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COOPERATIVE OPTIMAL CONTROL STRATEGY FOR MICROGRID UNDER GRID-CONNECTED MODE

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Abstract: This paper investigates the control performance of a physical configuration of a microgrid (MG), integrated with photovoltaic (PV) arrays, battery energy storage systems (BESSs), and variable loads. The main purpose is to achieve cooperative optimal control under both grid-connected and islanded modes for the MG. For the grid-connected mode, a voltage source inverter (VSI) based on swoop control is used to control the MG connection to the grid even if PV arrays are under partially shading conditions (PSC). Then, for the islanded mode, the paper analyzes the model of the PV unit and BESS unit detailed from the small signal point of view and designs the suitable control strategy for them. Finally, the whole MG system combines the droop control and the main/slave control to stabilize the DC bus line voltage and frequency. Both simulation and experimental results confirm that the proposed method can achieve cooperative control of the MG system in both grid-connected and islanded mode.

Keywords: *Grid-Connected Mode Mode, Microgrid Control, Distributed Generation, Energy Management, , Energy Storage, Frequency Control, Microgrid, Power System, Voltage Control.*

I INTRODUCTION

Microgrid is an important and necessary part of the development of smart grid. The microgrid is characterized as the "building block of smart grid" . It comprises low voltage (LV) system with distributed energy resources (DERs) together with storage devices and flexible loads. The DERs such as micro-turbines such as, fuel cells, wind generator, photovoltaic (PV) and storage devices such as flywheels, energy capacitor and batteries are used in a microgrid. The microgrid can benefit both the grid and the customer. From the customer's view: microgrids answer to both thermal and electricity needs and enhance local reliability, reduce emission, improve power quality by supporting the voltage and frequency and potentially lower costs of energy supply. From the utility's view: a microgrid can be seen as a controlled entity within the power system as a single dispatch able unit (load or generator) or ancillary services provider. Normally, a microgrid has two modes of operation: the island mode and the grid connected mode. In the island mode, the production is required to meet the loads demand. On the other hand, when the microgrid is connected to grid, it can either receive or inject power into the main grid. Furthermore, the gird connected microgrid can provide power supporting to its local loads demand. When a disturbance occurs, the microgrid is disconnected from the distribution network as soon as possible in order to avoid any further damage. In that case, the microgrid will operate in an island mode. Furthermore, the operation mode is related to the elasticity supply, local loads demand and the electricity market. Thus, the objectives of the optimal operation scheduling in microgrids concern with the economical, technical and the environmental aspects. A microgrid can provide a large variety of economic, technical, environmental, and social benefits to both internal and external stake-holders depending on its operation strategy. Microgrid control can be divided into the coordinated control (supervisory control or energy management) and local control. First, the coordinated control optimizes to allocate the power output among DER, the cost of energy production and emission. The forecast values of loads demand, the generation and the market electricity price in each hour on the next day are collected and calculated to find the optimal output power of DER, the consumption level of utility grid and the cost and the emission. Second, the intelligent local controllers for DER can enhance the efficiency of microgrid operation. In fact, these controllers participate to control the frequency and voltage in different operation modes of microgrid such as: islanded mode and grid connected mode.

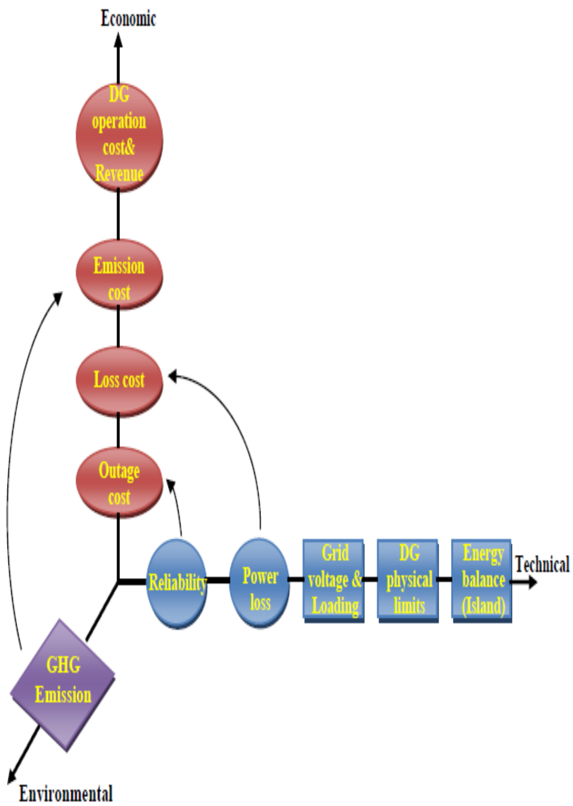

Figure 1: Microgrid operation strategy

II LITERATURE SURVEY

Optimal sizing, control and energy management strategies are known as important research issues. First, several methods for optimal sizing have been proposed in the literature. Some of the authors use the artificial intelligent (AI) methods such as genetic algorithm (GA), Particle Swarm optimization (PSO), whereas others utilize the iterative method to find the optimal configuration of a microgrid which satisfies the optimal operation strategy. Second, the optimal for microgrid energy management is also presented in some researches. The Rule-based method, optimal global methods (Linear programming (LP), Mix-Integer-Linear-Programming (MILP) and dynamic programming (DP)) as well as the artificial intelligent (AI) methods are used to find the optimal energy management for a microgrid. Last, the local controllers for DER can enhance the efficiency of microgrid operation by using the conventional methods (single master (centralize control), master/slave and droop control). Furthermore, the variations of conventional droop control are also addressed in some publications. The optimization sizing of island microgrid has been presented in the literature. It has two main aspects, which are the architecture sizing and the energy fluxes. Dealing with these problems, various simulation and optimization software tools on PV hybrid systems have been reviewed in the literature [7]-[12]. On the other hand, two main methods of optimization that are iterative and artificial intelligent (AI) based methods have been proposed in [13] Genetic Algorithm (GA) has been proposed for optimal sizing of a PV-diesel-battery system in [14]. The main objective is to define the optimum number of PV panels, battery banks and DG capacity. In [15], the GA is used to optimize a hybrid PV/diesel generator system which is divided into two parts. The first part aims to find the optimal configuration of the system. Then, the latter part optimizes the operation strategy by using each calculated configuration in the first part. The optimal configuration is the one that leads to the minimum cost of the system. A multi-objective optimization for a stand-alone PVWind – diesel system with battery storage by using Multi-Objective Evolutionary Algorithms (MOEAs) is described in [16]. The levelized cost of energy (LCOE) and the equivalent CO2 life cycle emission (LCE) are known as the objectives. In [17], a multi objective evolutionary algorithms (MOEAs) and a GA have been used to minimize the total cost, pollutant emissions (CO2) and unmet loads. An iterative optimization technique for a stand-alone hybrid photovoltaic/wind system (HPWS) with battery storage was proposed in [18]. The aim is to find the optimum size of system in order to respond to the demanded load and to analyze the impact of different parameters on the system size. In [19]-[20], another iterative optimization technique is used to optimize the capacity sizes of different components of hybrid solar wind power generation systems employing a battery bank.

III PROPOSED SYSTEM

3.1 PV Power Systems Working in Grid-Connected Mode

In grid connected mode, the dc-link voltage (Vdc) control is performed by the inverter, after a reference gave by the MPPT calculation. A PI controller (voltage controller-grid component in Fig.2) is utilized for the inverter voltage loop in this operational mode. A food forward term Ir, expressed by (1), is added to the yield of the PI dc-link voltage controller IF, yielding the amplitude of the current loop reference Ir. The term I∗r is derived from the dynamic power or active power that is being conveyed by the PV source The amplitude Ir is multiplied by the term cosθ, gave by a phase locked loop (dqPLL) working from the grid voltage.

$$I_r^* = \frac{P_{PV}.\sqrt{2}}{V_{acRMS}}$$

The dqPLL is implemented utilizing the synchronous rotating reference frame procedure . The angle θ is that of the fundamental part of the grid voltage. The present controller was actualized by method for a harmonic compressor.

3.2 MG Control Strategies under Grid-Connected Mode

When the MG works in grid-connected mode, the frequency and the voltage of the MG are maintained within a tight range by the main grid. In this section, we consider the MG control design under grid-connected mode. Normal Model of a PV Array. To control the MG with integration of PV power as shown in Figure 3, modeling the PV array is necessary. A PV array is composed of several PV modules connected in series parallel to produce desired voltage and current. Usually, more PV cells Aare needed to form the series-parallel PV array. The relationship of the output voltage and current of one PV cell can be represented as follows:

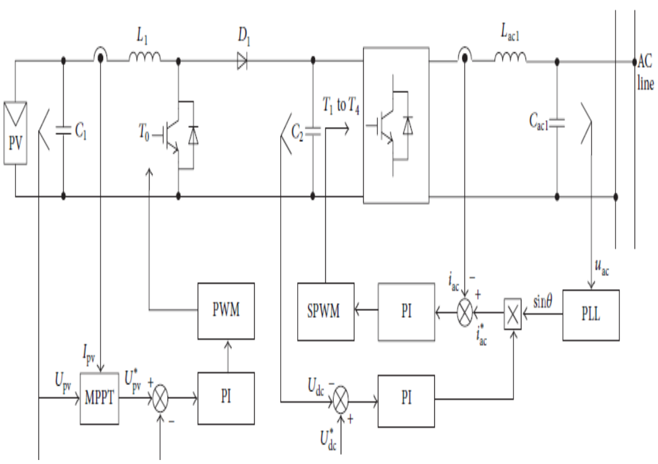

Figure 2: The whole control system configuration of MG under grid-connected mode

$$I = I_{ph} - I_s\left\{\exp\left[\frac{q}{AKT}(U + IR_s)\right] - 1\right\} - \frac{U + IR_s}{R_{sh}}$$

where I is the output current of PV cell; U is the output voltage of PV cell; Iph is the photocurrent; Is is the reverse saturation current of diode; q is the electronic charge (1.6 × 10−19 C); K is Boltzmann's constant (1.38 × 10−23 J/K); T is junction temperature; A is the diode ideality factor; Rs is series resister; Rsh is shunt resister. Due to the large value of shunt resistance Rsh, the last term in (2) is often omitted, the short-circuit current and photocurrent are considered to be equal (Isc ≈ Iph), and when the PV cell is on open circuit, the output current is zero, so output current of a PV cell can be approximated as

$$I = I_{sc}\left\{1 - \exp\left[\frac{q}{AKT}(U + IR_s - U_{oc})\right]\right\}$$

Then, the output power of a PV cell is

$$P = UI = \frac{AKTI}{q}\ln\left(1 + \frac{I}{I_{sc}}\right) - I^2R_s + IU_{oc}$$

MG Unit Control under PSC. To control the MG configured in Figure 1, we first aim to achieve the PV MPPT control and improve the efficiency of the PV array power conversion under PSC. Then, we use DC/DC converter to make the output current and the grid voltage following the same phase and frequency to realize the unit power factor control. An important target in MPPT control is to track the global MPPT under PSC. One of the key issues is to identify the PSC. DC bus line control is also necessary. Although MPPT control can make the PV array track the MPPT, the different levels of isolation will affect the power output, and the power change will cause the DC bus line to drift. If the PV output energy increases sharply, the power delivery of DC bus line will be increased if there is no converter or load to consume the extra energy. On the contrary, if the PV output energy is decreased and cannot satisfy AC line voltage peak value, the converter cannot work; therefore it is necessary to keep the DC bus line balanced. The second part has two loops, that is, the outer voltage loop and inner current loop. The function of the voltage loop is to keep the DC bus line balanced; it is controlled by a PI controller by comparing the actual value Udc and the given value $U*$ dc as the error for driving the PI controller. The output of the outer loop PI controller produces the AC given current value, which is multiplied by the sine output signal of the phase-locked loop (PLL) of the AC voltage $u$ac to produce the given current $i*$ ac. The aim of the inner current loop is to realize the AC current control. The given current $i*$ ac is compared with the actual $i$ac, producing the error, and is controlled by the inner loop PI controller. The output of the inner loop PI controller is compared with the triangle wave for generating the PWM signal to control T 1 to T 4 and thus produce the AC current output, which has the same frequency and phase with the grid side.

IV RESULTS

The proposed control schemes were then applied to physical setup for the grid-connected mode, and Figure 3 shows the experimental results when the PV was connected to the grid. It can be seen that the output current and the output voltage of converter have the same phase and the unit power factor has been achieved. power was fed back to the grid and the current had the same phase as the grid voltage. During 0.2 s~0.4 s, as light intensity was decreased, the total PV energy was reduced to 2200W, which could not meet the demands, so the extra power was injected from the grid, and the grid side current and the grid voltage had different phase. Between 0.4s and 0.6s, although the PV array produced 2200Wpower, the load demand was decreased, and the extra PV power was fed back to the grid again. It is evident from these figures that the quality of the output current of converter was satisfied and the response of MPPT control strategy was swift.

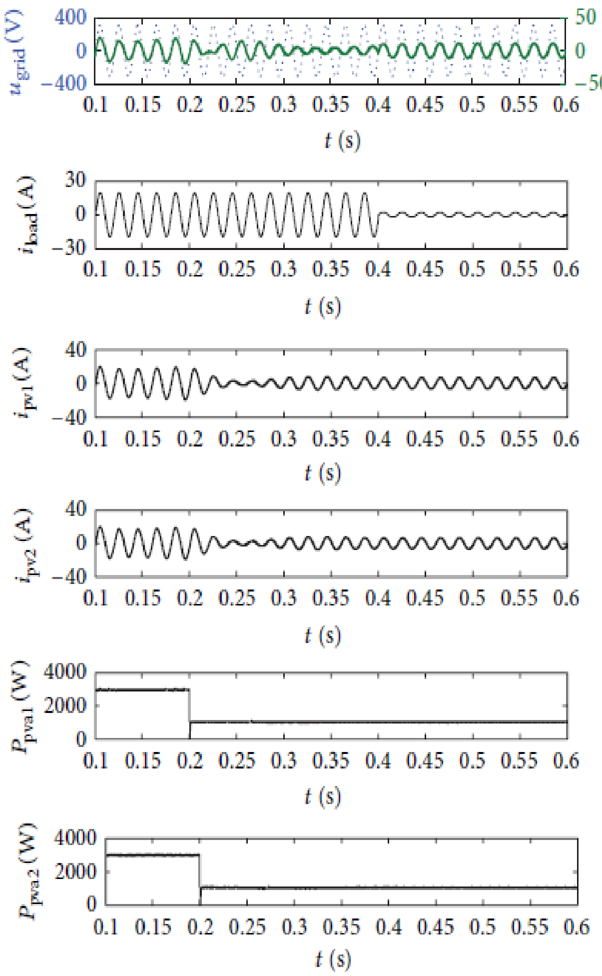

Fig.3. the simulation results of PV array connected to the grid.

Fig. 3 gives the response of the system to load steps (*P*out = 1 kW → 1.7 kW → 2.4 kW → 1.7 kW resistive load) working in islanded mode at a constant PV power (*P*PV =1.8 kW). The inverter output voltage is unaffected by the load step. Note that, when *P*bat < 0, the batteries are being charged whereas, when this power is positive, the batteries deliver the needed supplementary power to the loads. The inverter output power decreases or increases depending on the load power, whereas the PV output power and the dc-link voltage remain constant. The battery bank supplies or absorbs the necessary power to keep a constant dc-link voltage, tracking the MPP of the PV panel.

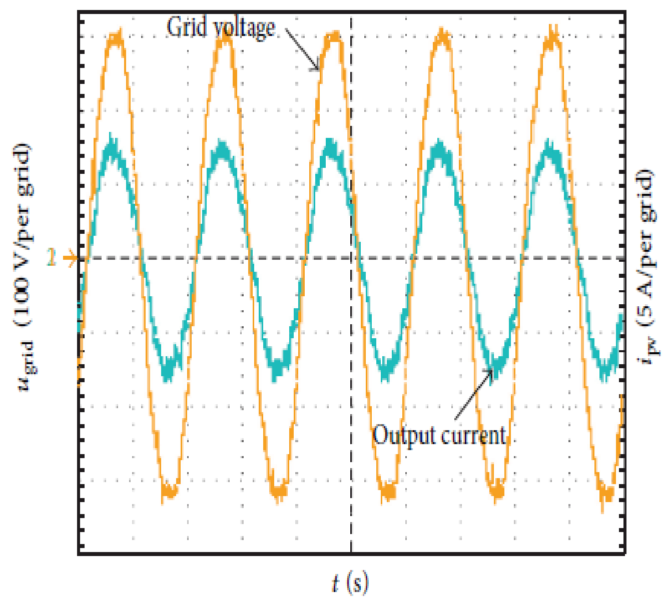

Figure 4: The experimental results in grid-connected mode

From the simulation results, it can be seen that, whether the BESS unit is in the master or the slave, the voltage of BESS unit is always kept stable and the output current changed with the AC line and kept the DC bus line voltage stable also. it can be seen that the DC bus line is stable in 400V quickly. It can be seen that when the BESS unit is in the charging state, the energy will flow into BESS from AC line and the phase angle between the charging state and the discharging state is 180∘. The simulation and experiment of BESS charging state. *U*bat and *I*bat are the voltage and current of battery, respectively. From the results, it can be seen that battery can realize from constant-current charging to constant-voltage charging and there is no current peak.

V CONCLUSION

This paper studied a MG system integrated with PV panels, variable loads, a BESS, and AC line under the grid-connected mode and islanded mode. For the grid-connected mode, the paper adopts the MPPT combined PSC judgment to get the maximum power, while for the islanded mode the paper proposed to combine the droop control and the main/slave control to achieve the demanded voltage and the frequency and analysis of the function of BESS unit. Finally, simulation and experimental results have shown that the proposed method can automatically track the global power point under grid-connected mode and realize collaborative control of the MG system.

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