Abstract—Single dwelling solar lighting systems fulfill the much-needed gaps in rural applications in less developed geographies. Many of these systems are designed to meet challenging cost objectives, but fail to consider the reliability and availability aspects. In this paper, a simple modification to the battery charging circuit for these applications is proposed that will increase the battery life and availability and also reduce the total cost of ownership significantly. The proposed circuit uses a linear regulator with smart control algorithm to provide temperature compensation, constant voltage charging and battery overcharging protection. Efficiency of the system is also optimized.

I. INTRODUCTION

The recent advances in high brightness LED lamp technology have opened new vistas for low cost rural lighting requirements in less developed geographies where there is limited or no access to the electric grid and to get illumination at night, people depend on environmentally unfriendly methods such as kerosene lamps. The ability of LED lamps to provide more illumination at low power and their ability to operate from dc, make them a natural ally to solar photovoltaic power generation with energy being stored in the battery during daylight hours. The connection between the solar cells, battery and the LED light can take many forms, but for cost sensitive rural applications, it is important to achieve longest battery life and always charge the battery to its maximum capacity with the simplest possible charging circuit. In most charging circuits, the charging of the battery during daylight hours is controlled by a simple switch, which stays on as long as the battery voltage is below a preset voltage. This level of simplicity [1] is dictated by the cost factor and also by the thinking that the end user is not sophisticated enough to deal with higher complexity and any possible tuning/control knobs. The size of the solar panel, the battery and the LED itself are matched to ensure that the storage and delivery capacity do not overly exceed or fall short of the load requirements.

II. PROBLEMS WITH EXISTING SYSTEMS

Fig. 1a represents the above-mentioned popular charging scheme where the PV panel is connected or disconnected to the battery by Q1, depending on the battery voltage. The battery voltage is sensed by a comparator through R3/R4 and compared with a reference voltage (REF) to turn on/off Q1. The turn-on and turn-off hysteresis is usually about 1 V and set by R1/R2. Since the charging is simplified and the charging voltage cannot be regulated, the charging circuit does not allow the battery to be charged beyond a certain stage to avoid overcharging, and as a result the battery capacity is not fully available to the load.

Fig. 1b shows the charging voltage and charging current pattern of the above scheme. It can be seen that a significant charging current is still flowing through the battery when the charging process is terminated due to the battery reaching the pre-set cut-off voltage. Thus the charging of the battery is incomplete as the charging is stopped before the battery is
fully charged. This results in incomplete charging of the battery resulting over sizing of the battery that increases overall system costs indirectly.

Further as the battery float voltage is temperature dependent, in remote rural applications where the ambient temperature variations can be large, the above charging scheme can often overcharge the battery at higher temperatures and undercharge the battery at lower temperatures. If the cut-off voltage at which the charging process is terminated is set low enough so that the battery does not overcharge at the highest temperature, the total charging capacity of the battery will significantly reduce at lower temperatures. Thus the battery life suffers as the battery charge voltage does not reduce as the temperature goes up.

While it is not intended that some kind of MPPT [2] scheme be used for these low cost stand alone systems, at the same time any other low cost solution to mitigate some of the above issues will be very helpful.

III. STRATEGIES FOR IMPROVING BATTERY CHARGING AND BATTERY LIFE

The above circuit only provides a constant current charging to the battery till it reaches a certain voltage after which the series MOSFET switch disconnects the solar panel from the battery [3] to avoid overcharging. To store more charge into the battery, the solar panel must not be disconnected from the battery and at the same time a voltage regulating circuit must be provided so that the battery is not overcharged. For larger systems this regulating circuit is often a switch mode regulator whose duty cycle is controlled to provide regulation and MPPT.

It is proposed here that this series MOSFET switch be operated in two stages. For most part of the operating range where the battery voltage is lower than the set float voltage, the MOSFET switch will remain fully on resulting in negligible drop across the MOSFET and thus directly connecting the solar panel to the battery. Once the battery charges to the set float voltage, by converting this series switch, usually a MOSFET, to a simple linear regulator and regulating the charging voltage rather than operating it as an ON/OFF switch, the second stage of constant voltage (CV) charging can be easily accomplished. Moreover, the low drop out (LDO) characteristics of this MOSFET based linear regulator and the relatively low charging current that flows into the battery once it [4] charges beyond 12.5 V, results in low losses in the MOSFET, even though it is in linear mode. Studies have shown that this CV charging extends the battery’s ability to accept the full charge and thus ensures longer availability in these applications. The use of the linear regulator concept also prevents overcharge of the battery by allowing the battery to be floated to a constant voltage.

The other key attribute to extending the battery life is temperature compensation. The battery characteristics change with temperature and thus reducing the charging voltage as the temperature goes up is very useful. Thus by using a voltage regulating circuit between the solar panel and the battery, temperature compensation can be easily achieved by adjusting the regulating circuit’s output voltage in proportion to the ambient temperature. Thus the battery charging voltage can be made dependent on the ambient temperature resulting in increased battery capacity and life.

In practice, the charging float voltage is reduced as the ambient temperature increases.

IV. EXPERIMENTAL RESULTS

The proposed charger circuit model is shown in Fig. 2a. The solar panel is connected to the battery through N-channel MOSFET Q1, driven by an error amplifier that is powered by a voltage doubler circuit that generates the

![Fig. 2a. Proposed charger circuit model.](image)

necessary higher drive voltage than the input voltage, necessary for driving the low cost high side N-Channel MOSFET. Voltage feedback to the error amplifier is provided by R1/R2 while integrating the PWM pulses generated by the microcontroller through R3/C1, sets its reference voltage which in turn sets the battery float voltage. When the battery voltage is less than the set voltage, the error amplifier is saturated and this turns on Q1 fully to connect the solar panel directly to the battery. Once the battery charges to the set float voltage, the error amplifier operates MOSFET Q1 as a simple linear regulator and regulates the charging voltage. The microcontroller also senses the ambient temperature through R7/NTC1 and provides temperature compensation by adjusting the PWM duty cycle, which in turn adjusts the error amplifier’s reference voltage to control the float voltage. The

![Fig. 2b. Various operation stages of the proposed converter.](image)
The microcontroller also senses the battery voltage through R4/R5 and the battery charging current through R6, to provide various announcements by LED1/LED2. Keeping in mind the end application cost factors, effort is made to make the whole circuit implementation as simple as possible. Compared to the original “simple” charging circuit, the only addition is the microcontroller and a couple of sensing circuits. It can be shown (though it is not the focus of this paper) that the cost of this addition can be more than compensated by supporting the load for longer hours or reducing the battery nominal capacity as may be desired.

Fig. 2b shows the charging voltage and charging current pattern of the above proposed scheme. It can be seen that the battery charging current is not interrupted and the battery is float charged with gradually decreasing charging current resulting in the battery being almost fully charged. Further the battery float voltage is adjusted according to the ambient temperature. This results in complete charging of the battery resulting in optimum battery sizing and increased battery life that reduces overall system costs indirectly.

The microcontroller-charging algorithm is shown in the flow chart shown in Fig. 3. Various set and measured parameters given in the flow chart refer to the charger circuit given in Fig. 2a.

The microcontroller continuously monitors the battery voltage and for the condition when the battery voltage is less than 12.5 V, it sets the PWM duty cycle to 100%. This sets the error amplifier’s reference voltage to the highest level, which in turn on Q1 fully. Once the battery voltage charges beyond 12.5 V, the microcontroller senses the ambient temperature and sets a reduced duty cycle. The duty cycle is set by reading from a look-up table and the duty cycle is set in a way that the duty cycle reduces with increasing temperature. The microcontroller also senses the battery charging current through R6, to provide various charging status announcements with LEDs.

To develop a better understanding about the proposed charging scheme, measurements were made on a 5 A prototype charge controller. The oscillogram shown in Fig. 4 shows the various signals in the charge control circuit. Here Channel 1 shows the PWM signal and Channel 2 shows the REF signal. As explained earlier, the Channel 2 value is the averaged version of Channel 1 pulses. Based on the sensed temperature, the duty cycle of Channel 1 is modulated and hence the Channel 2 voltage will move up or down. Channel 3 shows the charging voltage set by Q1 (13.64 V) - indicating that it is operating in the linear region.

V. CONCLUSION

This paper has aimed to debunk the myth that the lower cost applications cannot use better available technology. The fact that technologies such as PV solar and LED lamps have higher initial costs, sophisticated control solutions that extend the life, efficiency and availability of these systems to the end user are necessary. In this paper, a simple yet novel modification to the charging circuit for the battery of a stand alone PV system is described along with an implementation flow chart/algorithm. Results are described to show the effectiveness of this algorithm, compared to the traditional implementation.

REFERENCES

