

Fuzzy Logic Control of Robust Partial Feedback Linearizing Stabilization Scheme for Three-Phase Grid-Connected Photovoltaic Systems

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ABSTRACT: This paper presents a robust stabilization scheme for a three-phase grid-connected PV system to maintain the operation of the system at unity power factor. To achieve this, both the grid voltage and grid current must be in phase with each other. In a grid connected PV system, desired control objectives are met by a strategy using pulse width modulation (PWM) scheme based on two cascaded control loops that includes inner current control loop and outer voltage control loop, ensuring zero phase difference between voltage and current and MPPT production. In this paper, a non-linear controller of robust controller is designed by modelling and inclusion of uncertainties within the controller in the PV system model. The proposed system enables the operation of the system at unity power factor since both the grid voltage and grid current will be in phase with each other. The proposed system is verified through the simulation under standard and variable atmospheric conditions. Fuzzy controller can be used as Extension.

INTRODUCTION:

Photovoltaic's (PV) is a method of generating electrical power by converting sunlight into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. Power generation from solar PV has long been seen as a clean sustainable[1] energy technology which draws upon the planet's most plentiful and widely distributed renewable energy source – the sun. The direct conversion of sunlight to electricity occurs without any moving parts or environmental emissions during operation. It is well proven, as photovoltaic systems have now been used for fifty years in specialized applications, and grid-connected PV systems have been in use for over twenty years.[2]

SOLAR CELLS:

Photovoltaics are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. The photovoltaic effect refers to photons of light exciting electrons into a higher state of energy, allowing them to act as charge carriers for an electric current. The photovoltaic effect was first observed by Alexandre-Edmond Becquerel in 1839.[11][12] The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode.

MAXIMUM POWER POINT TRACKING

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different.

A. Fractional Open-Circuit Voltage

The method is based on the observation that, the ratio between array voltage at maximum power V_{MPP} to its open circuit voltage V_{OC} is nearly constant.

$$V_{MPP} \approx k_1 V_{OC}$$

This factor k_1 has been reported to be between 0.71 and 0.78. Once the constant k_1 is known, V_{MPP} is computed by measuring V_{OC} periodically. Although the implementation of this method is simple and cheap, its tracking efficiency is relatively low due to the utilization of inaccurate values of the constant k_1 in the computation of V_{MPP} .

B. Fractional Short-Circuit Current

The method results from the fact that, the current at maximum power point I_{MPP} is approximately

linearly related to the short circuit current I_{SC} of the PV array.

$$I_{MPP} \approx k_2 I_{SC}$$

Like in the fractional voltage method, k_2 is not constant. It is found to be between 0.78 and 0.92. The accuracy of the method and tracking efficiency depends on the accuracy of k_2 and periodic measurement of short circuit current.

C. Perturb and Observe

In P&O method, the MPPT algorithm is based on the calculation of the PV output power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase (decrease) in the output power of the PV, then the subsequent perturbation is generated in the same (opposite) direction. So, the duty cycle of the dc chopper is changed and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. To solve this problem, a variable perturbation size that gets smaller towards the MPP.

D. Incremental Conductance

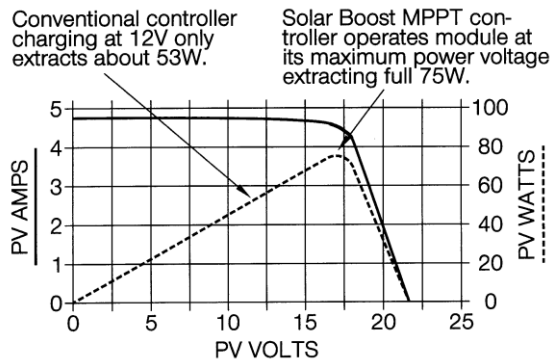
The method is based on the principle that the slope of the PV array power curve is zero at the maximum power point.

$(dP/dV) = 0$. Since $(P = VI)$, it yields:

$$\Delta I/\Delta V = -I/V, \text{ at MPP}$$

$$\Delta I/\Delta V > -I/V, \text{ left of MPP}$$

$$\Delta I/\Delta V < -I/V, \text{ right of MPP}$$



2. COMPONENTS:

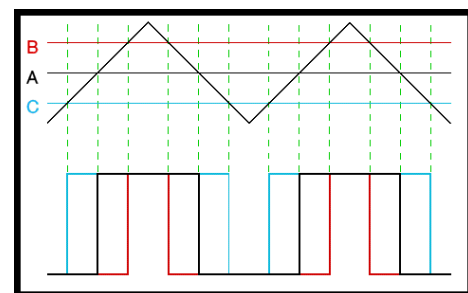
2.1 MOSFET: The Power MOSFET technology has mostly reached maturity and is the most popular device for SMPS, lighting ballast type of application where high switching frequencies are desired but operating voltages are low. Being a voltage fed, majority carrier device (resistive behaviour) with a typically rectangular Safe Operating Area, it can be conveniently utilized. Utilising shared manufacturing processes, comparative costs of MOSFETs are attractive. For low frequency applications, where the currents drawn by the equivalent capacitances across its terminals are small, it can also be driven directly by integrated circuits. These capacitances are the main hindrance to operating the MOSFETs at speeds of several MHz. The resistive characteristics of its main terminals permit easy paralleling externally also.

2.2 IGBT: It is a voltage controlled four-layer device with the advantages of the MOSFET driver and the Bipolar Main terminal. IGBTs can

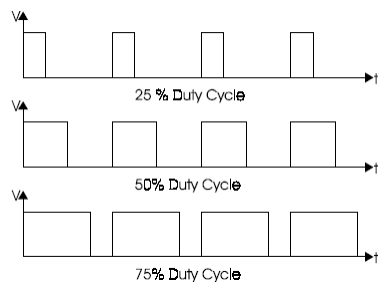
be classified as punch-through (PT) and non-punch-through (NPT) structures. In the punch-through IGBT, a better trade-off between the forward voltage drop and turn-off time can be achieved. Punch-through IGBTs are available up to about 1200 V. NPT IGBTs of up to about 4 KV have been reported in literature and they are more robust than PT IGBTs particularly under short circuit conditions. However they have a higher forward voltage drop than the PT IGBTs.

Pulse Width modulator:

It's actually very easy, there are circuits available in the TEC site. First you generate a triangle waveform as shown in the diagram below. You compare this with a d.c voltage, which you adjust to control the ratio of on to off time that you require. When the triangle is above the 'demand' voltage, the output goes high. When the triangle is below the demand voltage, the



The **duty cycle**, D, refers to the percentage of the period for which the signal is on. The duty cycle can be anywhere from 0, the signal is always off, to 1, where the signal is constantly on. A 50% D results in a perfect square wave. (Figure 1)



When a voltage, V , is applied across an inductive element, the current, I , produced in that element does not jump up to its constant value, but gradually rises to its maximum over a period of time called the **rise time** (Figure 2).

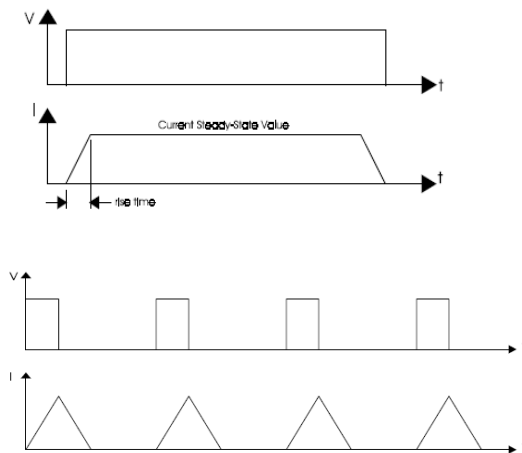
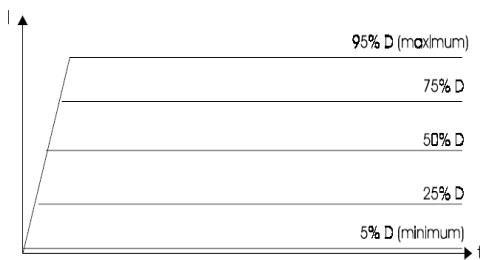
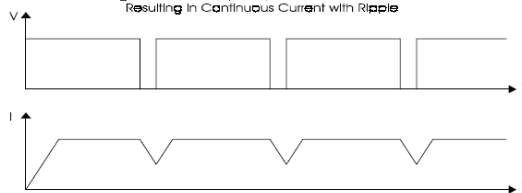


Figure 4 - Low Frequency PWM with $D > \text{rise time}$ Resulting in Continuous Current with Ripple



PROPOSED TECHNIQUE:

FUZZY LOGIC:

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of fl. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

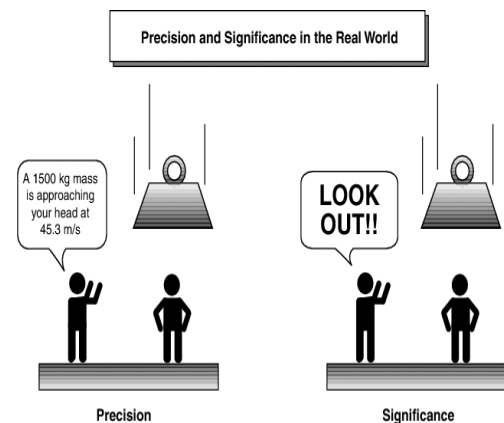


fig 5.1 fuzzy description

Building a fuzzy inference system:

Fuzzy inference is a method that interprets the values in the input vector and, based on user defined rules, assigns values to the output vector. Using the GUI editors and viewers in the Fuzzy Logic Toolbox, you can build the rules set, define the membership functions, and analyze the behavior of a fuzzy inference system (FIS). The following editors and viewers are provided.

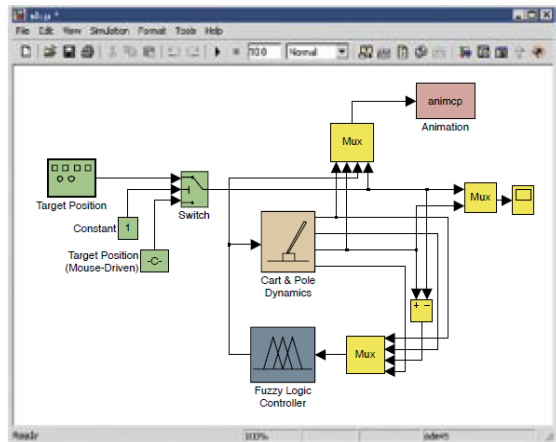


fig 5.2 fuzzy inference system

The FIS editor:

The FIS Editor displays general information about a fuzzy inference system. There's a simple diagram as shown in Fig.3 that shows the names of each input variable on the left, and those of each output variable on the right. The sample membership functions shown in the boxes are just icons and do not depict the actual shapes of the membership functions.

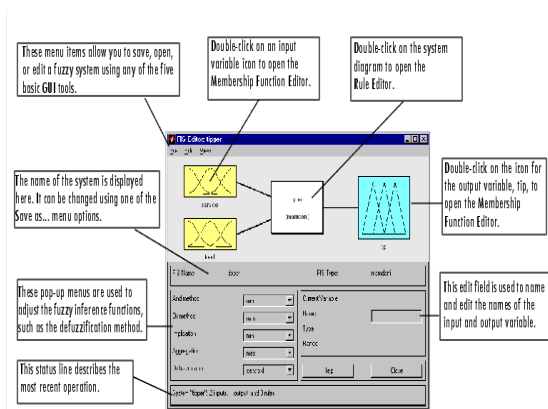
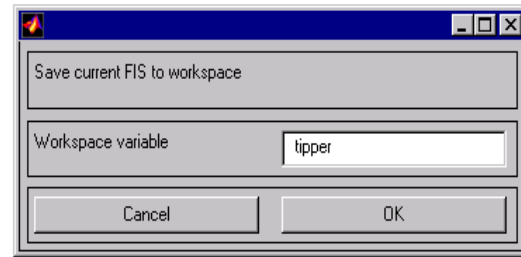


fig 6.3 The FIS Editor

You will see the diagram updated to reflect the new names of the input and output variables. There is now a new variable in the workspace called tipper that contains all the information about this system



WindowBy saving to the workspace with a new name, you also rename the entire system. Your window will look like as shown in Fig.5.

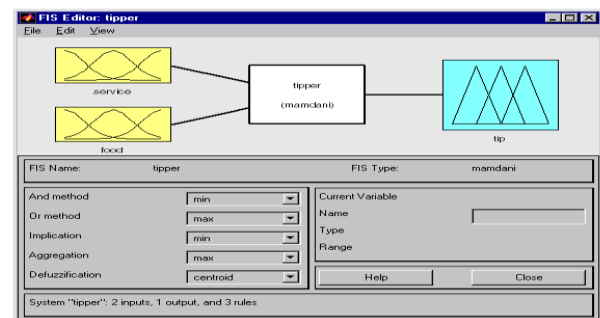


fig 6.5 The updated FIS Editor

RESULTS:

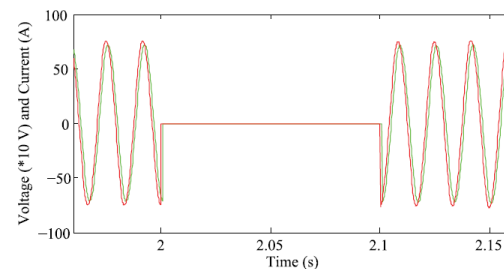
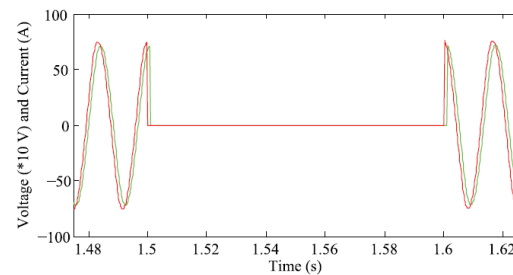
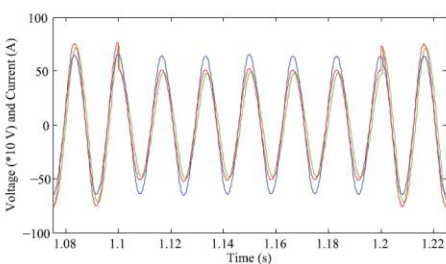
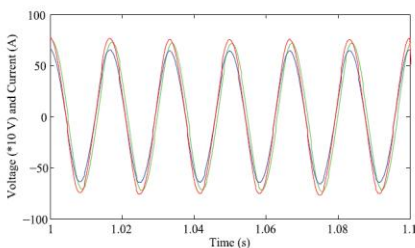
Case 1 (Performance evaluation under standard atmospheric conditions): the designed robust controller ensures the operation of the three-phase grid-connected PV system at unity power factor that is shown in Fig. 5. In Fig. 5, it can be seen the partial feedback linearizing scheme (PFBLS) is unable to transfer maximum power into the grid (green line) when 25% variations in the system parameters and 70% uncertainties in the solar irradiation and cell temperature are considered within the PV system model. However, the robust partial feedback linearizing stabilization scheme

(RPFBLSS) maintains the operation of the system at unity power factor (red line).

Case 2 (Controller performance under changing atmospheric conditions): At this stage, it is considered that the PV unit operates under standard atmospheric conditions until 1 s. At $t = 1$ s, the atmospheric condition changes in such a way that the solar irradiation of the PV unit reduces to 70% from the standard value.

Case 3 (Performance during short-circuit faults within the system): A three-phase fault is the most severe disturbance in power system applications. In this simulation, a symmetrical three-phase fault is applied at the terminal of the PV unit, and the following fault sequence is considered to evaluate the robustness of the designed scheme:

- a) Fault occurs at $t = 1.5$ s.
- b) Fault is cleared at $t = 1.6$ s.



CONCLUSION

A robust stabilization scheme is considered by modeling the uncertainties of a three-phase grid-connected PV system based on the satisfaction of matching conditions to ensure the operation of the system at unity power factor. In order to design the robust scheme, the partial feedback linearization approach is used, and with the designed scheme, only the upper bounds of the PV systems' parameters and states need to be known rather than network parameters, system operating points, or nature of the faults. The resulting robust scheme enhances the overall stability of a three-phase grid connected PV system, considering admissible network uncertainties. Thus, this stabilization scheme has good robustness against the PV system parameter variations, irrespective of the network parameters and configuration. Future work will include the implementation of the proposed scheme on a practical system.

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