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Control of Voltage in a Certs Microgrid of PV Inverter Using Fuzzy Controller

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ABSTRACT: In this paper the voltage source control of the PV inverter in CERTS microgrid is proposed.Micro grids are extremely good with photo voltaic (PV) sources as results of their capability to within total and leveling numerous renewable sources. Conventional grid-connected PV inverter control designs are basically present sourced what's additional, cannot without abundant of a stretch control ac voltage or frequency. The PV inverter using the consortium for electric reliability Technology Solutions (CERTS) concepts will control ac voltage and frequency however have a serious drawback with load transients. Throughout a load transient, the PV microsource becomes full with the chance of collapsing the dc bus voltage leading to an ac drop. This paper presents a PV inverter management strategy that permits PV to behave as a voltage supply and is capable of maintaining dc bus voltage stability during load transient. Here we are using the fuzzy controller compared to other controllers. The simulation results show the performance of the system.

KEYWORDS: Consortium for Electric Reliability Technology Solutions (CERTS), controller, intentional islanding, microgrid, photovoltaic (PV), Fuzzy logic controller.

I. INTRODUCTION

The CERTS microgrid concept [2] utilizes power-versus-frequency droop and reactive powerversus-voltage droop to produce a stable electrical grid throughout islanded operation while not additional inter-source communications. Stable power operative points are achieved during this form of microgrid by introducing grid-forming (droop style) sources that are designed to implement power vs. frequency droop characteristics. This droop adjusts the relative load angle across a coupling inductance between two voltage sources so as to manage the ability flow. Additionally, reactive power versus.Voltage droop is implemented to manage the reactive energy delivered by the microgrid sources whereas control the microgrid voltages to acceptable levels. Typical grid-tied PV inverters are generally designed to continuously operate at unity power issue by injecting a prescribed current in section with a 3-phase voltage vector. In contrast, the inverters employed in CERTS microgrids typically use a voltage-source primarily based droop-style controller topology that varies its frequency in direct proportion to the output power and voltage magnitude in response to reactive power changes

Traditional PV inverters control ways will be principally divided into two categories as: 1) grid-connected management and 2) stand-alone management. The grid-connected management primarily directly controls the currents of PV sources injected into the grid, that makes the PV supply as current sources.These management ways are appropriate for the grid-connected mode as a result of the grid voltage is usually stiff, therefore the PV sources will continuously output most power once the maximum power point tracking (MPPT) is embedded. However because of the lack of the flexibility to manage voltage and frequency, these control ways don't permit PV sources to figure alone in islanded mode. In distinction, the complete management allows PV sources to manage voltage and frequency, therefore the PV sources will work as voltage sources to provide load in islanded mode. However, because of the irregularity of daylight, energy storage must be connected to the dc bus, that will increase the price of the PV system. In a very microgrid atmosphere, the microsources got to add grid-connected mode and islanded mode, and to attain seamless transfer between these two modes. Many microsources adopt current sources management of microsources in

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grid-connected mode and voltage-sources management of microsources in islanded mode, and switch management modes during islanding.

With this PV inverter management con figuration, it's shown that the PV microsource will operate as a voltage supply within the CERTS microgrid.This strategy requires fast islanding detection to achieve seamless transfer ability. The failure of islanding detection may make the microgrid stop working. The microsources in the CERTS microgrid adopt a unified CERTS controller, which ensures them working in both modes without switching control methods. The seamless transfer is easily achieved because no islanding detection is needed. The CERTS concepts allow multiple microsources to regulate voltage and frequency independently and work together in an islanded system to share the load
Traditional current-sourced PV cannot back off their generation easily. In a microgrid, there are multiple fast responding microsources, which indicate that the energy storage required by the dc bus of the PV to work in stand-alone mode is no longer necessary, which significantly reduces the cost of the PV system. However, PV sources using CERTS control have a major problem when PV becomes overloaded.

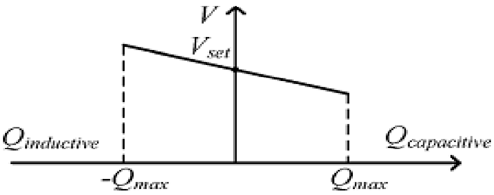

Fig. 1.Voltage versus reactive power droops.

A CERTS PV microsource controller is designed, which enables the PV to behave as a voltage source, and becomes capable of maintaining dc bus voltage stability during load transients.Any large disturbances, such as load transients, or a change of sunlight or temperature will cause the overload of PV with the possibility of collapsing dc bus voltage, resulting in ac voltage drop. This paper investigates the application of PV sources in a microgrid with CERTS concepts. The single-stage PV inverter is discussed here for its lower cost and higher power conversion efficiency.

II. CERTS MICROGRID CONCEPTS

i. Voltage Control

At least one microsource is required to behave as a voltage sourceStable power operating points are achieved in this type of microgrid by introducing grid-forming (droop style) sources that are designed to implement power vs. frequency droop characteristics.

By considering the reliability of the microgrid, more microsources are expected to behave as voltage sources. The following equations show the expressions of real power and reactive power from microsource:

$$P = \frac{EV}{X}\sin\delta \; \ldots . \; (1)$$

$$Q = \frac{E}{X}(E - V\cos\delta) \ldots\ldots \; (2)$$

Where E is the inverter output voltage magnitude, V is the microgrid-side voltage magnitude, X is the coupling reactance. If X is sized to makeδ less than 10,P islinear with , and Q is linear with V. All CERTS sources control the voltage but they also ensure that there are no large circulating reactive currents between units. With small errors in voltage setpoints, the circulating current can exceed the ratings of the units. This situation requires a voltage versus reactive power droop controller so that as the reactive power Q that is generated by the unit becomes more capacitive, the local voltage setpoint is reduced. Conversely, asQ becomes more inductive, the voltage setpoint is increased. This droop is dependent on the utility's voltage swings and reactive power available from the sources. Fig.1shows the voltageversus reactive power droop.

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ii. Frequency Control

Power versus frequency droop is used to balance the power between microsources. The slope is typically chosen by allowing the frequency to drop by 0.5 Hz as the power spans fromP_{min}toP_{max}. The CERTS microsources control the frequency directly. As shown in fig.2.

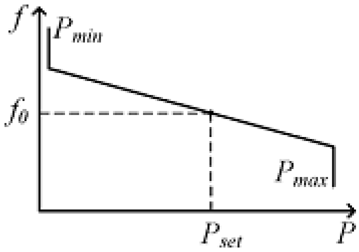

Fig. 2.Power versus frequency droop.

iii. Over load Issue of CERTS Microsources

In a microgrid, it's a standard phenomenon that some sources have reached their power limits whereas the opposite sources haven't. In these conditions, once a positive load transient happens, all of the microsources can instantly increase their output to compensate for the additional load as a result of their voltage-sources characteristics. The CERTS supply is expressly protected from self-overloading by driving the frequency down once the unit becomes full. an oversized load increase would possibly cause the microsource to overshoot its power rating Pmax .

Asustainedoverload can stall the internal combustion engine (ICE) or collapse the dc bus voltage of the PV. However, the microsources, which have reached their power limits, should not increase their output.

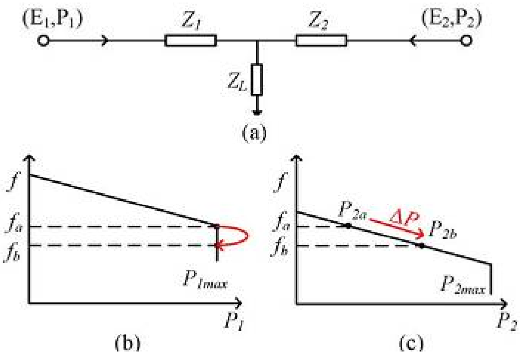

Fig. 3.Two-microsource network and versus droop. (a) Two-microsource network. (b) P Versus fdroopof microsource1. (c) PVersus fdroop of microsource2.

If measures are not taken, these microsources may stop working due to the overload. A two-microsource system is used to show how the extra load of one microsource is transferred to the other one.

$$P_1 = \frac{E_1^2}{|Z_{11}|}\sin\alpha_{11} + \frac{E_1E_2}{|Z_{12}|}\sin(\delta_{12} - \alpha_{12}) \ldots\ldots\ (3)$$

$$P_2 = \frac{E_1^2}{|Z_{11}|}\sin\alpha_{22} + \frac{E_1E_2}{|Z_{12}|}\sin(\delta_{12} - \alpha_{12}) \ldots\ldots\ (4)$$

P_1AndP_2 are expressed in (3) and (4) according to, where$Z_{ii}$and Z_{ij} (i≠j) are input impedances and transfer impedances, respectively; $\alpha_{ii}$and α_{ij}(i≠j) are the complementary angles of the impedance angles, respectively; and $\delta_{12}$is the phase angle of microsource1 relative to microsource2 . By regulating the frequency of the overloaded microsource, δ_{12}could be regulated; thus, P1 and P2 could be redistributed.

III. PV SOURCES IN THE CERTS MICROGRID

i. Advantages of Making PV Source a Voltage Source.

The PV microgrid is expected to be designed for high export of solar energy in grid-connected mode. As shown in Fig. 4by settingP_{set} the as its rated power, the maximum powerpoint (MPP) moves around the left side ofP_{set},

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so the PV could always output maximum power to the grid. When IEEE 1547 events occur, the voltage-sourced PV can automatically back off the solar generation during low-load islanding, companioned with a small increase in frequency. Besides, a voltage-sourced PV can regulate voltage and frequency within its power rating, which increases the reliability of the microgrid by considering the N-1 stability criterion.

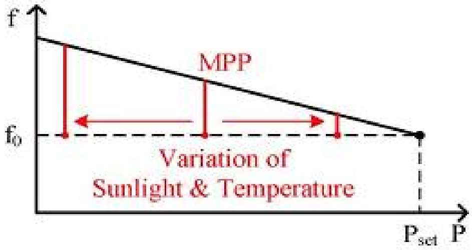

Fig. 4.Movement of PV on the versus droop curve.

ii. Challenges of Designing the CERTS PV Inverter Controller.

There are several challenges in designing a CERTS PV inverter controller. First, a major difference which distinguishes PV from other microsources is that the PV dc bus may collapse during a large load transient or dramatic change in environment. The only inertia of a commercial PV inverter is the limited energy stored in the dc bus, which is usually in the vicinity of 0.01 p.u.-second. This indicates that the designed controller has to respond in less than 10 ms or the dc bus collapse might happen. Second, economic incentives require PV output maximum power when it is possible. This requires that an MPPT be embedded in the controller. Third, the dc bus voltage will endure oscillation during load transient, and will deviate from its MPP voltage in light load conditions, which indicates the dc bus voltage of the PV is no longer a fixed value. The variation of dc

iii. Stability Analysis of DC Bus Voltage of the PV Inverter

References and reported that the current-sourced PV inverters may endure dc bus voltage V_{dc}collapse during a disturbance in grid-connected mode. Similar problems also exist when PV sources supply the load as voltage sources. Traditional CERTS droop control does not consider the dc bus voltage stability issue, and it does not control the dc bus voltage during a large load transient. Therefore, measures have to be taken to prevent the dc bus collapse from occurring.

iv.Studiedmicro grid system

In order to evaluate the effect of the designed controller, a two-source microgrid system is studied in this paper. The two-source system represents the most serious overload issue of microgrid, because each microsource has to stand a half of the extra load during a positive load step. The variation of sunlight and temperature is usually much slower than a fast load step, if theV_{dc_min} controller is capable of dealing with fast load transient, it can also deal with the variation of sunlight and temperature. Consequently, this paper only shows the cases of load transients.

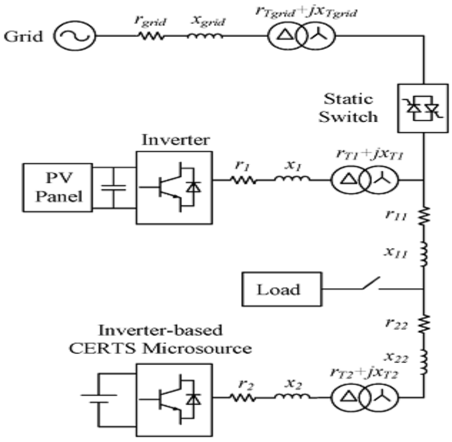

Fig. 5. Reduced AEP/CERTS Microgrid

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Laboratory test bed.

As shown in Fig. 5, a 100 kW traditional Inverter-based CERTS microsource and a 100 kW PV microsource is considered in a 480 Vrms microgrid. The microgrid is connected to the 13.8 kV grids through a static switch and a transformer. The traditional CERTS microsource adopts the standard droop control and is assumed to have enough operational power margins. The PVmicrosource adopts the controller as shown in Fig. 8 and is assumed to output maximum power at initial state.

IV. CERTS PV INVERTER CONTROLLER

With the considerations in Section III, the PV inverter controller should achieve the following control objectives:

(a) Avoid dc bus voltage collapsing during disturbances such as load transients and changes in isolation;

(b) Maintain the stability of ac voltage of PV inverter when the dc bus voltage changes.

(c) Adopt the CERTS concepts to enjoy the advantages of autonomously backing off solar generation during low-load islanding and controlling voltage and frequency independently;

(d) Have MPPT ability. Fig. 6 shows the main circuit of CERTS PV microsource.

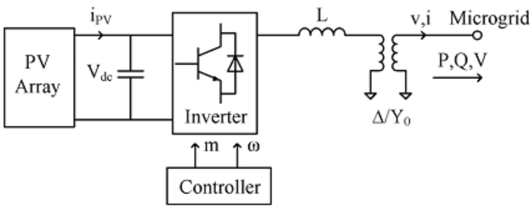

Fig. 6.Main circuit of the PV CERTS microsource.

The PV array is connected to the inverter through a dc bus. WhereV_{dc} is the dc bus voltage, $i_{pv}$is the current from the PV array, L is the coupled inductance, v and i are the three-phase instantaneous voltages and currents at the second side of isolation transformer,P and Q are real power and reactive power, and V is the voltage magnitude. The controller gives the frequency w and modulation index m to the inverter. Fig. 7 demonstrates the overall con-figuration of CERTS PV inverter controller, including CERTS droop control, V_{dc-min}control, and MPPT.

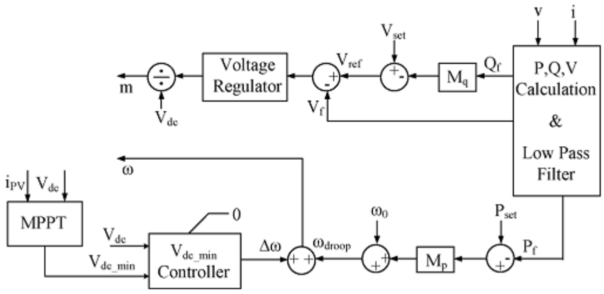

Fig.7. Overall con - figuration of the CERTS PV inverter controller.

A. CERTS DROOP CONTROL

The CERTS droop control includes the reactive power versus voltage droop and the real power versus frequency droop. The P,Q , and V are calculated instantaneously based on Clarke transform, and passed through a first-order low pass filter to obtain the valueP_r,Q_r and V_r. The Q versus V droop is used to obtain the microgrid-side voltage referenceV_{ref} ,where $V_{set}$is the voltage setpoint, andM_q is the droop coefficient.V_{ref} and V are passed to the voltage regulator, which is a Fuzzy controller. The output of voltage regulator is divided by to obtain the modulation index m. The division ofV_{dc} is used to decouple the ac voltage from dc bus transient. The P versus W droop is used to generate the inverter frequency W, where $P_{set}$is the power setpoint,M_p is the droop coefficient. $Wo$is the rated frequency, which is typically 376.99 rad/s (60 Hz). TheP_{set} is set as the rated power of the PV array. With this setting, the MPP moves around the left part of P_{set}as shown in Fig. 4.

B. V_{dc_min} ***CONTROLLER***

The V_{dc_min} controller is the key part of PV CERTS controller, preventing dc bus collapse from happening. According to the PV dc bus voltage stability analysis, the Vdc should work above the MPP voltage in steady state. Additionally, the should be higher than, V^*_{dc-min} which is the minimum dc bus voltage required by the inverter to generate the rated ac voltage. As shown in Fig. 8, V_{dc_min} the controller includes a fuzzy controller with an anti-wind-up zero upper limiter, and a derivative term of V_{dc}. There is a zero upper limiter at the output of controller. When V_{dc} is above, the frequency command is zero. The V_{dc_min} controller outputs negative value once the V_{dc} drops below V_{dc_min}. The function V_{dc_min} of controller could be explained as: Once V_{dc} is below V_{dc_min}, which indicates the output power at ac side is greater than the power from PV panel, which causes the drop of V_{dc}, the V_{dc_min} controller will rapidly reduce the frequency,

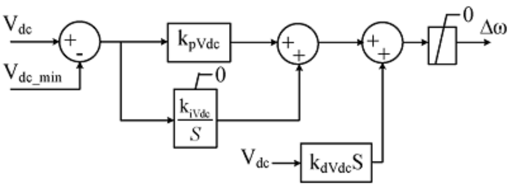

Fig. 8. V_{dc-min} Controller.

so the power angle of PV source could be adjusted, and the extra ac power could be transferred to the other microsources which have marginal capacities. By this, the power from the PV panel and the power at the ac side of the inverter could be balanced again, and the V_{dc} operates at V_{dc_min}.

C. MPPT

The MPP changes with the variation of environment. By regulating V_{dc_min}, the PV microsource can track maximum power. A conventional perturbs and observes method is adopted as an external loop of the V_{dc_min} controller. It increases a small step in V_{dc_min}, and waits for the to converge to V_{dc_min}. Once the V_{dc} converges to V_{dc_min}, the MPPT measures the power from the PV panel and compares it with the power measured before the changes in V_{dc_min}, and decides to increase or decrease the V_{dc_min}. The V_{dc_min} will finally be the MPP voltage, which is also the minimum voltage that should operate in steady state.

V.FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

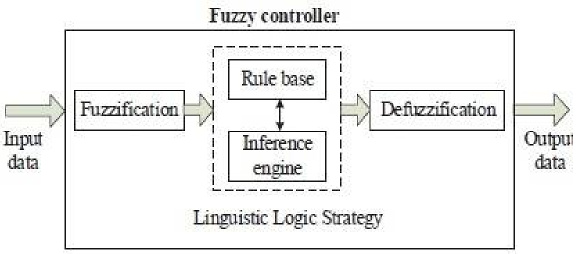

Fig.9.Fuzzy logic controller

The FLC comprises of three parts: Fuzzification, interference engine and Defuzzification. The FC is characterized as (i) seven fuzzy sets for each input and output. (ii) Triangular membership functions for simplicity. (iii)Fuzzification using continuous universe of discourse. (iv) Implication using Mamdani's, 'min' operator. (v)Defuzzification using the height method.

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TABLE I: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

i. Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership CE (k) E(k) function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.In this system the input scaling factor has been designed such that input values are between -1 and +1 as shown in fig10. The triangular shape of the membership function of this arrangement presumes that for any particular E(k) input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E\,(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad \ldots\ldots\ldots \quad (5)$$

$$CE\,(k) = E\,(k) - E\,(k\text{-}1) \quad \ldots\ldots\ldots \quad (6)$$

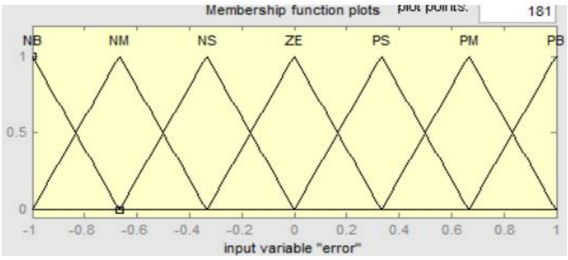

Fig.10.Membership functions

ii. Inference Method: Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In proposed work Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

iii. Defuzzification: As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, "height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u = -[\alpha\, E + (1-\alpha)^{*}C] \quad \ldots\ldots\ldots\ldots \quad (7)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

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V. SIMULATION AND RESULTS

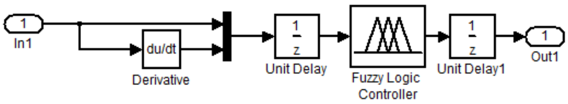


Fig. 11 Simulation model of fuzzy controller

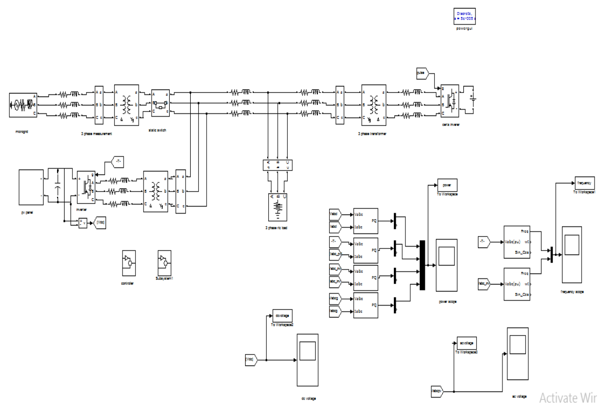
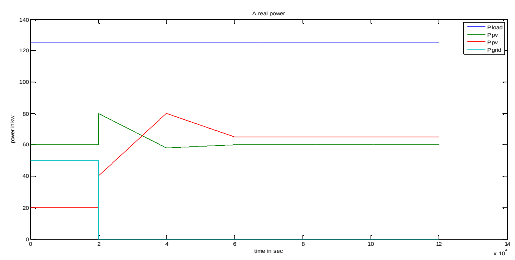


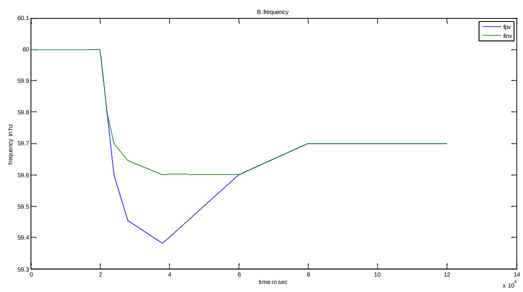
Fig.12 Simulation model of proposed system.

Two intentional islanding are studied in simulation software to investigate the interactions between a PV microsource and a traditional CERTS microsource. Both micro sources have a 100 kW rating. The traditional CERTS microsource is modeled with a fixed dc voltage and an inverter. The MPP voltage of the PV panel is assumed to be 850 V in simulation. In both cases, the same - curve is adopted; whose maximum power is 60 kW.

1) Case A: Islanding When Micro grid is Importing Power:



(a)



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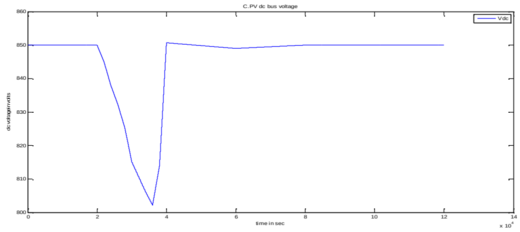

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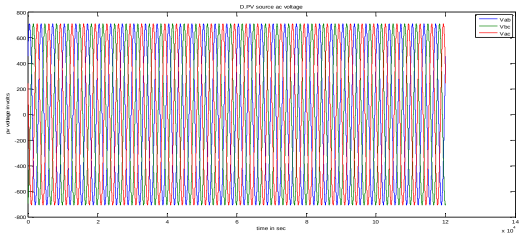
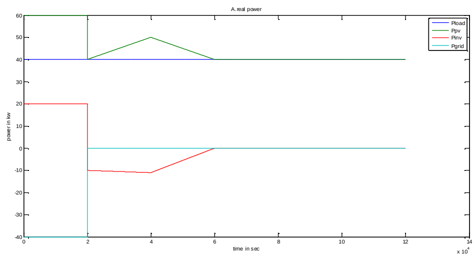


(d)

Fig. 13. Dynamic responses of case A. (a) Real power. (b) Frequency. (c) PV dc bus voltage. (d) PV source ac voltage.

2) Case B: Islanding When Micro grid is Exporting Power:



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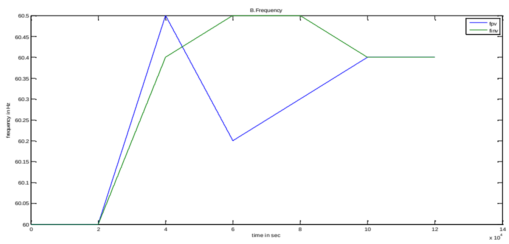

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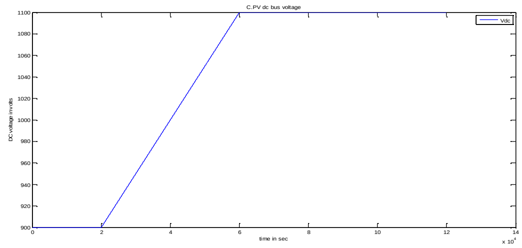

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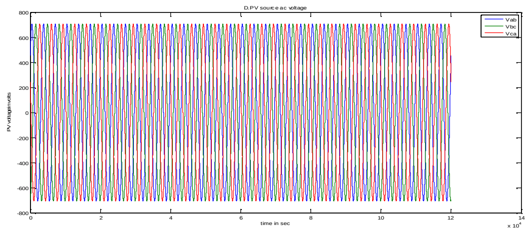

(d)

Fig. 14.Dynamic responses of case B. (a) Real Power. (b) Frequency. (c) PV dc bus voltage. (d) PV source ac voltage.

VII. CONCLUSION

Conventional CERTS droop management is adopted within the control configuration, and a fuzzy controller is fabricated. This paper styles a controller that allows the PV source to behave as a voltage supply within the CERTS microgrid and maintains the dc bus voltage stability throughout load transients. The overload issue of the CERTS microgrid and also the dc bus voltage collapse issue of the PV microsource are analyzed. The influences of the parameters of the controller on system small signal stability are analyzed. Two intentional islanding are simulated to demonstrate however the designed management achieves the control objectives, such as maintaining dc bus voltage stability throughout load transients, automatically backing off PV generation throughout low load islanding, and seamless transfer between grid-connected mode and islanded mode. it's shown that the fuzzy controller will with success prevent the dc bus voltage collapse from occurring throughout the load transient and also FFT analysis is carried out to study the harmonic spectrum of ac voltage. By using this fuzzy controller we can reduce this harmonics.The PV sources with CERTS droop management will have the benefits that the standard CERTS microsources have. The PV microsource will work as a voltage source within the CERTS microgrid with the designed controller.

TABLE I
RATED VALUE

S_{base}[kW]	V_{base}[V]	V_{dc_base}[V]	ω_{base} [rad/s]
100	480	850	376.9911

TABLE II
MICROGRID SYSTEM PARAMETERS

r_{11}[pu]	x_{11}[pu]	r_{22}[pu]	x_{22}[pu]
0.0046	0.0045	0.0015	0.0015
r_{grid}[pu]	x_{grid}[pu]	r_{Tgrid}[pu]	x_{Tgrid}[pu]
0.0042	0.0250	0.0042	0.0250

TABLE III
CERTS MICROSOURCE CONVERTER PARAMETERS

r_2[pu]	x_2[pu]	r_{T2}[pu]	x_{T2}[pu]	S_{rated}[pu]	V_{dc_rated}[pu]
0.0055	0.0981	0.0021	0.0182	1	1

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