Hybrid PV and diesel as multi master in islanding microgrid system

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Abstract

The electrification for remote or isolated communities which are inaccessible by national grid is a demonstrated challenge anywhere. The conventional solution for these off-grid sites is diesel generator set because of its ease in design and installation however they have higher operational & maintenance costs, and negative environmental impact. Photovoltaic (PV) is a sustainable green energy source with proven economic benefits under operation. Integration of PV panels, PV inverters and energy storage batteries into an off-grid diesel generation (DG) system to form a hybrid PV-DG system can help enrich system stability, cost efficiency and reduce pollution emissions. This paper introduces the PV-DG hybrid multi-master operation microgrid system under the concept of distributed generation configuration, as opposed to the traditional central generation configuration. PV inverters will be in parallel operation with generators without any communication link, whilst utilizing AC line voltage/frequency alongside with droop-control algorithm in the coordination and management of each source operation for load sharing. Although PV power plant requires a large land space for installation, the hybrid PV-DG under multi-master concept will allow PV inverters to be developed in different location with DG, resulting in highly proficient system flexibility, stability and efficiency. Furthermore, the investment cost of the multi-master concept can prove to be more financially viable in comparison to central hybrid generation.

Keywords: *Hybrid photovoltaic-genset, Multi-master, Distributed generation, Droop control*

1. Introduction

In remote, rural areas, the problem of lack of electricity deficiency is often solved by the use of small synchronous generators in the process of electrification [1]. When supply security is not a major concern, the use of a single diesel generator is sufficient. At a higher demand for capacity or system reliability, however, multi diesel generators working in parallel with generator controllers are required. Although both are valid methods of energy transmission, these solutions are considerably costly to operate in terms of fuel and other expenses, and are detrimental to the environment.

The demand for a clean, renewable energy distribution system is a growing concern. While renewable energy sources such as solar photovoltaic, especially PV and wind turbines are appealing source of green energy, the inertia-less structure and dependency upon weather conditions to produce a continuous stream of power renders them unreliable and impractical for real-life usage. It is necessary to incorporate energy storage and electric power converters into these renewable technologies to ensure a constant supply of energy that can overcome any transience or fluctuation from both the demand and supply sides.

When several types of generators, loads and energy storages are distributed and interconnected as a cluster of a small power system and operate systematically, it is called Microgrid. This distributed generation grid -- which supplies energy into areas of consumption -- could potentially increase supply reliability, shorten black-out restoration, minimize grid system complexity, reduce losses in power transmission, and help spur on the shift towards renewable energy.

This paper investigates a microgrid system consists of two diesel generators and two PV inverters with battery storage that are parallel configured in islanding condition under multi master concept. Active power-frequency droop and reactive power-voltage droop are implemented to control the generated power based on available local information without any communication link with other units [2]. Experimental results indicate total active and reactive power sharing is achievable under various load and supply conditions.

2. Microgrid system with hybrid photovoltaic and diesel genset

In normal conditions, a microgrid needs to operate under both grid-connected and island mode in order to enhance power quality and distribution reliability. In parallel operation to the gridline, high-inertia generators in the main grid provide a stable reference voltage and frequency; this allows the microgrid to determine and corroborate power mismatches. Should any faults occur in the gridline, the microgrid would isolate and operate independently in island mode. All energy sources in the system are required to supply uninterrupted power to the loads.

Microgrid control strategies can be classified into two types: master-slave control, and distributed control. In a master-slave configuration, the master unit collects information and delivers control data to distributed slave units, a communication system is necessary. However, in a distributed or multi-master configuration, multiple AC sources in the network simultaneously regulate power based on available local data measurements, without signal interconnection lines.

Table. 1. Comparison of master-slave and multi master microgrid

	Advantages	Disadvantages
Master Slave Microgrid	- Simple control algorithm in components level	- Supervisory control is required - High expenditure for busses and cabling - Difficult for future system expansion
Multi Master Microgrid	- Increase stability since system does not rely on main power source, but redundant each other as peer-to-peer - Simple expansion with flexibility due to plug-and-play concept - Distributed generation can help improve on transmission lost	- More complex control algorithm in the components level

The low inertia of the diesel generator implies that large stepping load will impose changes on the generator speed before a reaction to adjust its fuel feed rate via speed governor. This response will result in transient deviations of voltage and frequency that may last several seconds, until the generator has reached a new steady-state operating point. In order to provide more spinning reserve, the diesel generator must be operated at a load level less than its rated capacity. However, this contradicts its fuel efficiency, because optimum fuel efficiency point is always a value close to the rated capacity.

Photovoltaic which is renewable energy generator in isolated microgrid system also has drawback side on electrical production stability since its generated power is intermittent and fluctuate with the solar radiation. At high levels of PV penetration, fluctuations in the gridline voltage may lead to network instability and eventual system failure if not adequately regulated. The usage of a PV inverter with energy storage can ease these aforementioned constraints, as inverters have the ability to sufficiently supply energy from a battery and vice versa, whilst minimizing deviations in voltage and frequency [3].

2.1 Multi master microgrid system

In a multi-master configuration, there is no main source to form the system voltage and frequency, but all energy sources in the system have to monitor the ac line voltage and frequency as feedback signal to co-ordinate between all sources. Fig. 1 shows a single-line diagram of the studied multi master microgrid system AC 380 Volt, 3 phases 4 wires, which operates in islanding mode. The system comprises of two units of synchronous diesel generators, each equipped with a generator controller and two units of inverters (LEONICS STP-219C rating, output power 15kW) modified for generator droop compatibility and 1 unit of RLC load.

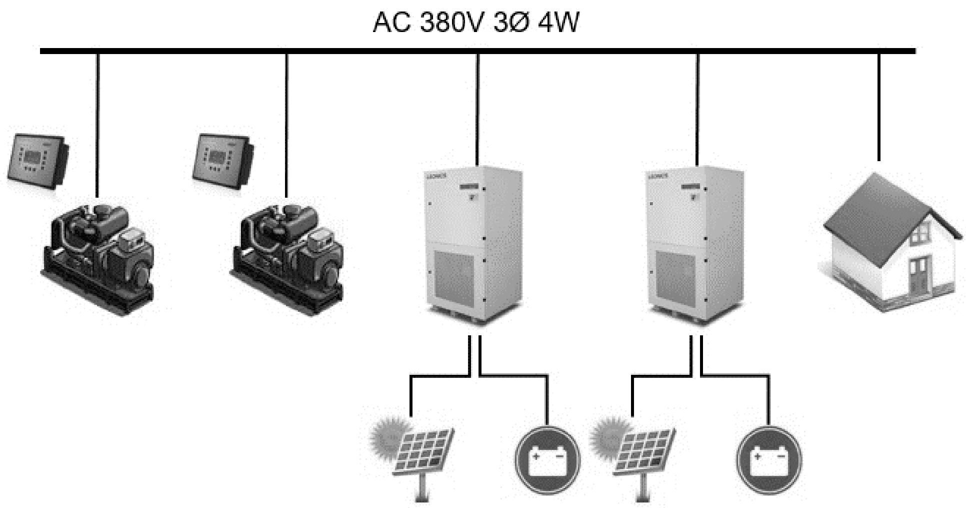

Figure 1 Single-line diagram of the studied multi master microgrid system

2.2 Droop control method

Droop control is a common technique applied to parallel generators into a system which shares and balances power from generating stations with the system's total load. [4][5] Based on Fig. 1 system single-line diagram, the active and reactive power flow from energy source into a lossless power line can be expressed as below equation

$$P_o = \frac{V_o E}{X} \sin\delta \quad (1)$$

$$Q_o = \frac{V_o^2}{X} - \frac{V_o E}{X} \cos\delta \quad (2)$$

Where P_o and Q_o are active output power and reactive output power of energy source, V_o and E are RMS of energy source output voltage and PCC voltage, δ is power angel of source output voltage and PCC voltage, X is line inductance. In a small microgrid system power angel is not much, so $\sin\delta = \delta$ and $\cos\delta = 1$ which make above equation (1) – (2) simplified to

$$\delta \cong \frac{XP_o}{V_o E} \quad (3)$$

$$V_o - E_o \cong \frac{XQ_o}{V_o} \quad (4)$$

Both equations imdicate that power angle depends on the active power and the voltage difference depends on the reactive power. In islanding microgrid system, each energy source does not know the initial phase values of the other units. Frequency is used to control active power flows. Therefore, the regulation of active and reactive power flows to a power system can be determined by the voltage and frequency as below active *P-f* droop and *Q-v* droop equation and graph in Fig. 2.

$$\omega^* = \omega_{ref} - K_p * P \quad (5)$$

$$V^* = V_{ref} - K_q * Q \quad (6)$$

K_p is the frequency droop coefficient and K_q is the voltage droop coefficient, while ω_{ref} is the angular frequency reference and V_{ref} is the output voltage reference when there is no load.

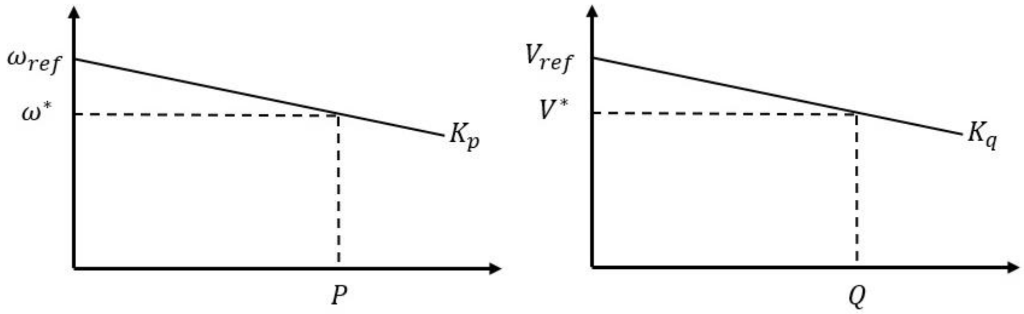

Figure 2 Active power-frequency droop and reactive power-voltage droop characteristic

2.3 Droop control structure of inverter

A controller of battery storage inverter has been modified from the usual PQ control topology to the multi-loop active/reactive power droop control, shown in Fig. 3. The measured value of inverter output V_o and i_o are used for calculating the feeding output P_o and Q_o, then droop equation (5) and (6) will be applied to calculate V^* and ω^*. The 2 results are used in voltage reference calculation to obtain the three phase output reference voltage V_{abc}^* of inverter. Next, this reference voltage is used in voltage and current loop feedback controller to generate the gate firing pulse for PWM inverter circuit.

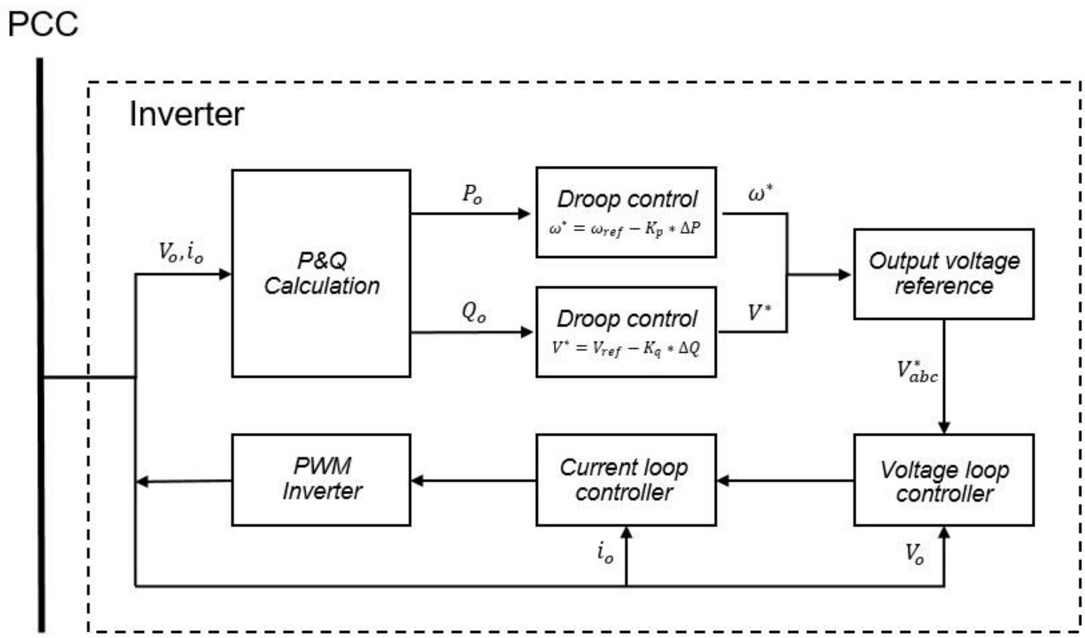

Figure 3 Inverter droop control structure

3. Study system and experiment result

An island microgrid system was set up in accordance to the single-line diagram depicted in Fig. 1. Two inverters are developed following droop control algorithm in Fig. 3. Parameters of generator controller after parallel droop mode setting experiment, were tuned as shown in Table 2. Case studies were then conducted under various scenarios, illustrating multi master PV-diesel hybrid system operation in both steady and dynamic transient state response of the system.

Firstly, one unit of inverter and one unit of diesel generator are parallel droop with variable droop gain factor to study the impact on load sharing and stability. Result of appropriate inverter droop parameters are defined as in Table 3. Next, the complete system is configured and the voltage and frequency deviation, and active and reactive load sharing are examined as shown in Fig. 4 and Fig. 5.

Table. 2 Parameter of diesel genset

Description	Symbol	Value
Voltage control droop	K_q	3%
Voltage proportional gain	k_{pv}	1.5
Voltage integral gain	k_{iv}	1.3
Frequency droop	K_p	2%
Frequency proportional gain	$k_{p\omega}$	1.3
Frequency integral gain	$k_{i\omega}$	1.0/3.0

Table.3 Parameter of droop inverter

Description	Symbol	Value
Voltage control droop	K_q (DROOP_Q)	7.0V
Voltage proportional gain	k_{pv} (VO_KP)	0020
Voltage integral gain	k_{iv} (VO_KI)	0720
Frequency droop	K_p (DROOP_P)	1.0Hz
Frequency proportional gain	$k_{p\omega}$ (P_KP)	0007
Frequency integral gain	$k_{i\omega}$ (P_KI)	02E7
Max. rate of change of frequency	$MXdW$	0.5000

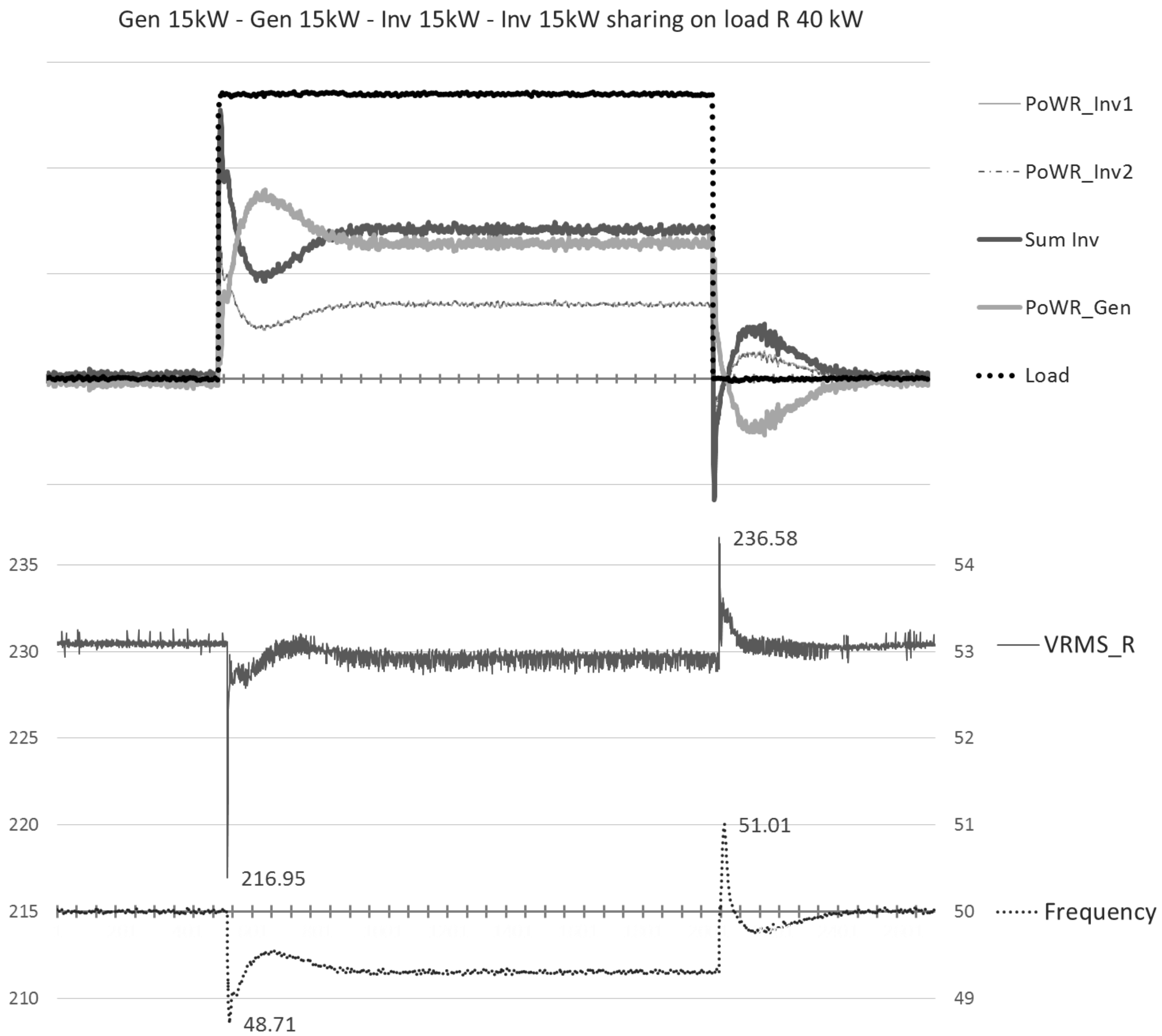

Figure 4 Experiment result on active load (R)

When the load is increased to 40kW, the voltage at PCC drops by 5.7%, and the frequency drops by 2.6%. The inverter, which improves response speed, drastically feeds in power before the generator ramps up its engine speed. The inverter and generator, now sharing an equal load, sustain a stabilized stage after six seconds. After the load is lost, the inverter absorbs the generator's excess inertia and completes the energy flow regulation in six seconds. Voltage and frequency increase from the nominal, rising to a peak at PCC 2.8% and 2.0% respectively.

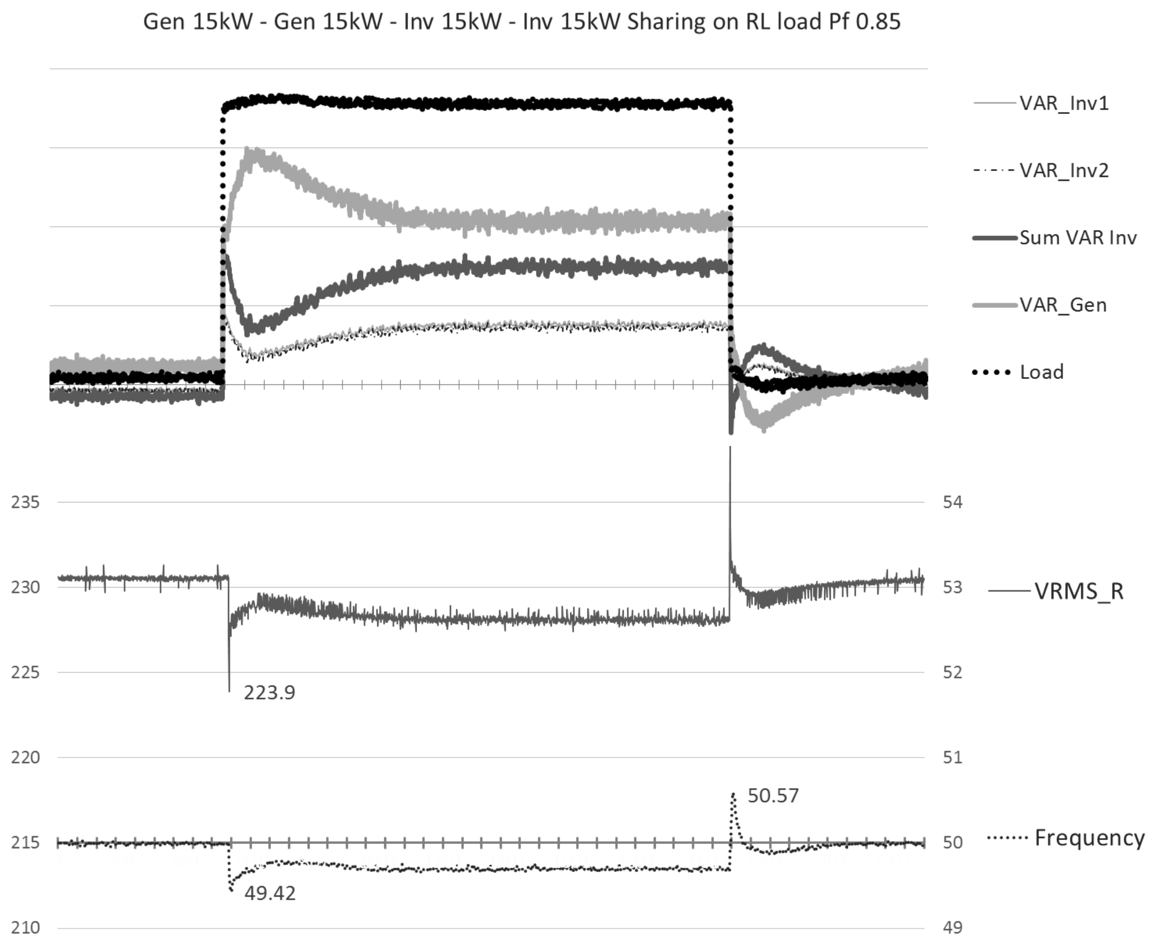

Figure 5 Experiment result on R-L load Pf 0.85

The characteristics of reactive load sharing were similar to that of active load sharing, although there was a slight difference in the ratio of energy supplied by the inverter and generator. Fine-tuning the inverter and generator voltage droop coefficients can be implemented to balance such sharing.

4. Conclusion

Concept of PV inverter that parallel droop with diesel generator as multi master configuration under islanding operation has been analysed and developed. Experiment show that inverter has the ability to support voltage and frequency stabilization during transient load fluctuation. Inverters and generators can share active and reactive load without any mutual communication link. As a result, this configuration can be extended to bigger system with more number of energy sources. Further studies on autonomous operation should be considered for generator start/stop algorithm based on load level, inverter battery level and etc. in order to optimize generator operation and minimize the fuel consumption.

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