Performance Analysis of Solar Power Optimizer for DC Distribution System

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ABSTRACT: Solar Power Optimizer for DC Distribution System is composed of a high step-up solar power optimizer (SPO), efficiently harvests maximum energy from a photovoltaic (PV) panel outputs energy to a dc-micro grid. Its structure integrates coupled inductor and switched capacitor technologies to realize high step-up voltage gain. The leakage inductance energy of the coupled inductor can be recycled to reduce voltage stress and power losses. A low voltage rating and low-conduction resistance switch improves system efficiency by employing the incremental conductance method for the maximum power point tracking (MPPT) algorithm. Because of its high tracking accuracy, the method is widely used in the energy harvesting of PV systems. The power reduction caused by the shadow effect on PV panels is an inevitable problem in a centralized PV system. The use of a micro inverter or ac module has recently been proposed for individual PV panels.

KEYWORDS: SPO, PV array, MPPT, Micro grid, PI Controller, Fuzzy Controller.

I.INTRODUCTION

The Solar Power Optimizer for DC Distribution System,a development of photovoltaic (PV) power generation system, which uses a renewable resource, has been extensively used in emergency facilities and in generating electricity for mass use[1]. A conventional PV generation system is either a single- or a multi string PV array that is connected to one or several central PV inverters. Numerous series-connected PV modules are connected in the PV array to achieve the DC link voltage that is high enough to be connected to electricity through the DCAC inverter[2]-[3]. Though, reduction in power caused by the shadow effect is an unavoidablenature in a centralized PV system. The use of a micro inverter or ac module has recently been proposed for individual PV panels. Although this discrete PV power generation solution may partially eliminate the shadow problem, a micro inverter structure constrains the system energy's harvesting efficiency and entails high costs [4]-[7]. The SPO attempts to improve the use of distributed renewable resources and lower system cost. It may also potentially improve the efficiency of PV systems, has an anti-shadow effect, and can monitor the status of PV modules. Moreover, the dc-grid voltage is regulated by bidirectional inverter and battery tank. [8-11] In case of low-loading condition, the redundant energy will store into battery or through bidirectional inverter to ac grid. A solar power optimizer (SPO) was developed as an alternative to maximize energy harvest from each individual PV module. [12-18].

Voltage lift technique used in Micro-power-consumption technique, requires high-power-density dc/dc converters in electronic circuit design. A switched capacitor with voltage lift technique are used to construct dc/dc converters of small size and has a numerous advantages [19]. A step-up dc-dc converter with a negative-to-positive voltage-conversion path for the negative dc-voltage source has the voltage boost ability significantly using the switched capacitor and self-lift techniques. It is featured with single power switch operation, common ground, transformerless structure, and clear energy delivery process[20].Voltage-lift-type switched-inductor cells have been proposed to improve the boost abilities of those traditional transformerless DC-DC converters and fabricated as integrated cells and inserted into all the basic converters [21]. A high step-up DC/DC converter is needed to boost low input voltage to high voltage output with a voltage multiplier and a coupled inductor. The secondary voltage of the coupled inductor is rectified using a voltage multiplier and the boost voltage is obtained with low duty cycle [22],[23]. A high step-up dc-dc converter for fuel cell energy conversion utilizing a multiwinding coupled inductor with voltage doubler to achieve high step-up voltage gaincan practically achieved for low-input-voltage power conversion process. The voltage on the active switch is clamped, and the energy stored in the leakage inductor is recycled and the conversion efficiency is improved[24]. An ac PV module with a high voltage gain converter is for the module's grid connection through a dc-ac inverter employing a floating active switch to isolate energy from the PV panel when the ac module is off and the design protects installers and users from electrical hazards. The converter achieves a high step-up voltage-conversion

ratio and the leakage inductor energy of the coupled inductor is efficiently recycled to the load explains the module's high-efficiency performance [25].

II.SOLAR POWER OPTIMIZER FOR DC DISTRIBUTION SYSTEM

Fossil fuels continue to be depleted, and their use has been instrumental to climate change, a problem that grows more severe each year. A photovoltaic (PV) power generation system, which uses a renewable resource, has been extensively used in emergency facilities and in generating electricity for mass use. A conventional PV generation system is either a single- or a multi string PV array that is connected to one or several central PV inverters. Numerous series-connected PV modules are connected in the PV array to achieve the DC link voltage that is high enough to be connected to electricity through the DCAC inverter. The decrease inoutput power caused by the shadow effect is an inevitable problem in a centralized PV system. The use of a micro inverter or ac module has been proposed in recent times for individual PV panels.Although this discrete PV power generation solution may partially eliminate the shadow problem, a micro inverter structure constrains the system energy's harvesting efficiency and entails high costs.
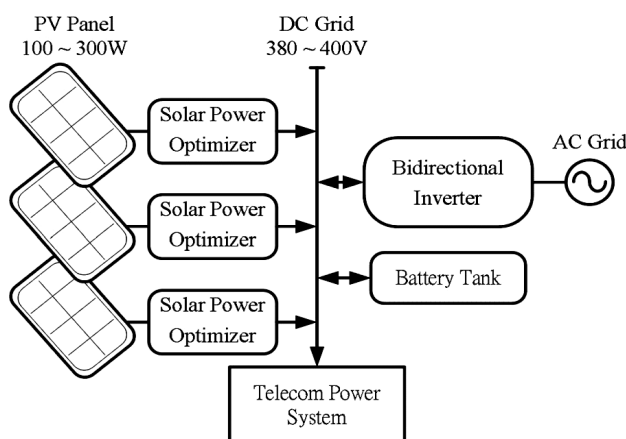

Figure 1: Configuration of multiple parallel SPO for a dc-micro grid system.

A solar power optimizer (SPO) was developed as an alternative to maximize energy harvest from each individual PV module. An SPO is used as a dc–dc converter with maximum power point tracking (MPPT), which increases PV panel voltage to optimum voltage levels for a dc microgrid connection or through a dc–ac inverter for electricity [3]–[6]. Figure 1 shows a single PV panel's energy, which passes through an SPO to a dc microgrid system. A 400 V dc-microgrid system was proposed as an energy-efficient distribution option for data centre systems and telecommunication facilities. The SPO attempts to improve the use of distributed renewable resources and lower system cost. It may also potentially improve the efficiency of PV systems, has an anti-shadow effect, and can monitor the status of PV modules. Moreover, the dc-grid voltage is regulated by bidirectional inverter and battery tank. In case of low-loading condition, the redundant energy will store into battery or through bidirectional inverter to ac grid.The Optimizers increase the maximum power point tracking (MPPT) of inverters and constantly monitor the array voltage and current and work to mitigate mismatch effects so that each module can operate at its maximum power level. This results in optimal energy harvest. "Higher MPPT resolution helps the system recover more energy that would otherwise be lost from electrical imbalances due to environmental mismatches. This results in greater energy production." Traditional inverters monitor the AC output side of the array and in some cases may provide string level data. However, they do not provide enough data to detect problems at the module level and maintain production levels. This can lead to energy losses that are invisible to system owners and difficulties in diagnostics for maintenance personnel. Power optimizers, in combination with a monitoring system, can provide greater transparency into system performance, pinpointing any issues from a remote location. This enables more efficient maintenance and higher system uptime. "Power optimizers only deploy minimal electronics on the rooftop to handle the MPPT and DC to DC conversion, leveraging a centrally located inverter at the end of the string, allows installers to reduce hardware, improve reliability, and slash costs. By eliminating any string-design constraints that would decrease the size of a PV system, power optimizers also allow designers to install more modules on the rooftop. For installers, this means increased revenues. For end-users, the added system output equates to lower electricity bills."

A solar power optimizer is a DC-DC converter technology to maximize the energy harvesting from solar photovoltaic / wind turbine systems. Solar modules are connected in series in an array, they produce optimal power when all the modules performance is good. When temperature changes, or fall leaves, winter snow or shade covers part of a module, causes outputs less energy and underperform, modules heat up and drag down the performance of the other modules by squeezing the flow of energy through the array. This can cause the array to lose power. This drawback can overcome by using power optimizers. Power optimizers are DC-DC converters attached at the module level, correct for module "mismatch" by allowing each module to function at its maximum power point (MPP) and convert the energy to the optimal voltage and current for the array. This enables the entire array to yield more energy. The SPO can individually tuning the performance of the panel /wind turbine through maximum power point tracking techniques, and optimally tuning the output to match the performance of the string inverter. SPO's are particularly used when the performance of the power generating components such as the PV Panel, Wind Generator in a distributed system will vary widely, differences in equipment, shading effect of light or wind, or being installed facing different directions or widely separated locations. Power optimizers for solar applications, can be similar to microinverters, in that both systems attempt to isolate individual panels in order to improve overall system performance. A power optimizer integrated with the solar panel into a solar module or a smart module . A microinverter essentially combines a power optimizer with a small inverter in a single case that is used on every panel, while the power optimizer leaves the inverter in a separate box and uses only one inverter for the entire array. The advantage of using this hybrid approach is lesser overall system costs and avoiding the distribution of electronics.

III.CONTROL OF PROPOSED SOLAR POWER OPTIMIZER

This method deals a high power application with low input voltage.The proposed SPO structure is based on a high step-up dc–dc converter with a MPPT control circuit. The converter includes a floating active switch S and a coupled inductor T_1 with primary winding N_1, which is similar to the input inductor of a conventional boost converter capacitor C_1, and diode D_1 recycle leakage inductance energy from N_1. Secondary winding N_2 is connected to capacitors, C_2 and C_3, and two diodes D_2 and D_3. The Rectifier diode D_4 is connected to the output capacitor C_0 and the load R. The duty ratio is modulated by the MPPT algorithm, which uses PI and Fuzzy controller that is employed in the proposed SPO. It detects PV module voltage V_{PV} and current I_{PV} to determine the increase and decrease in the duty cycle of the dc converter. The proposed converter has the following features

1. It is a voltage conversion ratio efficiently increased by using the switched capacitor and coupled inductor technique.
2. The leakage inductance energy of the coupled inductor can be recycled to increase efficiency, and the voltage spike on the active switch is restrained.
3. The floating active switch S isolates the PV panel's energy during non-operating conditions, thereby preventing any potential electric hazard to humans or facilities. The MPPT control algorithm exhibits high-tracking efficiency. Hence, it is widely used in the energy harvesting of PV systems.
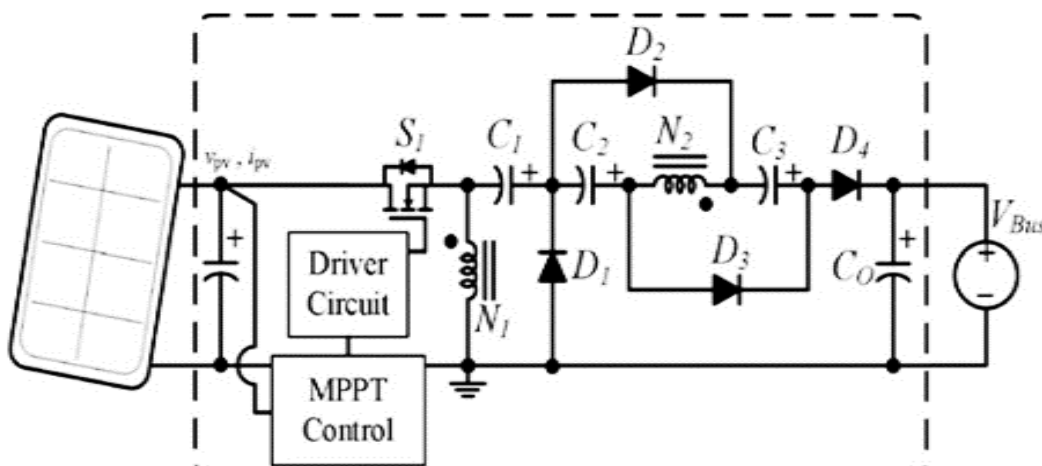

Figure 2: Circuit diagram of the Proposed Solar Power Optimizer

The operating principles includes Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM) with typical waveform of several major components in CCM operation during one switching period. To simplify the circuit investigation of the proposed converter, the following assumptions are made

1. All the components used in optimiser circuit are ideal, except for the leakage inductance of coupled inductor T_1 is taken into account. On-state resistance R_{ds} (ON) and all the parasitic capacitances of main switch S are disregarded, as are the forward voltage drops of diodes D_1 to D_4.
2. Capacitors C_1 to C_3 and C_0 are sufficiently large that the voltages across them are considered constant,
3. The equivalent series resistance (ESR) of capacitors C_1 to C_3 and C_0, as well as the parasitic resistance of coupled inductor T_1, is neglected
4. Turns ratio n of coupled inductor is equal to N_2/N_1.

A solar power optimizer can be controlled by a number of techniques of which the PI and Fuzzy Logic controller are discussed in this paper.

IV.SIMULATION RESULTSAND DISCUSSION

Simulation has become a very powerful tool on the industry application as well as in academics, nowadays. It is now essential for an electrical engineer to understand the concept of simulation and learn its use in various applications. Simulation is one of the best ways to study the system or circuit behavior without damaging it .The tools for doing the simulation in various fields are available in the market for engineering professionals. Many industries are spending a considerable amount of time and money in doing simulation before manufacturing their product. In most of the research and development (R&D) work, the simulation plays a very important role. Without simulation it is quiet impossible to proceed further. It should be noted that in power electronics, computer simulation and a proof of concept hardware prototype in the laboratory are complimentary to each other. However computer simulation must not be considered as a substitute for hardware prototype using MATLAB tool.
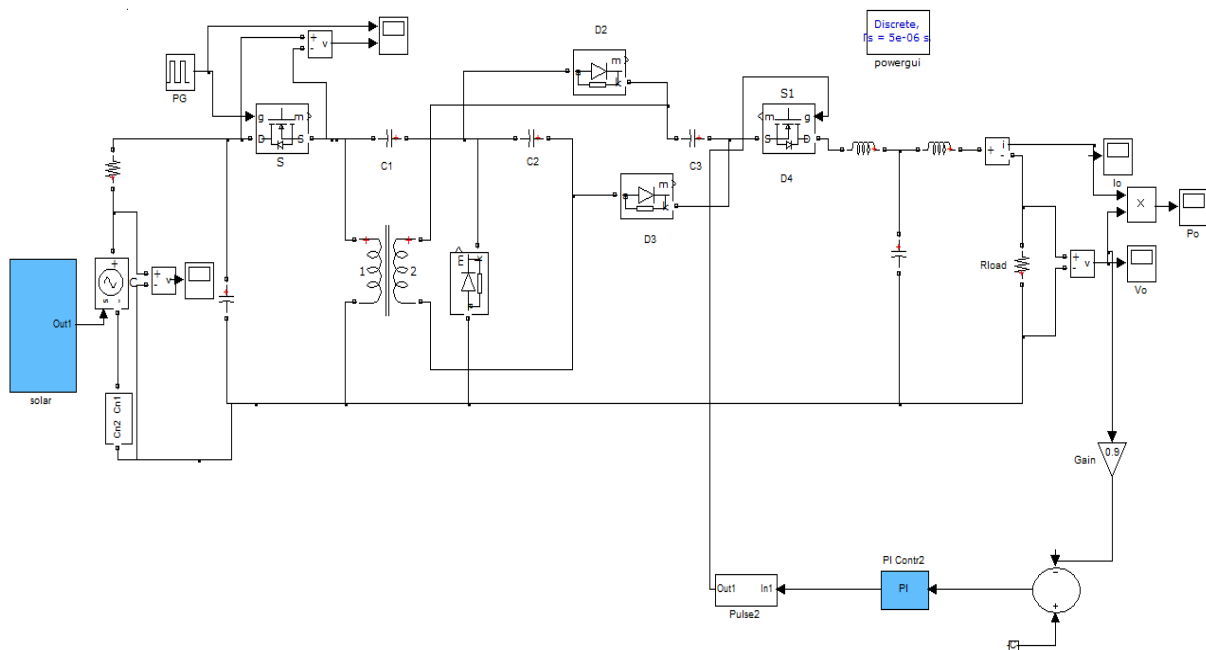

Figure 3: Closed loop control of SPO with PI controller
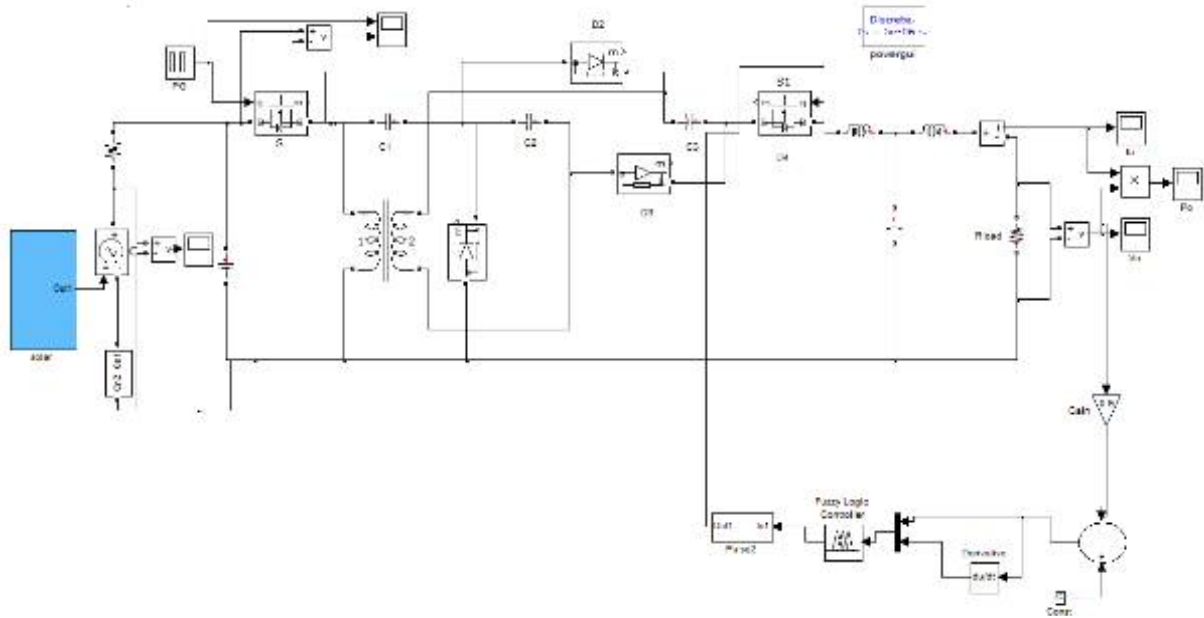
Figure 4: Closed loop control of SPO with Fuzzy Logic Controller

The closed loop control of the solar power optimizer system using PI controller and Fuzzy Logic Controller are as shown in the Figure 3 and Figure 4 respectively.
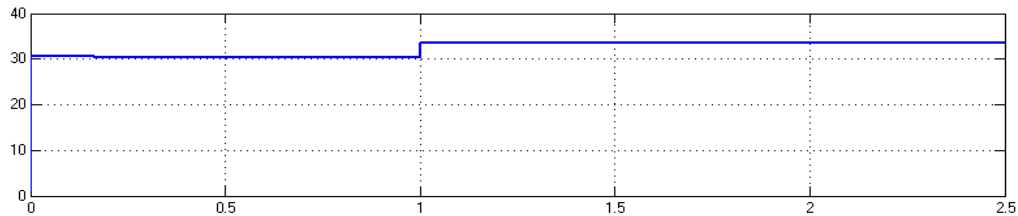

Figure 5: Input voltage to the SPO

The closed loop control of SPO using the PI controller are as shown from Figure 6 to Figure 9. The input voltage is shown in Figure 5, where there is a step change in the input voltage at time T=1 Seconds.
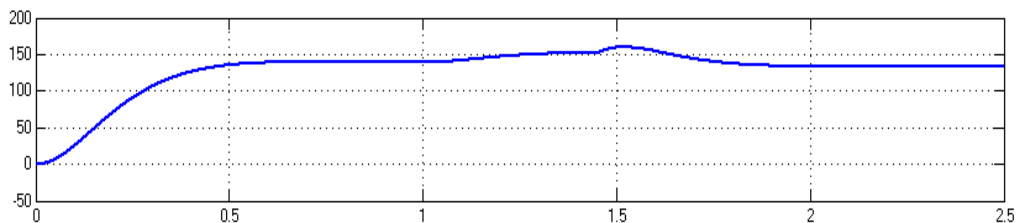

Figure 6: Output voltage of the SPO using PI Controller

The output voltage is shown in Figure 6, where a step change in the input put voltage at time T=1 Seconds cause the output voltage change disturbed between 1.2 to 1.8 Seconds.

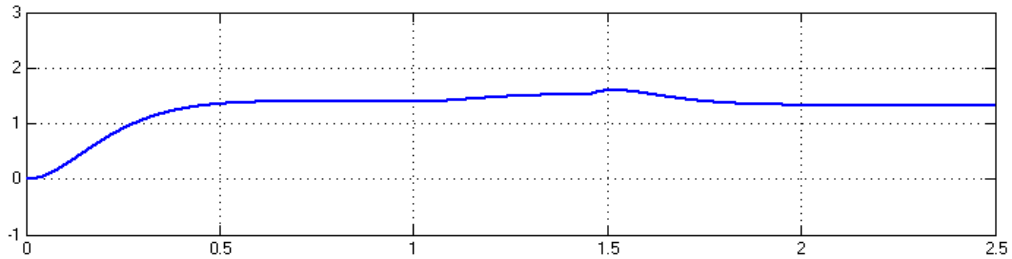Figure 7: Output current of the SPO using PI Controller

The output currentin Figure 7 shows the disturbance around 1.5 Seconds for the step change in the input voltage.

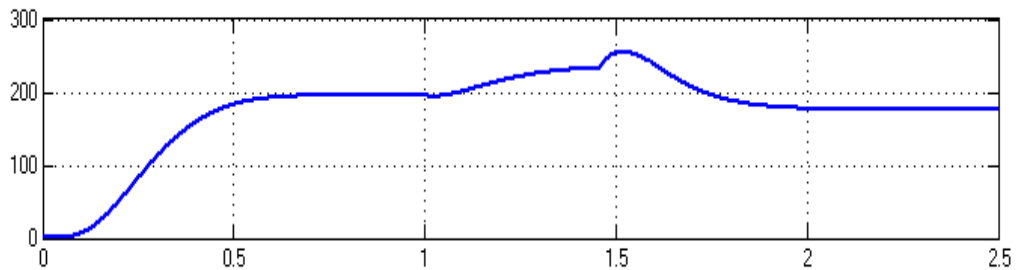

Figure 8:Output power of the converter using PI Controller

The output power as in Figure 8 shows the variation of the output power with respect to power, and the disturbance here in the output power due to change in the input voltage is noted.
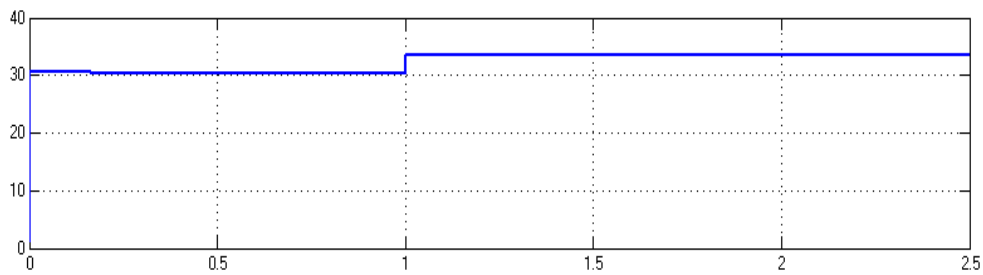

Figure 9: Input voltage to the SPO

Similarly, the closed loop control of SPO usingFuzzy Logic controller are explained with the help of step change input voltage from Figure 9 to Figure 12, where figure 9 shows the input voltage to the SPO.
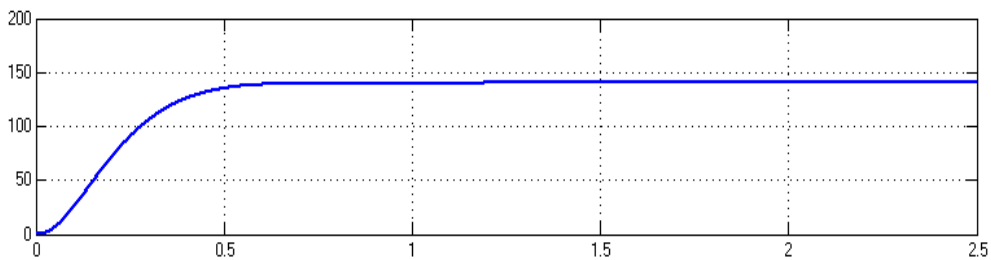

Figure 10: Output voltage of the SPO using Fuzzy Logic Controller

The input voltage is shown in Figure 9, where there is a step change in the input voltage at time T=1 Seconds. The output voltage is shown in Figure 10, where a step change in the input put voltage at time T=1 Seconds cause the output voltage change disturbed and reach the same voltage at the same time.
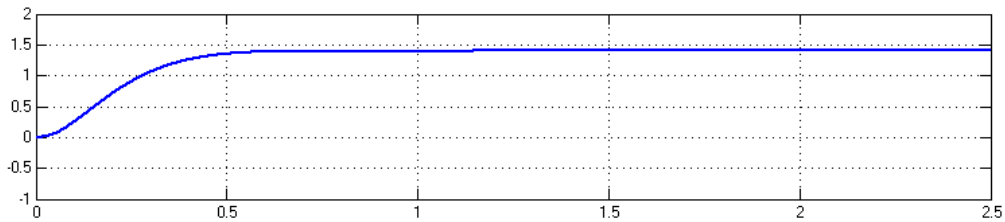

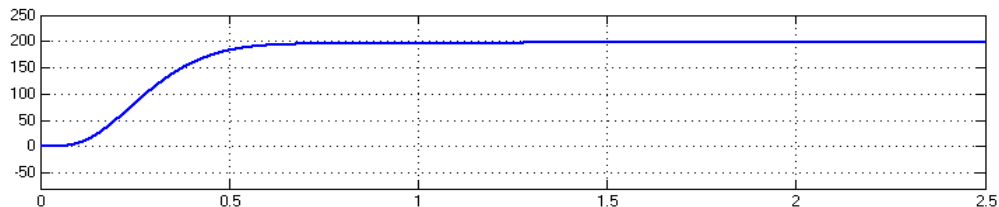Figure 11: Output current of the SPO using Fuzzy Logic Controller

Figure 12: Output power of the SPO using Fuzzy Logic Controller

The Figure 11 and Figure 12 shows the output currentand output power curves, at time t=1 seconds the current and power reaches the set value as soon as they are disturbed in Fuzzy Logic Controller.

Table I: Summary of the time domain parameters

Converter	T_r	T_s	T_p	V_p	E_{ss}
PI controller	0.4	2	1.6	5	2.8
Fuzzy controller	0.24	0.6	0	0.06	0.08

Table I gives the summary of the time domain parameters rise time, settling time, peak time, peak voltage and steady state error. The rise time for a fuzzy controller is 0.24 seconds whereas it is 0.4 seconds in PI controller and the settling time of fuzzy controller is 0.6 Seconds and 2 seconds for PI controller. The steady state error for PI controller is 2.8 seconds and 0.08 seconds for fuzzy controller.

V.CONCLUSION

The high step-up SPO uses the coupled inductor with anappropriate turn's ratio design and switched-capacitor technology toachieve a high-voltage gain that is 20 times higher than the input voltage.The proposed circuit elements are designed usingrelated equations, developed using the functional components of Simulinklibrary. The Simulation is successfully done by closed loop PI and Fuzzy controller. The closed loop system are simulated and theirresults are presented. From the Table I, it is concluded that the response of FuzzyLogic Controller in solar power optimizer is superior than aPI controlledsystem.

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