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A Novel Structure Adaptive Decentralized Inverter Voltage Control Approach for Solar PV and Storage-Based Islanded Microgrid

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Abstract: *This paper proposes a new distributed control strategy for isolated microgrids (MGs). The distributed control strategy is applied to control the output voltage of the voltage source inverter using a sinusoidal pulse width modulation (SPWM) based control strategy. Consider an island MG based on photovoltaic power generation (SPV) and a storage system with a common inverter. This inverter is connected to a three-phase AC system. An algorithm based on maximum power point tracking has been applied to extract maximum power from the SPV system. The common inverter is triggered in a way controlled by SPWM-based technology, allowing the output voltage to be maintained. The storage system load and unload were also controlled by the control algorithm. Fluctuations in PV data are captured using a series of fluctuations in solar irradiance data. An adaptive discrete proportional integral derivative (CURRENT PI CONTROLLER) based controller is used for inverter voltage control in the dynamic MG model. The peak value of the AC voltage signal is used as the reference signal and dq control is applied. The performance of the proposed scheme provides better voltage stability and easier implementation compared to the traditional proportional-integral-differential (PID) and adaptive model reference schemes of separation MG under various test conditions. Offers.*

Keywords: Adaptive controller, dSPACE, microgrids (MGs), renewable energy, sinusoidal pulsewidth modulation (SPWM), voltage control. etc.

I. INTRODUCTION

MICROGRIDS (MG) is a promising unit for demanding more control functions and reliability within a defined zone on the distribution side. There are two types: grid connection and isolation MG. Island or isolated MGs are more demanding and require more accurate operation of all connected systems and subsystems while controlling system voltage and active and reactive power. There are two effects of power generation and load fluctuations on the performance of Island MG.

On the one hand, renewable energy systems are becoming more and more popular, while at the same time destabilizing the entire system, reducing total cost of ownership and promoting the use of green and clean electricity. Therefore, from a control standpoint, Island MG requires a more robust system voltage control method, especially if the system has an uncertain dynamic generation and load model [1]. The distributed control strategy of the separated MG has certain advantages over the centralized control strategies [2], [3]. Adaptive Model Reference Control (MRAC) can be implemented in combination with several heuristic approaches, which require a more complex centralized system for optimizing the plant model [4], [5].

There are many approaches to implementing decentralized control for stand-alone MGs, namely, in [6], the multi-level inverter topology proposed in a renewable energy-based hybrid MG system independent of the battery storage system; Different topologies were considered for an autonomous system, and the best one was chosen among them. Authors in [7] and [8] have proposed two distributed generation (DG) models of microturbines for speed control and real power control via PI controller.

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Two modes of operation were considered and results were obtained regarding the overall performance of the DG. We found that a classical PI was not enough to provide robust solutions under the intermittent effect of solar photovoltaic (SPV).

The distributed control strategy is given in [9] for DC MGs using voltage and current regulators. For this purpose, a global dynamic model of the MG is created. Powerful control model to reduce frequency deviation proposed in [10] caused by Renewable Energy Sources (RES). The dynamics of the storage system have also been integrated into the system. In [11], a voltage and frequency control model is proposed, in which the finite time dispersion method is used to recover the voltage. Controllers here are allowed to communicate with neighboring controllers to implement control methods. A more sophisticated decentralized voltage control in the inverting MG using an adaptively integrated proportional differential (CURRENT PI CONTROLLER) controller. The conventional MRAC strategy has some limitations because it requires a high degree of accuracy in understanding plant dynamics. In addition, for a very dynamic and uncertain system, it is difficult to obtain an accurate factory model. Similarly, a conventional PID controller also requires better and longer gain adjustment to achieve the desired result. As a result, fixed gain PID controllers cannot cope with sudden changes in load conditions, unpredictable failures, or unexpected system disturbances. In addition, a small-signal state-space model is considered to analyze the stability of the MG system. The decentralized approach presented in this article covers the aforementioned issues.

II. LITERATURE SURVEY

In (Oct. 2015), "B. Lasseter. "microgrids (distributed power generation)". Observes that Microgrids (MGs) are the small scale energy grids that feed loads at the distribution side, these small scale grids has control capabilities within and are broadly categories into grid connected and islanded or isolated MGs.

In (2016) Kumar Maneesh and Tyagi Barjeev. "A state of art review of microgrid control and integration aspects", says In grid connected MGs, the voltage and the frequency are governed by the main supply grid. On the other hand the islanded type of MGs are require to be self sufficient to overcome any variation in frequency and voltage.

In (Sep. 2017) Louis-A. Dessaint Loubna Yacoubi, Kamal Al-Haddad and Farhat Fnaiech. "a dsp-based implementation of a nonlinear model reference adaptive control for a three-phase three-level npc boost rectifier prototype"says that a design implementation of the controller, for a three phase boost rectifier is presented, that utilizes the MRAC strategy to control the output voltage of rectifier, while maintaining the unity power factor.

In (Jan. 2018), Zeljko Ban Toni Bjazic and Igor Volaric. "control of a fuel cell stack loaded with dc/dc boost converter". a robust non-linear model of a boost converter is presented that traces non minimal phase voltage output with uncertain time-varying parameters.

In (Apr. 2019) Bismark C. Torrico Matheus K. C. Cunha, Fabricio G. Nogueira. "selftuning adaptive controller applied to the boost converter voltage control".says a fix and adaptive pole placement control strategy for the output voltage control of a boost converter. An MRAC is designed to control the speed of the steam turbine with the help of MIT rule for quick adaption is proposed. The design and implementation of MRAC for maximum power point tracking (MPPT) system.

In (Mar. 2018) N E Jaffar Sherin A Kochummen and Nasar A. "model reference adaptive controller designs of steam turbine speed based on mit rule". says that a composite MRAC scheme to mitigate the model mismatch due to parametric uncertainty in dc-dc boost converter, a cascade PI model predictive controller is designed here to improve dynamic response of the system and then an observer is employed to construct an accurate model.

In (Mar. 2019) M Swathi and P Ramesh. "modeling and analysis of model reference adaptive control by using mit and modified mit rule for speed control of dc motor" says a new parameter model is presented using MIT rule with variations in input only. A linearization model of dcdc boost converter is given and P, PI and PID controller is designed by the step response of Ziegler Nichols tuning rule to compare the performance of each type of controller.

III. MODELLING AND ALGORITHM

The proposed MG has a structure given in Fig. 1, where an SPV system is considered with a maximum power point tracking (MPPT) controller, which is based on the P&O algorithm.

3.1 Dynamic Model Of Considered Microgrid System

A Fig.3.1.Layout of the microgrid system under consideration. boost converter is also connected at the output of the SPV system and is then connected to an isolated three-phase ac MG bus through an Insulated Gate Bipolar Transistor (IGBT)/diodebased six pulse sinusoidal pulsewidth modulation (SPWM) inverter. The SPV system is being supported by an ESS, which again has a boost converter at its output.

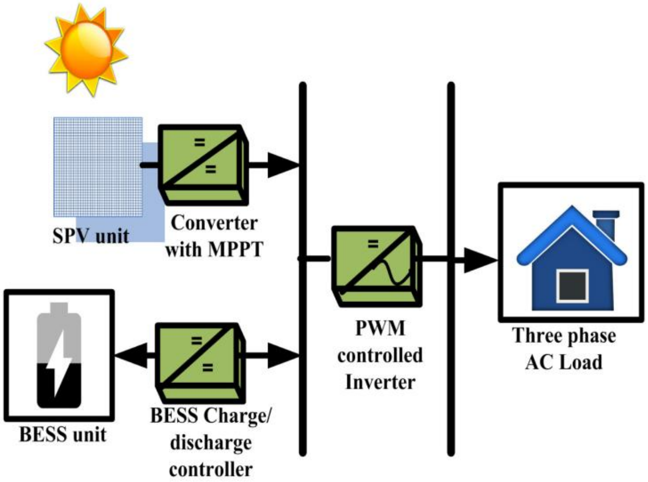

Fig 3.1 Layout of the microgrid system under consideration

The charging and the discharging of the connected ESS are being controlled with the help of a PID controller, which maintains its state of charge (SOC), voltage, and current levels. The ESS is connected to the ac MG via a common inverter. The sine pulsewidth modulation (PWM) technique is being utilized for the inverter voltage control using an CURRENT PI CONTROLLER controller.

3.2 Control Model For An Islanded MG System With The Inverter Connected DG

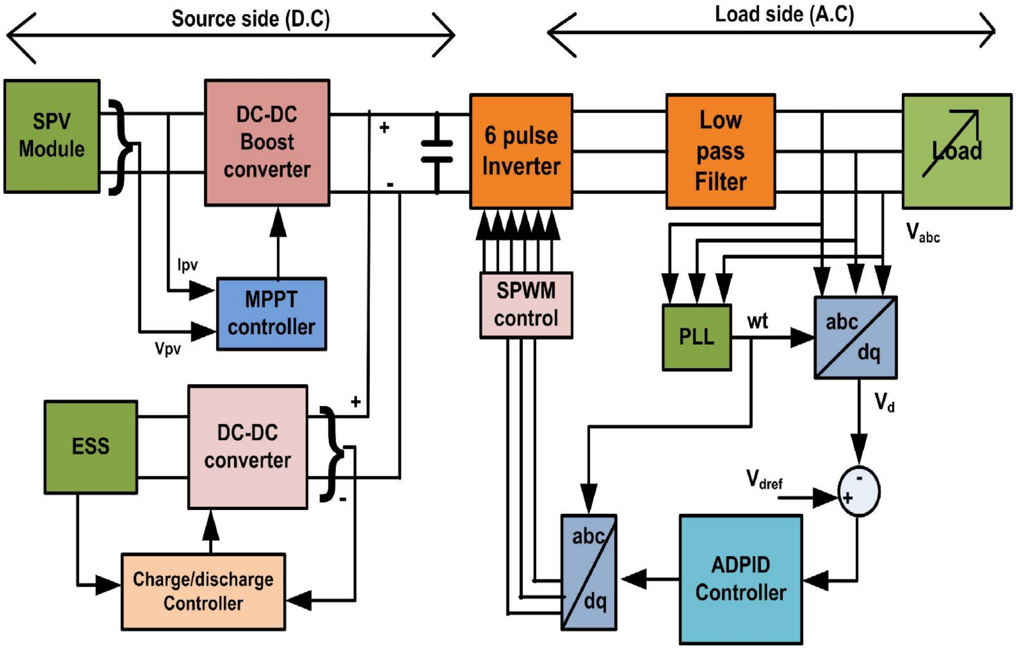

Fig. 3.2 Schematic diagram of inverter-based DGs with closed-loop feedback control.

The three-phase output voltage (Vabc) of the IGBT/diode-based six-pulse inverter is used as feedback. The three-phase output voltage feedback signal is converted to a dq frame using Park's transformation. This transformation converts the three phase voltage into a dq frame, i.e. Vd and Vq. To facilitate tension control, the q component is assumed to be 0 and only the d axis tension component is taken into account. "wt" is the angular position of the rotating frame dq, in radians. A low-pass LC filter is also connected between the inverter and the time-varying load to maintain the rate of voltage change and eliminate harmonics in the output voltage waveform. The repository of one DG is considered to be shared with another DG, i.e. for SPV and ESS. The peak of the three-phase voltage is used as a reference to generate modulation signals for the MG inverter.

To eliminate phase angle error, a phase-locked loop block is connected. It also helps with system synchronization. The nonlinear model of MG connected DG is represented by the dq frame of reference. The input to the adaptive controller is a voltage error signal (Vdref - Vd). The current signal is taken for the measurement. The output signal from the controller is used to activate the gate circuit of the inverter through the SPWM technique.

3.3 Solar Photovoltaic Model

The SPV module can be represented by an equivalent circuit given in Fig. 3 with various circuit parameters as shown. The relationship between current and the voltage can be seen from the fllowing equation:

$$I = I_{\mathrm{ph}} - I_o \left[\exp\left(\frac{V_{\mathrm{pv}} + I_{\mathrm{pv}} R_s}{n_d V} \right) - 1 \right] - \left(\frac{V_{\mathrm{pv}} + I_{\mathrm{pv}} R_s}{R_{\mathrm{sh}}} \right) \qquad (1$$

3.4 ESS Model

The considered ESS has Li-ion batteries connected to it. These kinds of batteries have a hysteresis phenomenon between the charging and the discharging that provides an exponentially varying voltage as given by (1), although it is less as compared to lead-acid batteries,

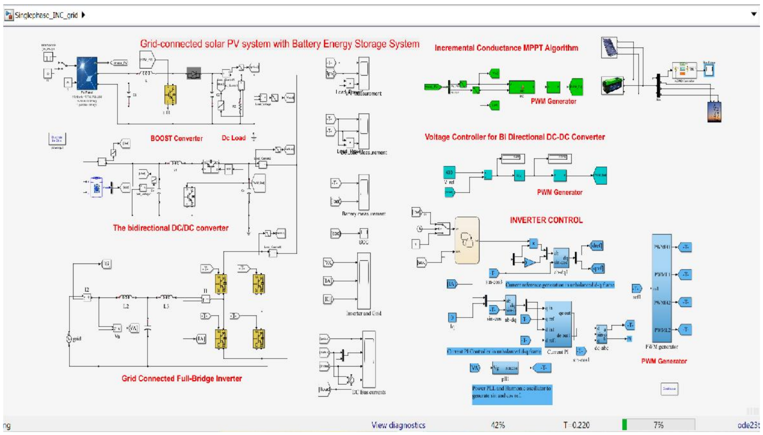

Fig 3.3 Simulation for Adaptive Decentralized Inverter Voltage Control Approach for Solar PV and Storage-Based Islanded Microgrid

The whole design procedure can be summarized as follows:

- Calculation errors for each control objectives or state variables
- Calculation of error dynamics
- Calculation of unknown parameter estimation errors
- Calculation of CLFs and their derivatives based on the errors
- Repetition of the first four-steps until the control laws appear
- Calculation of the parameter adaptation laws to estimate the unknown parameters
- Calculation of the control laws to stabilize the error dynamics at the final steps
- Checking the stability of whole systems with the derived control and parameter adaptation laws.

IV. RESULT ANALYSIS

The voltage control has been implemented in such a way that the following conditions are fulfilled.

1. An overall decentralized control structure has been achieved.

2. The overall MG closed-loop system is stable under various system conditions.
3. All the connected DGs track the reference signal provided through the SPWM technique. Each controller has to maintain the above three conditions successfully and provide a robust control within its application area. To test the effectiveness of the proposed controller, various cases have been considered as given in the following subsections. The results obtained by the Current PI Controller are also compared with the results obtained by a conventional PID and the MRAC controllers.

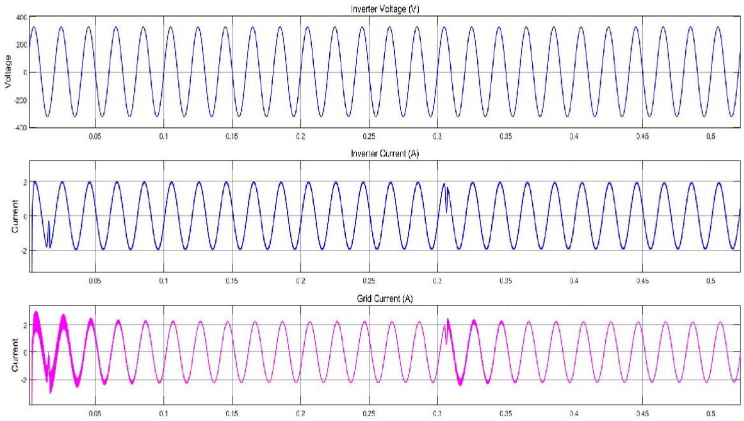

Fig. 4.1 Inverter output voltage and load current with Current PI Controller for balanced load variations

Fig. 4.1 shows a controlled voltage profile after a certain load variation, and, therefore, a variation in load current can also be seen. After every switching operation in the MG system, the voltage profile is maintained with the Current PI Controller.

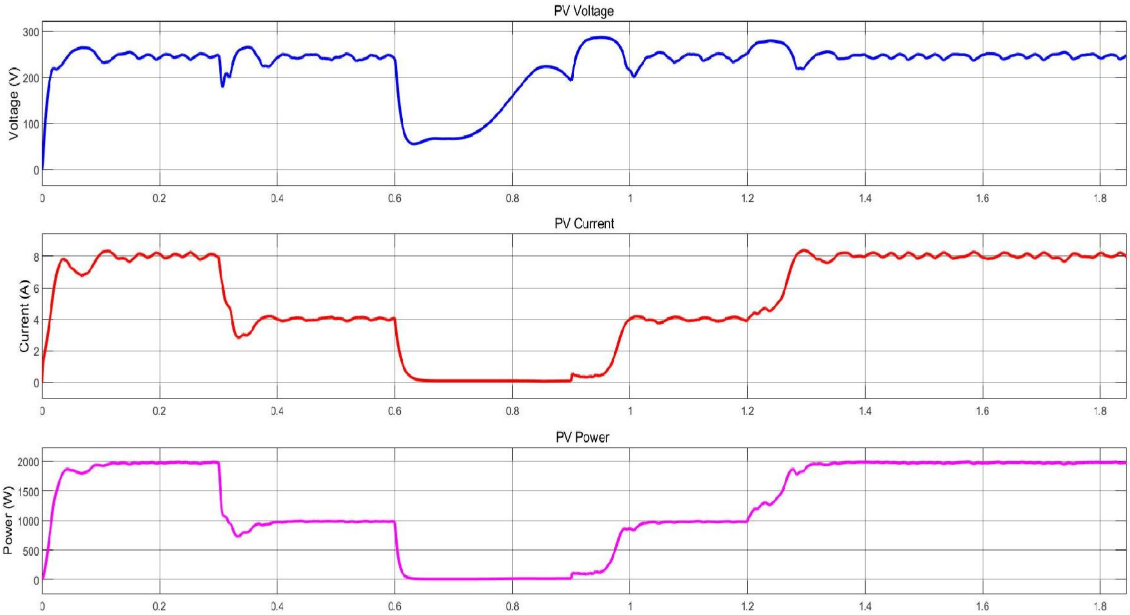

Fig. 4.2 PV output voltage and load current and power for unbalanced Load

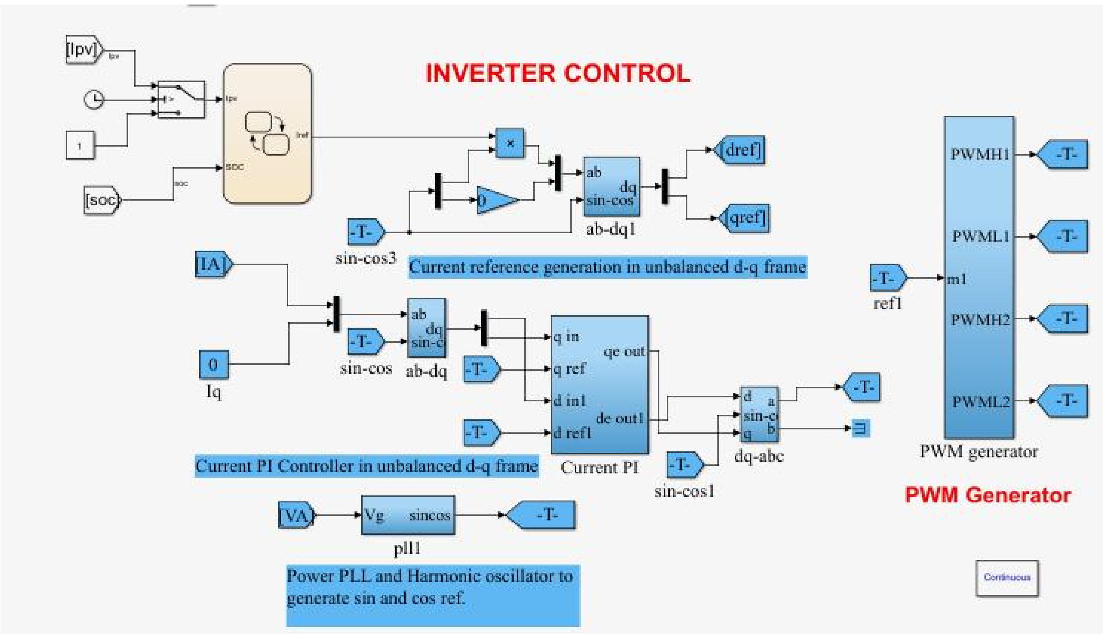

Fig. 4.3 Inverter Control using Current PI Controller

Fig. 4.3 shows a comparative assessment of error profiles with Current PI Controller MRAC, and the PID controllers. The values of parameters considered for the comparison of PID controller are Kp = 0.001, Ki = 0.2, and Kd = 0, and the MRAC controller considered has the following step profile; rise time: 21.6, settling time: 38.20, overshoot: 0, undershoot: 0, peak: 0.9998, peak time: 79.90, which is a critically damped system profile for all the cases. The figure shows that the error stabilizes very fast with the Current PI Controller compared to the other two controllers. Moreover, the error profile with the MRAC controller destabilizes rapidly with the variations in system dynamics after a certain period.

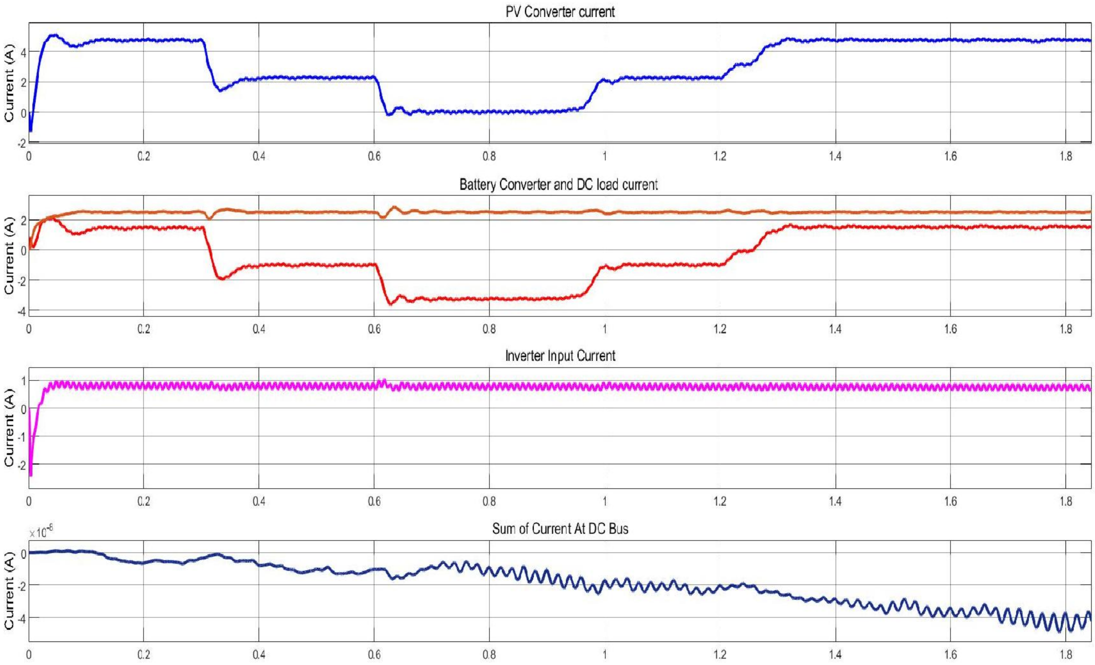

Fig. 4.4 PV converter current, Battery converter and DC load current, inverter input current Sum of current and DC Bus waveforms.

The reactive power consumption has been increased in both the critical and the noncritical parts of the overall load equally. It is observed from Fig. 4.4 that the overall voltage profile is maintained.

V. CONCLUSION

A renewable source-based MG, powered by ESS, is expected. Several scenarios were considered to confirm the effectiveness of the proposed program. It can be seen that the proposed decentralized control scheme works well under the different conditions considered. Variations of the load's operational demand and response to the initial non-critical load transition are applied for validation purposes. Load-side failure conditions have also been considered for the same purpose. It is observed that after a single L-G failure, the voltage of the MG system is maintained by different distributed controllers placed at different locations.

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