FUZZY CONTROL FOR DISTRIBUTION VOLTAGE CONTROL OF DC-MICRO GRIDS AND GAIN SCHEDULING TECHNIQUE

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Abstract— ***Gain scheduling has proven to be a successful design methodology in many engineering applications. The idea is to construct a global feedback control system for a time-varying and/or nonlinear plant from a collection of local linear time-invariant designs. However, in the absence of a sound analysis, these designs come with no guarantees on the robustness, performance, or even nominal stability of the overall gain scheduled design. We describe a novel Bayesian ensemble methodology involving three diverse predictors. Each predictor estimates mixing coefficients for integrating PV generation output profiles but captures fundamentally different characteristics.Therefore, we added another energy storage unit and adopted gain-scheduling control technique as the droop controls for sharing the outputs. Here, we used a new voltage control method that combines fuzzy control with gain-scheduling control technique in order to accomplish both power sharing and energy management simultaneously. In this paper, electric-double-layer capacitors (EDLC) were used as the energy storage unit, and each dc/dc converter of EDLC controlled the dc distribution voltage when the system was operated under an intentional islanding mode. The simulation results demonstrate the effectiveness of the proposed adaptive GS-PID and show that this approach can achieve a good maximum power operation under any conditions such as different levels of solar radiation and PV cell temperature for varying PV sources.***

Index Terms— ***Photovoltaic Energy Conversion System (PECS); Voltage Sourced Inverter (VSI),DC power systems,gain-scheduling control.***

I. INTRODUCTION (HEADING 1)

Nowadays, the power generation from renewable energy sources highly escalates due to the increasing such as carbon emission reduction and lack of conventional fossil fuel. Among renewable sources, the photovoltaic (PV) generator, which is inexhaustible, clean, environmentally friendly, etc., gets a lot of attention. Many large PV farms have been operated around the world. At the end of 2012, the total capacity of PV farms is almost 100 GW. Among PV systems; the grid connected PV systems have been extensively applied. Nevertheless, the large penetration of grid-connected systems of PV farms diminishes both system inertia and synchronizing coupling. This may be harmful to the system transient stability. The impacts of PV farms on power system transient stability reveal that high PV penetration levels, system topologies, disturbance types, and fault locations are main factors. In the effect of PV penetration levels on the system response under the critical contingency in the transmission system. It is found that the transient stability improvement by distributed PV generators is superior to the centralized PV generators.

In the transient stability assessment of power system with high penetration of PV generators is carried out under various conditions such as levels of PV penetration, variety of power sources (inverter or synchronous machine), and existence of low-voltage-ride-through capability. The results signify that an appropriate penetration of the PV generators enhances the transient stability. However, the large penetration of PV sources deteriorates the transient stability, under the occurrence of disturbance. On the other hand, with the large amount of PV generators in the future, they are highly anticipated to contribute ancillary services to the future power grids. With the ability of inverter control, the decoupled active and reactive power control of PV can be performed.

This leads to sophisticated applications of PV generator, such as frequency control, voltage control, reactive power control, power oscillation damping, wide area stabilization, etc. This paper proposes the new application of the PV farm to a transient stabilization of a multimchine power system. Depending upon the control ability of the PV inverter, the active power output of PV can be modulated, so that the transient power swing can be stabilized. In the control part, it is well known that the proportional–integral–derivative (PID) controller is widely used due to its simple and practical structures. However, the conventional PID controller with fixed gains cannot provide the satisfactory control performance over a wide range of operating conditions.

To overcome this problem, a fuzzy gain scheduling of PID (FGS-PID) controller is used to adapt the PID gains.In [12] the FLC improves tracking performance when compared with the conventional method P&O, then the FLC is compared to the optimized fuzzy logic MPPTcontroller, this OFLC showed much better performancesand robustness. It has not only improved the response time in the transitional state but has also reduced considerably the fluctuations in the steady state under different temperature and irradiance conditions.

II. DC MICROGRID FOR A RESIDENTIAL COMPLEX

Renewable Energy Sources integrated together with other distributed generation (DG) are steadily becoming more competitors in new electricity grids because it had gained popularity. Fig. 1 shows a proposed DC micro-grid for a residential complex. These system consists of around 50–100 houses, each having a micro combined heat and power unit which is called micro-CHP unit, such as a gas engine or a fuel cell. The micro-CHP units are connected to a DC distribution line (3 wired, ±170 V), and the output electric power is shared among the houses. Cogenerated hot water is either used by individual house or shared between adjacent houses. By using Rectifier circuit the utility grid is connected to the system. At the load side, various forms of electric power (such as AC 100 V and DC 48 V) can be obtained by using various type converters. Electric Double Layer Capacitors (EDLCs) are used as the main energy storage unit because of having more advantages such as fast response, easy measurement of the stored energy, safety (especially compared with Li-ion batteries) and no toxicity of the constituent materials. If energy storage system using an EDLC unit, the voltage and maximum energy limits are 500 V and 5 MJ, respectively. So EDLC is considered viable as an energy storage system in a small grid. The capital cost per kilowatt-hours (kWh) for EDLC is 300–2000 dollars, while that for lead-acid and Li-ion batteries is 200–400 and 600–2500 dollars, respectively. The capital cost per kWh-per cycle for EDLC is 2–4 cents, while that for lead acid and Li-ion batteries is 20–100 and 15–100 cents, respectively. EDLCs having more life compared to others because it can handle many charge–discharge cycles as well as low cost per cycle. The capital cost per kWh-per cycle for EDLC is 2–4 cents, while that for lead-acid and Liion batteries is 20–100 and 15–100 cents, respectively. The disadvantage of EDLC is its low-energy density. If a large energy capacity is needed for a micro-grid, a relatively large EDLC is required. However, a large energy capacity is not necessary for the proposed DC micro-grid because the micro-CHP units are operated to prevent over charge/discharge of the EDLCs as described in the following section.

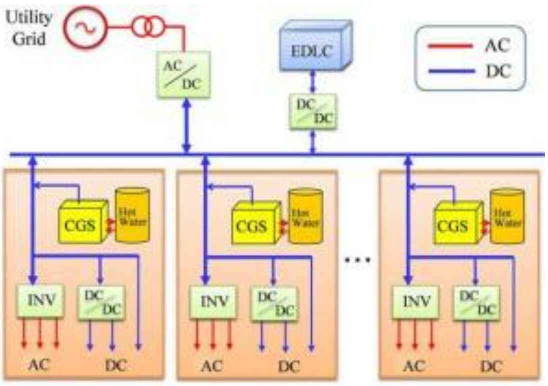


Figure 1 System configuration of the DC micro-grid for a residential complex.

III. GAIN SCHEDULING

The robust control theory is well established for linear systems but almost all real processes are more or less nonlinear. If the plant operating region is small, one can use the robust control approaches to design a linear robust controller where the nonlinearities are treated as model uncertainties. However, for real nonlinear processes, where the operating region is large, the above mentioned controller synthesis may be inapplicable. For this reason the controller design for nonlinear systems is nowadays a very determinative and important field of research. Gain scheduling is one of the most common used controller design approaches for nonlinear systems and has a wide range of use in industrial applications. In this section the main principles, several classical approaches and finally the linear parameter-varying based version of gain scheduling are presented and investigated.

Introduction to gain scheduling

In literature a lot of term are meant under gain scheduling (GS). For example switching or blending of gain values of controllers or models, switching or blending of complete controllers or models or adapt (schedule) controller parameters or model parameters according to different operating conditions. A common feature is the sense of decomposing nonlinear design problems into linear or nonlinear sub-problems. The main difference lies in the realization. Consequently gain scheduling may be classified in different way

- According to decomposition
1. GS methods decomposing nonlinear design problems into linear subproblems
2. GS methods decomposing nonlinear design problems into nonlinear (affine) sub-problems
- According to signal processing
1. Continuous gain scheduling methods
2. Discrete gain scheduling methods
3. Hybrid or switched gain scheduling methods
- According to main approaches
1. Classical (linearization based) gain scheduling
2. LFT based GS synthesis
3. LPV based GS synthesis
4. Fuzzy GS techniques
5. Other modern GS techniques

The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the setpoint, and the degree of system oscillation [1, 2]. However, since the controller parameters are fixed during control after they have been chosen through a certain (optimal) method, the conventional C-PID controller can't always keep satisfying performances, so, the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. To overcome these disadvantages, C-PID controller should be improved. The gains of PID controller should be adjusted dynamically during the control process. Many on-line tuning algorithms, such as fuzzy logic, neural network and genetic algorithm, adaptive PID controller, model predictive PID controller, analytical PID controller and GS-PID controller have been introduced into C-PID controller to achieve desired control performances for the entire operating envelope of system [3-7]. Usually, PID tuning to find the proper values for PID controller gains involves trial and error. With the analytical PID libraries included in the LabVIEW Control Design and Simulation Module, the tools to find sets of PID gain values automatically for a given user model (process) are available, which ensures system closed-loop stability. Also, it is possible to input minimum gain and phase margin values to specify the optional performance constraints on the PID controller [8].

DC Voltage Control

As mentioned in the previous section, the dc distribution voltage is normally controlled by a grid connected rectifier in the interconnected operation. The dc/dc converters of the storage systems are controlled to maintain the dc distribution voltage within a specified range [13]. In intentional islanding operation, the dc/dc converters of the storage systems need to maintain thedc distribution voltage.

Therefore, if the dc microgrid has two ormore energy storage units and those converters can be operated in parallel, it contributes to the voltage regulation and system redundancy.

Droop control is a well-known method for voltage control when two or more converters are used. In general, the droop controller detects the output power or current as a feedback parameter, and the deviation of dc voltage is controlled in proportion to the output power. However, if the converters connect to energy storage units, the controller should consider not only the output power balance, but also the stored energy.

In particular, stored energy balance is important to carry out the operation described in the previous section because microCHP units have to start or stop frequently under an unbalanced condition of the stored energy. Therefore, we propose a novel control method combining gain scheduling and fuzzy control, which accomplishes good voltage regulation, load sharing, and energy balance simultaneously.

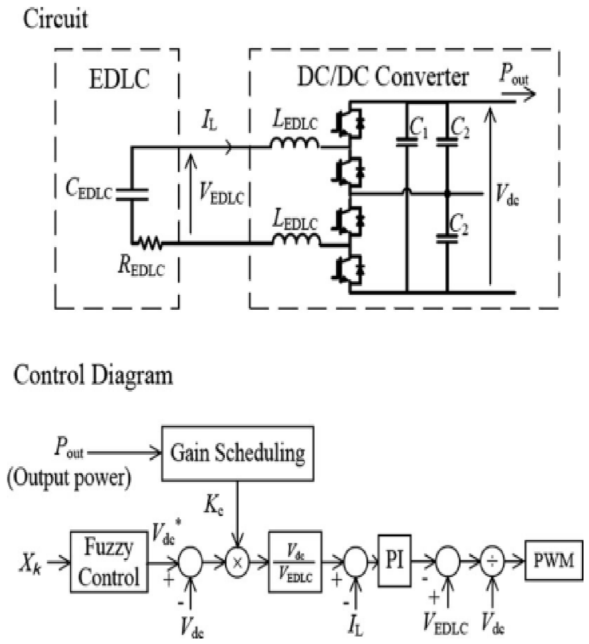


Figure 2 Control for dc/dc converter for energy storage.

IV. CONTROL STRATEGY OF CONVERTER FOR ENERGY STORAGE UNIT

Figure 2 shows the circuit and proposed control diagram of a dc/dc converter for EDLC banks. We designed the circuit to be symmetric with respect to the neutral line, because the converter is supposed to function as a voltage balancer under the appropriate control. We examined the steady-state dc voltage error when the gain Kc or the output power was changed by numerical simulations. Fig. 3 and the circuit, control diagram, and parameters for the simulation. The rated output voltage and capacity were 340 V and 3 kW,respectively.

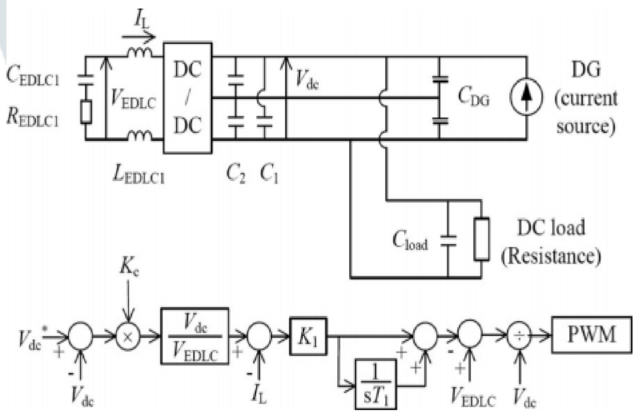


Figure 3 Circuit and control diagrams to obtain the relation between the steadystate error and the gain Kc

V. EQUIVALENT CIRCUIT OF PV SYSTEM

In the literature different models of solar photovoltaic cell are presented: single diode and single resistance model [10], single diode and two resistances model [9] and more than one diode models [11]. In this paper, one diode and one resistance model is prepared and shown in Fig.4. As most of PV manufacturers give only three operating points: such as short circuit current, the maximum power point defined as maximum power current and maximum power voltage, open circuit voltage and since this work is not based on a PV intrinsic study, the one diode model is considered satisfactory and easy to implement under MATLAB Simulink software. From the equation describing the voltage versus current (V-I) cells characteristic, and taking into account the NP number of PV system parallel branches and the NS number of cells in series inside the PV panel, the Eq. (1) gives the PV system voltage (VPV) as a function of output current (iPV). We consider the PV system NP=1,NS=36

$$V_{pv} = 2nN_s V_T \ln\left(\frac{N_p i_L - i_{pv}}{N_p i_o} + 1\right) - \frac{2NsR}{N_p} i_{pv} \qquad (1)$$

The photovoltaic IL is given by Eq(2) and the diode saturation current io is given by Eq.(3).

$$i_L = \frac{T}{G^*} I_{sc}\left(1 + K_o\left(T - T^*\right)\right) \tag{2}$$

$$i_o = I_o^*\left(\frac{T}{T^*}\right)^{3/n}\left[\frac{1}{\exp\left[\frac{V_G T^*}{nV_T}\left[\frac{1}{T} - \frac{1}{T^*}\right]\right]}\right] \tag{3}$$

Where n is the diode ideality factor (generally between 1 and 2, the value 1 is for an ideal diode); VT = kT*/q is a constant with T*=298 K the reference temperature, q=1.6022*10-19 C the elementary charge and k =1.38*10-23 J/K the Boltzmann's constant. The variables are the input light irradiance G (W/m2) with G* =1000 W/m2 the reference irradiance and the cell temperature T(K) with K0=0.0044 A/K the temperature coefficient for current. For polycrystalline cells, the band gap energy semiconductor, here noted as VG, is equal to 1.12 eV. Under the G* reference irradiance and the T* reference temperature, the diode saturation current is calculated by Eq. (4).

$$I_o^* = \frac{1}{\exp\left(\frac{V_{OC}}{nV_T}\right) - 1} \tag{4}$$

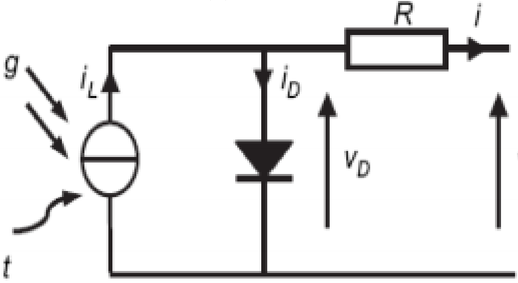


Figure 4. Simplified PV Equivalent Circuit Model.

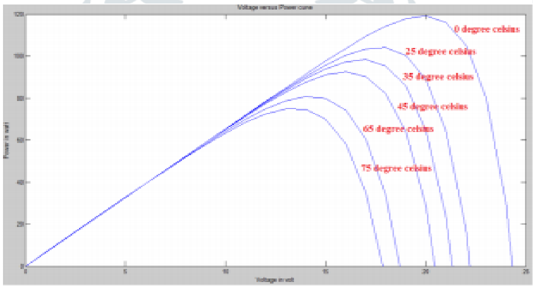
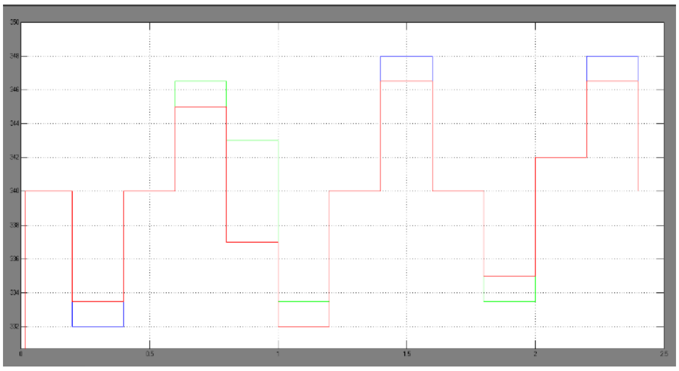


Figure 5 voltage versus power characteristics for a typical PV device at different temperatures

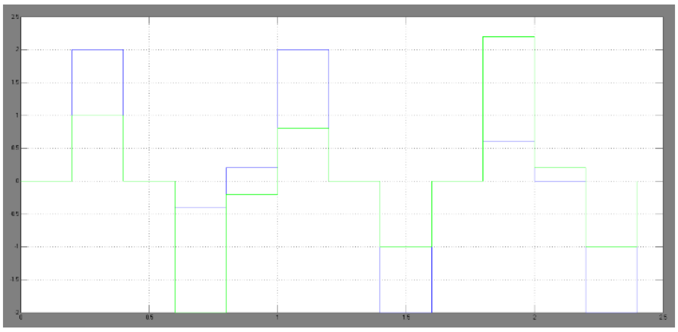
From equation we notice that the output of PV cells is a complex variable, it depends on the PV insolation and the junction temperature of the cell. Solar energy production devices have a complex relationship between the produced power, the load that they supply and the efficiency of delivery. The time and speed it takes to convert energy from the solar PV device into current varies from cell to cell since the conversion of photons into electron depends on many factors. Which are not unique for all the PV devices. The voltage versus power characteristics for a typical PV device at different temperatures are presented in Fig.5.

VI. MATLAB/SIMULATION RESULTS

Figure 7 Shows the simulation results (the dc distribution voltage, the stored energy ratio, the current from EDLC, and the terminal voltage of EDLC) when only the gain-scheduling control technique was used. The maximum voltage of Vdc(EDLC1) and Vdc(EDLC2) was 346.7 V which was about 340 V + 2%, and the minimum voltage of them was 332.9 V which was about 340 V – 2%. Therefore, the distribution voltages at the output converter of the EDLCs were within 340 V ± 2%. However, thestored energy of EDLCs was not balanced, and the maximum of the ratio (W2/W1) reached 4.2.



(a)



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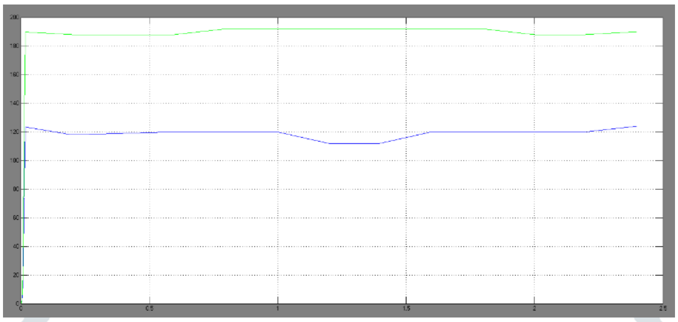

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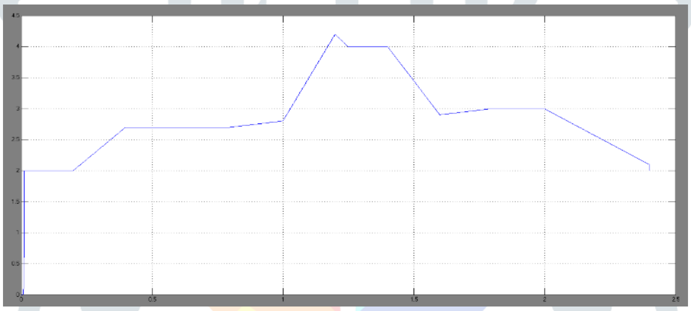
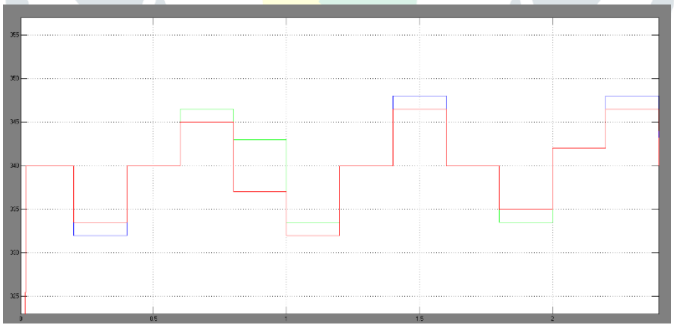


(d)

Figure 7. Simulation results for (a).EDCL voltages,(b).current form converter of EDLC,(c).DCL terminal voltages and (d).ratio of EDCL change for condition one.



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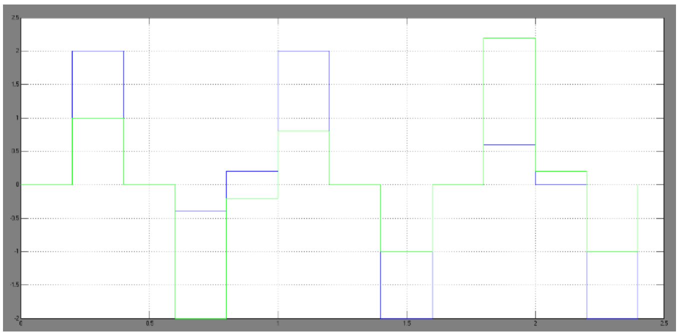

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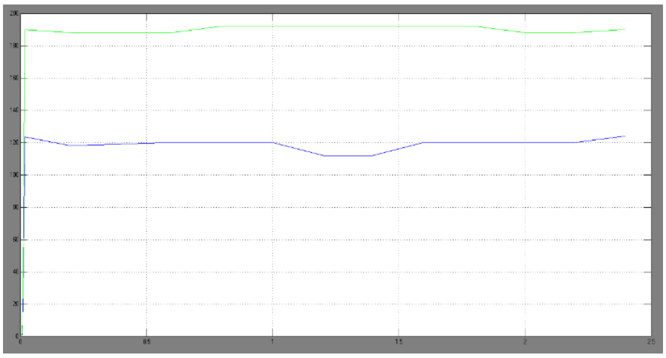

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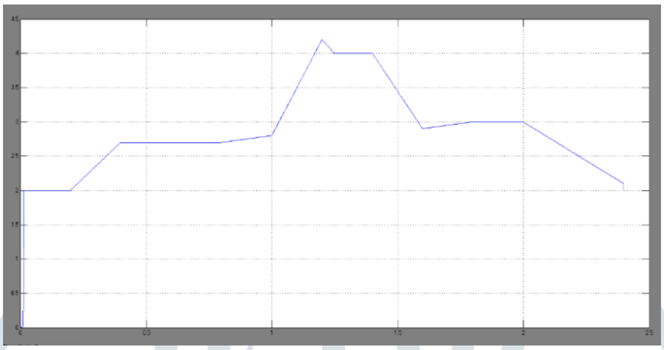

(d)

Figure 8. Simulation results for (a).EDCL voltages,(b).current form converter of EDLC,(c).DCL terminal voltages and (d).ratio of EDCL change for condition two.

Figure 8. shows the simulation results when the proposed control was used. The stored energy ratio tended to be 1. The features of EDLC currents were different from those in Fig.8 because EDLC2 had 1.3 times energy at the initial state. EDLC2 initially discharged its power, and then the energies of both EDLCs balanced at around 80 s. The reason for the difference in the EDLC terminal voltages, VEDLC1 and VEDLC2, despite an almost unity ratio of EDLC charge (W2/W1), is the difference in the maximum voltages of EDLC1 and EDLC2. Regarding the distribution voltages at the output converters of the EDLCs, the maximum and the minimum were 349.9 and 331.7 V, respectively.

VII. CONCLUSION

This paper presents a general framework for the control of interconnections of time varying and/or nonlinear operators. We derived sufficient conditions for the stability and performance control of such systems. Characteristics of the solar photovoltaic system have been offered for emerging the accurate model of solar PV module. It is verified that the a new FLC search technique trace the peak power when numerous peaks exist in the I-V and V-P characteristics using Matlab/simulation and practical experimental. Here purely implemented in the electrical tracking technique. In addition, it is also confirmed that the optimized FLC control advances the tracing performance matched with the traditional P&O which eludes the modification of controller parameters. Using the designed optimized Fuzzy Logic controller enhanced standalone photovoltaic module tracing performance is realized under different weather conditions. The merits of the designed artificial intelligent FLC techniques like various weather conditions and variance evolution for modification the fuzzy rules need to be inspected.

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