Design of topology for maximum energy efficient charge pumps as storage device for renewable energy applications

M.Murali*, R.Arulmozhiyal
Sona College of Technology, Salem.

ABSTRACT

Energy demand is growing rapidly in current scenario in the world. The renewable energy will be key factor for reducing crisis. The Electrical power generated through renewable energy requires more efficient and effective storage of power. The Charge pumps are switched capacitor elements that stores power is referred as green energy storage device. This paper design topology for enhancing performance of the charge pump output power, thereby increasing efficiency power output. This designed topology can be applied for solar energy, Wind Power plant, Bio-mass for harvesting maximum energy from these resources and delivers with effective efficiency. Charge pump is a type of DC-DC converters that can boost the input voltage. It has the preference of using on-chip transistors and capacitors only that can be cut out for low cost integration. The proposed topology is based on the basic linear charge pump and helps in increasing the power efficiency of the charge pump through decreasing the MOSFET ON resistance and increasing the knee frequency. The results of designed topology increases the output power by 12.4% and efficiency of charge pumps compare with conventional topology.

Key Words: Charge Pump, DC-DC converter, Storage, MOSFET, renewable energy

INTRODUCTION

Power Management is contemplated one of the advance topics in the integrated circuits especially in the field renewable energy storage research. As the electronics side is targeting mobile applications and standalone systems like wireless sensor operation, they need more efficient power supply with relatively higher power density than normal storage devices such as batteries. One of the most extensive blocks in the power management area is the power converter. There are several power converters one of such is charge pumps. The charge pumps are storage device which stores energy in capacitor and restores when energy is required. The Design implemented in charge pumps is inefficient which has more losses. To overcome the conventional topology performance a circuit design changes has been made in charge pumps. The proposed designs topology is suitable for renewable energy harvesting applications such as solar, wind and biomass, since energy transducers give ultra-low terminal voltages. The feature of this paper is to increase the charge pump output current and power efficiency. Power converters have type called DC-DC converters that has three different operations. The low drop-out (LDO) voltage regulator is one of these operations. LDO has the advantage of offering low Electromagnetic (EMI) problems since it is a switching-free topology. However, its drop out voltage has to be small to provide high efficiency output of DC-DC converters. It also does voltage step-down only. The second type of the power converters is the DC-DC buck - boost converters which can do voltage buck and boost in circuit. They generate high power efficiency provided that the inductor used has a high quality factor, so they have to be implemented off-chip. This type of converter requires large area. It also generates electromagnetic interference (EMI) and power supply noise. The third type is the switched capacitor charge pump (SCCP). SCCP consists of MOSFE transistor switches performs buck and boost operation of voltage.

SCCP has the advantage of low cost integration since there are no coils used and EMI problems have been reduced in SCCP type. SCCP has two non-inverting clock phases in order to do power conversion process. The first invented linear charge pump is Dickson charge pump.

Conventional Converters Topology: There are different types of optimized topology for linear charge pumps that can be identified in. Other degrees of optimization of topology are done on looking the optimum number of stages based on the voltage in(Vin) and voltage out(Vout) values are investigated in SCCP. Figure 1 show an optimized 3-stage linear charge pump topology which is conventional topology used. It can be shown that the voltage is boosted and bucked across each stage. Charge pump design has many performance parameters. The most important parameters are knee frequency (the frequency at which the output current reaches (1/√2) of the maximum current value), High power handling capability, and switching/conduction power losses of the charge sharing switches.

\[ I_{cpo} = f_{clk} * Q_{avg} = \frac{1}{3} C f_{clk} (4V_m - V_{buffer}) \]  \hspace{1cm} (1)

where fclk is the operating frequency. Qavg is the average pumped charge to the buffer. C is the value of the flying capacitors used. Vin is the input voltage value. Vbuffer is the target amplified voltage at the buffer side. The operation of the charge pump is based on
charge splits between the capacitances, thus careful model and selection of switches and capacitor sizes is required for efficient power delivery operation of the DC-DC converter.

\[
Ron = \frac{1}{\mu_{COX}(\frac{W}{L})(V_{GS}-V_{TH})-\frac{1}{2}(V_{DS})}
\]  

(2)

Where, \( R_{ON} \) is the Resistance during ON time of the MOSFET switch. \( \mu_{COX} \) is a technology constant. \( W/L \) is the switch size. \( V_{GS} \) is the gate-source voltage difference. \( V_{TH} \) is the threshold voltage. \( V_{DS} \) is the drain-source voltage difference. The parameters of operation of switches are calculated using ON time Resistance and current of MOSFET switches. The Power conduction of MOSFET switches is given as

\[
P_{conduction} = \frac{I_{ON}}{\mu_{COX}(\frac{W}{L})(V_{GS}-V_{TH})-\frac{1}{2}(V_{DS}+V_{S})}
\]  

(3)

where \( I_{ON} \) is the ON current of the MOSFET switch. It can be shown that decreasing the ON resistance also decreases the conduction power loss, thus the output power is expected to be increased

**Proposed Converters Topology:** This Proposed converters topology deals with the new circuit topology to increase the knee frequency of the linear charge pump and the output current as well. The proposed topology is the multi-level clock based linear charge pump. The multi-level clock type topology deals with driving clock voltage across the stages to enhance the gate voltages of the switches as shown in figure 4.

**Figure 4 Multi-level clock phase generator circuit**

Figure 4 shows the proposed multi-level clock phase generator. This generator applied to the 3 stage linear SCCP shown in Fig. 1. The design of the topology is based on two original non-overlapping clocks Clk1,Clk2, those clocks are applied only to the first stage. The generated Clk11,Clk22 are applied to the second stage, accordingly the generated Clk111,Clk222 are applied to the final stage. In order to generate Clk22 from Clk2, the capacitor C22 is initially charged through M(1,2) in the previous phase. Then, the voltage is boosted-up on the next phase through M(3,4) producing an amplified version of Clk2. The pass transistor M5 is inserted to guarantee a grounded output while charging C22 in the previous phase. The pass transistor M5 is inserted to guarantee a grounded output while charging C22 in the previous phase. The proposed design guarantees perfect pull up through M(3,4) and perfect pull down through M5. The same scenario is applied to Clk11. Similarly, Clk111, Clk222 are generated however the excitations are the new amplified versions. The size of this circuit should be small enough to prevent power consumed from the input source and maximize the absorbed power by the charge pump.

**Simulation Results:** This section is discussed with the simulation results of the proposed topology enhancement. The test bench settings are stated. The test bench is based on Fig.1 and Fig.4 to create a new charge pump. The input voltage is set to two different values (0.38V, 0.42V) for ultra-low input voltages. The switch size is set to 300μm width; the capacitor size is set to 700 pF. Figure 5 shows the charge pump output current vs the clock frequency for three different input voltages for the linear charge pump and the same new topology is implementation is proposed in this paper for an optimized linear charge pump. The idea is based on decreasing the ON resistance of the MOSFET switches in splitting of capacitance and output voltage. This is in order to increase the power capability of the charge pump and to increase the knee frequency. The controlling parameter in decreasing the ON resistance is the gate voltage of the switches. It is controlled by generating a Multi-level clock phases across the subsequent stages, in order to compensate for the increase in the source and drain voltage across each stage for the proposed technique. The concept is verified by implementing a switched capacitor circuit responsible for generating higher voltage levels of the input clock phases. The circuit shows its reliability across process corners. Further the proposed topology can be integrated the charge pump in a renewable energy applications system, to verify its stability to deliver efficient power for user levels. Table I shows comparison of knee frequency and output current of Charge pump for a solar photo voltaic applications.
CONCLUSION

The Circuit topology implemented in this paper for an optimized linear charge pump for renewable energy applications. The concepts proposed in this paper based on reduce the ON resistance of the MOS switches during splitting of charge in capacitance during storage and return. This is in order to increase the power handle capability of the charge pump and to enhance the knee frequency. The controlling parameter is by varying the ON resistance through which the gate voltage of the switches values can be verified. It is controlled by generating a Multi-level clock phases across the subsequent stages, in order to compensate for the increase in the source and drain voltage across every stages. The concept is verified by implementing a switched capacitor circuit responsible for generating higher voltage levels of the input clock phases. The circuit shows its reliability across process corners. Future work can be integrating the charge pump in an energy harvesting system, to verify its performance for efficient power delivery at the system level.

REFERENCES