pulse of the three phase inverter is generated using FPGA processor using Vivado software. Fig.4 (d) shows the gate pulse generated using the FPGA kit.

The integrated power module for one three phase inverter is shown in Fig. 5(a). It composes of the driving and protection circuits along with the input power rectifier for the inverter.

The input step down transformer, three 3-phase inverters and its respective power supplies are shown in Fig. 5(b).

The implemented hardware of the microgrid comprises of three 3-phase inverters are along with suitable filter design for the inverter (Fig. 5(c)). The outputs from each inverter after filter is given to the isolation transformers and the output from the transformers are paralleled and the paralleled output is given to the load.

The output from an inverter will be a square wave as shown in Fig. 5(d).

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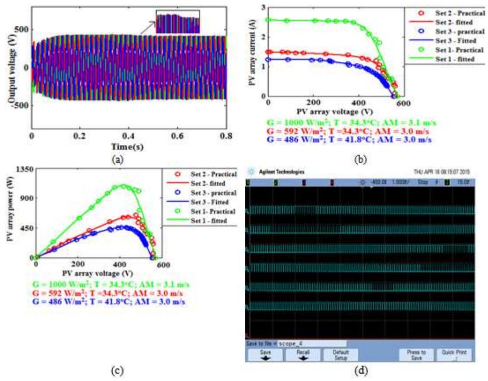

Fig. 4: (a) Operation of system under grid instability (b) Practical output VI characteristics of the photovoltaic system (c) Practical output PV characteristics of the photovoltaic system(d) Gate pulse generated using the FPGA kit.

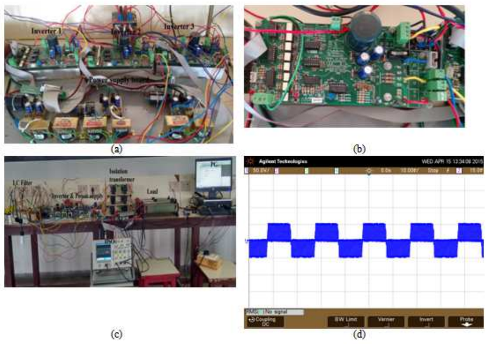

Fig. 5: (a)Module for one three phase inverter (b) Hardware setup of three phase inverter and its power supply(c) Overall hardware setup (d) Practical three line voltage of the three phase inverter before filtering.

In practical applications only sine wave output is acceptable hence suitable filter is included at the inverter output terminal to give sine wave output. The sinusoidal three phase voltage of the microgrid is shown in Fig. 6(a). Fig. 6(b), 6(c) and 6(d) 19 show that the three phase ie, R phase, Y phase and B phase voltages and currents are in phase with the corresponding phase voltages.

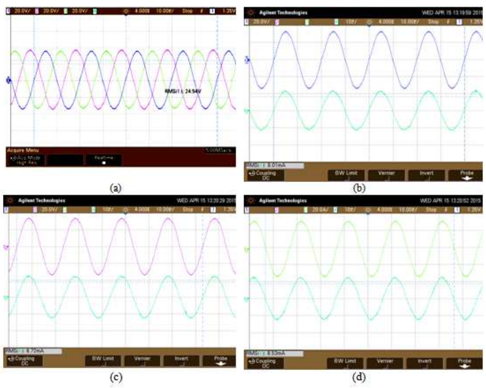

Fig. 6: (a) Practical three phase sign wave output of the inverter after filtering (b) R-phase voltage and current of the microgrid (c) Y-phase voltage and current of the microgrid (d) B-phase voltage and current of the microgrid.

The hardware results have been compared with the simulation results and results are found to be alike.

VI. Conclusion:

In this paper, an oscillator based control methodology was proposed for islanded microgrids and the developed control was tested under various conditions like load variations, input variations and grid instability. The simulation results demonstrate that the system of inverters continuously adjusts their output to maintaining the output voltage regulation of the microgrid within prescribed limits say ±5% of rated voltage and the output remains synchronized both for sudden changes in input and disturbances or instabilities in the grid. The results are validated and the hardware results are found to be identical to the simulation results.

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