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Boost Converter Optimization for Electrotherapy Applications Powered by Renewable Energy

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Abstract - *The increasing demand for electrotherapy devices calls for sustainable and eco-friendly solutions to reduce environmental impact. Traditional electrotherapy systems rely heavily on disposable components and non-renewable energy sources, contributing to environmental waste. This paper explores the integration of solar power in electrotherapy devices, focusing on the design of a solar-powered system that steps up DC signals using MOSFET technology and photovoltaic (PV) cells. The developed model successfully steps up the voltage, providing a sustainable, portable, and eco-friendly alternative for electrotherapy treatments. The use of solar energy not only minimizes resource consumption but also enhances device portability, making it suitable for off-grid and remote locations. The paper highlights the potential of renewable energy technologies to reduce the ecological footprint of electrotherapy devices while ensuring effective and safe treatment. By combining electrical engineering with electrotherapy, this research paves the way for future innovations in sustainable healthcare solutions.*

Key Words: Electrotherapy, Solar Energy, Boost Converter, MOSFET.

1. INTRODUCTION

As the demand for sustainable and portable electrotherapy devices continues to increase, solar-powered solutions offer an excellent opportunity to reduce reliance on non-renewable energy sources while ensuring effective treatment. The ability to power electrotherapy devices using solar energy not only addresses environmental concerns but also enables treatment in remote or off-grid locations where conventional electrical grids are unavailable[1]. However, to ensure that the energy generated by solar panels is efficiently converted into a usable electrical signal for electrotherapy, power conversion technologies must be employed. Specifically, this paper focuses on the use of Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) technology to step up the low-voltage direct current (DC) signals produced by solar panels to the appropriate voltage levels needed for electrotherapy applications[2].

MOSFETs are widely recognized for their high efficiency, fast switching capabilities, and reliable performance in power conversion circuits, making them ideal for use in stepping up low-voltage DC signals. In this paper, the MOSFET technology is utilized to increase the voltage from the solar panel to the necessary level for electrotherapy treatments. The use of MOSFETs ensures stable, efficient voltage conversion with minimal energy loss, allowing for optimal power delivery to electrotherapy devices. This step-up converter design, driven by MOSFET technology, is critical for ensuring that the electrotherapy devices receive the correct voltage for various types of treatment[3].

Furthermore, this paper also explores the conversion of the stepped-up DC signal into both alternating current (AC) and DC outputs for testing purposes. AC output is typically required for treatments like Transcutaneous Electrical Nerve Stimulation (TENS) or Interferential Current Therapy (IFC), while DC output is more commonly used in treatments such as Neuromuscular Electrical Stimulation (NMES). The ability to produce both AC and DC outputs from the stepped-up DC signal makes this system versatile and adaptable to a wide range of electrotherapy techniques, offering flexibility in treatment approaches for different patient needs[3].

To model and simulate this power conversion process, MATLAB 2021a is used as the simulation tool. MATLAB provides an advanced simulation environment that allows for detailed modeling and testing of power electronics circuits. By utilizing MATLAB, the design of the step-up converter that uses MOSFET technology to increase the low-voltage DC signal is carefully analyzed. The simulation also facilitates the conversion of the DC voltage into both AC and DC outputs for electrotherapy applications, enabling the evaluation of the system's performance under various conditions[4-7].

The simulation process begins with the modeling of the solar panel's low-voltage DC signal. This signal is then fed into the step-up converter, where the MOSFET-based technology increases the voltage to the desired level. The simulation includes both AC and DC output testing, where parameters such as frequency, waveform, and voltage are adjusted for compatibility with different electrotherapy modalities. Through MATLAB simulations, various conditions—such as changes in solar intensity, variations in load, and voltage regulation—can be tested and optimized for better system efficiency and performance[8-10].

By utilizing MATLAB simulations, it becomes possible to thoroughly test and evaluate the performance of the system before building a physical prototype. The simulation results provide valuable data regarding the efficiency, voltage stability, power losses, and overall effectiveness of the power conversion system. These insights will serve as the foundation for the development of a practical, solar-powered electrotherapy device capable of providing reliable and efficient therapeutic treatments.

The objective of this research is to design and develop a solar-powered electrotherapy system that leverages MOSFET technology for efficient power conversion. This approach not only offers a sustainable and eco-friendly solution for electrotherapy but also increases the versatility and accessibility of treatments. With this system, patients can benefit from reliable, off-grid electrotherapy, making it especially valuable in regions with limited access to traditional power sources. By combining MOSFET-based power electronics and MATLAB simulations, this paper presents a practical and innovative solution for the future of sustainable, solar-powered electrotherapy devices[11-13].

2. Modelling

The operation of a PV cell is similar to that of a diode with a junction, whereby absorbed light energy produces charge carriers separated at the junction. In an ideal PV cell, there is no series loss or leakage to ground, but in real PV cells, resistances are introduced in equivalent circuits to account for these non-idealities. Figure 1.1 illustrates the equivalent electrical circuit for the composite physics of PV cells, which is the basis for the proposed PV model's developmental model. A constant current source, Iph, represents the current produced by photons, while the shunt resistance, Rsh, accounts for shunt-leakage current, Ish. The series resistance, Rs, represents the voltage drop at the output. Small changes in Rs significantly affect the output of the PV module, and PV power conversion efficiency (PPCE) is sensitive to such changes, but not to changes in Rsh. The current and voltage of the PV panel depend on the load value and exhibit nonlinear, power-limited electrical characteristics. Equivalent Electrical circuit model of PV cells. The Equation (1) defining output current of the non-ideal PV cell was derived using Kirchhoff's current law as follows: $Icell = Iph - Id - Ish$ (1)

Equation (2) formulates the total current that a PV cell can provide, taking into account active radiation (G) and reference radiation (Gr), as well as the module temperature (Tc) and reference temperature (Tcr) of the component. Electrical specifications for PV modules are typically provided by manufacturers at standard conditions, with solar radiation at 1000 W/m2 and a cell temperature of 25 oC, which correspond to the values of Gr and Tcr, respectively. $Icell = Ir + [a(G/Gr)(Tc - Tcr) + (G\,Gr - 1)Isc]$ (2) Equation (3) and (4) are used to formulate the voltage of a PV cell, where the temperature coefficient of open circuit voltage is represented by ß. The short circuit current of the module is characterized by the parameter Isc and α represents the temperature coefficient of short circuit current. $Vcell = (-\beta)(Tc - Tcr) - Rs\Delta I + Vr$ $\Delta I = [a(G\,Gr)(Tc - Tcr) + (G\,Gr - 1)Isc]$ (3) (4) In this context, Rs is the: parameter used to indicate the voltage drop at the PV cell's output. The reference values for current and voltage are denoted by Ir and Vr, respectively, which are obtained from the I-V curve. To design a PV module, individual PV cells are connected in series and parallel. This configuration gives the output current and voltage of the PV module as shown in Equation (5) and Equation (6), respectively. $Vm = NscVcell$ $Im = NpcIcell$ (5) (6) In this context, Vm represents the output voltage, while Im represents the output current. Nsc and Npc denote the number of PV cells connected in series and parallel, respectively. The suggested PV module can be used in transient analysis of power systems that have PV panels. It is also helpful for testing Maximum Power Point (MPP) tracking methods. Currently, integrating solar energy into microgrids is a top priority for the power systems industry. Modelling renewable energy sources for large-scale power system integration simulations is now more critical than ever, as these simulation tools will be a crucial part of the optimal design and intelligent management processes.

The cells convert solar energy into power very efficiently. They are made of various semiconductor materials. There are two types: positive rate and negative rate. This modular technique is used to fabricate solar cells with high conversion efficiency and low cost. When a solar cell collects photons, silicon atoms are excited. A grid of metal conductors captures the freed electrons and pulls them away, causing an electric current to flow. A photovoltaic (PV) module is the main component of a PV system, consisting of solar cell circuits sealed in an environmentally friendly laminate. To meet the energy demand, multiple PV modules are often connected in series and parallel. The specifications of the PV module used in the circuit are as follows:

Sr. No.	MODEL PARAMETER	
1	Maximum Power (W)	200.14
2	Cell Per Module (Ncell)	54.01
3	Open Circuit Voltage (VOC)	32.89
4	Short Circuit current (ISC)	8.22
5	Voltage at Maximum Power Point (VMP)	26.40
6	Current at Maximum Power Point (IMP)	7.59
7	Light Generated Current (IL)	8.24
8	Shunt Resistance (RSH)	126.9892
9	Series Resistance (RS)	0.32701

Table 2.1: PV module parameter

The metal oxide semiconductor field effect transistor (MOSFET) is a semiconductor device that can be controlled by a gate signal (g > 0). The MOSFET device is connected in parallel with an internal diode that turns on when the MOSFET device is reverse biased (Vds < 0 g = 0). > 0 or g = 0), the diode is connected in parallel.

A MOSFET device turns on when a positive signal is applied to the gate input (g > 0) regardless of whether the drain-source voltage is positive or negative. With no signal at the gate input (g=0), only the internal diode conducts when the voltage exceeds the forward voltage Vf.

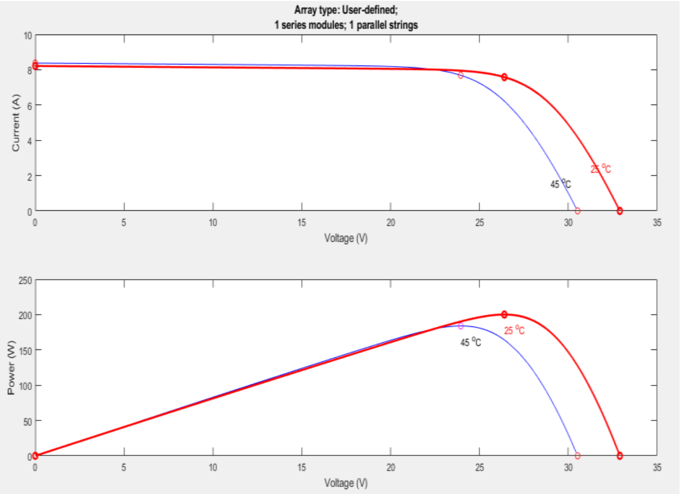

Figure 2.1: Current-voltage and power-voltage characteristics of the PV array model

When a positive or negative current flows through the device, the MOSFET turns off when the gate input goes to 0. If the current I is negative and flows through the internal diode (no gate signal or g = 0), the switch is turned off when the current I reaches 0.

The forward voltage Vds varies:

Vds = Ron×I

When a positive signal is present at the gate input.

Vds = Rd×I-Vf +Lon×dI/dt

When the anti-parallel diode conducts (no gate signal). Ron Diode Inductance is only available in continuous models. Most applications should set Lon to zero for both continuous and discrete models. The MOSFET block also includes a series Rs-Cs snubber circuit that can be connected in parallel with the MOSFET (between nodes d and s).

In this section, we present a simulation evaluation of the proposed method and verify its performance against existing systems. Her Simulink of the proposed method is designed in MATLAB. A Simulink model of the proposed model is shown in Figure 4.2. The circuit from his MATLAB simulation of the step-up DC-DC converter is shown above. The purpose of this circuit is to track the output voltage and current waveforms while fully charged. The input voltage of the circuit is 32.72 V and the output voltage is 231.1 V. The input voltage source for the simulation model is a solar panel with a nominal power of 200.14 watts, which is a RES

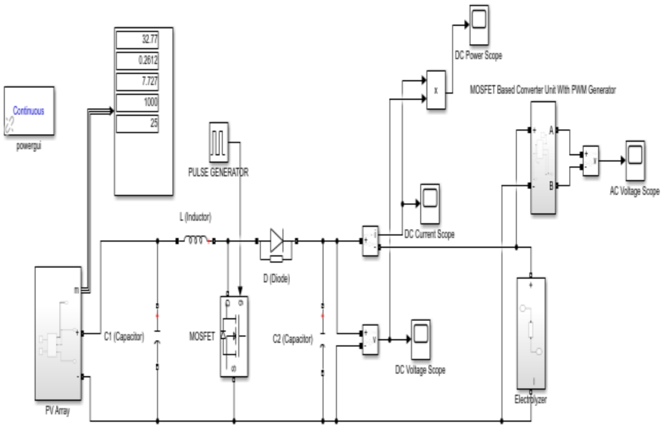

Figure 2.2: Simulink Model of proposed Method

The parent above suggests how the evaluation predicts the overall performance of the Renewable Energy Source (RES) version for the minimal enter voltage Vin, min = 32.seventy two V beneath no-load situations with an output voltage Vo = 231.1 V. In the experiment, the improve inductance L = 0.001 H and the resonance capacitors C1 = 33.e-6 F and C2 = 33.e-6 F have been used as passive parts. Stages boom the output voltage through showing diverse waveforms captured and not using a load from a low enter voltage (32.72V) to (231.1V). The output voltage dropped from 231.1V to 95.15V while a complete load became carried out to the circuit, even as the sun panel voltage dropped from 231.1V to 87.83V. Since the sun panel is a modern source, the modern within side the panel is consistent and the voltage. We understand that water and blood are simply resistive loads. Therefore, we use a resistor in place of the load, referred to as electrolyzer loads.

Graphically Representation

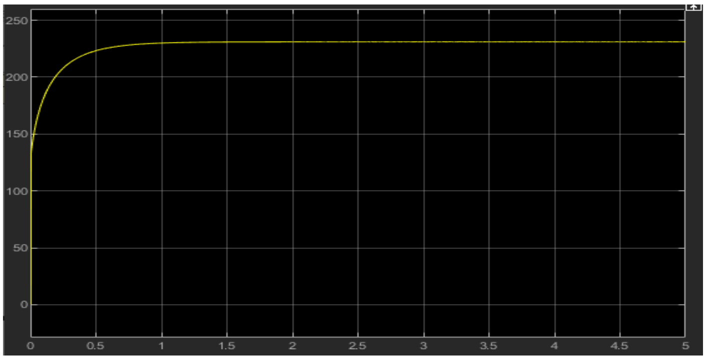

Figure 2.3: DC voltage without load

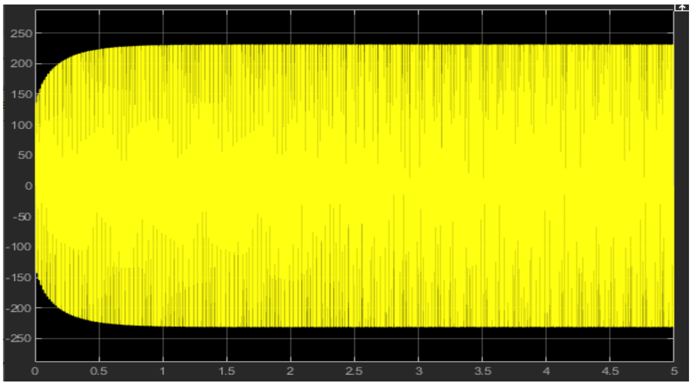

Figure 2.4: Alternating voltage without load

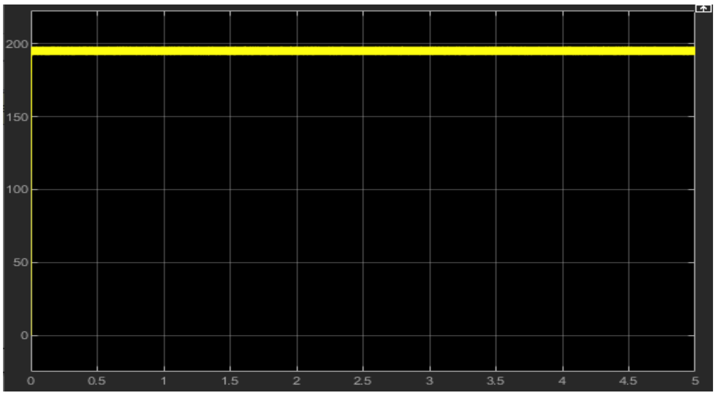

Figure 2.5: DC power with load

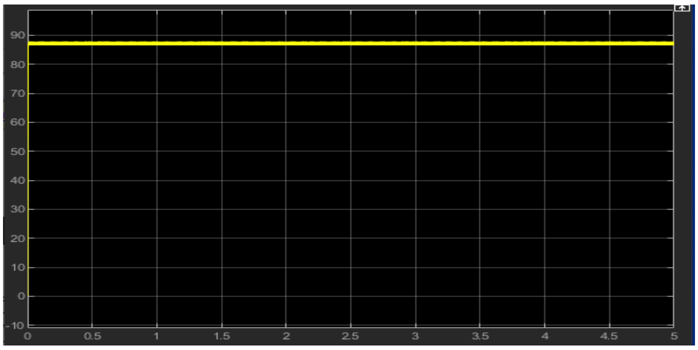

Figure 2.6: Full load Voltage

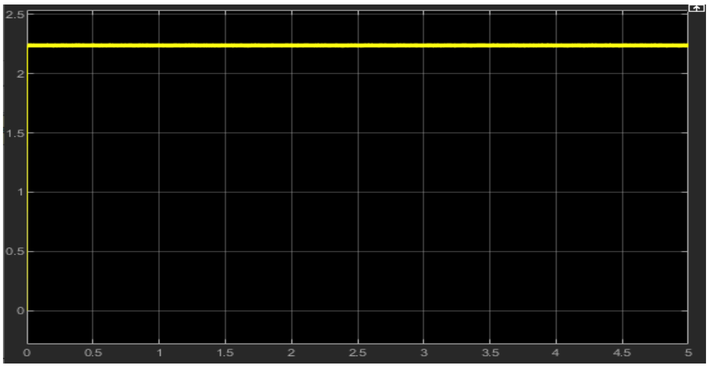

Figure 2.7: DC current at full load

Results at Various Load Level

V_{IN}	I_{IN}	V_{OUT}	I_{OUT}	P_{IN}	P_{OUT}	η%	$V._{DROP}$	R_L
32.72	0.3445	231.1	0.004	11.27	1.068	9.48	0.00	OC
1.005	8.203	2.498	2.498	8.24	6.238	75.70	98.92	1
2.464	8.191	7.422	2.474	20.18	18.37	91.03	96.79	3
4.656	8.173	14.78	2.464	38.06	36.43	95.72	93.60	6
4.836	8.156	21.96	2.44	55.76	53.58	96.09	90.50	9
9.001	8.144	29.24	2.437	73.26	71.26	97.27	87.35	12
11.15	8.124	36.51	2.435	90.06	88.09	97.81	84.20	15
13.28	8.106	43.52	2.419	107.7	105.3	97.77	81.17	18
15.41	8.09	50.58	2.41	124.7	121.9	97.75	78.11	21
17.51	8.073	57.06	2.401	141.4	138.3	97.81	75.31	24
19.56	8.45	64.07	2.398	157.4	155.1	98.54	72.28	27
25.19	7.823	83.86	2.331	197.1	195.5	99.19	63.71	36
26.39	7.582	87.83	2.254	200.1	197.5	98.70	61.99	39

Table 2.2: Results at Various Load Level

According to the simulation result, this circuit offers a maximum efficiency of 99.19% using a signal MOSFET with PWM technology and a voltage drop of up to 61.99V.

3. CONCLUSIONS

This research focused on the advancement of eco-friendly, solar-powered electrotherapy devices, integrating modern power electronics technologies and simulation tools like MATLAB. A solar-powered system was designed to step up the voltage from 32.71V to 231.1V for electrotherapy applications, utilizing a MOSFET-based step-up converter to achieve the required voltage levels for effective treatment. The simulation model successfully demonstrated the conversion of solar power into both AC and DC signals, with the voltage being stepped up to meet the necessary specifications for electrotherapy. Furthermore, the electrotherapy load, represented by an electrozer upto1 ohm to 39 ohm, was used to assess the full-load voltage drop 61.99V, providing valuable insights into the system's performance. Maximum efficiency of the circuit is 99.17%

This work has successfully established a foundation for solar-powered electrotherapy devices that are both environmentally sustainable and efficient. The use of solar power, combined with high-efficiency power conversion, holds significant potential in reducing the carbon footprint of traditional electrotherapy devices, making them suitable for use in off-grid areas and reducing reliance on conventional power sources. By combining advanced power electronics with solar energy, the system is not only eco-friendly but also highly adaptable to a wide range of therapeutic applications.

Future Scope

While this research has demonstrated the effectiveness of stepping up the voltage for solar-powered electrotherapy, there are several areas for future development that could further enhance the functionality and versatility of the system:

1. Voltage Step-Down Conversion: Future work can focus on designing a step-down converter that can efficiently reduce the voltage levels while maintaining optimal power delivery. This would be particularly useful in scenarios where low-voltage signals are required for specific electrotherapy treatments.
2. Frequency and Current Control: By incorporating different types of converters, future designs can include the capability to control not just voltage but also frequency and current. This would enhance the system's versatility, allowing it to cater to a broader range of electrotherapy techniques that require varying frequencies and current strengths, such as neuromuscular electrical stimulation (NMES) and transcutaneous electrical nerve stimulation (TENS).
3. Advanced Power Management Systems: Integrating advanced power management systems with feedback control mechanisms will help optimize the performance of the solar-powered electrotherapy device. These systems could monitor the battery charge levels, adjust the energy flow based on solar intensity, and improve the efficiency of energy conversion under varying environmental conditions.
4. Battery Storage and Energy Efficiency: Incorporating battery storage systems into the design could allow the electrotherapy device to function effectively even in low sunlight conditions. Optimizing battery charging and discharging cycles would ensure continuous availability of power, particularly in remote locations or areas with intermittent sunlight.
5. Prototype Development and Testing: The next step involves developing a physical prototype of the solar-powered electrotherapy device and conducting real-world testing to validate the simulation results. This will provide further insights into the practical performance, reliability, and efficiency of the system under different operating conditions.

In conclusion, the advancements made in the design of solar-powered electrotherapy devices in this paper offer a promising pathway toward more sustainable and efficient therapeutic treatments. Future work in voltage regulation, frequency control, and energy management will significantly enhance the functionality of these devices, making them more adaptable and accessible for widespread use in diverse clinical and home care settings

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