

Research into and Assessment of the Efficiency of Innovative DC-DC Converters with a Single Switch for Use in DC Microgrids

Gujjarlapudi. Sumanth¹, Maisakshi Pavan Kumar², Arpula Krishnaiah³

¹Electrical and Electronics Engineering & KLR College of Engineering and Technology

²Electrical and Electronics Engineering & KLR College of Engineering and Technology

³Electrical and Electronics Engineering & KLR College of Engineering and Technology

Abstract - In this paper, a new high gain non-isolated single switch DC-DC converter for fuel cell and solar photovoltaic is proposed. The current from these sources is always the same, hence a high gain DC-DC converter working in the continuous conduction mode (CCM) is frequently needed. The conversion is fed with a constant current at its source and supplies the same to its load. We analyze the performance of the converter with the use of a state space model, highlighting the dynamics in motion. In this stage we calculate the signal transfer function of the transient. Extensive comparison of current converters is also included. The k-factor technique is also used in the construction of output voltage controllers. These controllers can easily handle input voltage changes and don't even need a current sensor. Then a 150W prototype was built and tested experimentally to verify the performance of the controller and converter.

Key Words: High-gain, dc-dc converter, fuel-cell, solar PV, quadratic boost, dc microgrid, k-factor method.

1. INTRODUCTION

The energy sector is witnessing a tidal transition towards renewable and sustainable sources with growing environmental consciousness and the ever-increasing demand for energy. Technologies such as fuel cells (FC) and solar photovoltaic (PV) systems enable clean distributed power generation from renewable energy sources. Hybrid systems cannot be connected to DC-link buses or supply high voltage DC loads due to low and variable output voltage of fuel cells and PV panels. Therefore, tiny and highly efficient DC-DC converters are becoming important in the power processing network of renewable energy systems. Higher DC voltages of more than 200 V are required for both energy storage and inverter-based systems. The PV systems are tested at an output voltage level of 20 to 40 V per module under typical conditions. Most DC applications do not require load dependent output voltages but PEM fuel cells and other FC systems must. In order to raise the voltage to a tolerable level, the power electronic converters used should be compact, reliable and energy efficient.

1.1 The special problems of high gain power conversion The high gain DC-DC converter must be capable of converting low level input voltages to high level output voltages and its efficiency should not be affected by all input and load situations. In theory, a conventional boost converter can achieve a huge voltage gain at a very high duty cycle. However, in fact, conventional boost converters cannot meet the requirements at the limits in harsh conditions. Here are some examples of: • At low input voltages, the high current stress increases the conduction and switching losses. With higher voltages the efficiency reduces due to parasitic resistance and diode reverse recovery. It is very important to minimize the instability of the control and phase margin during large variations of the duty cycle. Very high levels of electromagnetic interference (EMI) need more sophisticated temperature control systems.

To solve these problems, many novel boost converter topologies have been developed. Examples of such topologies are the hybrid structure, the coupled-inductor topology, the quadratic boost converter and the switched-capacitor converter. Their extraordinary efficiency partly results from low duty cycles and strong voltage gain. They can be unstable and costly because of active clamping circuits, several switches, sophisticated control systems and individual transformers. We require a high-voltage-gain converter with a simple design (preferably with one switch) that is able to manage continuous input and output currents suited with PV and FC characteristics. Sensor less Architecture and Controls Requirements (Section 1.2) The converters must have their output controlled.

PV and FC systems have to work with a fixed output voltage because the input voltage can vary depending on temperature, fuel pressure and irradiance. Two basic techniques are used to regulate dc-dc converters: Another complicated and expensive method is current-mode control (CMC). It uses voltage and current feedback to improve dynamic performance. Voltage-mode control (VMC) uses only voltage feedback to maintain the simplicity of the system. However, a correctly built compensator is necessary for stability and performance. The ideal approach to reducing complexity and cost, particularly in large-scale

renewable energy systems, is voltage-mode operation without sensors. It is not a simple undertaking to develop a voltage mode controller that is consistent and reliable in many scenarios. The k-factor approach is a systematic method for locating poles and zeros of the compensator such that the bandwidth and phase margin are correct. It works, it's well-liked. Even with k-factor design, human tuning and trial and error is generally necessary to achieve optimal dynamic performance for all input and load circumstances. Having said that, the findings are unimpressive and the method is inefficient. Optimization techniques are used to simplify and improve the controller design.

1.3 Control techniques for electric power converters Metaheuristic optimization methodologies have lately developed as a tool for engineers to solve difficult, nonlinear, and multi-objective issues. Here the algorithms are inspired by evolutionary processes and real-world events. These algorithms are finding more and more applications in power electronics, particularly in areas such as: PID, Type II and Type III are some types of compensators that can be changed. Programmable options include duty cycle, inductance and capacitance. Reduce waste, increase production. MPPT (Measuring Power at Peak Conditions) Some of the popular methods include Grey Wolf Optimizers/GWO, Particle Swarm Optimization/PSO, Ant Colony optimization/ACO and Genomics optimization/GO.

Each of these strategies is an attempt to find the greatest global strategy by looking for the blueprints in nature. Grey Wolf optimizer is a simple, efficient and effective algorithm. It was designed to mimic the hunting tactics and methods of natural grey wolves. Then it ranks the leading choices. Each solution is given a score of alpha, beta, delta and omega and the search field narrows iteratively. There are several methods available but GWO is unique because of its stability, speed of convergence and ability to avoid local minima. In this research, the GWO is used to optimize the voltage mode control loop compensator parameters of the proposed high-gain converter. In the steady state the overshoot and settling time should be decreased and the ripple voltage.

1.4 Assessments The advantages of this study are as follows: An unique design of a DC-DC converter is shown. There is only one switch and it is not insulated. It has one important perk. It boasts simple manufacturing, stable conduction and high voltage gain, and is potentially useful in fuel cells and photovoltaics. Secondly, a small-signal transfer function is derived and the dynamic behavior of the converter is simulated by state-space averaging, to facilitate the controller design. Thirdly, the controller designing, voltage mode controller with k-factor technique to obtain a good

dynamic performance without current sensing. To automate the process of fine-tuning the controller design for best performance in all instances, we use the Grey Wolf optimizer (GWO). Fifth, success for the converter and improved controller is guaranteed as a 150 W hardware prototype is built and tested under various input and load conditions. Then the experiments will be tested.

2. Converter Topology

Single-Switch DC-DC Converter for Electricity Generation from Fuel Cells and Solar Panels
2.1.1 General introduction The expanding number of renewable energy sources (e.g. fuel cells (FC) and photovoltaic (PV) panels) has created the demand for power conversion equipment that is efficient, portable, and reliable. The low voltages of these power sources typically require the need to raise the voltages they offer when connected to DC microgrids, energy storage systems, or inverter interfaces. These systems have to meet certain conditions prior to evaluation. They are perfect due to their tiny size, low switching and conduction losses, high voltage gain, and compatibility with PV and FC sources. Microgrids with fuel cell (FC) or solar photovoltaic (PV) are more advantageous because of longer lifetimes and lesser environmental impact. The DC microgrid as depicted in Figure 1 is fed by the combination of the solar panels and fuel cells. The DC bus constant voltage ensures the utility supply will be reliable. The voltage levels obtained from the solar PV and FC stack are low and variable, which are not enough to fulfil the DC bus voltage requirements. Therefore, a high gain DC-DC converter is used [...].

The high gain DC-DC converter may boost the fuel cell stack and solar PV voltage levels, to provide a constant DC bus voltage. One of the many problems of the typical boost converters is high $r_{ds(on)}$ which results in conduction loss and extra voltage stress [5]. Another issue is the expensive price of the switch used in these converters. However, when significant values of duty ratio are required, the diode reverse recovery becomes a concern [7]. In fuel-cell applications, where efficiency is crucial, high-gain converters tackle these challenges, as well as the need for higher gain. Recently, non-isolated DC-DC converters have been employed more often in a multistage process where the stages are cascaded to provide high gain [8].

One disadvantage of standard boost converters is the high $r_{ds(on)}$ which increases the conduction loss and strains the expensive switch [5]. However, for large duty ratio values diode reverse recovery becomes a difficulty [7]. The need for efficiency is crucial in fuel-cell applications and high-gain converters solve these difficulties as well as the need for higher gain. In recent years, multistage non-isolated DC-DC converters with

cascade coupling have been more common to attain high gain [8]. 14 recommends converters that put less pressure on the output capacitor current and have a voltage gain of $(1+D)/(1-D)$. The five-switch SC step-up topology is most suitable with boost converters [15]. It works at low duty ratio values and it automatically avoids the problem of diode reverse recovery. This circuit configuration with five switches makes the gate driver circuit design more complex and less efficient. 18. References 16, 17 and 18. The voltage gain is given by $1/(1-D)^2$. The output voltage is the maximum voltage that the converter can maintain during its operation.

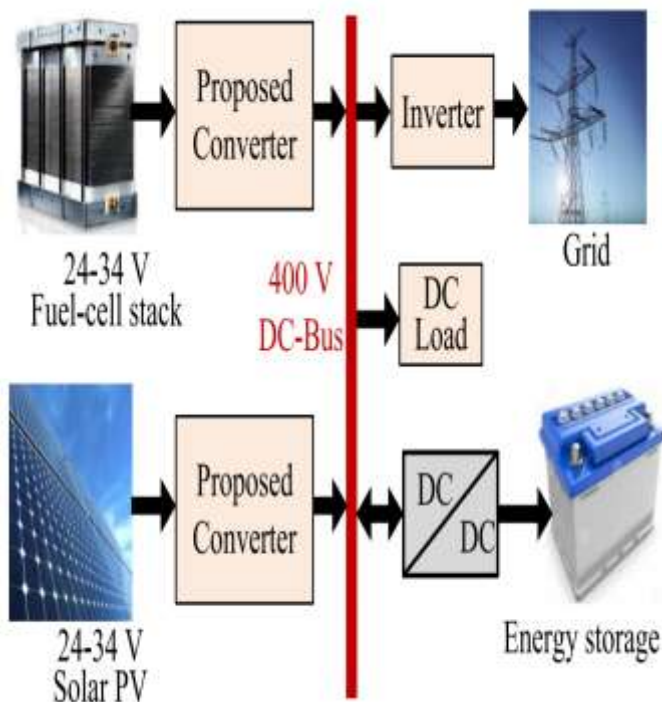


Fig .1. Structure of solar PV and fuel-cell powered DC microgrid.

In [19], the authors presented an active switch inductor QBC with voltage gain $(1+D)/(1-D)$. In [20], the converter is presented for the voltage gain of $(2 \div D)/(1 \div D)$. 2. A problem with this converter is that the input current is pulsating. In the converter described in reference [21], a voltage gain of $(1+2D-2D^2)/(1-D)$ can be attained using 16 components. 2. However, a variable current input is not required. As stated in [22], a QBC must precede a voltage multiplier (VM) cell to produce a voltage gain of $2/(1-D)$. 2. The three bulk supply inductors keep the switch under a high voltage stress equal to the output voltage during converter operation. Another twelve-component converter employs half the output voltage to trigger the switch, resulting in pulsed current [23]. The switched-capacitor high-gain converter of [24] has a voltage gain of $(2 + D)/(1 - D)$ and utilizes sixteen components. 2. The

pulsing supply current of the Converter does not suggest its use with solar PV or FC.

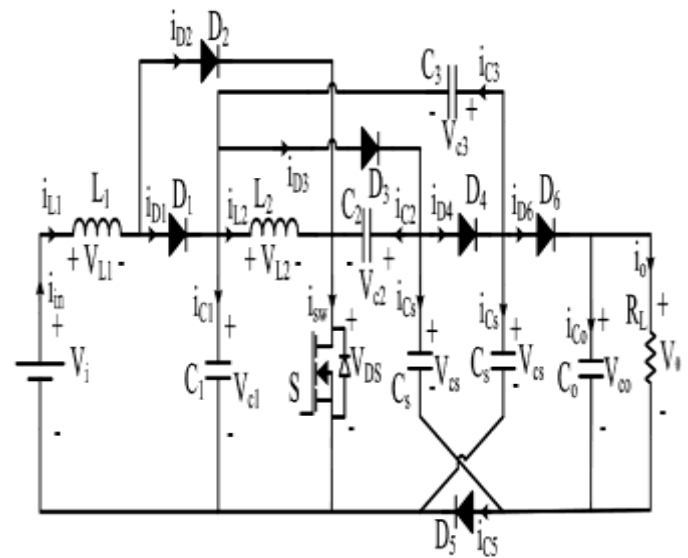


Fig.2. (a) Circuit configuration

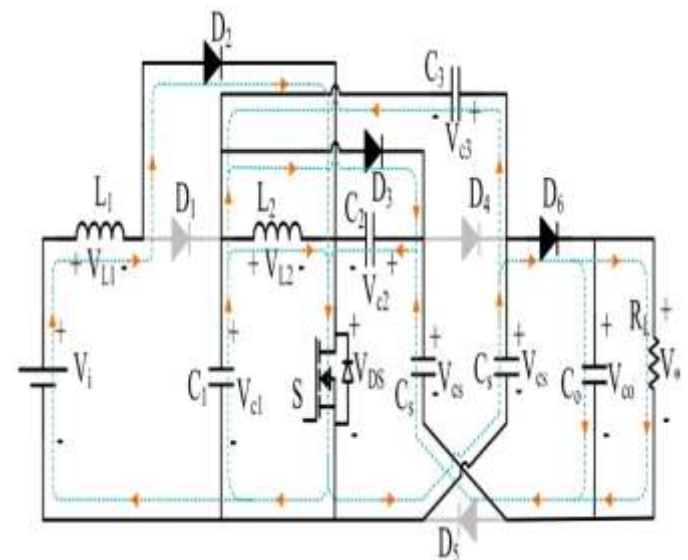


Fig.2. (b) Mode-I

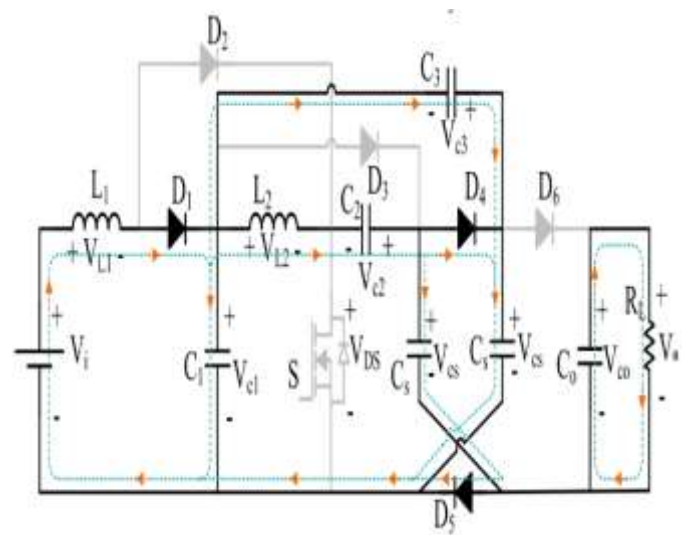


Fig.2. (c) Mode-II.

A new high gain boost converter with eightfold voltage gain is shown in [27] for the integration of renewable energy sources. "This is a two-switch converter here. The high gain coupled inductor converters presented in [28] and [29] were able to convert considerable quantities of voltage. To solve these problems, a new type of DC-DC converter dubbed single switch non-isolated high gain converter is proposed. This converter is a must have, as it provides all necessary functions:

1. The converter in [24] employs two switches, however, it can transfer the input voltage to output voltage with only one switch when $D = 0.5$. It has the capacity to give a constant current. Finally, it may help to relieve the pain that comes with transition. 4. Unlike the converter in [24] that employs three inductors to achieve a tenfold voltage conversion ratio from input to output, this converter only needs two inductors for $D = 0.5$. This work introduces a new design of high gain DC-DC converters using a single non-separated switch to tackle the long-standing difficulties with boost converters. Some of the features of the proposed converter are: High voltage conversion gains reduce duty cycle needs. Single switch design simplifies operations and reduces switching losses. The fuel cells and solar panels are not stressed when operated in continuous conduction mode. Due to the low voltage generated, renewable energy sources are well suited for portable power applications. The large, affordable, and easy-to-install construction is unconcerned with its position

3.2. Definition of Scope 3.2.1 Montaggio del circuito Figure 2(a) shows the schematic of the proposed converter. Here is defined the load resistance (RL), the converter input voltage (V_i) and the converter output voltage (V_o). The circuit of comprises diodes D1, D2, D3, D4, D5 and D6, inductors L1 and L2 and capacitors C1, C2, C3, Cs and Co. 4. Section 3.2. Basic Concepts The particular procedures to follow to implement the suggested converter in CCM are given below. As shown in Fig. 2(b-c), the converter can function in two different modes and each mode requires different configuration of components. The steady-state waveforms of each mode are shown in Fig. 3. The Mode-I converter uses the variable duty cycles (D) and the fixed switching frequencies (T_s) (t_0 - t_1) for the toggle switches. In this scenario, diodes 1, 4, 5 are inactive, whereas switches 2, 3, 6 are active. At this time, the L1 and L2 inductors are charging linearly.

The capacitor C1 delivers the energy from the source to the inductor L2. The energy can be stored in the inductor L1. Phase Two (t_1 -). Simultaneously, capacitor Cs provides energy to load RL, capacitors C2 and capacitor Co. At this instant switch S is off. Diodes D2, D3 and D6 are also off. Then the current is transferred from inductor L1 to capacitor C1. Inductor L2 and capacitor C2 energizes

capacitors Cs and C3. So we obtained the RL load from Capacitor Co. At each point in a shift there are two possible outcomes. The converter must go through this cycle continually, to keep everything running smoothly, to convert electricity all the time, and to keep the output voltage high enough to satisfy the load.

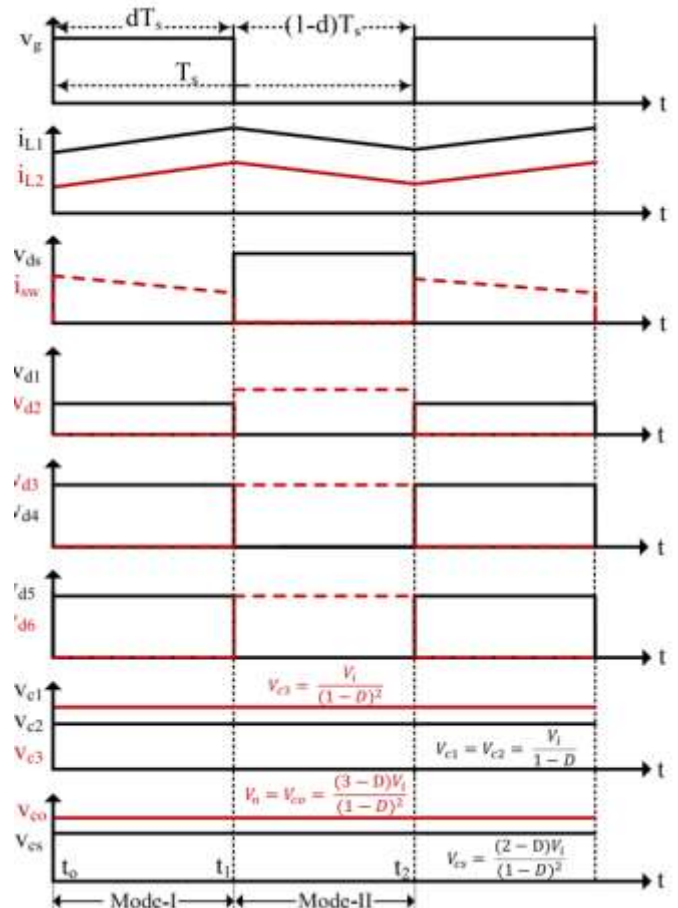


Fig.3.Steady-state waveforms of proposed Converter operating in CCM.

DC voltages are commonly stepped up using standard boost converters, but they have their own drawbacks (see section 3.3 for more on this). Problems include low input voltages (20-40V from PV panels) and large voltage step-ups (>10x): To achieve large improvements the converter has to work at very high duty cycles ($D > 0.9$) with high duty ratio ($D \rightarrow 1$). Parasitic resistances and non-ideal diode behavior contribute to the output voltage being slow and unpredictable.

The efficiency is lowered due to high voltage stress on the switch and diode. Furthermore, the high currents between the inductor and the switch led to a large amount of conduction loss. Operating in less demanding control modes such as Discontinuous Conduction Mode (DCM) reduces the efficiency of the converter even at small loads. Constant, steady current is needed for the operation of photovoltaic or fuel cell systems; hence, pulsed input currents cannot be used. The third concern is the ripple effect of a big input current.

To overcome these constraints and to get high gain instead of increasing duty cycle new topologies based on structural alterations are required.

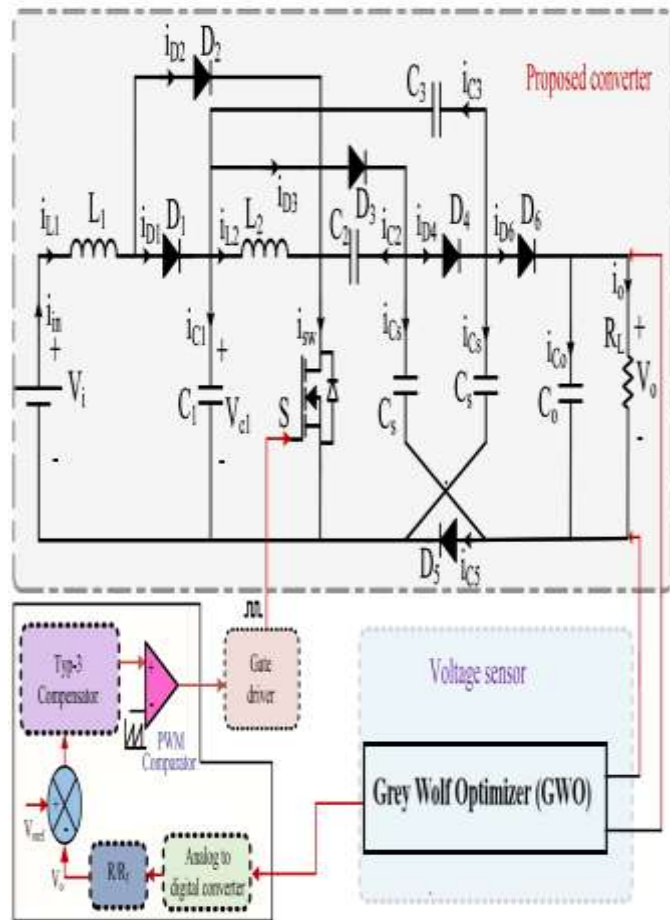


Fig.4. Closed loop output voltage control of proposed converter.

A High-Power DCDC Converter Based on an Optimized Controller: A 150 W Model 7.1. Summary Validation of the performance of DC-DC converters must be done via simulation before hardware implementation. Using MATLAB/Simulink, a 150 W software prototype of the proposed new single-switch non-isolated high-gain converter is implemented. Some of the goals of the model making system are: Make sure you have a strong rationale for static and dynamic performance, Test the k-factor voltage-mode controller to determine its performance. • Learn what happens when you change the input and load, • Confirm the enhancement of the system performance by the controller tuning based on Grey Wolf optimizer (GWO). Much simulation work is done in this area, for example, modelling of converters, incorporating controllers, evaluating performance and interpreting results. The simulation of the suggested 150 W single switch non-isolated high gain dc-dc converter has been successfully done by utilizing Matlab/Simulink. Results showed that: • continuity for varied inputs and loads, • fast transient response and minimal ripple, • performance of the GWO optimized voltage mode controller, • Installation of the required hardware for the

experiments. Simulation results show that the converter can meet the performance standards needed for renewable energy systems like photovoltaics and fuel cells with a controller optimized by metaheuristics.

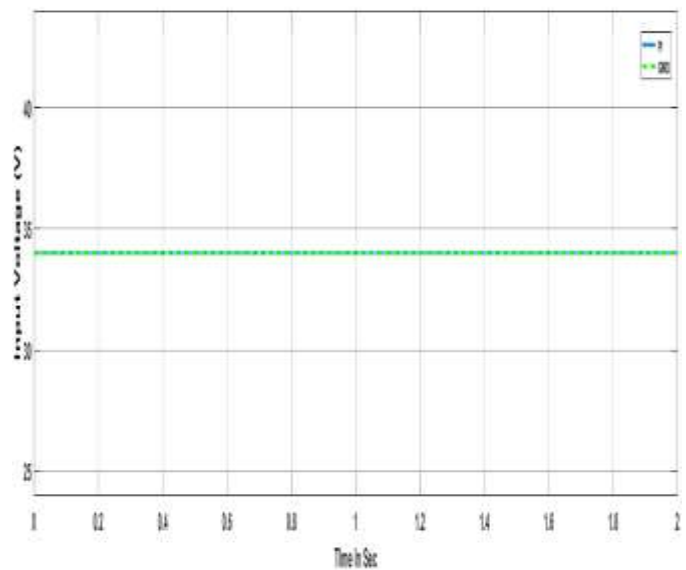


Fig.5. Input Voltage Response for PI and GWO Controllers

The two controllers were tested using a fixed input voltage to determine the performance of the controllers as in the figure.

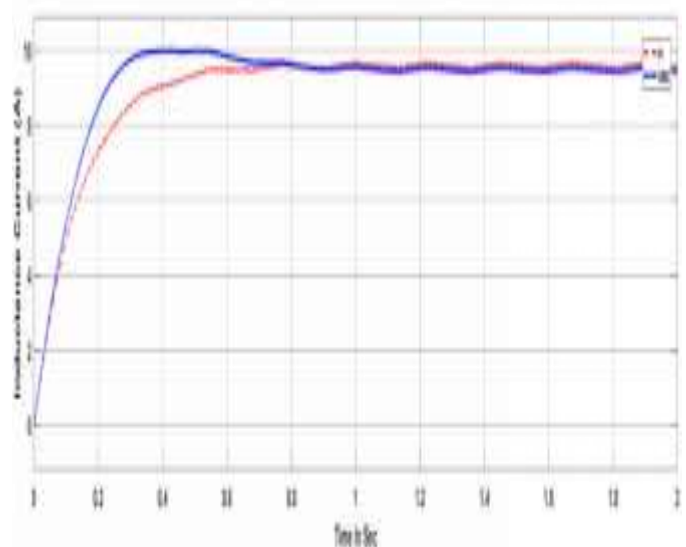


Fig.6. Inductor Current Response under PI and GWO Control

Here are depicted the rising, overshoot and settling periods of the inductor current and its variations.

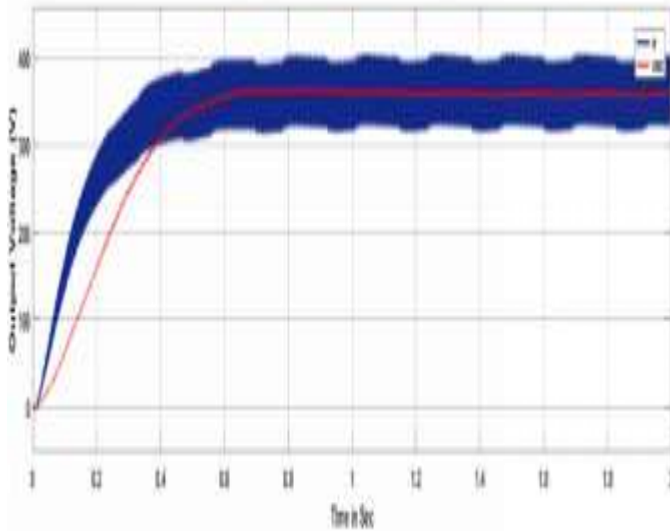


Fig. 7. Output Voltage Response for PI and GWO Controllers

The figure shows how each controller can control the output voltage under steady-state and transient conditions.

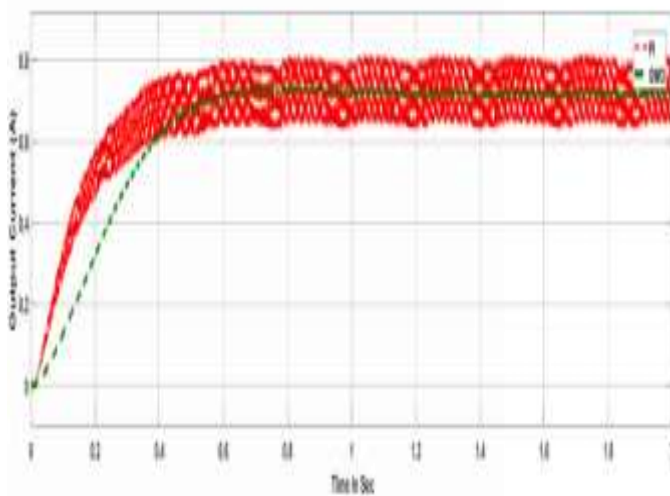


Fig. 8. Output Current Response under PI and GWO Control

3. CONCLUSIONS

Last Words and Point of View The results show that the PI controller optimized by GWO has better performance than traditional PI controller in static and dynamic environment. The GWO optimized controller is found to be better than the conventional PI controller in all the aspects including inductor current, output voltage and output current. Its many advantages include shorter rising time, greater damping, less overshoot and less ripple. The GWO technique has greater parameter optimization. So the system stabilizes faster with less

oscillations and less steady-state inaccuracy. The results indicate that GWO can be applied to find optimal controller gains in dynamic systems like power electronic converters. The GWO-based PI controller has better performance in terms of stability, accuracy, and lifespan than the conventional PI tuning methods. It enhances performance by greater exploration of the solution space and better control of the solution space to avoid local optima. This makes it well-suited for applications that require reliable performance. Also, the GWO based modified PI controller has better adaptation to change of operating conditions and disturbance rejection.

The results indicate the potential applicability of GWO optimized PI controllers for power electronic systems in general. Potential aims for the future We have pointed out several possible directions for further research on this topic. The easiest way to identify the optimal controller tuning strategy for different operating scenarios is to compare the performance of GWO with other powerful optimization algorithms such as PSO, ABC, DE or hybrid swarm-intelligence methods. Adaptive or self-tuning GWO-controllers may increase real-time performance in the presence of varying loads and disturbances. You can also try adding a microcontroller or field-programmable gate array (FPGA) to the controller, or you can test it in a hardware-in-the-loop (HIL) environment to make sure it works properly in the real world. Optimizing across numerous targets can give greater knowledge regarding controller design. Such goals include, for example, temperature limits, efficiency, ripple and dynamic response. Finally, the technique can be tested on systems with nonlinear, multivariable or grid-connected converters, to assess its performance on increasingly complicated power electronics tasks and its scalability.

REFERENCES

- [1] Z. Geng, Q. Chen, Q. Xia, D. S. Kirschen, and C. Kang, "Environmental generation scheduling considering air pollution control technologies and weather effects," *IEEE Trans. Power Syst.*, vol. 32, no. 1, pp. 127–136, Jan. 2017.
- [2] G. Du, W. Cao, S. Hu, Z. Lin, and T. Yuan, "Design and assessment of an electric vehicle powertrain model based on real-world driving and charging cycles," *IEEE Trans. Veh. Technol.*, vol. 68, no. 2, pp. 1178–1187, Feb. 2019.
- [3] H. Bi, P. Wang, and Y. Che, "A capacitor clamped H-type boost DC–DC converter with wide voltage-gain range for fuel cell vehicles," *IEEE Trans. Veh. Technol.*, vol. 68, no. 1, pp. 276–290, Jan. 2019.
- [4] F. Herb, P. R. Akula, K. Trivedi, L. Jandhyala, A. Narayana, and M. Wöhr, "Theoretical analysis of energy

management strategies for fuel cell electric vehicle with respect to fuel cell and battery aging,” in *Proc. World Electr. Vehicle Symp. Exhib. (EVS27)*, Nov. 2013.

[5] X. Wu, M. Yang, M. Zhou, Y. Zhang, and J. Fu, “A novel high-gain DC–DC converter applied in fuel cell vehicles,” *IEEE Trans. Veh. Technol.*, vol. 69, no. 11, pp. 12763–12774, Nov. 2020.

[6] P. Shaw and M. Veera chary, “Analysis and controller design for positive output boost converter with low current stress on output capacitor,” *IEEE Trans. Ind. Appl.*, vol. 57, no. 3, pp. 2625–2637, May 2021.

[7] M. Lakshmi and S. Hemamalini, “Non isolated high gain DC–DC converter for DC microgrids,” *IEEE Trans. Ind. Electron.*, vol. 65, no. 2, pp. 1205–1212, Feb. 2018.

[8] W. Li and X. He, “Review of non-isolated high-step-up DC/DC converters in photovoltaic grid-connected applications,” *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1239–1250, Apr. 2011.

[9] R.-J. Wai, C.-Y. Lin, R.-Y. Duan, and Y.-R. Chang, “High-efficiency DC–DC converter with high voltage gain and reduced switch stress,” *IEEE Trans. Ind. Electron.*, vol. 54, no. 1, pp. 354–364, Feb. 2007.

[10] J. P. Rodrigues, A. J. Perin, S. A. Mussa, and M. L. Heldwein, “Three-level ZVS active clamping PWM for the DC–DC buck converter,” *IEEE Trans. Power Electron.*, vol. 24, no. 10, pp. 2249–2258, Oct. 2009



Maisakshi Pavan Kumar

received the B.Tech and M.Tech from JNTU Hyderabad, He is currently working as an Assistant Professor in the Department of Electrical and Electronics Engineering at KLR College of Engineering and Technology, where he has been serving for the past five years. He has published in 11 international publications.



Arpula Krishnaiah

received the B.Tech and M.Tech from JNTU Hyderabad, working as Assistant professor and Head of the Electrical and Electronics engineering department in KLR Engineering College, he has Teaching in 17 years of experience in various institutions, published in 11 international publications.



Gujjarlapudi.Sumanth,

Received B.Tech and from JNTU Hyderabad, pursuing M.Tech in Electrical Power Systems. in KLR College of Engineering and Technology.