

A new technique in reducing self-power consumption in the controller of off-grid solar home system

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Article Info

Article history:

Received Jul 1, 2022

Revised Aug 26, 2022

Accepted Sep 15, 2022

Keywords:

Latching

Push switch mechanism

Self-power consumption

Sizing of solar panel

Solar home system

Time hold on

ABSTRACT

Reducing the self-power consumption of an off-grid solar home system is an economic model in which consumer employs photovoltaic (PV) system for its own electrical requirements. The latch-based clock gating approach has been employed in existing solar charge controllers to reduce integrated circuit (IC) power being used in the low-powered intended mode, although the reducing power is limited. This paper presents a self-power reduction technique based on wake-up power and latch-hold time; which minimize power supply during idle time for a solar home system. Wake-up power introduces a push-switch mechanism using typical transistor technology. Latch-hold time function is designed using an operational amplifier and negative-positive-negative (NPN) transistor. A technique with dynamic self-supply mechanism is also introduced for decreasing self-power consumption. The self-power consumption is identified via simulation studies where the result shows that the power usage is 70% lower than traditional approaches. This is determined using a simulated wave-shape analysis.

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1. INTRODUCTION

Installing off-grid solar photovoltaic (PV) systems in rural areas in developing countries dramatically reduces the electric load mainly on the local utility grid, lessening load shedding in the country [1]. An off-grid Solar Home System (SHS) is suitable for isolated areas with typical energy consumption for two or three lamps, one fan, and/or one television that does not exceed 150 watt peak (Wp) [2]. An off-grid SHS consists of five main elements that are a solar module, a lead-acid battery, a direct current to alternative current (DC-AC) inverter or direct current to direct current (DC-DC) converter, DC-powered home appliances, and solar charge controlling device [3]. SHS has a big challenge in minimizing self-power consumption when solar panel is only employed for power generation, and the battery is employed for energy storage [4]. The solar charge controller has been one of the fundamental elements attached to the battery, solar panel, as well as loads that monitor the charging and discharging of the battery. It is necessary to reduce its self-power consumption since the solar charger has been connected to the system for 24 hours [5].

Quoilin *et al.* [6] several research studies have been attempted to quantifying self-consumption in terms of system design. The winter self-sufficiency rate (SSR) ranges from 30% to 66%, whereas the summer SSR ranges from 46% to 99%. When SSRs above 70%, the solar PV and battery system become prohibitively huge. The system monitoring management increases self-consumption by just 7%, and the method does not appear to be economically feasible. However, this causes a shorter of backup time due to battery depletion. Chowdhury and Mourshed [7] presented a charge controller's self-power consumption should not exceed 20mA in the operating voltage range. It has been observed that charge controllers that employ an electromagnetic relay instead of a metal-oxide-semiconductor field effect transistor (MOSFET) for low voltage disconnect (LVD) and high voltage disconnect (HVD) operations have higher self-power consumption. In [8], on the other hand, as the internet of everything (IoE) grows in popularity, the development of power sources to efficiently power IoE devices is becoming increasingly vital in off-grid areas. Off-grid solar power systems presently face significant difficulties in terms of energy storage and load monitoring.

Additional power is necessary to operate the DC-powered switchboards and solar charge controller. Throughout most cases, electrochemical batteries have been used to power the sensors, this will also result in elevated costs due to the need for battery replacement and more significantly there are environmental pollution issues due to battery waste [9]. Even though some of them have been constructed to use energy from the wind or the sun, devices are constrained by these circumstances [10]. On the other hand, these devices have often been enormous, and even as fabrication technology advances, the devices have complicated structures that are accompanied by a reduced size [11]. It is crucial to channel as much energy as possible into the photovoltaic panels while somehow attempting to reduce the energy consumption of the wireless sensor node to a minimal level [12].

Wake-up technology has shown to be an effective method for reducing power consumption and extending the service life of home appliances [13]. In other words, the wake-up system recognizes extrinsic incentives with low consumption and activates the power networks. The 0.18μm complementary metal-oxide-semiconductor (CMOS) technology of the piezoelectric energy harvesting circuit may operate well for varied flipping inductances with a completely integrated control [14]. An active rectifier with an unbalanced Schmitt trigger is used to decrease static power usage and therefore also improve the power quality efficiency [15]. Moreover, the cold-start capability implies that the circuit remains functioning effectively even in the absence of an applied wake-up signal. In normal conditions, the energy extraction efficiency of the circuit is 4.6 times greater than that of the traditional complete bridge rectifier circuit [11]. The device is powered through an on-chip solar cell including an output voltage of up to 600mV; the device implements a cross-coupled charge pump DC-DC converter and Stacked MOSFET high voltage drivers to generate and handle a 6.5V to 10V signal used to induce the gate oxide breakdown of 100μm² metal-oxide-semiconductor (MOS) capacitors (memory cells) working as anti-fuses through the use of a digital control signal that is executed in tens of milliseconds [16].

According to Do *et al.* [17] battery storage can significantly enhance self-consumption, even with the performance of each unit storage area decreasing with battery size. Performance improvements from load balancing and battery storage are almost similar when compared to daily PV power output. Self-power consumption management in a solar home system seems to have the potential to enhance power generation values by a few percent on a yearly basis [18]. Belattar *et al.* [19] charging controls used were mostly based on the single-ended primary-inductor converter (SEPIC) - pulse width modulation (PWM) technique. The SEPIC-based converter is often used in battery-powered operating devices because it can be executed either on a step-up or perhaps a step-down device. A PWM-based charge controller can be used to maximize output power depending on the temperature of both the panel and the irradiance condition [20]. The SEPIC converter could also be controlled by a PWM-based charge controller to ensure a stable load voltage [21]. Nevertheless, some key considerations such as self-consumption, electromagnetic interference (EMI), the algorithm of fixed frequency current mode control, surge voltage, and lightning protection were not identified.

This research study is intended to reduce the self-power consumption of an SHS, with an emphasis on reducing the size of solar modules and energy storage devices, which are the major elements of an SHS. In order to achieve the research goals, the solar controller's algorithm of fixed frequency current control mode and push button switch approaches have been employed. This research study simulates a technique for reducing self-power consumption employing LT-Spice software.

2. OFF-GRID SOLAR CONTROLLER DESIGN

This research work was applied in an off-grid solar controller which has two functions: PWM solar charge controller and DC-DC converter including a common ground device. Both parts of the controller are designed based on the fixed frequency current mode algorithm. The algorithm has evolved into a dynamic self-supply mechanism that significantly simplifies the configuration of the auxiliary supply and voltage common

collector (V_{cc}) capacitor by enabling internal startups, transients, latch standby, and other features. Dynamic self-supply is important for keeping the controller alive when no switching pulses are accessible, including when the controller is blown out, or to keep the controller from stopping during a transient load when V_{cc} can drop. It also contains a timer-based fault detection mechanism for overload detection and dynamic compensation to ensure maximum power despite input voltage. Figure 1 shows a block diagram of the research framework for this study.

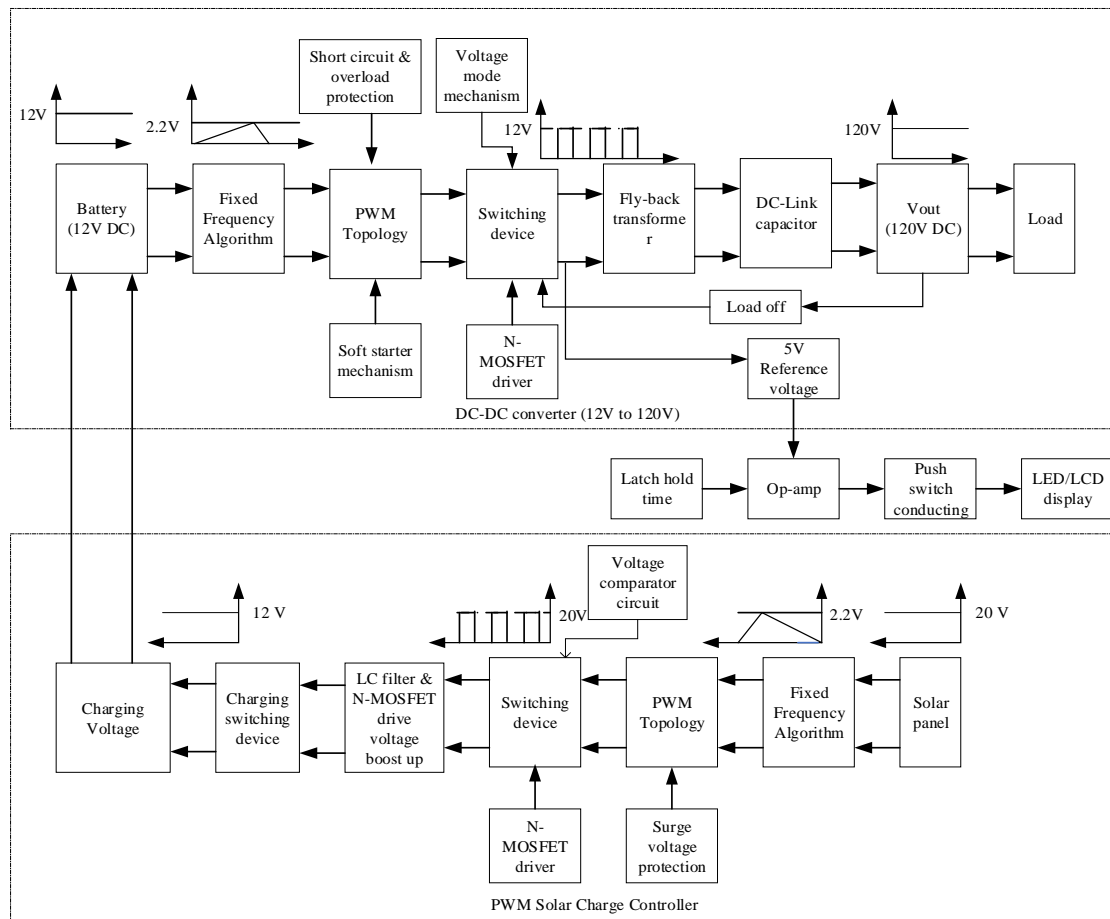


Figure 1. Block diagram of push switch technique in a system

It is essential to consider the relevant variables based on maximum and minimum values (1 and 0) with respect to time while developing design concepts for push button switch mechanisms of the solar charge controller. The design considerations include the latching time, low consumption off-mode and frequency foldback mode.

2.1. Latching -time hold

The latching time is determined to correlate to the customer-required observation of system function. Latch mode is focused on the latch-off function as well as where it usually has two detection levels i.e. a high and a low latch. The system controller is allowed to proceed within two specific thresholds. Nevertheless, if either a low or high threshold is exceeded, the system controller will latch off. It uses a manual pushbutton switch to set the latching time.

2.2. The low consumption off-mode

The low consumption off-mode has been incorporated, providing for an incredibly low no-load input power. The PWM controller IC has a feedback (FB) port, and once the port voltage level falls below 0.4V, the controller switches to the off mode. When the internal voltage common collector (V_{cc}) is activated, the PWM controller consumes very little current, and the self-supply circuit just maintains the voltage at the external

capacitor. The self-supply circuits shall maintain the V_{CC} voltage at its threshold level [22]. The FB port imbalance is delivered by low consumption current sources from the external V_{CC} capacitor. When the FB port voltage is raised, this mode will change.

2.3. Frequency foldback mode

As enhance efficiency under light load situations, the frequency of the internal oscillator is linearly decreased from its setpoint to the oscillation frequency. The maximum on-time duration control is maintained during frequency foldback mode to ensure natural transformer core anti-saturation protection. The frequency foldback reduces operating frequency under no-load conditions at the output voltage. For the frequency foldback mode, the current setpoint is fixed to 300 mV, which is below the feedback voltage level.

3. DEVELOPMENT OF THE PROPOSED DESIGN

Push switch mechanism and fixed frequency current control algorithm are being applied together to develop a controller device. These are the off-program mode approach and accessible set time for system monitoring signals. As system status indicators, electronic devices that use LCD and LED displays are employed [23]. These operational systems should be performed two to three times every day, for approximately 30 seconds each time. Although the power has been consumed for 24 hours, it has only been used for approximately 30 seconds; this is also a form of power consumption. This procedure is carried out by the push switch circuit mechanism, which consists mostly of an Op-amp and an NPN transistor, as illustrated in Figure 1. This research work's attention is focused on reducing the self-power consumption between the photovoltaic system and energy storage mechanism with connected AC power operated home appliances. Meanwhile, the dynamic self-supply mechanism significantly reduces the complexity of the auxiliary supply and V_{CC} capacitor by activating the internal start-up current source to power the controller during start-up, transients, latch, and stand by. Based on input voltage and loading parameters, this operation can be performed either in continuous conduction or discontinuous conduction mode.

A dedicated off program allows the fixed-frequency current control mode to achieve an exceptionally low no-load input power consumption through the “sleeping” of the entire system, thus reducing the power consumption of the control circuitry. Based on the frequency fold-back, the controller has outstanding efficiency in light load conditions whilst also maintaining very low stationary power usage. Specific frequency, ramp compensation and versatile latch feedback enable the controller to produce an outstanding output for the desired design. Timing model is a key factor for the research work. The mode is a timing of the circuit with a level-sensitive latch and is presented as a manual push switch mechanism. Timing model for the latch-controlled circuit is described by a sample clock schedule, which is illustrated in Figure 2.

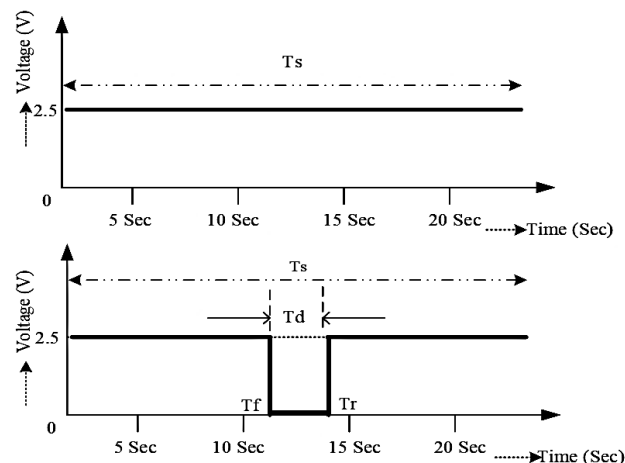


Figure 2. Sample clock schedule

Positive voltage sensitivity, which represents a single cycle operation is considered in Figure 3. Variable in the clock model denote the set time T_s , hold time T_d , time fall T_f , time rise T_r and voltage across the switch V_{sw} . This enables the simulation of both positive and negative level sensitive algorithms, as these clock events govern the releasing and shutting of each latch involved. The difference throughout clock hold

lengths is being used to determine switching activity between latches. Time constraints used are shown in (1) and (2):

$$(T_f - T_r) \text{ mode } V_{sw} > 0 \quad (1)$$

$$(T_f + T_r) \text{ mode } V_{sw} < 0 \quad (2)$$

Parameters in the circuit model include the minimum and maximum combinations between each connected pair of events. Variables in the circuit model denote earliest time duration d_i , the minimum delay time δ_t and maximum delay time Δt . Consequently, the minimum time and maximum time combination is represented in (3). Timing verification and a clock schedule as illustrated in Figure 4 should be specified.

$$\delta_t \pm \Delta t = \text{ON MODE} \quad (3)$$

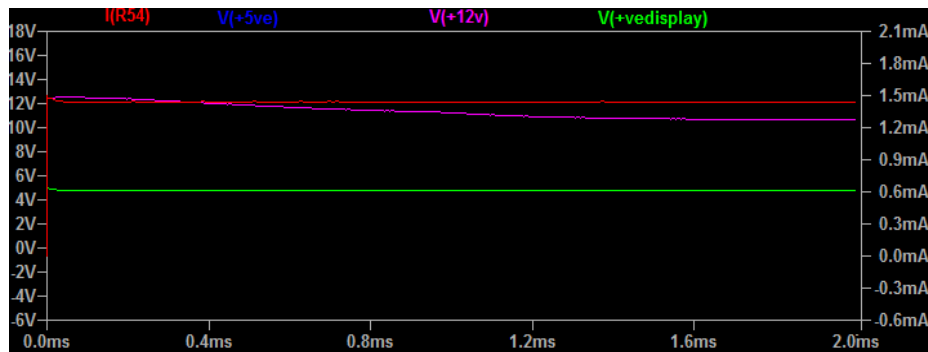


Figure 3. Lockup latch time voltage

4. RESULTS AND DISCUSSION

During the push switch operating mode, the system latching time is provided to correspond with the voltage and current value at high (1) or low (0) consumption levels. It employs a manual push-button switch to determine the latching time, as illustrated in Figures 3 and 5. When the no-load input power is zero, the low power consumption off-mode is activated from across the self-supply circuit to keep the V_{CC} voltage of the controller at its threshold level. The functional waveform during that period is shown in Figure 6.

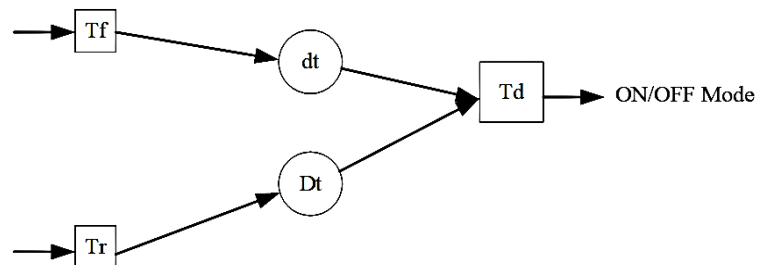


Figure 4. Modeling of circuit section

The design was simulated under the no-load conditions followed by others relevant test conditions such as device power connection being connected with a battery (12V), and the disconnection of the solar panel from a battery (12V). The system nominal voltage applied was 12V. The current was measured separately in accordance with all relevant functions of device and these measured voltage-current values are shown in Table 1.

Table 1. The measurement of self-power consumption during no-load conditions

Portion	Voltage (V)	Current (μ A)	Power(mW)
PWM Solar Charger	12.2	53.32	0.651
DC-DC converter controller	12.2	994.56	12.13
Voltage comparator	12.2	251.78	3.07
Push switch mechanism	4.81	216.32	1.04
Total self-power consumption		1.52(mA)	16.89

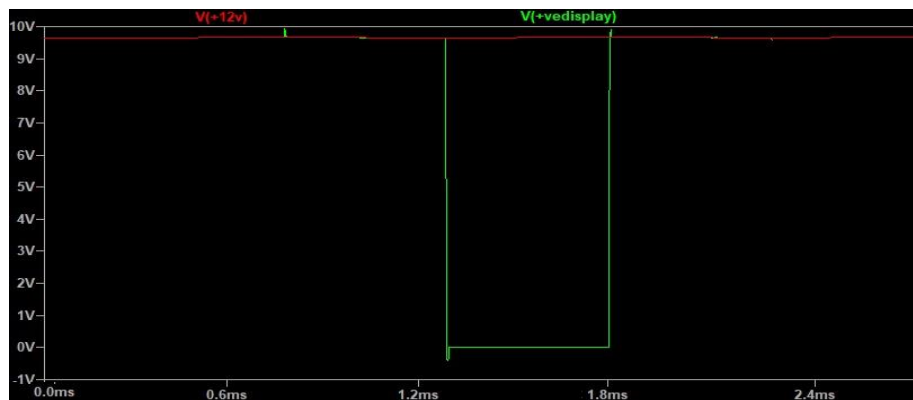


Figure 5. Voltage shape when pressing the push button switch

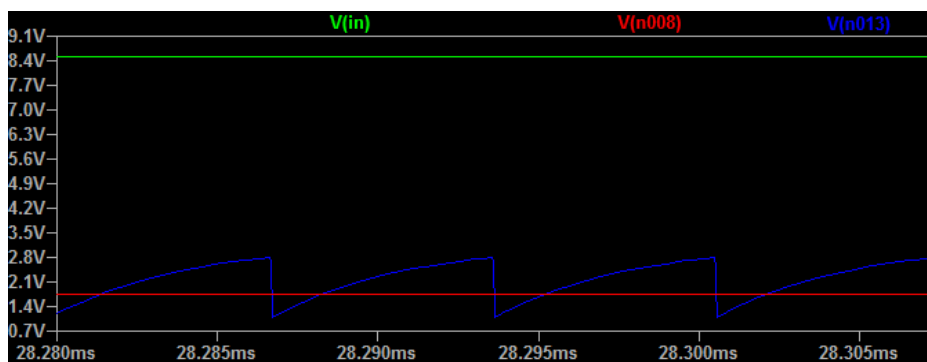


Figure 6. Waveform of low consumption off-mode point

The mechanism has been applied in a solar controller that obtained these test result values of self-power consumption: 0.651mW for PWM solar charger part, 12.13mW for DC-DC converter part, 3.07mW for voltage part, and 1.04mW for push button switch mechanism. Consequently, total self-power consumption during no load condition is 16.89mW. The solar charge controller portion requires less self-power than the voltage comparator portion since its controller IC consisted of self-supply circuits at its threshold voltage level under no-load circumstances. However, if the current and voltage were measured individually based on the device function under various load conditions, the resulting power values are as presented in Table 2.

Table 2. Test measurement of various load conditions during day and night time

Solar irradiance (W/m ²)	PWM Solar charge controller			DC-DC converter (12V-120V)			
	Charging Voltage at battery end (V)	Charging current at battery end (A)	Charging Efficiency (η%)	Connected load resistor (Ω)	Input power (W)	Output power (W)	Conversion efficiency (η%)
1000	10.37	11.21	89.41%	300	62.12	55.97	90%
800	10.37	9.22	89.64%	250	82.45	73.01	88%
600	10.77	7.28	93.37%	200	103.41	88.23	85%
400	10.96	5.32	97.96%	150	128.33	109.49	85%
200	11.16	3.36	96.19%	100	166.79	142.93	85%
Night Hours							
Dark	0	0	0	90	168.02	143.14	85%

All test results obtained include the device's self-power under all load conditions. This signifies that self-power consumption is present at any period under any load scenario, which is shown in Table 2. When the household appliances are connected as loads at the output of the DC-DC converter, the self-power consumption and actual loaded power consumption constitute total power consumption. Off-grid SHS customers use the load at night, but solar charging processes occur during the day, hence the system must be operational 24 hours a day, seven days a week [24]. As a consequence, the system power usage per day is 732.24mW. According to

previous research, the power consumption of solar charging systems during idle circumstances is 26.35 watts per day.

Figure 7 shows the simulated V-I curve where $V(+12V)$ is the supply voltage across the battery port; $I_x(U3:V+)$ is the current across the comparator IC of load switching alignment; $I_x(U4:Vcc)$ is the current across the DC-DC converter controller IC; $I_x(U1:V+)$ is the current across the comparator IC of solar charging switching alignment; $I_x(U2:Vcc)$ is the current across the PWM solar charging controller IC; and $I_x(U5:V+)$ is the current across the comparator IC of push button switching signal. According to the design principles of the analogue PWM controller IC, the current mode control scheme includes pulse-by-pulse detection. The close loop error voltage detection with pulse-by-pulse recognizing techniques has been used to obtain low power consumption during the no-load circumstances. $I_x(U4:Vcc)$ and $I_x(U2:Vcc)$ indicate the current waveform across the V_{CC} power supply port during no-load conditions, with the waveform deriving from the pulse-by-pulse detection approach [25].

Under no-load circumstances, the system output connected load is practically zero watts; however, all controller IC (solar PWM charge controller portion and DC-DC converter portion) and op-amp IC (voltage comparator part and push-button switch mechanism part) are activated and consume power, which really is the self-power consumption of the system.

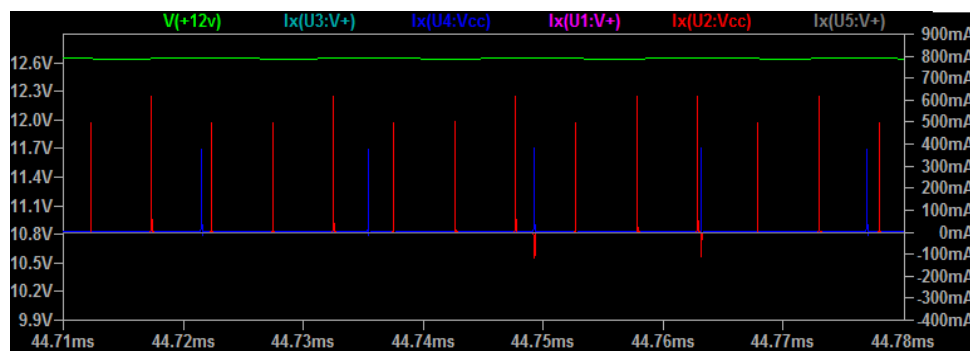


Figure 7. V-I curves under no-load condition.

5. CONCLUSION

This research paper has presented the techniques for reducing the self-power consumption in a power controller for an off-grid solar home system (SHS). A new solution that employs a combination of the push switch mechanism and fixed frequency current control algorithm to directly solve the self-power consumption concerns while reducing prices has been presented. This technique can be applied to both designated positive and negative voltage levels. As a result, users will be able to reduce self-power consumption, which is equal to the size of 50 Wp solar panels; this allows a reduction in the size of the solar modules while keeping the same features.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to the College of Engineering, Universiti Teknologi MARA (UiTM), Shah Alam, Selangor, Malaysia for knowledge, facilities and financial support.




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