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A Voltage Controlled PV Inverter for Certs Microgrid Applications

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***Abstract*- The Photovoltaic (PV) sources are more compatible for Microgrids because of their ability to internally aggregate and balance with other renewable sources. The conventional grid connected PV inverters are basically current source controlled so unable to control ac voltage or frequency. The PV inverter using the Consortium for Electric Reliability Technology Solutions (CERTS) concepts can control ac voltage and frequency but have a major problem with load transients. The over loaded PV micro source causes dc bus voltage collapse and finally resulting in an ac voltage drop during the load transients. A photovoltaic inverter is capable of operating in both island and grid-connected mode by means of a reconfigurable control scheme. This paper presents an efficient control strategy which causes the PV inverter to act as voltage source to maintain stable dc bus voltage under load transients. With this PV inverter control configuration, it is shown that the PV micro source can operate as a voltage source in the CERTS microgrid.**

Index Terms- Distribution Generation, photovoltaic (PV), Distribution Energy Resources (DER).

I. Introduction

Evolutionary changes in the regulatory and operational climate of traditional electric utilities and the emergence of smaller generating systems such as micro sources have opened new opportunities for on-site power generation by electricity users. In this context, distributed energy resources (DER) - small power generators typically located at users' sites where the energy they generate is used - have emerged as a promising option to meet growing customer needs for electric power with an emphasis on reliability and power quality. The portfolio of DER includes generators, energy storage, load control, and, for certain classes of systems, advanced power electronic interfaces between the generators and the bulk power provider. This paper proposes that the significant potential of smaller DER to meet customers' and utilities' needs can be best captured by organizing these resources into Micro Grids. ***The Consortium for Electric Reliability Technology Solutions (CERTS) MicroGrid concept assumes an aggregation of loads and micro sources operating as a single system providing both power and heat. The majority of the micro sources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. This control flexibility allows the CERTS MicroGrid to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security***. The CERTS Micro Grid represents an entirely new approach to integrating DER. Traditional approaches for integrating DER focus on the impacts on grid performance of one, two, or a relatively small number of micro sources.

The IEEE Standard 1547.4-2011 suggests that the voltage-source mode is preferable for micro sources when planned for islanding. The micro sources 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 micro sources to regulate voltage and frequency independently and work together in an islanded system to share the load. All CERTS micro sources behave as voltage sources.

II. CERTS MICROGRID CONCEPTS

A critical feature of the CERTS Microgrid is its presentation to the surrounding distribution grid as a single self-controlled entity. A CERTS Microgrid appears to the grid as indistinguishable from other customer sites that do not include DER. This presentation means that the microgrid avoids many of the current concerns associated with integrating DER, such as how many DER the system can tolerate before their collective electrical impact begins to create problems like excessive current flows into faults and voltage fluctuations.

A) Voltage Control

There are two basic classes of micro sources: DC sources, such as fuel cells, photovoltaic cells, and battery storage; and high-frequency AC sources such as micro turbines, which need to be rectified. In both cases, the DC voltage that is produced is converted using a voltage source inverter. The general model for a micro source is shown in Fig 1.

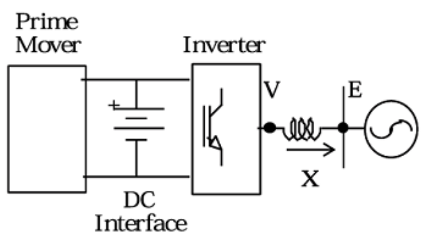

Fig 1. Interface Inverter System

It contains three basic elements: prime mover, DC interface, and voltage source inverter. The micro source couples to the MicroGrid using an inductor. The voltage source inverter controls both the magnitude and phase of its output voltage, V. The vector relationship between the inverter voltage, V, and the

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local MicroGrid voltage, E, along with the inductor's reactance, X, determines the flow of real and reactive power (P &Q) from the micro source to the MicroGrid. The P & Q magnitudes are coupled as shown in the equations below. For small changes, P is predominantly dependent on the power angle, δp, and Q is dependent on the magnitude of the inverter's voltage, V. These relationships constitute a basic feedback loop for the control of output power and bus voltage, E, through regulation of reactive power flow.

$$P = \frac{3}{2}\frac{VE}{X}\sin\delta_p$$
$$Q = \frac{3}{2}\frac{V}{X}(V - E\cos\delta_p)$$
$$\delta_p = \delta_V - \delta_E$$

Integration of large numbers of micro sources into a MicroGrid is not possible with basic P-Q controls; voltage regulation is necessary for local reliability and stability. Without local voltage control, systems with high penetrations of micro sources could experience voltage and/or reactive power oscillations. Voltage control must insure that there are no large circulating reactive currents between sources. The issues are identical to those involved in control of large synchronous generators. In the power grid, the impedance between generators is usually large enough to greatly reduce the possibility of circulating currents. However, in a MicroGrid, which is typically radial, the problem of large circulating reactive currents is significant. With small errors in voltage set points, the circulating current can exceed the ratings of the micro sources.

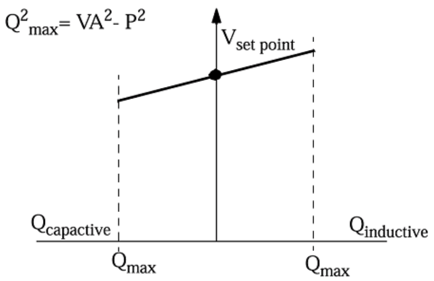

Fig.2. Voltage Set Point with Droop

B. Frequency Control

Micro Grids can provide premium power functions using control techniques where the MicroGrid can island smoothly and automatically reconnect to the bulk power system, much like a UPS system. In island mode, problems such as slight errors in frequency generation at each inverter and the need to change power-operating points to match load changes must be addressed. Power vs. frequency droop functions at each micro source can take care of the problems without the need for a complex communication network. When the MicroGrid is connected to the grid, MicroGrid loads receive power both from the grid and from local micro sources, depending on the customer's situation. If the grid power is lost because of voltage drops, faults, blackouts, etc., the MicroGrid can transfer smoothly to island operation. When the MicroGrid separates from the grid, the voltage phase angles at each micro source in the MicroGrid change, resulting in an apparent reduction in local frequency.

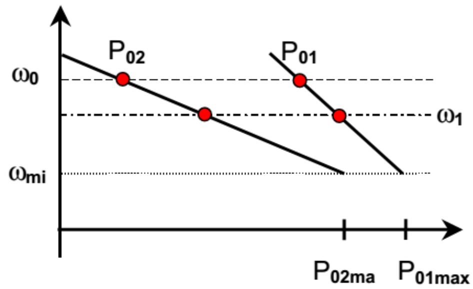

Fig. 3. Power vs. Frequency Droop Control

This frequency reduction coupled with a power increase allows for each micro source to provide its proportional share of load without immediate new power dispatch from the Energy Manager.

Consider two micro sources as in Fig 3. In this example, the sources are assumed to have different ratings, P1max, and P2max. The dispatched power in grid mode (P01and P02) is defined at base frequency, ω0. The droop is defined to insure that both systems are at rated power at the same minimum frequency. During a change in power demand, these two sources operate at different frequencies, which cause a change in the relative power angles between them. When this change occurs, the two frequencies tend to drift toward a lower, single value for ω1. Unit 2 was initially operating at a lower power level than Unit 1. However, at the new power level, Unit 2 has increased its share of the total power needs. Because droop regulation decreases the MicroGrid frequency a restoration function must be included in each controller. Droop control design is based on each micro source having a maximum power rating. As a consequence, droop is dependent on the dispatched power level while the micro sources are connected to the grid.

III. PV SOURCES IN THE CERTS MICROGRID

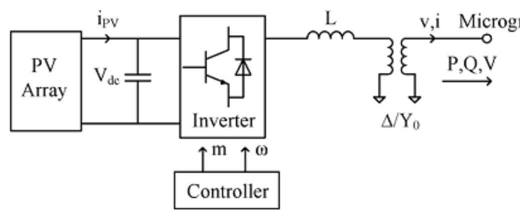

Fig. 4. Main circuit of the PV CERTS micro source.

Fig. 4 shows the main circuit of CERTS PV micro source. The PV array is connected to the inverter through a dc bus. Where V_d 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 trans-former, P and Q are real power and reactive power, and V is the voltage magnitude. The controller gives the frequency ω and modulation index m to the inverter. Fig. 5 demonstrates the overall con figuration of CERTS PV inverter controller, including CERTS droop control, V_{di} control, and MPPT.

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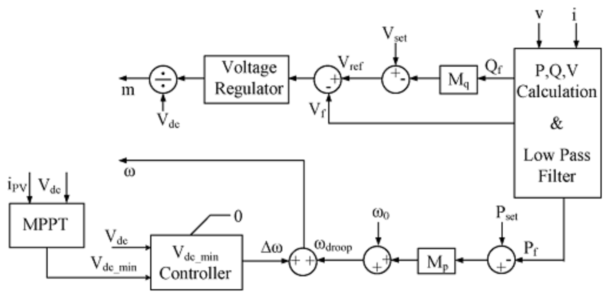

Fig. 5. Overall configuration of the CERTS PV inverter controller

With the considerations in above, 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 insolation; 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 con-trolling voltage and frequency independently; d) have MPPT ability.

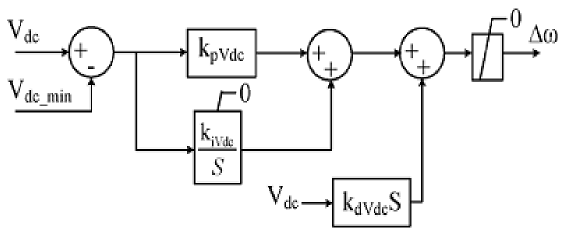

Fig 6. V_{dc_min} Controller

III. SIMULATION RESULTS

The proposed voltage source controlled CERTS Micro grid is simulated using MATLAB/Simlink in both islanding and grid connected modes. This micro grid includes an efficient controlled PV inverter as voltage source and wind power generation system and utility grid near to the micro grid. In islanding mode the micro grid importing power from the grid. The frequency, power, inverter ac voltages and dc bus voltages in islanding and grid connected modes are shown.

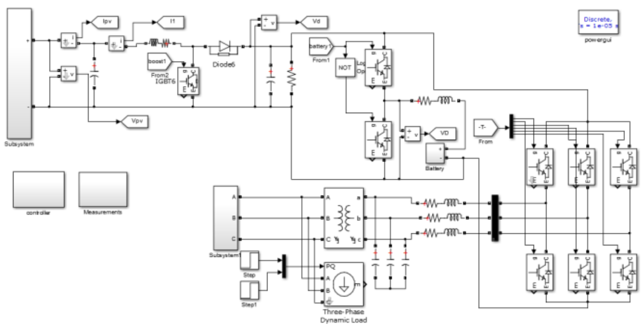

Fig 7. Simulation diagram of voltage controlled PV system with wind power source under Islanding mode

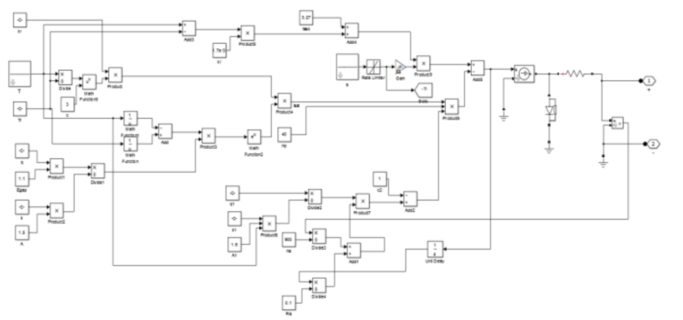

Fig 8. Simulation diagram of the Photovoltaic cell

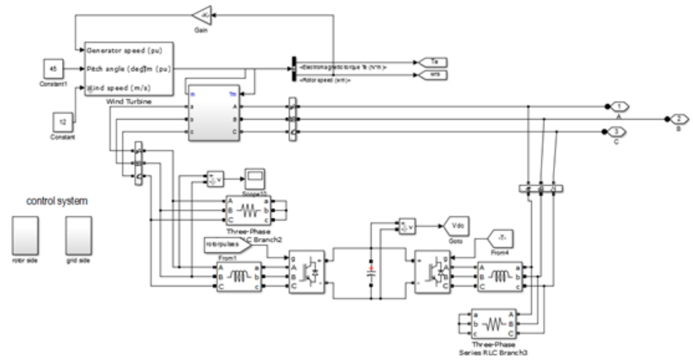

Fig 9. Simulation diagram of Wind Power generation as micro source.

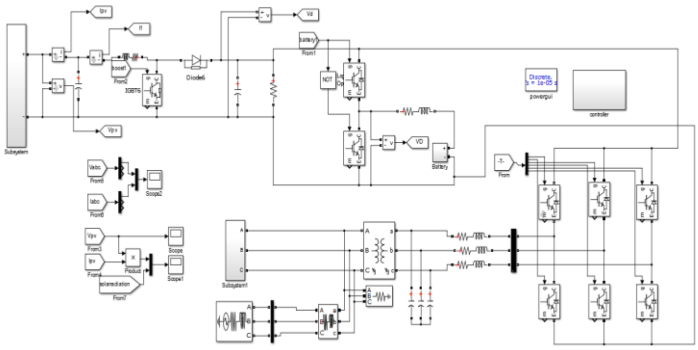

Fig 10. Simulation diagram of voltage controlled PV system with wind power source connected grid.

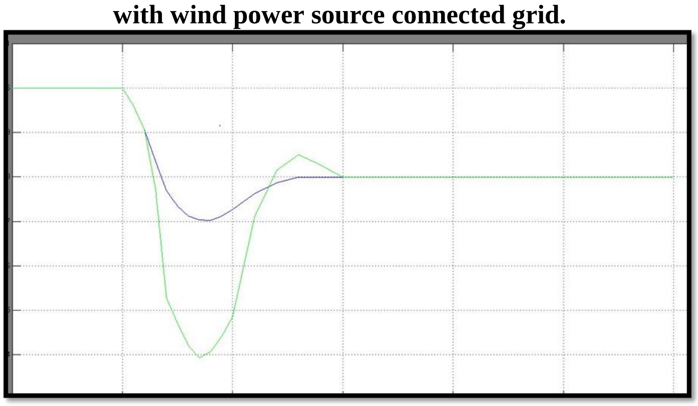

Fig 11. Variation of frequency of the system under islanding mode

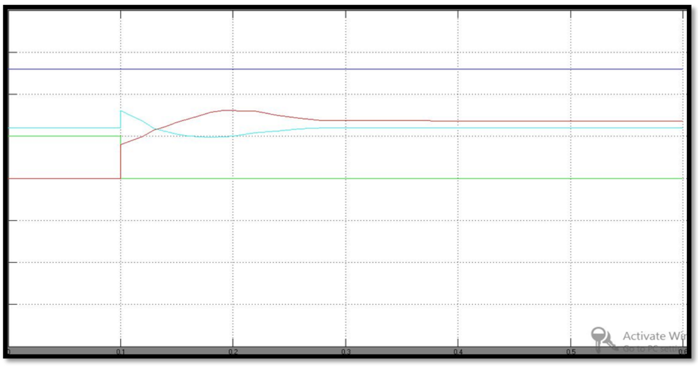

Fig 12. Variation of power of the micro sources under islanding mode

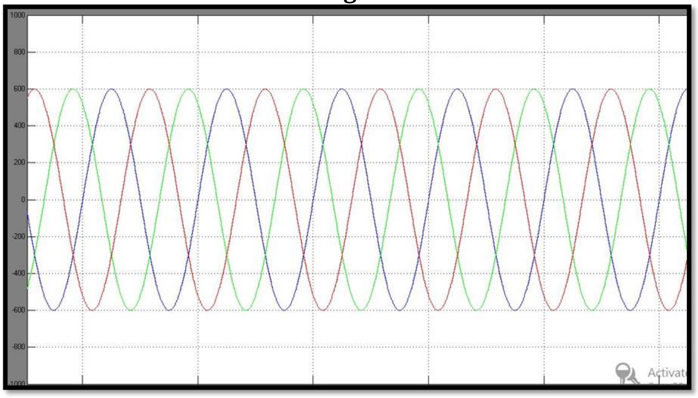

Fig 13. Three phase voltages of the PV inverter under islanding mode.

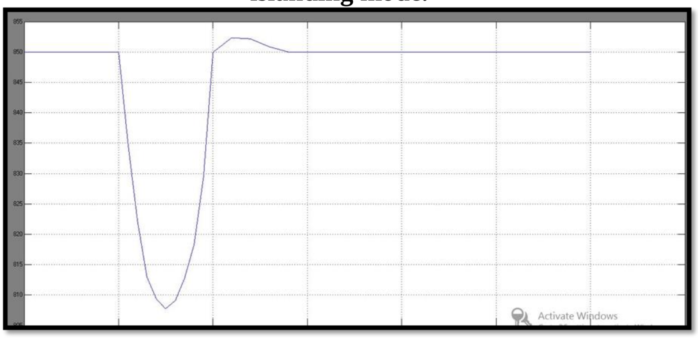

Fig 14. The dc bus voltage of the PV Inverter in islanding mode

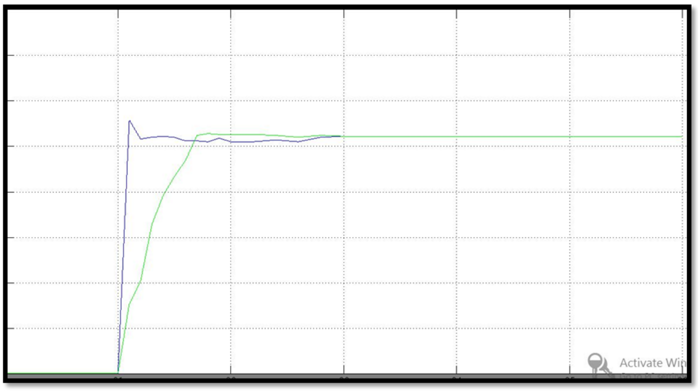

Fig 15. The variation of frequencies of two micro sources in grid-connected mode

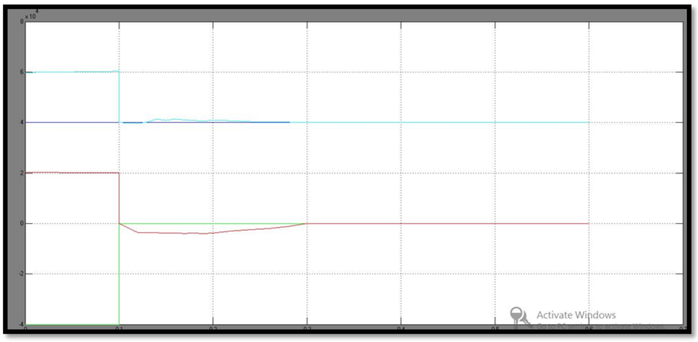

Fig 16. Power supplied by the sources in grid connected mode

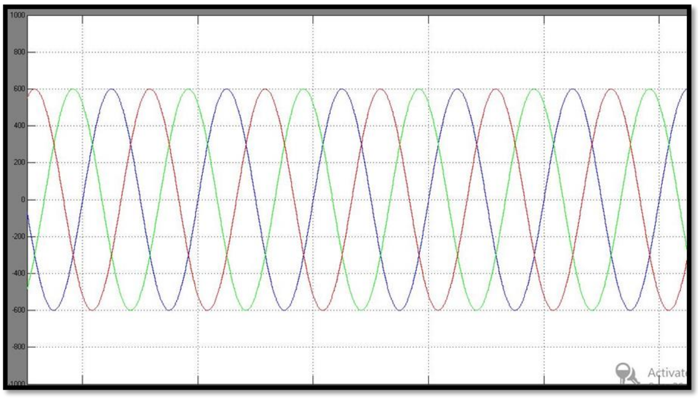

Fig 17. Three phase output ac bus voltages in grid-connected mode.

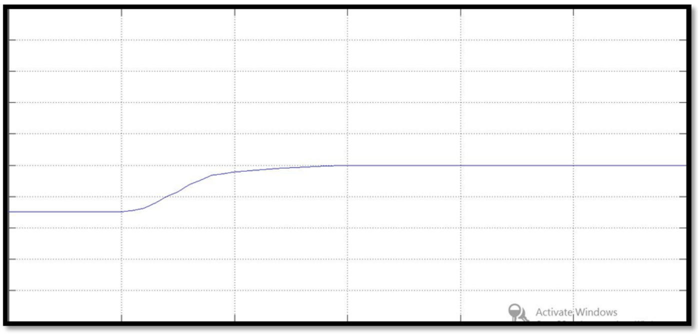

Fig 18. Voltage at the dc bus of PV inverter in grid-connected mode

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IV. CONCLUSION

The proposed control scheme which enables the PV source to behave as a voltage source in the CERTS microgrid and maintains the dc bus voltage stability during load transients. Traditional CERTS droop control is adopted in the control configuration, and a new controller is invented. The overload issue of the CERTS microgrid and the dc bus voltage collapse issue of the PV micro source are analyzed. The influences of the parameters of the controller on system small signal stability are analyzed. Two intentional islandings are simulated to demonstrate how the designed controller achieves the control objectives, such as maintaining dc bus voltage stability during load transients, automatically backing off solar generation during low load islanding, and seamless transfer between grid-connected mode and islanded mode. It is shown that the designed controller can successfully prevent the dc bus voltage collapse from occurring during the load transient, and the PV sources with CERTS droop control can have the advantages that the traditional CERTS micro sources have. The PV micro source can work as a voltage source in the CERTS microgrid with the designed controller.

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