Development of a simplified data acquisition kit for PV systems in Africa

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Abstract. Renewable resources have made consistent progress in satisfying the increasing world energy demand and are today an important fraction of power generation in many African countries. However, the running of photovoltaic systems involves a large quantity of data to be collected in real time and to process in order to ensure monitoring and an optimal control of photovoltaic plants. In recent years, a number of data-logging devices have been developed using conventional electronics or based on microcontroller data acquisition system. Most of these devices are commercially available and their cost is quite high and unaffordable in the African context of poverty. In this paper, a low-cost kit microcontroller-based, suitable for Sub-Saharan Africa is developed to collect and store significant and quality data of temperature, irradiance, voltage and current for control and maintenance purposes. The experimental setup based on fuzzy logic algorithm modelled for maximum power point control of a buck converter has been carried out to store data in removable memory cards. The data acquisition kit proposed is suitable for statistic usages; for the maintenance and improvement system's parameters through analysis of data harvested.
Keywords: Microcontroller, Data storage, Fuzzy Logic, PV systems, Sub-Saharan Africa.

1 Introduction

The main source of climate change is energy production which accounts for 2/3 of global green gas emissions with an increasing global warming and the global climatic variations as consequences [1]. Today, renewable resources are recognized as alternative solutions in fighting climate change. Renewable energies have made consistent progress in satisfying the increasing world energy demand and are today an important fraction of power generation in European countries while the transition to clean sources has a low progress in African countries. Photovoltaic (PV) energy exhibits several advantages, such as: cleanliness, noiseless, pollution-free, low maintenance, and his sustainability. However, the running of PV systems involves a large quantity of data to be collected in real time and to process in order to ensure maintenance and optimal control of PV plants. The monitoring in PV generation is related to statistical analysis of data and the validation of the technical feasibility of the system [2]. In recent years, a number of data-logging devices have been developed using conventional electronics or based on microcontroller data acquisition system (DAS) - to collect, register, integrate and record meteorological data and also their electrical characteristics - which aim at an analysis on the performance of PV systems. Most of these devices are commercially available PV monitoring systems and their cost is quite high and unaffordable in the African context of poverty. For example, DAS systems such as the TED Pro Home Energy Monitor or the Outback Power Flexware (Advanced DC System Monitor) are residential electricity monitoring systems that measure and manage home's energy usage; can cost more than $1500 [3].

In this paper, a low-cost and simplified DAS based on microcontroller 16LF18856, suitable for developing countries is designed and developed to collect and store significant and quality data of temperature, irradiance, voltage and current which can be used for maintenance and control purposes of PV systems. The experimental setup has been carried out to store various data in removable memories such as micro Secure Digital (SD) cards. The proposed system is equally used to monitor in real time temperature, solar radiation and power characteristic of PV array based on fuzzy logic algorithm modelled as maximum power point tracking (MPPT) control for a buck converter. The DAS system proposed is suitable for statistic usages; for the maintenance and improvement the PV system's parameters through analysis of data gathered in SD cards.

The paper is organized as follows: in Section 2, the structure of the data acquisition kit (DAK) with PV system.. Section 3 presents the MPPT based fuzzy logic. In Section 4, the DAK is designed and implemented. Observed results are presented in Section 5 to show that the DAK operates satisfactorily. Finally, some concluding remarks end the paper in Section 6.

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2 Structure of DAK with PV systems

The system considered in this paper is shown in Fig. 1 and consists of PV module, a buck converter and the DAK

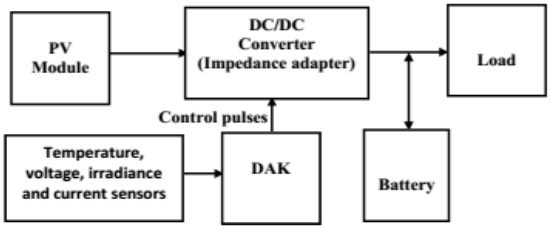

Fig. 1. PV-DAK system block diagram.

2.1 PV module

A PV module is composed of solar cells organized in series and/or in parallel. The characteristic equation of the PV module is expressed as [4]:

$$I_{pv} = N_p I_{ph}(G, T_a) - I_s(T_a) N_p \left[e^{\frac{V_{pv}+R_s I_{pv}}{nV_T}} - 1 \right] - \frac{V_{pv}+R_s I_{pv}}{R_{sh}} \quad (1)$$

Where V_{pv} and I_{pv} are the output voltage and output current of the PV module; I_{ph} is the photocurrent which depends on irradiance rate G and temperature T_a; I_s is the saturation current; n is the quality factor of the diode; $V_T = N_s k_B T/q$ is the thermal voltage of the module with q the absolute value of the electron's charge k_B the Boltzmann's constant; N_s is the number of cells connected in series, N_p is the number of strings connected in parallel; R_s and R_{sh} are the equivalent series and shunt resistances, respectively.

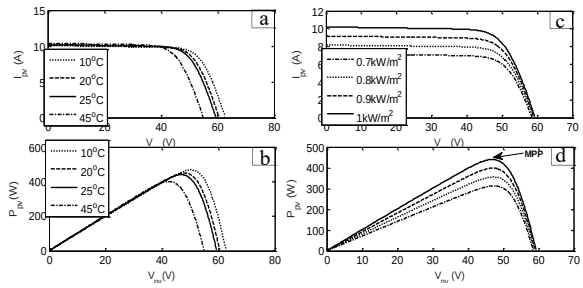

Fig. 2. (a)- I-V and (b)- P-V characteristics under temperature variation and nominal irradiance rate (1000W/m^2); (c)- I-V and (d) P-V characteristics under irradiance variation and nominal temperature(25°C).

I-V and P-V characteristics, under nominal irradiance rate $1000 W/m^2$ at different temperature levels are shown in Fig.2(a) and (b) show the while Fig.2(c) and (d) show the I-V and P-V characteristics, respectively at 25°C under different irradiances. It can be noticed that the maximum power point (MPP) varies according to temperature and irradiance. Therefore, the PV power increases with irradiance increasing or temperature decreasing.

2.2 DC-DC Buck converter

The DC-DC converter considered for the study is a buck converter in Fig. 3 with a switching period T and a duty cycle $\boldsymbol{D}$. It simply scales down the output of the PV module to the desired level and consists of a controllable switch Q, a diode D, an inductor L and a filter capacitor C . The state equations corresponding to the converter in continuous conduction mode (CCM) can be easily obtained by applying Kirchhoff's laws. When the switch is ON, the dynamics of the inductor current $i_L(t)$ and the capacitor voltage $v_C(t)$ are given by equation (2)

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(V_{in} - v_o) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C}(i_L - \dfrac{v_o}{R}) \end{cases}, \quad 0 < t < dT, \quad Q:ON \quad (2)$$

and when the switch is OFF, by equation (3)

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{1}{L}(-v_o) \\ \dfrac{dv_o}{dt} = \dfrac{1}{C}(i_L - \dfrac{v_o}{R}) \end{cases}, \quad dT < t < T, \quad Q:OFF \quad (3)$$

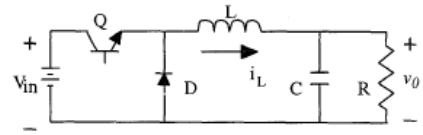

Fig. 3. Buck converter diagram.

The average output of the buck converter is given by:

$$V_o = \frac{1}{1-\boldsymbol{D}} V_{in} \quad (4)$$

3 MPPT control based fuzzy logic

Fuzzy logic method used for controlling MPPT presents some advantages compared to some classical control techniques (Perturb and Observe, Incremental Conductance): no need for accurate mathematical model, possibility to work with imprecise inputs, suitable to handle nonlinearities, more robust than conventional nonlinear controllers [5].
The three principal elements to a fuzzy logic controller are: fuzzification module (Fuzzifier), Inference engine, and defuzzification module (Defuzzifier).

3.1 Fuzzification

The fuzzification module assigns suitable linguistic values for the input data. Seven fuzzy subsets are called negative large (NL), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM), positive large (PL). The variables are defined as follows:

$$\Delta P(k) = P(k) - P(k-1) \quad (5)$$

$$\Delta V(k) = V(k) - V(k-1) \quad (6)$$

$$\Delta D(k) = D(k) - D(k-1) \quad (7)$$

where ΔP and ΔV are selected as input variables, and ΔP as the error between the previous power and the actual power, and ΔV the error between the previous voltage and the actual voltage. The output variable is the change

ΔD in the duty cycle. Triangular membership functions (trimf) have been selected for all the singletons.
A fuzzy logic controller has been designed in MATLAB/Simulink and the membership functions obtained for *ΔP*, *ΔV*, ***ΔD*** are shown in Figs. 4, 5, 6, respectively. The range of each membership function has been defined to fall in the per unit interval (-1, 1) by using input or output scaling gains obtained from the previous knowledge on the proposed variables.

3.2 Inference engine

The inference engine or knowledge-base, consisting of input and output membership functions (fuzzy implication), along with the fuzzy rule-base provides information for the appropriate fuzzification operations. Table 1 shows the rule base of fuzzy logic algorithm where all the entries of the matrix are fuzzy sets of errors *ΔP*, *ΔV*, ***ΔD.***
The commonly used fuzzy implication method is MIN–MAX and the same is used in this paper.

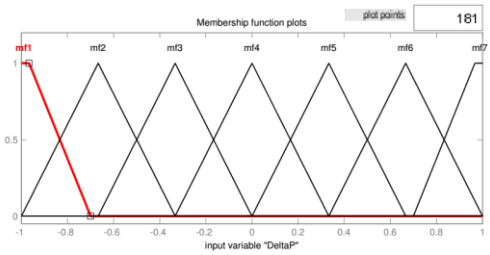

Fig. 4. Membership function plots for *ΔP*.

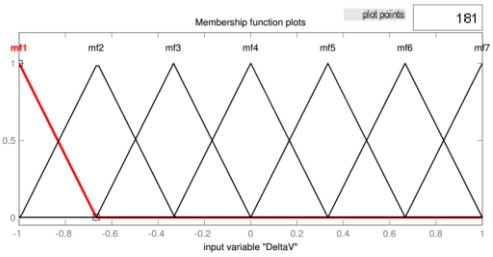

Fig. 5. Membership function plots for *ΔV*.

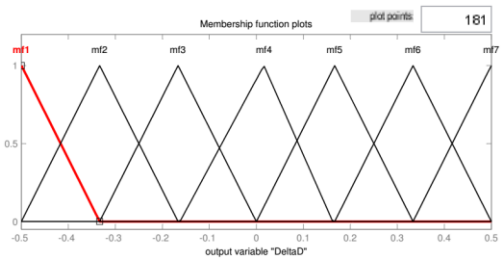

Fig. 6. Membership function plots for ***ΔD***.

3.3 Defuzzification

Defuzzification is carried out by center of gravity method for determining the output of the Fuzzy Logic Controller which is the duty cycle *D*. Here, the actual value of the change in firing angle is calculated by using equation (7) [7-9].

$$\Delta D = \frac{\sum_{j=1}^{n} \mu(\Delta D_j) * \Delta D_j}{\sum_{j=1}^{n} \mu(\Delta D_j)} \qquad (8)$$

The fuzzy logic controls *ΔD* which is used to adjust the duty cycle of the switching signal.

Table 1. Rule base of Fuzzy Logic

ΔD		***ΔP***						
		NL	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
ΔV	**NL**	PL	PM	PS	NS	NS	NM	NL
	NM	PM	PS	PS	NS	NS	NS	NM
	NS	PS	PS	PS	NS	NS	NS	NS
	ZE	NS	NS	PS	ZE	ZE	NS	NS
	PS	NS	NS	NS	PS	PS	PS	PS
	PM	NM	NM	NS	PS	PS	PS	PS
	PL	NL	NL	NM	PS	PS	PM	PL

4 PV-DAK electronic diagram

The electronic diagram of the proposed system is shown in Fig.7 and consists of a controller part realized with a 16LF18856 microcontroller, 2 voltage/current sensors for input and output voltages/currents, a temperature sensor, a light sensor for irradiance, a SD cards module, and Buck converter.

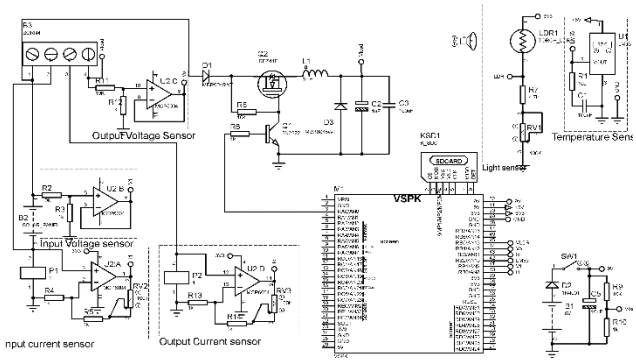

Fig. 7. Electronic diagram of the proposed system.

The majority of the modules on the DAK are remappable, giving the possibility to easily prototype, multiplex and extend its capabilities. The DAK is suitable for practical programming with means to display, use testing buttons, count time and calculate mean values for remote control applications.
Furthermore, the DAK can be widely used for attaching lower-speed peripheral ICs to processors & microcontrollers for intra-board communications and within short-distances. The DAK is compatible with well-known C compilers (IDE MPLABX MicroC Pro, CCS), to MicroPascal (pascal language) and to MicroBasic (Basic language).

4.1 Selection of microcontroller and electronic components

The microcontroller 16LF18856 has been selected for the proposed kit, based on some significant features

presented in its data sheet. It is characterized by core independent and communication peripherals, combined with eXtreme Low-Power (XLP) technology for a wide range of general purpose and low-power applications [6]. It has a configurable internal oscillator, three 8-bit timers, and four 16-bit timers (7 timers in all). It is equipped with a good capacity memory: 256 bytes-EEPROM, 2kB-SRAM, 28kB-Flash memory; with interrupt capabilities (all pins have configurable interrupts on rising and falling edges); multiple signal sources; five Capture/Compare/PWM (CCP) modules, two 10-bit PWMs; and a Numerically Controlled Oscillator (NCO). The controller can generate true linear frequencies with high resolution. Other interesting features of microcontroller 16LF18856 are found in the datasheet [6].
The various components, passive, active and integrated Ones have been selected through a careful process involving electronic calculations, and application notes from manufacturers.

4.2 DAK Software

The DAK software developed using embedded C language [10]. Compiler tool to compile this code is IDE MPLABX compiler and block diagram of system software shown in Fig. 8. Initialization of complete system by sending control or data bits, process data acquisition, and forward to host system or storage media such as: local storage media, distant storage media using internet of Things (IoT).

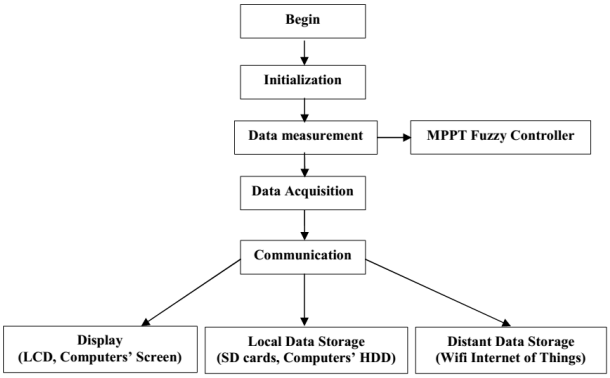

Fig. 8. Software System Block Diagram.

The DAK is used to collect information that can be stored in SD cards, in computers or in the internet using IoT and be processed to analyze some special phenomenon. It is also used as MPPT Fuzzy Logic controller.
The detailed codes for the main program and some activities of the DAK are shown in appendixes A and B.

5. Implementation and experimental results

To validate the DAK, an experimental setup was mounted in the site of the University of Bamenda to collect the input voltage, the input current and the temperature of the PV module.

It consisted of a LW-MS solar panel of 100W, the DAK, a 12V battery and a DC 12V LED as load. Data were collected at intervals of 15 min. from 9:30am to 4pm on the 15/02/2022 during the dry season. These data were used to generate a signal of 27 points regularly spaced between 0−2*s* in order to represent the time period of 9:30am to 4pm. Figs.10 and 11 show the curves of input voltage and input current generated while Fig. 12 shows power. It can be noticed that the maximum point of each curve occurs during the noontime period.

Fig. 9. Experimental setup of DAK with PV Module

Table 2. Format of data in the SD Card

Time	Temp.(°C)	Input voltage (V)	Input Current (A)
9:30	36.4	15.09	1.33
9:45	40.1	16.8	1.58
10:00	42.1	17.54	1.64
10:15	40.1	17.49	1.66
10:30	40.1	18.02	1.78
10:45	42.6	18.37	1.92
11:00	48.2	19.83	2.15
11:15	46.9	19.91	2.28
11:30	48.1	19.98	2.3
11:45	45.9	19.67	2.31
12:00	45.5	19.84	2.33
12:15	46.3	20.25	2.35
12:30	50	20.89	2.43
12:45	50	20.83	2.48
13:00	53.6	20.86	2.63
13:15	56.2	21.72	2.76

13:30	53	21.2	2.59
13:45	50.5	20.81	2.53
14:00	50	20.57	2.43
14:15	50.2	20.49	2.46
14:30	39.6	18.06	2.02
14:45	38.3	17.41	1.66
15:00	37.8	17	1.62
15:15	37.3	16.82	1.53
15:30	37.3	16.73	1.52
15:45	36.8	16.6	1.49
16:00	34.4	16.35	1.40

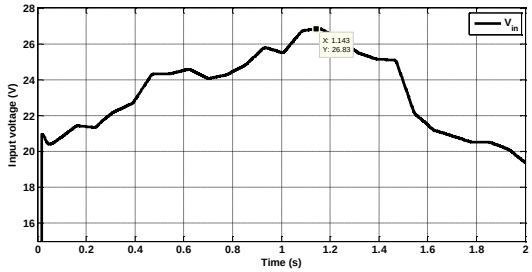

Fig. 10. Input voltage generated from data collected

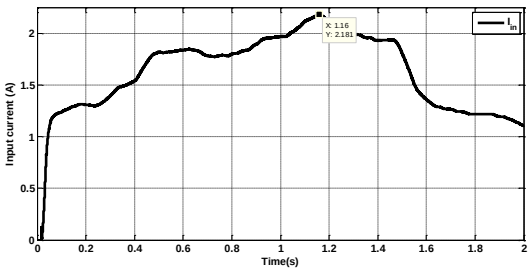

Fig. 11. Input current generated from data collected.

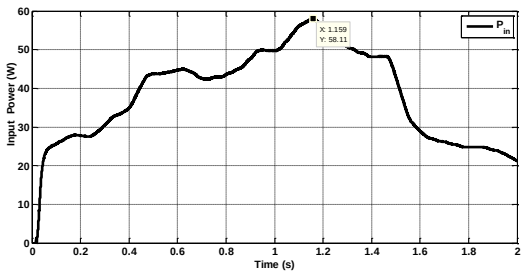

Fig. 12 Input Power generated from data collected.

6. Conclusion and future work

In this paper, a low cost (less than $50) Data acquisition kit suitable for monitoring PV systems in developing countries has been developed.
The DAK can be readily used for attaching lower-speed peripheral ICs to processors & microcontrollers in short-distance and intra-board communications.
An experimental setup has been carried out for validation of DAK operations. The results obtained show that DAK operates satisfactorily and provides good performance. Our future work is to improve the distant data storage part with integration of the Internet of Things to enable automatic data storage in the Internet.

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