AN APPROACH TO CONTROL OF PHOTOVOLTAIC MICROGRID BASED ON NET POWER FLOW

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Abstract-This paper proposes a novel approach control strategy and protection scheme for the microgrid. It does not require any islanding detection scheme to change the control or protection philosophy. The feasibility of the proposed structure is tested with the photovoltaic microgrid. The control strategies are active-reactive (P-Q) power control when it is connected to the utility grid and voltage-frequency (V-f) control when it becomes isolated from the utility grid. Battery storage and super capacitors are configured for prolonged energy back up.

Index Terms- Net power flow, Negative sequence protection, hierarchical control.

I. INTRODUCTION

Renewable energy is drawing attention in present day situation as there is increase in electricity demand but the extinction of fossil fuels is taking place. The major research topic is regarding reliability and sustainability of electricity, as it’s an essential basic need to mankind. Microgrid is a new promising area in the energy sector for distributed generation using renewable energy such as wind, tidal, solar, fuel cell, biomass, etc., which helps to reduce the power demand on the conventional generators and transmission lines [2]. Varieties of power circuit configuration in microgrid assures increase in robustness of power supplied if equipped with the sophisticated and suitable control strategies such as power sharing schemes for PV sources in various operating modes.

Microgrids are future system configuration providing clear environmental and economic benefits compared to extension of our legacy modern power systems. To overcome the issues like economic, technical and commercial, development of microgrid concepts require noticeable effort [1]. Connection of microgrid to the utility grid is done at the point of common coupling (PCC) through circuit breakers [3]. Connecting the microgrid to the conventional grid, operational control of frequency and voltage is done entirely by grid; however microgrid still supplies the critical loads at PCC, thus acting as a PQ bus. The grid acts as a PV bus when it is operating independent of the grid, and also controls the voltage and frequency of the microgrid. Many opportunities and challenges are introduced by the increasing variety and scale of distributed energy systems and microgrids, due to the different modes of power generation, storage and transmission. And they are important aspects of sustainable energy development during electric utility deregulation and restructuring effort [4]-[5]. In [6], the authors have presented a coordinated voltage/frequency (V/F) and active power and reactive power (PQ) control system for both islanded and grid-connected mode in a PV microgrid that shows effective coordination between inverter V/F (or PQ) controls. Several other strategies have been proposed for seamless transfer between different micro grid operation modes [7]-[9]. They include a seamless control methodology for a PV-diesel generator microgrid that can operate both in the grid-connected and islanded modes, and at the same time does not require any islanding detection mechanism [7].

Microgrid needs effective protection systems along with the advanced control strategies [10]-[12]. A range of advanced methodologies is available in the microgrid protection. They include a simple three-phase four-wire system with differential current and zero sequence current used to detect faults in a microgrid [13]; protection using directional over current relays and its optimal settings as per system requirement operates for both modes of microgrid [14]; as well as other protection schemes with voltage restraint algorithms or inverse time characteristics [15], [16]. Many recently built microgrid laboratory systems have been based on the above mentioned control strategies and protection schemes [17]-[19]. However, microgrids that are integrated with advanced control and protection systems have received relatively less attention.

This paper proposes a coordinated control and protection structure for PV microgrid. The rest of the paper is organized as follows: Section II presents the control system. The integrated and layered protection system is described in detail in Section III. The field applications and test results are demonstrated in Section IV, and the conclusion is given in Section V.
II. CONTROL STRUCTURE

A. System Structure

The microgrid has two states of operation viz., grid connected mode and stand-alone mode. Requirements for the operation in these two modes are: i) the voltage and frequency should be maintained almost constant to realise the operation of the microgrid in two modes of operation; ii) transfer between modes of control without any transients in the microgrid. The proposed structure is shown in Fig. 1.

![Diagram showing control structure](image)

The above figure shows the control structure proposed for the photovoltaic microgrid in which the modes of operation are interchangeable depending upon the power vacancy. The control and protection has two levels: system level strategy and the device level strategy.

This paper proposes a control algorithm through which the capability of PV generators for voltage and frequency (V-F) control and active and nonactive/reactive power (P-Q) control in islanded and grid connected microgrids could be harnessed. Detailed models of PV, battery, inverter and converter are considered for the study. The major contribution and novelty of the proposed control methods lie in the coordination among individual proposed control methods: MPPT control at the PV side, battery control, and V-F/P-Q control algorithm at the inverter side. Also, the proposed control methods have the capability of handling battery state of charge (SOC) and charge at super-capacitor constraints through the coordination of controls between participating microsources in the microgrid. At the same time, the controls can seamlessly transform from one mode e.g., inverter P-Q control in grid connected mode to V-F control in islanded mode. The proposed control methods are validated with satisfactory results.

The controls are developed in dq reference frames using the RMS/average values of voltages and active and reactive power. Hence, it is easy and efficient to implement, and avoids the transformation to and from other reference frames which greatly simplifies the control strategies. The chosen control parameters in the proposed methodologies are, however, dependent on the PV, battery, and external power grid conditions.

B. Stand-alone Mode:

When the microgrid operates in stand-alone mode, the Li-battery energy storage system is the main power source for providing stable voltage and frequency with the V/F control [20]. To improve the practical application of this system, the proposed V/F control block diagram is shown in Fig. 2.

In Fig. 2, Vref, Vbref, and Vcref denote the reference of the three-phase output voltage of battery. V_d and V_q represent the d axis and q axis component of the measured three phase voltage (V_a, V_b, and V_c) based on the dq coordinate transform, respectively. V_dref and V_qref are the d axis and q axis component of the reference voltage (V_dref, V_bref, and V_cref), respectively. The proposed V/F control mainly corresponds to layer 2 in Fig. 1, which is based on the coordinate transform and proportion integration (PI) regulation with some basic techniques, such as magnitude and phase angle calculation and sinusoidal pulse width modulation (SPWM). The proposed V/F control has good dynamic response though it only adopts voltage loops. Moreover, only two PI regulators are included in the V/F control, which is more effective than the traditional V/F control.

![V/F control block diagram](image)

C. Grid-Connected Mode:

The BESS (Battery Energy Storage System) is controlled as a power buffer to provide power flow with PQ control when the microgrid operates in grid connected mode. Based on the fact that the current can be obtained from power and voltage, a simplified PQ Control is proposed as in Fig. 3.

In Fig. 3, the quantities of current reference are obtained by utilizing the instantaneous power theory, and the current loops are used to regulate the output value with PI regulators. In addition, the SPWM technique is also adopted in generating PWM signals. The proposed PQ control strategy, as shown in Fig. 3, with two PI control units reduced and the decoupling control of active and reactive power realized, has more applicability in engineering and is equivalent to the traditional control methods in both power loops and current loops.

![PQ control block diagram](image)

D. Operation Modes Transition:
Logic built for Transition between modes:
- If the power from (PV array) > load = stand-alone mode
- If the power from (PV array < load < battery & super capacitor) = load is supplied from battery and super-capacitor.
- If the power from (PV array + battery + super capacitor) < load = grid connected mode.

1) Transition from Stand-alone Mode to Grid-connected Mode:
Self-synchronization control is adopted to realize the seamless transfer from stand-alone mode to grid-connected mode. The detailed stages are demonstrated as follows.

Stage 1: Preparation-voltage regulation:
The microgrid voltage is regulated through V/F control with the calculated voltage reference. Take the voltage magnitude control scheme as an example; the control block diagram is shown in Fig. 4.

![Fig. 4. The voltage magnitude regulation control](image)

In Fig. 4, $V_{grid}$ represents the power grid voltage magnitude of phase A/B/C, and $V_i$ is the voltage of phase A/B/C of the microgrid, respectively. In the control block, only proportion control is utilized due to the fact that the voltage is of AC sinusoidal quantity. The regulated voltage ($V_{ref}^i$) is applied to V/F control. Then, the voltage magnitude, phase angle, and frequency are adjusted consistently with those of the main grid.

Stage 2: Control modes transition
The V/F control mode is immediately switched to PQ control according to control logic. At this point, the transition from stand-alone mode to grid-connected mode is achieved.

2) Transition from Grid-connected Mode to Stand-alone Mode
Stage 1: Preparation.
The power flow regulation is the first stage, which can be achieved by adjusting the power reference of the BESS. The corresponding control block diagram is depicted as in Fig. 5.

![Fig. 5. The power flow regulation control](image)

In Fig. 5, $P_{PCC}$ and $Q_{PCC}$ means the expected active power and reactive power on the tie line, which are preset as zero. $P_{pcc}$ and $Q_{pcc}$ are the measured power on the tie line. The reference power values ($P_{ref}^i, Q_{ref}^i$) put into the PQ control module are obtained from proportion control and difference calculation, which are described in Fig. 5.

Stage 2: Control modes transition
The PQ control mode should be quickly changed to the V/F control mode as the contactor is turned on. The transition from grid-connected mode to stand-alone mode is then completed.

III. HIERARCHICAL PROTECTION SYSTEM

A. System Structure

The microgrid has many advantages when compared to the bulk power grid because of its smaller scale and fewer feeders. More information can be acquired through reasonable configuration of measurements and establishment of a data centre, which provide possibilities for designing a comprehensive protection system.

A hierarchical protection system is proposed as shown in Fig. 6. The proposed hierarchical protection system, consisting of relay protection and regulation is aimed at improving microgrid security.

![Fig. 6. Structure of the hierarchical protection system](image)

Therefore, it has many advantages. First, it is straightforward with two layers of hierarchical structure; second, many techniques, such as relay protection and regulation are integrated to improve the reliability of the PV microgrid. Negative sequence protection is provided for the feeders at times of fault and unbalance in the line. In normal operating condition the line will be symmetrical, but when fault occurs negative sequence components flow in the line and when the value of this negative sequence current crosses threshold value signal will be sent to circuit breaker. Once the fault is cleared the regulation of power becomes priority. A flow chart is built on how the regulation of load i.e., power vacancy is balanced.

IV. SIMULATION RESULTS

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To validate the proposed control strategies and protectionschemes, many tests have been undertaken on the PV microgrid.

1) Stand-alone Operation:
   In this test, to realize a smooth start, the output voltage reference is raised from 0 to 300 V and the frequency is set as 50 Hz. The test result is shown in Fig. 7.

![Fig7. Voltage and Currents from microgrids](image)

The RMS voltage of the microgrid is about 300V /50 Hz with little harmonic distortion, the voltage and frequency is observed to be stable. RMS current of microgrid is 150amps.

2) Grid-connected Operation:
   In grid connected mode, the voltage and current waveform of the tie line is shown in Fig 8.

![Fig 8. Voltage and Currents from grid](image)

The RMS voltage and RMS current of the microgrid is seen to be 300V/50 Hz with little harmonic distortion, the voltage and frequency is observed to be stable. RMS current of microgrid is 150amps.

3) Operation Modes Transition:
   Here the transition happens based on the net power passing in every branch of the system and the logic is built according for the smooth transferring. When the output power of PV units is reduces than load then shifts to grid connection and transition toislanding mode happens when the DG and backup power are capable to handle the power. The test result shown in fig 9.

![Fig 9. Voltage and Currents from microgrids](image)

The transition between stand-alone mode and grid-connected mode is seen to be smooth compared to the earlier control strategies. The transient state of the transition is within 4ms, which means that the seamless transfer between those two modes is achieved.

3) Protection Tests:
   The proposed protection system has been integrated into the built microgrid, and the simulations are carried out to validate the effectiveness and feasibility of the protection schemes.

![Fig 10. Negative sequence current flowing in the load during fault](image)

The unbalance in load causes the flow of negative sequence component and the fault is detected using the sequence analyser the threshold value is set in the relay. When the unbalance occur the negative sequence current is
measured and if the value crosses threshold limit fault is cleared in 0.04s.

V. CONCLUSION

In this paper, an integrated protection and control system with a hierarchical structure is proposed and a 70kW photovoltaic micro grid is built to validate the effectiveness and feasibility of the proposed strategy. Test results show that stable and flexible transitions between different operation modes of the PV microgrid are achieved and the viability of the microgrid under fault is greatly improved.

REFERENCES


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