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Intelligent Control of Standalone Photovoltaic/Fuel Cell Power Plant with Super Capacitor Energy Storage

Dr. G. Mahesh Manivanna Kumar., M.E., Ph.D

Department of Electrical and Electronics Engineering, JEPPIAAR SRR Engineering College, Chennai, Tamilnadu, India

ABSTRACT

This is the paper based on "Intelligent Control of a Standalone Photovoltaic / Fuel cell Power Plant With Super capacitor Energy Storage" .A renewable energy hybrid power plant, fed by photovoltaic (PV) and fuel cell (FC) sources with a super capacitor(SC) storage device and suitable for distributed generation applications, is proposed herein. The PV is used as the primary source; the FC acts as a backup, feeding only the insufficiency power (steady-state) from the PV; and the SC functions as an auxiliary source and a short-term storage system for supplying the deficiency power (transient and steady-state) from the PV and the FC. For high-power applications and optimization in power converters, four-phase parallel converters are implemented for the FC converter, the PV converter, and the SC converter, respectively. Using the intelligent fuzzy logic controller based on the flatness property for dc grid voltage regulation, we propose a simple solution to the fast response and stabilization problems in the power system. Because of this, two or more renewable energy sources are required to ensure a reliable and cost-effective power solution. Such a combination of different types of energy sources into a system is called a hybrid power system.

Keywords : FC Converter, PV Converter, SC Converter, Voltage Regulation

I. INTRODUCTION

In an existing system, a PI controller calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to reduce the error by adjusting the process through the use of a manipulated variable. The error values are calculated via sensor or transducer and compared with desire set point. The detection is in terms of voltage, current, temperature, movement, angle and etc. The PI controller is adjusted manually by setting the value of *Ki* equal to zero. The PI controller will ensure the boost converter deliver a sufficient amount of voltage to the load. By increasing the value of *Ki* the system until the offset, it will decrease the rise time of the system. However, the system will become unstable and the overshoot will be increased. The value of *Ki* must be adjusted in certain amount to make sure the system ensure the overshoot while decreasing the settling time and keeping the stability. The drawbacks of the existing system is, response time is slow, produces Oscillation in output, settling timing is more, Increases damping and peak over time, Increase in peak over time decreases Efficiency. In a developed system, PID controller is adapted to the systems operating characteristics by altering the gain of the controller. This approach is an attractive option for power converters where the PID parameters can be altered according to the load, as well as for disturbances. An approach which has proven to be popular is the use of Fuzzy logic control (FLC) to provide the gain-scheduling for the PID. This approach has also been successfully adopted in power converter systems. These papers demonstrate the improved performance which can be achieved in non-linear systems when this type of controller is introduced. The main attraction of the fuzzy logic controller in the gain scheduling scheme is its ability to make decisions. This paper a novel control scheme is presented for a boost type power converter which is considered to be a second order, state dependent plant. The advantages of developed system is, Quick response, Reduce Oscillation in output, Faster settling timing, Reduce damping, Increase Efficiency, Cut off overall power loss, More adaptable for wide range of inputs.

1.1 Boost Converters

Switched mode supplies can be used for many purposes including DC to DC converters. Often, although a DC supply, such as a battery may be available, its available voltage is not suitable for the system being supplied. For example, the motors used in driving electric automobiles require much higher voltages, in the region of500V, than could be supplied by a battery alone. Even if banks of batteries were used, the extra weight and space taken up would be too great to be practical. [1] The answer to this problem is to use fewer batteries and to boost the available DC voltage to the required level by using a boost converter. Another problem with batteries, large or small, is that their output voltage varies as the available charge is used up, and at some point the battery voltage becomes too low to power the circuit being supplied. However, if this low output level can be boosted back up to a useful level again, by using a boost converter, the life of the battery can be extended. The DC input to a boost converter can be from many sources as well as batteries, such as rectified from the mains supply, or DC from solar panels, fuel cells, dynamos and DC generators. The boost converter is different to the Buck Converter in that its output voltage is equal to, or greater than its input voltage. However it is important to remember that, as power (P) = voltage (V) current (I), if the output voltage is increased, the available output current must decrease. However, in this example the switching transistor is power MOSFET, both Bipolar power transistors and MOSFETs are used in power switching, the choice being determined by the current, voltage, switching speed and cost considerations. The rest of the components are the same as those used in the buck converter except that their positions have been rearranged.

1.2 Inverters

Three phase inverters are generally used for high power applications. Three single phase half bridge inverters are to be connected in parallel to form a three phase inverter. The inverter is fed by a fixed dc voltage and has three phase-legs each comprising two transistors and two diodes. With SPWM control, the controllable switches of the inverter are controlled by comparison of a sinusoidal control signal and a triangular switching signal. The sinusoidal control waveform determines the desired fundamental frequency of the inverter output, while the triangular waveform decides the switching frequency of the inverter. The ratio of the frequencies of the triangle wave to the sinusoid is referred to as the modulation frequency ratio.

Three-phase inverters are used for variable-frequency drive applications and for high power applications such as HVDC power transmission. A basic three-phase inverter consists of three single-phase inverter switches each connected to one of the three load terminals. For the most basic control scheme, the operation of the three switches is coordinated so that one switch operates at each 60 degree point of the fundamental output waveform[2]. This creates a line-to-line output waveform that has six steps. The six-step waveform has a zero-voltage step between the positive and negative sections of the square-wave such that the harmonics that are multiples of three are eliminated as described above. When carrier-based PWM techniques are applied to six-step waveforms, the basic overall shape, or envelope, of the waveform is retained so that the 3rd harmonic and its multiples are cancelled. To construct inverters with higher power ratings, two six-step three-phase inverters can be connected in parallel for a higher current rating or in series for a higher voltage rating. In either case, the output waveforms are phase shifted to obtain a 12-step waveform. If additional inverters are combined, an 18-step inverter is obtained with three inverters etc. Although inverters are usually combined for the purpose of achieving increased voltage or current ratings, the quality of the waveform is improved as well.

1.3 Fuzzy logic Controller

Fuzzy logic can be conceptualized as a generalization of classical logic. Modern fuzzy logic was developed by Lotfi Zadeh in the mid-1960s to model those problems in which imprecise data must be used or in which the rules of Inference are formulated in a very general way making use of diffuse categories [170]. In fuzzy logic, which is also sometimes called diffuse logic, there are not just two alternatives but a whole continuum of truth values for logical propositions.

A proposition A can have the truth value 0.4 and its complement Ac the truth value 0.5. According to the type of negation operator that is used, the two truth values must not be necessarily add up to 1.Fuzzy logic has a weak connection to probability theory. Probabilistic methods that deal with imprecise knowledge are formulated in the Bayesian framework, but fuzzy logic does not need to be justified using a probabilistic approach[3]. The common route is to generalize the findings of multi valued logic in such a way as to preserve part of the algebraic structure. In this chapter we will show that there is a strong link between set theory, logic, and geometry. A fuzzy set theory corresponds to fuzzy logic and the semantic of fuzzy operators can be understood using a geometric model. The geometric visualization of fuzzy logic will give us a hint as to the possible connection with neural networks.

Fuzzy logic can be used as an interpretation model for the properties of neural networks, as well as for giving a more precise description of their performance. We will show that fuzzy operators can be conceived as generalized output functions of computing units. Fuzzy logic can also be used to specify networks directly without having to apply a learning algorithm. An expert in a certain field can sometimes produce a simple set of control rules for a dynamical system with less effort than the work involved in training a neural network. A classical example proposed by Zadeh to the neural network community is developing a system to park a car. It is straightforward to formulate set of fuzzy rules for this task, but it is not immediately obvious how to build a network to do the same nor how to train it. Fuzzy logic is now being used in many products of industrial and consumer electronics for which a good control system is sufficient and where the question of optimal control does not necessarily arise.

II. METHODS AND MATERIAL

2.1 Intelligent Control Scheme

This is the proposal based on "Intelligent Model-Based Control of a Standalone Photovoltaic/Battery Power Plant With Super Capacitor Energy Storage" Power Plant With Super capacitor Energy Storage" A renewable energy hybrid power plant, fed by photovoltaic (PV) and Battery(BT) sources with a super capacitor (SC) storage device and suitable for distributed generation applications, is proposed here in. The PV is used as the primary source; the BT acts as a backup, feeding only the insufficiency power (steady-state) from the PV; and the SC functions as an auxiliary source and a short-term storage system for supplying the deficiency power (transient and steady-state) from the PV and the BT[4]. For high-power applications and optimization in power converters, four-phase parallel converters are implemented for the BT converter, the PV converter, and the SC converter, respectively.

A mathematical model (reduced-order model) of the BT, PV, and SC converters is described for the control of the power plant. Using the intelligent fuzzy logic controller based on the flatness property for dc grid voltage regulation, we propose a simple solution to the fast response and stabilization problems in the power system. This is the key innovative contribution of this research paper.

The prototype small-scale power plant implemented was composed of aPEMBT system (1.2kW, 46A), a PV array (0.8kW), and an SC module (100F, 32V). Experimental results validate the excellent control algorithm during load cycles. Index Terms—Flatness control, batteries, fuzzy control, nonlinear system, photovoltaic, super capacitor. The advantage of this project is electricity produced by solar cells is clean and silent. Because they do not use fuel other than sunshine, PV systems do not release any harmful air or water. Renewable energy sources are predicted to become competitive with conventional power generation systems in the near future. Unfortunately, they are not very reliable.

For example, the PV source is not available during the night or during cloudy conditions. Other sources such as FCs may be more reliable but have economic issues associated with them. Because of this, two or more renewable energy sources are required to ensure a reliable and cost-effective power solution. Such a combination of different types of energy sources into a system is called a hybrid power system [1]. A combination of PV and FC sources forms a good pair with promising features for distributed generation applications .Obviously, the slow response of the PEMFC needs to be compensated with a super capacitor or a battery. A super capacitor storage device is preferable due to its high power density, high dynamics, and long lifetime [5].

FC/Li–Ion battery hybrid power source, and Uzunoglu and Alamhave studied control based on a wavelet-based load sharing algorithm of an FC/SC hybrid power source. A classical boost converter is often used as an FC converter and a PV converter, and a classical two-quadrant (bidirectional) converter is often used as a super capacitor or battery converter. However, the classical converters will be limited when the power increases or at higher step-up ratios. As such, the use of parallel power converters (multiphase converters in parallel) with interleaving may offer better performance.

The interleaved converter can benefit both high current and high power density designs. It is ideal for merchant power applications because the reduced input ripple current and reduced output capacitor ripple current less than the electrical stress on the dc capacitors. Current work on controlling an FC/SC hybrid power plant is reported in, where a linear control using PI compensator was proposed for dc-link stabilization. Design controller parameters based on linear methods require a linear approximation where this is dependent on the operating point. Because the switching model of the hybrid power plant is nonlinear, it is natural to apply model-based nonlinear control strategies that directly compensate for system nonlinearity without requiring a linear approximation[6].

In the early1990s, the flatness control theory was introduced by Fliess et al. in a differential algebraic framework. It is simple, clear-cut, and appropriate for robustness, predictive control, trajectory planning, and constraints handling. Recently, this idea has been used in a variety of power electronic systems .Thounthong has proved with real test bench results that the flatness-based control of a PV/super capacitor power plant is absolutely robust. The fast response, efficiency, and stability of the operation of hybrid power plants are of particular interest. In this work, a hybrid power generation system is studied, consisting of the following main components: a PV, protonex change membrane FCs (PEMFC), and an SC as a high-power density device. In this study, a novel framework is proposed for the intelligent fuzzy logic-based flatness control approach of a solar-hydrogen power generation system with a super capacitor storage device.

2.2 Block Diagram and Circuit Diagram

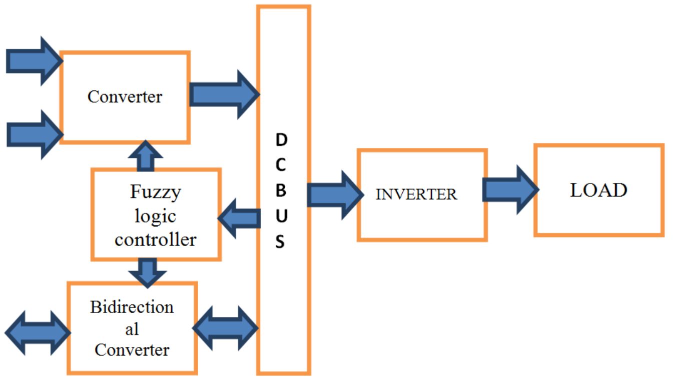


Figure 1: Block Diagram

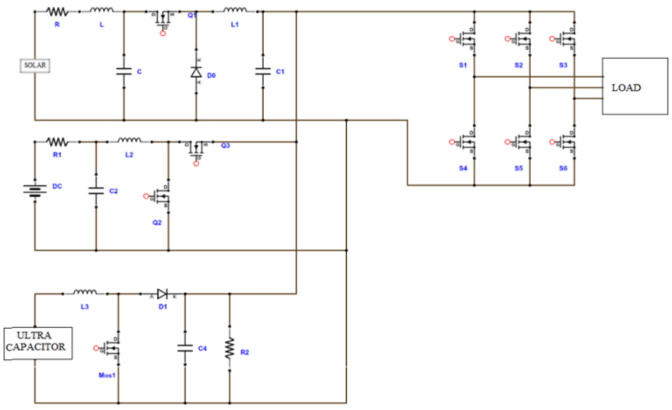


Figure 2: Circuit diagram

Figure 1 and 2 shows the block diagram and circuit diagram of intelligent control system. In our system we have used 3 sources such as PV, BATTERY and ULTRA-CAPACITOR. We have 2 boost converters for boosting the input voltage and 1 bi-directional converter across the ultra-capacitor and DC-bus for charging and discharging. We have a 3-phase inverter for converting DC-AC for supplying the load. For switching between the various converters can be controlled by FUZZY LOGIC controller. The main control objectives are stability, high overall efficiency, and fast response. As for supply in energy to the load demanded and the charging storage device, the multivariable control here involves set-point control of the dc-bus voltage (representing the dc-bus energy , called “DC link stabilization”) and set-point control of the SC voltage (representing the super capacitive energy). The principle behind the proposed hybrid energy management lies in using the SCs (the fastest energy source) to supply the energy required to achieve the dc grid voltage regulation (or the dc bus energy regulation). Then, the PV and FC, although clearly the main energy source of the system, function as the generator that supplies energy for both the dc bus capacitor and the to keep them charged. Fuzzy control algorithms offer many advantages over traditional controls because they give fast convergence, are parameter insensitive, and accept noisy and inaccurate signals. In recent years, it has been used in many control applications where the system is complex .Because the SC energy storage has a massive size capacity, and the super capacitive energy is defined as a slower dynamic variable than the dc-bus energy variable. The key contribution of this paper is to authenticate the intelligent fuzzy logic control based on differential flatness estimation of a PV/FC/SC hybrid power plant for standalone applications [7].

The prototype power plant studied was composed of a PEMFC system (1200 W), a PV array (800 W), and an SC module (100F). Its working principle, analysis, and design procedure were presented. The PV is the main source, while the FC serves as a support source to compensate forth uncertainties of the PV source in the steady state. The SC functions as a storage device (or an auxiliary source) to compensate for the uncertainties of the PV and FC sources in the steady state and transient state. Using the intelligent fuzzy logic control ford clink stabilization based on the flatness property, we proposed simple solution to the fast response and stabilization problems in the nonlinear power electronic system. This strategy is based on a standard dc link voltage regulation, which is simpler than standard state machines used for hybrid source control, and free of chattering problems. This is the novel concept for this kind of application. Experimental results authenticated the control algorithm and control laws.

2.3 Fuzzy Logic Controller

Fuzzy logic can be conceptualized as a generalization of classical logic. Modern fuzzy logic was developed by Lotfi Zadeh in the mid-1960s to model those problems in which imprecise data must be used or in which the rules of Inference are formulated in a very general way making use of diffuse categories [170]. In fuzzy logic, which is also sometimes called diffuse logic, there are not just two alternatives but a whole continuum of truth values for logical propositions. A proposition *A* can have the truth value 0.4 and its complement *A*ct the truth value 0.5. According to the type of negation operator that is used, the two truth values must not be necessarily add up to 1.Fuzzy logic has a weak connection to probability theory. Probabilistic methods that deal with imprecise knowledge are formulated in the Bayesian framework, but fuzzy logic does not need to be justified using a probabilistic approach. The common route is to generalize the findings of multi valued logic in such a way as to preserve part of the algebraic structure. In this chapter we will show that there is a strong link between set theory, logic, and geometry[8]. A fuzzy set theory corresponds to fuzzy logic and the semantic of fuzzy operators can be understood using a geometric model. The geometric visualization of fuzzy logic will give us a hint as to the possible connection with neural networks, shown in figure 3.

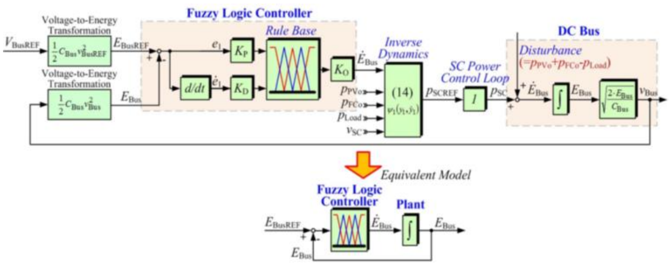
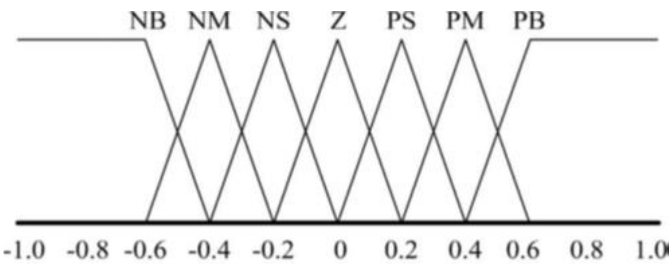


Figure 3: Fuzzy Logic Controller

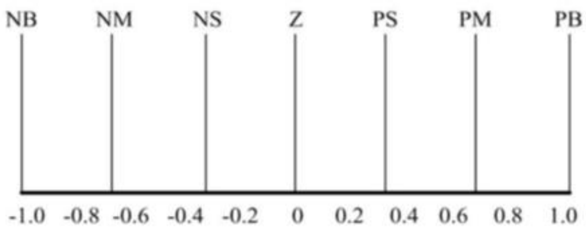
Fuzzy logic can be used as an interpretation model for the properties of neural networks, as well as for giving a more precise description of their performance. We will show that fuzzy operators can be conceived as generalized output functions of computing units[9]. Fuzzy logic can also be used to specify networks directly without having to apply a learning algorithm. An expert in a certain field can sometimes produce a simple set of control rules for a dynamical system with less effort than the work involved in training a neural network. A classical example proposed by Zadeh to the neural network community is developing a system to park a car. It is straightforward to formulate set of fuzzy rules for this task, but it is not immediately obvious how to build a network to do the same nor how to train it. Fuzzy logic is now being used in many products of industrial and consumer electronics for which a *good* control system is sufficient and where the question of *optimal* control does not necessarily arise.

2.4 Fuzzy Concept

The difference between crisp (i.e., classical) and fuzzy sets is established by introducing a membership function. Consider a finite set X = {x1, x2, . . . , xn}which will be considered the universal set in what follows. Figure 4 shows the rules of fuzzy logic.



(a)



(b)

e \ ė	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PB	PB	PM
NM	PB	PB	PB	PM	PM	PM	PM
NS	PM	PM	PM	PS	PS	Z	Z
Z	PB	PM	PS	Z	NS	NM	NB
PS	Z	Z	NS	NS	NM	NM	NM
PM	NM	NM	NM	NM	NB	NB	NB
PB	NM	NB	NB	NB	NB	NB	NB

(c)

Figure 4: Rules on fuzzy

The subset A of X consisting of the single element x1 can be described by the n-dimensional membership vector Z(A) = (1, 0, 0, . . . , 0), where the convention has been adopted that a 1 at the i-th position indicates that xi belongs to A. The setB composed of the elements x1 and xn is described by the vector Z(B) =(1, 0, 0, ..., 1). Any other crisp subset of X can be represented in the same way by an n-dimensional binary vector. But what happens if we lift the restriction to binary vectors? In that case we can define the fuzzy set C with the following vector description: Z(C) = (0.5, 0, 0, ..., 0)In classical set theory such a set cannot be defined[10]. An element belongs to a subset or it does not. In the theory of fuzzy sets we make a generalization and allow descriptions of this type. In our example the element x1 belongs to the set C only to some extent. The degree of membership is expressed by areal number in the interval [0, 1], in this case 0.5. This interpretation of the degree of membership is similar to the meaning we assign to statements such as “person x1 is an adult”. Obviously, it is not possible to define a definite age which represents the absolute threshold to enter into adulthood [11][12]. The act of becoming mature can be interpreted as a continuous process in which the membership of a person to the set of adults goes slowly from 0 to 1.There are many other examples of such diffuse statements. The concepts "old” and “young” or the adjectives “fast” and “slow” are imprecise but easy to interpret in a given context. In some applications, such as expert systems, for example, it is necessary to introduce formal methods capable of dealing with such expressions so that a computer using rigid Boolean logic can still process them. This is what the theory of fuzzy sets and fuzzy logic tries to accomplish [13][14].

2.5 Simulation

The following figure 5.1 to 5.5 shows the simulation of the entire system. And also figure 5.6 show the prototype of the intelligent control.

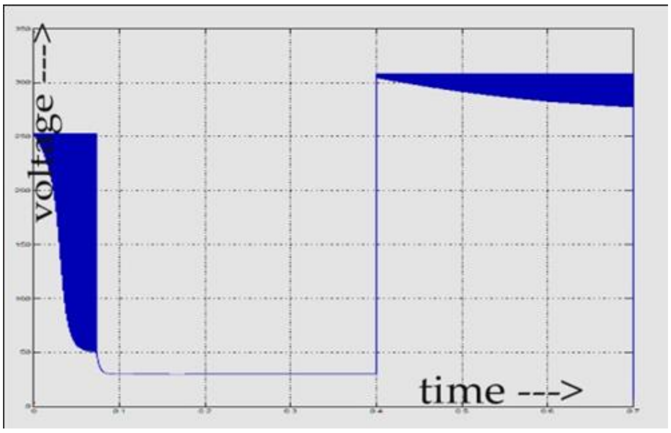


Figure 5.1: PV with DC bus

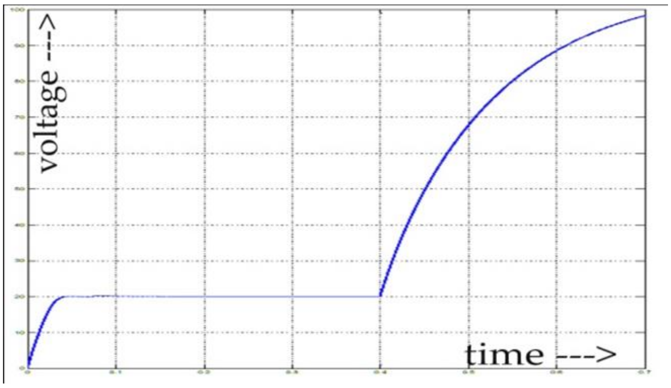


Figure 5.2: Battery with DC bus

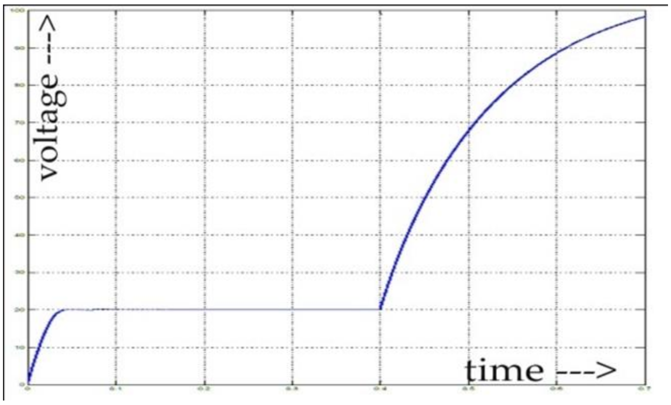


Figure 5.3: Ultra Capacitor with DC bus

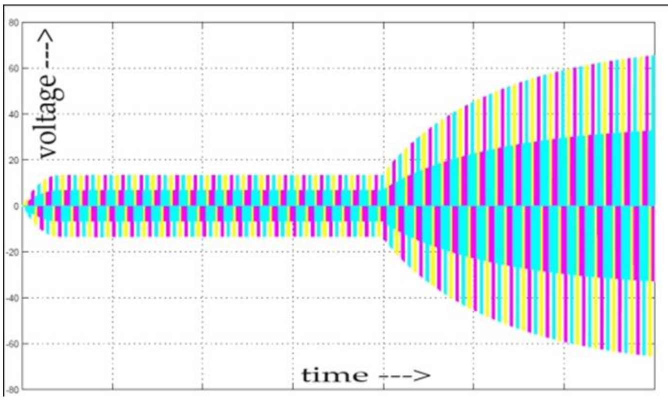


Figure 5.4: AC Output Waveform with respect to Voltage

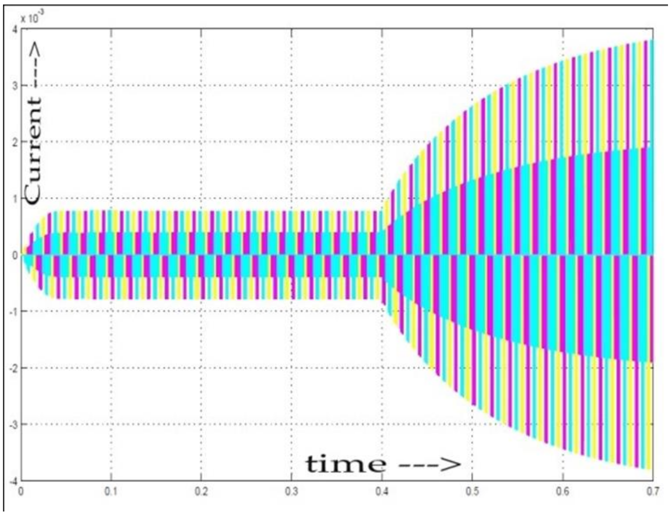


Figure 5.5 AC Output waveform with respect to Current

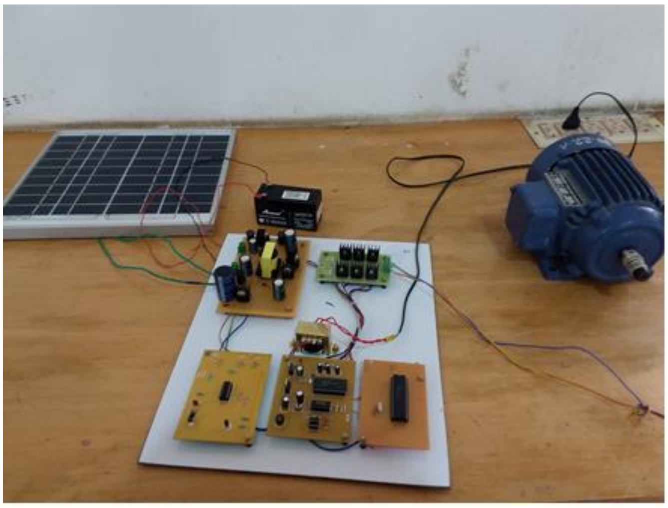


Figure 5.6: Prototype Model

III. CONCLUSION

The key contribution of this paper is to authenticate the intelligent fuzzy logic control based on differential flatness estimation of a PV/FC/SC hybrid power plant for standalone applications. The prototype power plant studied was composed of a PEMFC system (1200 W), a PV array (800 W), and an SC module (100F).Its working principle, analysis, and design procedure were presented. The PV is the main source , while the FC serves as a support source to compensate for the uncertainties of the PV source in the steady state. The SC functions as a storage device (or an auxiliary source) to compensate for the uncertainties of the PV and FC sources in the steady state and transient state. Using the intelligent fuzzy logic control for dc link stabilization based on the flatness property, we proposed simple solution to the fast response and stabilization problems in the non linear power electronic system. From these results, we conclude that fuzzy-flatness-based control provides better performance than the classical PI controller. This strategy is based on a standard dc link voltage regulation, which is simpler than standard state machines used for hybrid source control, and free of chattering problems. This is the novel concept for this kind of application. Experimental results authenticated the control algorithm and control laws.

IV. ACKNOWLEDGEMENT

The above paper both simulation and prototype model has implemented in the Electrical and Electronics department in JEPPIAAR SRR Engineering College.

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