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Integrated Control And Protection System With A Hierarchical Coordination Control Strategy For Grid Connected PV System

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Abstract: ***The microgrid has shown to be a promising solution for the integration and management of intermittent renewable energy generation. This paper looks at critical issues surrounding microgrid control and protection. It proposes an integrated control and protection system with a hierarchical coordination control strategy consisting of a stand-alone operation mode, a grid-connected operation mode, and transitions between these two modes for a microgrid. This approach provides a more reliable and robust grid as the systems can supplement each other. However, protection and control in a meshed power network setup is a challenge. This is because a meshed microgrid has more interconnections and interfaces compared to radial architecture power grid. This is further complicated by effects of DG on power quality, such as transients. This study is expected to provide some theoretical guidance and engineering construction experience for microgrids in general.***

Keywords: Control strategies, integrated protection, microgrid, operation modes.

1. INTRODUCTION

WITH the development of dc coupled devices, such as photovoltaic generations, batteries, super capacitors, LEDs, computers, and electronics equipment, low-voltage dc distribution networks, structured dc micro grids are emerging as a natural platform to integrate renewable energy sources. However, there are a number of technical challenges: lack of standardized equipment, inadequate stability, and versatile control design. In the past, the interest of power electronics community was moving from a single power electronics converter to multiple distributed systems that encompass a number of converters connected in either series/parallel, forming a number of dc busses with different voltage levels. Recently, with the advance of new dc power technologies, several ongoing standards, alliances, and initiatives are bringing the possibility of developing future homes, offices, buildings, campuses, datacenters, ships, satellites, aircrafts, and other electrical power systems to operate totally or dominantly in dc. Research is being carried out in both the system and component levels of modeling, control, and stability of structured dc microgrids. New high-efficiency topologies and protections are also key nontrivial issues when developing practical dc microgrids. This Special Issue brings together recent advancements in dc microgrids, which are broadly classified into three themes: power electronics converters, energy storage systems, and the control of dc microgrids. Eleven papers are accepted for publication in this Special Issue: four papers related to control of dc microgrids; four papers related to power electronics converters for dc microgrids; and three papers on energy storage for dc microgrids. A brief discussion of each paper is presented in the following.

DG proliferation is already a reality in numerous markets around the world and can impact several aspects of T&D planning, operations, engineering, analysis, policy and regulation. The industry is actively engaged in evaluating the severity of those impacts on existing T&D grids and developing solutions to ensure seamless integration. The growing interest and increasing penetration levels of DG, particularly of renewable generation technologies such as photo voltaics, and the emergence of energy storage, have also spurred attention to revisiting the microgrid concept as a solution to effectively manage, integrate, and benefit from variable DG. This involves additional monitoring, protection, automation, and control challenges. Finally, it is expected that penetration levels of DG will continue growing, given the favorable business, regulatory and policy landscape, decreasing technology prices, and evolving end-user expectations (including the emergence of the presume). Widespread adoption of DG will increase the complexity of the T&D grid, accentuating the need for reliable real-time operations and control, and triggering additional engineering issues. In this context, one of the key topics that the industry needs to address is the development of new solutions for protection and real-time monitoring of T&D systems with high penetration of DG and microgrids. This Special Section focuses on exploring methodologies and applications that address the challenges and needs associated with this new paradigm. We received numerous high quality submissions, conducted a careful review process and finally accepted 25 papers. The selected articles include authors from the Americas, Europe, and Asia, and provide readers with a variety of perspectives and approaches to address the challenges proposed by DG proliferation and microgrids. The technical areas covered by the selected papers encompass different aspects of protection and real-time monitoring of T&D grids, including design, coordination, reliability, and testing of protection methods, fault detection and modeling, signal processing, dynamic line rating, state estimation, and applications of Synchro phasors. These proposals cover a heterogeneous set of problems, from analyses of high-voltage transmission systems to specific studies of low-voltage micro grids. It is our expectation that they help generate further discussions and contributions from subject matter experts, and motivate new generations of researchers to actively participate in this rapidly growing and increasingly complex field

2. HIERARCHICAL CONTROL SYSTEM

A. System Structure

Grid-connected and stand-alone operations are the two typical operation modes in a microgrid. The requirements of PV microgrid operation modes include: 1) The rnicrogrid voltage and frequency should be stable and the power flow should be balanced, so as to realize the independent operation in different modes; 2) The two modes can transfer smoothly from one to the other, which can help avoid transient surge in the microgrid. The proposed hierarchical coordination control architecture is shown in Fig. 1.

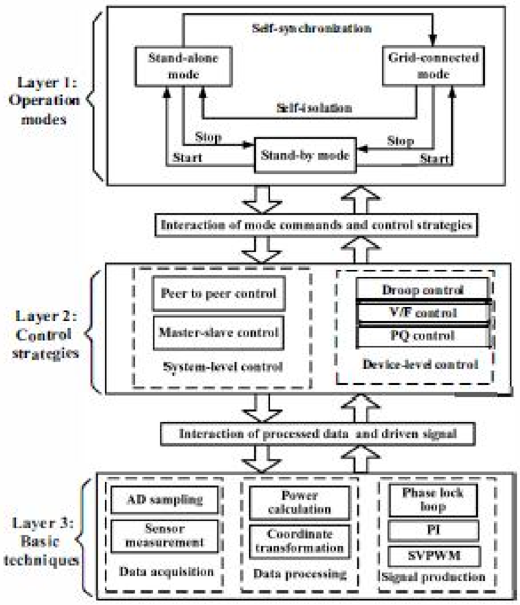

Figure 1 Control structure of PV microgrid.

Fig. 1 shows the three-layered hierarchical control architecture of a PV rnicrogrid in which the microgrid operation modes are interchangeable based on the control strategies and some basic techniques. The microgrid control strategies mainly include two parts: the system-level control modes and the device-level control strategies. The first part includes the peer-to-peer and the master-slave controls. The second part mainly refers to the idiographic control techniques, used in the local controllers, such as V IF control, PQ control, and droop control. The proposed structure is flexible so that different control strategies and basic techniques can be applied to realize different microgrid operation modes. This paper mainly discusses the master-slave control combined with V /F control and PQ control, which is demonstrated in the following sections.

B. Stand-alone Operation

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

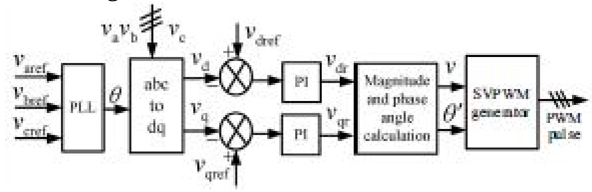

Figure 2 V/F control block diagram.

In Fig. 2, Varef, Vbref, and Vcref denote the reference of the three-phase output voltage of BESS. Vd and Vq represent the d axis and q axis component of the measured three phase voltage (Va, Vb, and Vc) based on the dq coordinate transform, respectively. Vdref and Vqref are the d axis and q axis component of the reference voltage (Varef, Vbref, and Vcref), 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 space vector pulse width modulation (SVPWM). 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.

C. Grid-connected Operation

The BESS 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 PWM technique is also adopted in generating

3. CONTROL SYSTEM AND FUNDAMENTAL OF GRID-CONNECTED INVERTERS

This section discusses the control systems of the grid connected inverter, and provides detailed discussion of the control variables that could be manipulated from a power electronic systems standpoint, including most of the possible physical limitations imposed by the ac-side passive elements which are not well documented. A generic phasor diagram and P − Q envelope are presented that could be used to illustrate the operation of grid-connected converters. Fig. 3(a) and (b) shows a schematic diagram and scaled down experimental test rig of a three-phase VSI connected to grid through an LC filter and interfacing transformer. The active and reactive powers are regulated using direct power control, where the filter bus voltage is assumed constant. Inverter power injection into the grid is regulated in the synchronous reference frame, where the voltage magnitude at the filter bus is aligned with the d-axis (the reference for the whole system, in other words all measurements in the dq axes will be relative to the filter bus voltage). Based on this principle, the inverter ac-side dynamic can be expressed in the dq axes as

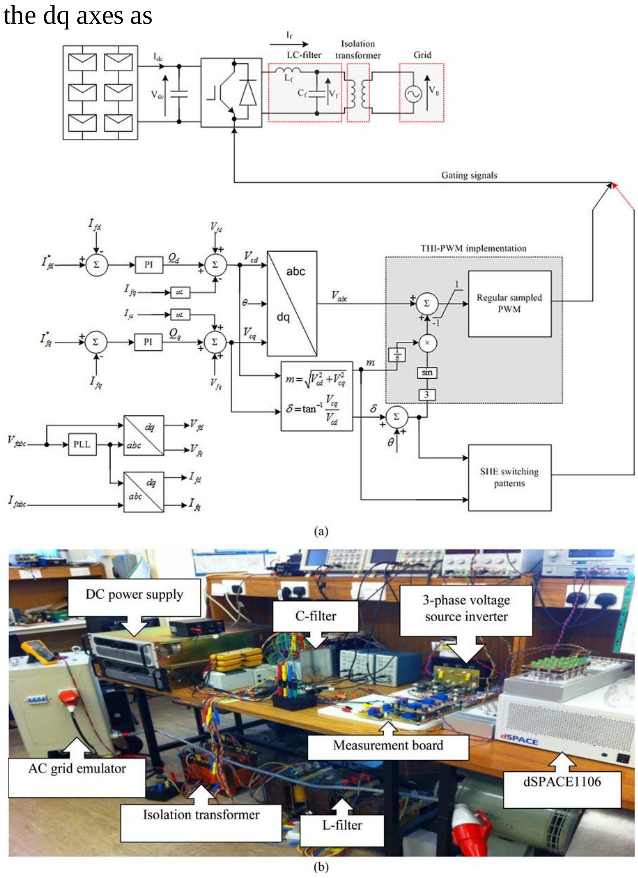

Figure 3 (a) Schematic diagram of a grid-connected PV inverter with SHE and THI PWM using a dSPACE1106 hardware implementation and (b) p.u. scaled-down test rig of a multimegawatt PV inverter prototype.

3.2.1 Table

Table 1: Parameters Of A Multi mega watt PV Inverter

Parameters		Values
Converter power rating (MVA)		25
DC link voltage (kV)		20
AC voltage (line-to-line in kV)		11
Active power capability (MW)		20
Reactive power capability (MVAr)		15
Grid frequency		50
Switching frequency (kHz)	THI-PWM	2
	SHE	0.95
Current control proportional gain, K_p	THI-PWM	70
	SHE	220
Current control integral gain, K_i	THI-PWM	3000
	SHE	5000

The variables Qd and Qq can be obtained from the proportional-integral controller.
The dq voltage components at the converter, which represent the voltage references to the modulator, can be estimated from the expressions for Qd and Qq , taking into account feed-forward terms.

$$Vcd = Qd + Vf\,d - \omega Lf\,If\,q \qquad (1)$$

In PV applications, P□ can be obtained from maximum power tracker or a dc voltage controller that adjusts the PV cells operating point in order to maximize power extraction. Fig. also summarizes the grid-connected inverter control systems used in this paper, including the SHE implementation and THI PWM. Fig. 4(a) shows the generic phasor diagram for the voltage source grid-connected inverter. This phasor diagram illustrates the control principle of the voltage source converter, including operating regions and boundaries in steady state. When the voltage vector at converter terminal Vc advances the filter bus Vf , the power flow is from the dc side to the ac network, and vice versa. When the voltage magnitude at converter terminal Vc is larger than the filter bus Vf , where power injection to the grid is controlled, reactive-power flow is from the converter to the ac network (provision of leading VAr), and the opposite is true. Therefore, converter active and reactive powers can be manipulated using the load angle δ and voltage magnitude at converter terminal Vc . In voltage source converters, the phase interfacing inductor Lf is not only required for filtering and fault purposes, but also necessary to provide phase shift δ to enable active power control. Also, it has to be sized appropriately not to limit the converter’s ability to generate reactive power for a given dc-link voltage. In this paper, the interfacing inductor Lf is sized so as to ensure that the converter is able to provide its maximum design reactive power. The selection criteria for Lf are described as follows: as Rf is normally small compared to the reactance of the phase interfacing reactor, resistance can be neglected. Therefore, the steady-state If d and If q can be obtained by setting the derivatives terms to zero, and Vf q = 0 since the voltage vector is aligned with the d-axis

$$If\,d = Vcq/\omega Lf \quad (2)$$

$$If\,q = -(Vcd - Vf\,d)/\omega Lf \quad (3)$$

Active and reactive powers P and Q at the filter bus can be expressed as

$$P = 1.5 * Vf\,dIf\,d \quad (4)$$

4. Intelligent Protection Strategy of Micro Grid

One of the major challenges of micro grid protection system is that it must respond to both island and grid connected faults [1-13]. In the first case the protection system should isolate the smallest part of the micro grid when clears the fault. In the second case the protection system should isolate the micro grid from the main grid as rapidly as necessary to protect the micro grid loads [1- 3].
Modern micro grid consist of many different distributed energy resources like solar PV, wind turbines, fuel cells, small-scale hydro, tidal and wave generators, micro-turbines, combined heat power (CHP) systems, energy storage, etc.. When different type of distributed resource connected to micro grid and Utility grid, the DR contribute fault current to the system and the contribution level depends on distribution resource type. To ensure safe operation of micro grid the protection equipment should be updated accordingly.
So the dynamic structure of micro grid and their various operating conditions required the development of adaptive protection strategies. One such strategy is proposed in Figure 1. Here central control unit communicate with all relays and distributed generators in the micro grid to record their status as ON/OFF, their rated current and their fault current contribution. Communicate with relay is required to update the operating current and to detect the direction of the fault currents and thus mitigate the fault properly. The control unit also records the status of utility grid as connected or micro grid is.

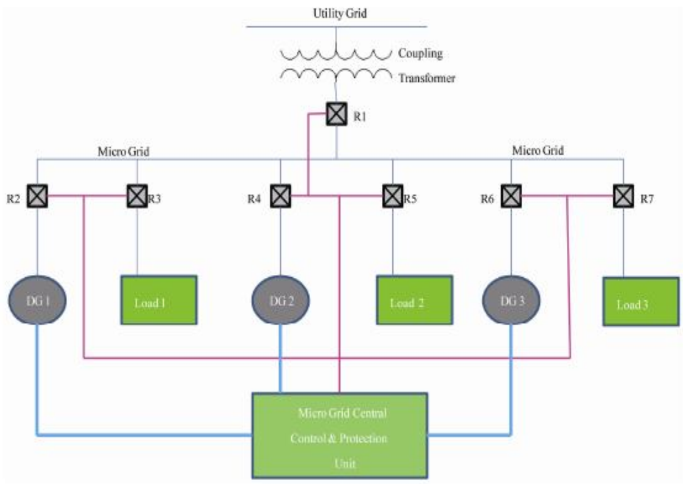

Figure 4 Topology of micro grid protection system

4.1 Fault Mitigation Technique of Micro Grid

A simple model of micro grid protection structure and fault mitigation process is described in Figure 5. Micro grid protection system and fault analysis done based on data acquisition from control and monitoring unit. Based on data acquisition disturbance is measured and fault detection alarm found based on disturbance value.

At first fault should be determined by detecting change in bus bar voltage. Power direction is measured and based on this fault location detected. The fault point is in the utility grid if the power direction of the common connection point of utility grid and point of micro grid is positive.

The direction of bus bar pointing to the line sets as power positive direction. According to the power directions of the lines connected to bus bar, the system can determine whether there is a bus short-circuit fault. The fault is a bus short circuit fault and breakers of each side of bus trip, if the power directions of all micro source lines are negative directions. Based on power direction inner fault, bus fault, line fault is determined. Once line fault is detected fault area/zone is determined and then fault is removed by tripping signal from relay.

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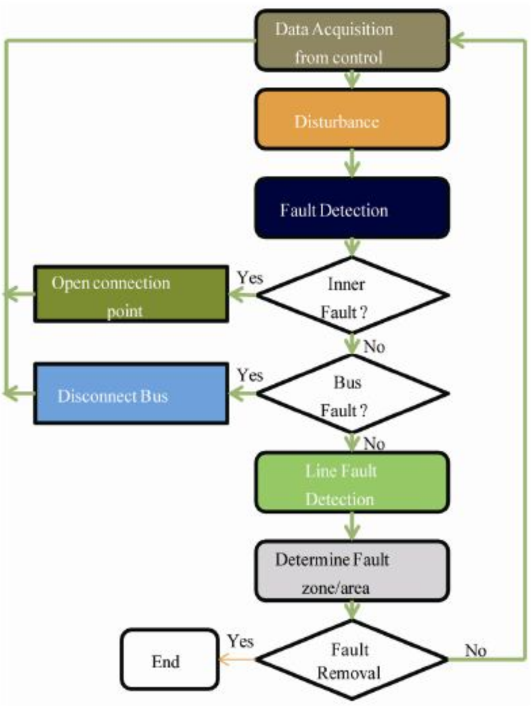

Figure 5 Fault mitigation technique of micro grid

5. Results and System Simulation on MATLAB

5.1 Solar Photovoltaic Array Modeling and Simulation MATLAB model of proposed system

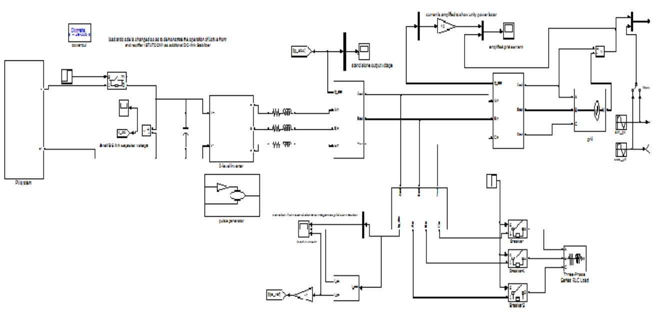

Figure 5 MATLAB model of proposed system

5.2 Boost, (Step-Up) DC/DC Convertor Model

The boost (step-up) configuration was selected to connect the PV panel to the system and apply MPPT control. In addition, the necessarily small size of its components, like inductor and capacitor at low power applications make it a good candidate to mount behind the PV panel. The boost is one of the most common DC/DC convertor topologies that are used for power applications. The boost contains a MOSFET switch, a diode, an inductor, and a capacitor. At the following, the built Matlab® Simulink model for the boost connected to the PV model is shown:

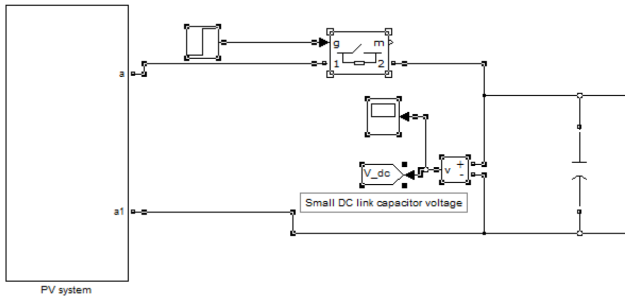

Figure 6 PV and Boost DC/DC Converter

5.3 two level pulse generator

The PWM Generator (2-Level) block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can control switching devices (FETs, GTOs, or IGBTs) of three different converter types: single-phase half-bridge (1 arm), single-phase full-bridge (2 arms), or three-phase bridge (3 arms).
The reference signal (Uref input), also called modulating signal, is compared with a symmetrical triangle carrier. When the reference signal is greater than the carrier, the pulse for the upper switching device is high (1), and the pulse for the lower device is low (0). To control a single-phase full-bridge device, you can select unipolar or bipolar PWM modulation. Using the unipolar modulation, each arm is controlled independently. A second reference signal is internally generated by phase-shifting the original reference signal by 180 degrees. Using the bipolar modulation, the state of the lower switching device of the second arm is the same as the state of the upper switch of the first arm, and the state of the upper switch of the second arm is the same as the state of the lower switch of the first arm. The unipolar modulation produces better quality AC waveform, but the bipolar modulation produces very low-varying common-mode voltage. The figure describes the three techniques to sample the reference signal Uref. The natural sampling technique models the behavior of an analog implementation of a PWM generator. Using the two regular sampling techniques, Uref can be sampled twice at both the valley and the peak of the carrier or only once at the valley of the carrier. The former is referred to as asymmetrical sampling or double-edge technique. The latter is called symmetrical sampling or single-edge technique.

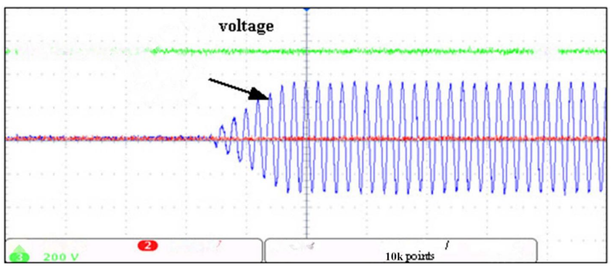

Figure 6 stand alone voltage

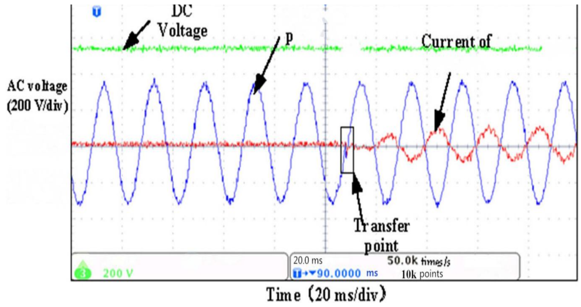

Figure 7 proposed PV stand alone voltage

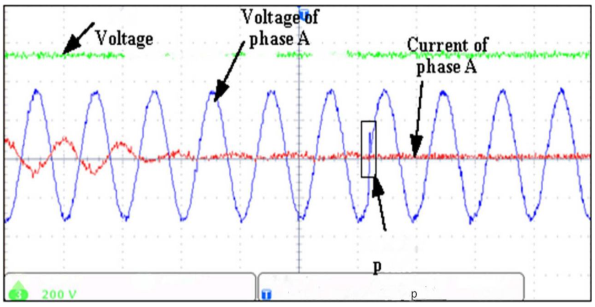

Figure 8 amplified currents and voltage

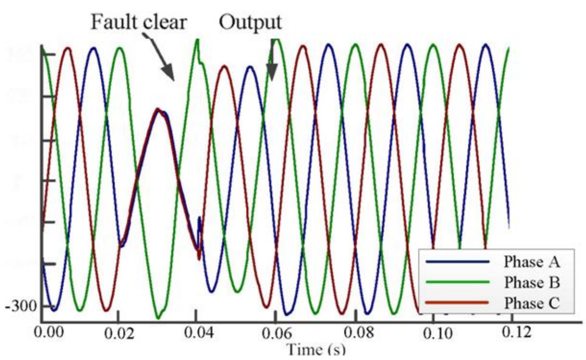

Figure 9 BUS voltage

6. COCLUSION

The main features of the developed PV system, which uses the improved permutation algorithm, are: (i) the upholding of operation of all PV sources (shaded and non shaded) at their MPPs, (ii) the delivery of all extracted power from PV sources to the load and (ii) the generation of improved multilevel voltage waveforms with low THD.

The proposed system was simulated using the Matlab–Simulink for five and seven-level DC-link converter. The comparison between the previous and the improved permutation algorithm have shown that the latter generates a lower distortion of the output waveform and a higher amplitude of the fundamental harmonic of the output voltage. The time varying irradiance levels were applied to test dynamic behavior of the system in terms of the MPP tracking. The algorithm enables each shaded PV source to be recovered to its MPP without affecting other PV sources in the circuit.

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