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# FUZZY LOGIC CONTROLLER FOR A MULTISTAGE CURRENT-CONTROLLED SWITCHED-CAPACITOR STEP-DOWN DC-DC CONVERTER

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**Abstract :** Switched-capacitor (SC) based step down voltage dc-dc converter can be used for efficient power conversion when inductors are not used in order to reduce size and cost. In addition, switched capacitor dc-dc converters are superior to inductor –based converters for high-conversion ratio and wide range of load variation. In this paper, a multistage current - controlled switched - capacitor step down dc-dc converter is analyzed, designed and simulated. The converter features are good regulation capability and continuous input current waveform when two step-down converter cells are connected in parallel and operating them in antiphase. Classical SC converter with pulse width modulation technique is also analyzed, designed and simulated. For the PWM converter and current - controlled converter, third – order state-space averaging method is used for analysis. A fuzzy logic controller is used with the current – controlled converter to obtain fast dynamic response, low ripple in the output voltage and robustness against load and supply variations. A 70W ,48/12V converters are designed and simulated and Matlab/Simulink is used for simulation. The simulation results are obtained and compared for above converter with different control techniques (PWM ,current control with PI controller and current control with fuzzy controller). The results for current - controlled converters with fuzzy controller show higher efficiency, lower ripple in the output voltage, fast transient response, good disturbance rejection and very small steady state error of output voltage.

**Keywords:** *Fuzzy Logic Controller, FLC, DC - DC converter, Buck converter, Boost converter.*

# محول خفض الفولتية المستمرة ذو المكثف المفتاحي باستخدام مسيطر التيار متعدد المراحل نوع المسيطر الضبابي

***الخلاصة*** *: المحول الخافض للفولتية المستمرة ذو المكثف المفتاحي (Switched capacitor dc –dc converter) يمكن أن يستعمل للتحويل الكفوء للطاقة حيث نجد انه عندما لا تستعمل المحاثات في دوائر التحويل يؤدي الى خفّض حجم الدائرة و تقليل الكلفة .اضافة لذلك، المحولات الخافضة للفولتية المستمرة ذات المكثفات المفتاحية تستخدم بشكل اسهل واكثر في دوائر التحويل التي تحتاج نسبة تحويل عالية (high conversion ratio ) ومدى واسع من التغير في قيمة الحمل. في هذا البحث , تم التطرق الى تحليل وتصميم محول متعدد المراحل ويحتوي على دوائر سيطرة خاصة على التيار الداخل للمحول . إنّ من ميزّات هذا المحول هي قابليته العالية على تنظيم او تقويم الاشارة الخارجة وكذلك الحصول على موجة تيار داخل مستمر عندما تربط خليتان( دائرتي محول اساسيتان ) من خلايا المحول ربط توازي ويتم*

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*تشغيلهما الواحدة عكس الاخرى . كذلك المحول الكلاسيكي بتقنية تضمين عرض النبضة (pulse width modulation ) تم التطرق الى تحليله وتصميمه ، وذلك من اجل معرفة سلوك المحول وادائه باختلاف دائرة المسيطر . لكلا المسيطرين ( تضمين عرض النبضة والسيطرة عن طريق تيار المفتاح ) تم استخدام الدرجة الثالثة من طريقة ( state-space ) للتحليل. تم اقتراح جهاز سيطرة منطق ضبابي( fuzzy controller) كنوع من دوائر مسيطرات التيار للحصول على ردّ ديناميكي سريع،تشوه موجة( قيمة الزيادة والنقصان عن القيمة او الحد المطلوب من الموجة) بنسبة قليلة جدا في فولطية الناتج ومتانة ضدّ إختلافات التجهيز والحمل .تم تحليل و تصميم محول اساسي في هذا البحث (70 W )( 12 / 48 V )حيث ان برنامج Matlab / Simulink استعمل للمحاكاة. إنّ نتائج المحاكاة التي تم الحصول عليها لفرق المحوّلين بتقنيات السيطرة المختلفة ( تضمين عرض النبضة (PWM)، وكذلك المسيطر التكاملي التناسبي ( PI - controller ) وكذلك نتائج السيطرة المقترحة باستخدام المسيطر الضبابي). اظهرت ان دائرة المحول المسيطر عليها باستخدام المنطق الضبابي (fuzzy controller ) كانت ذات اداء عالي وكفاءة عالية ونسبة قليلة في تشوه الموجة الخارجة، جيدة من ناحية تقليل الاضطراب في الموجة الناتجة ونسبة الخط عند الاستقرار قليلة جدا في الفولتية الناتجة .*

## 1.Introduction

A DC output voltage obtained with a different voltage level than input by using a device that accepts a DC input voltage and produces a DC output voltage this device called a dc – dc converter. These devices used for Portable electronic devices, such as cell phones, PDAs, pagers and laptops, and any devices supplied by batteries or needed to change the level of voltage to ensure the correct operation. Some problems occurred in the operation of the electronic devices powered by the batteries because the battery voltage drops depending on the types of batteries and devices after the battery has been used for a period of time. So, DC/DC converters are often used to provide a stable and constant power supply voltage for these portable electronic devices**[1]**.

Converter circuits can be classify according to many parameters one of these parameters is storing and transferring energy elements, therefore inductive converters and switched capacitor converters are two main kinds of topologies in dc – dc converters. Inductor is used as energy storing transferring component in the inductive converter and it has been a power supply solution in all kinds of implementations for along time . It was stayed a good way to pass a high load current. But in recent years, small size was one of the requirements of modern techniques and the load current and input voltage are getting lower and lower, the Inductorless converters based on switched capacitor are more popular with in held up applications with a different level of power . Inductors and magnetic components are avoided to use in these converters because bulkiness and noise . They are in stock in small reams, added to that this converter operate with low quiescent current and require minimal external components therefore the cost of building this converter is reduced . These converters was the main power supply solution for handheld portable instrumentations**[1]**.

The main part in circuit of switched capacitor DC-DC converters is the switched capacitor array, which is consisted of the switches elements and the capacitors, usually called ( flying capacitors ), by which the energy was storied and transferred. When switches are turning on and turning off, the connection of flying capacitors changed, these capacitors can be charged or discharged and the charges can be reached to or removed from the load. This technique is called charge pump and the switched – capacitor converter is also called charge pump converter**[1]**.

The analysis and design of switched-capacitor (SC) step-down dc-dc current-controlled converter which has multistage with a low – profile are presented. The converter not only exhibits all advantages of SC converter with pulse width modulation controller, but also features of the good regulation capability and continuous input current waveform resulting in low conducted electromagnetic interference with the supply network. The input and output converter cells are put in parallel form and operate in antiphase to achieve the concept of energy transfer. Controlling the charging trajectories of the capacitors in each cell give the ability to determine the voltage conversion ratio. Because the circuit does not need any inductive elements, it is possible to make integrated circuit fabrication with high power density. The state-space averaging technique is applied to derive a third-order state-space model for an n-stage converter. Small-signal dynamic and static behaviors of the converter are discussed. A 70-W 48V/12 V converter is built. Theoretical analysis is verified with experimental measurements [2].

In the past few years the dc-dc converters are controlled using analog integrated circuit technology and linear system design methods. Traditional control methods used for dc-dc converters are PID controllers which tend to provide linear properties. But dc-dc converters exhibit non- linear properties. The causes of nonlinearity in the power converters involve a variable structure within a single switching period, saturating inductances, voltage clamping, etc. Thus whenever there is any change in system, any parameter variations or even load disturbances, PID controllers don’t respond powerfully with these variations. Satisfactorily non linear controllers are often developed to control non linear systems. It is always desirable for buck converters with a constant output voltage so the output voltage remains unchanged in both steady and transient operations whenever the supply voltage and/or load current is changed. This condition is known as zero-voltage regulation, which can be introduced that the output voltage is independent of the source voltage and the load current. To achieve zero-voltage regulation, the choice of the control method is played a very important option in the performance of converters. The direct duty ratio control is considered the most widely used method in converters. This method is too complex to be practically executed. Another popular method is the current control mode control. But this method cannot eliminate the load current disturbances. Using human linguistic terms and common sense, several fuzzy logic based controllers have been developed. The main problem with fuzzy logic is that there is no systematic procedure for the design of fuzzy controllers. Fuzzy logic, which is the logic on which fuzzy control is based, is much closer in spirit to human thinking and natural language than the traditional logical systems. Basically, it supplies an effective means of capturing the approximate, inexact nature of the real world .The essential part of the fuzzy logic control ( FLC ) is a set of linguistic control rules related by the dual concept of fuzzy implication and the compositional rule of inference. The FLC provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. Experience shows that the FLC yields results superior to those obtained by conventional control algorithms. The FLC appears very useful when the processes are too complex for analysis by conventional quantitative techniques **[3]**.

In this paper a70W , 48/12 V current Controlled Multistage Switched-Capacitor DC-DC Converter is analyzed, designed and simulated using Matlab/Simulink. A fuzzy logic controller is used as voltage controller to obtain fast transient response, very 20Wsteady state error and good disturbance rejection.

## 2. Switched Capacitor Step-Down Converter Circuit With PWM Controller

An overall closed loop configuration of circuit based switched capacitor step down DC–DC converter, is shown in Figure (1), the circuit consists of two mainly parts: ‘power part’ and ‘control part’. Power part of SC step-down converter is shown in figure (2) **[4]**.

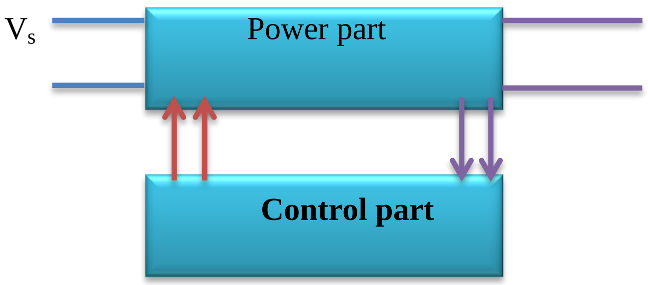


Fig. (1): Configuration of converter circuit.

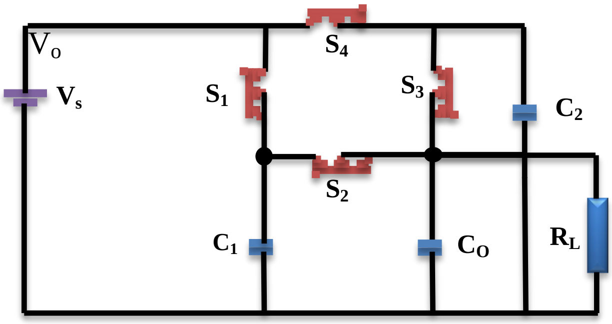


Fig. (2): Power part of converter circuit.

The circuit given in (Fig. (2)) is formed by two capacitors ($C_1$ and $C_2$) and four MOSFET switches ($S_1$ to $S_4$). The operating sequence of the switches is determined by the timing diagram given in Fig. (3), resulting in a two phases per cycle dynamic behavior. In each phase, the circuit operates at two topologies, therefore four topologies per cycle dynamics resulting ( Fig. (4)). A typical steady-state cycle for a conversion ratio of 0.5 looks as follows: in the state 1, $S_1$ and $S_3$ are switched on and $S_2$ and $S_4$ are switched off. Consequently, $C_1$ is charged slightly greater than the voltage $V_s$ /2, the charging time must be designed in such a way to be able to cover the losses in the parasitic resistances, and to result in phase 2 an output voltage of $V_s/2$. At the same time, $C_2$ is discharged on the load ,see Fig.(4) **[4]**.

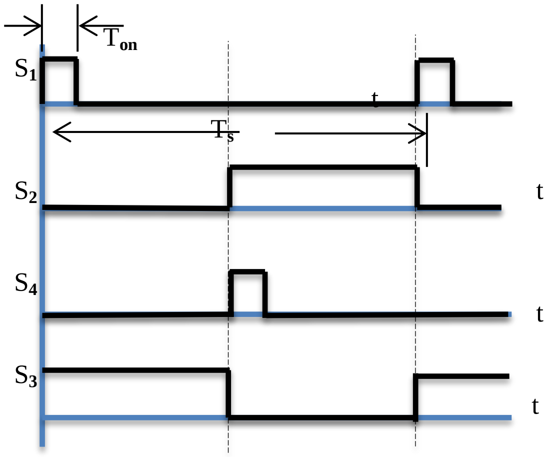


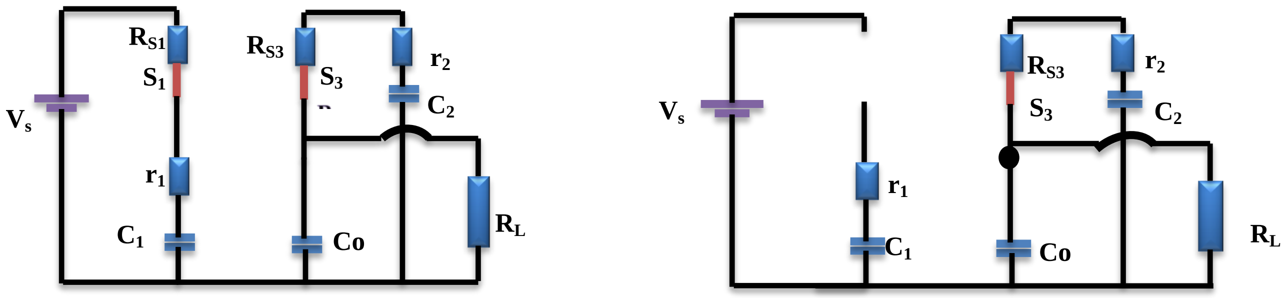
Fig. (3): timing diagram for driving switches.

In the state 2, the capacitor $C_2$ still discharges on the load, while $C_1$ being disconnected. The phase II operated in antiphase to the phase 1. In state 3, $C_2$ is charged slightly greater than the voltage $V_s/2$, and $C_1$ is discharged on the load. In state 4, $C_2$ is disconnected and $C_1$ continues its discharge. The discharging time of $C_2$ and respectively $C_1$ are determined, therefore as a resulting the voltage of $C_2$ at the end of phase I, or the voltage on $C_1$ at the end of phase II is slightly less than voltage $V_s/2$. These operating cases provided a constant value for output voltage of $V_s/2$, with a small output ripple value, and implies very short time for the state 1 and 3 when the capacitors $C_1$, respectively $C_2$ are charged. therefore, the variation of the voltage on the capacitors through the charging time is small, obtaining an efficient transfer of energy. The durations of the two phases are the same and equal to half of the switching period $T_s$. The duty cycle d is introduced as [4]:

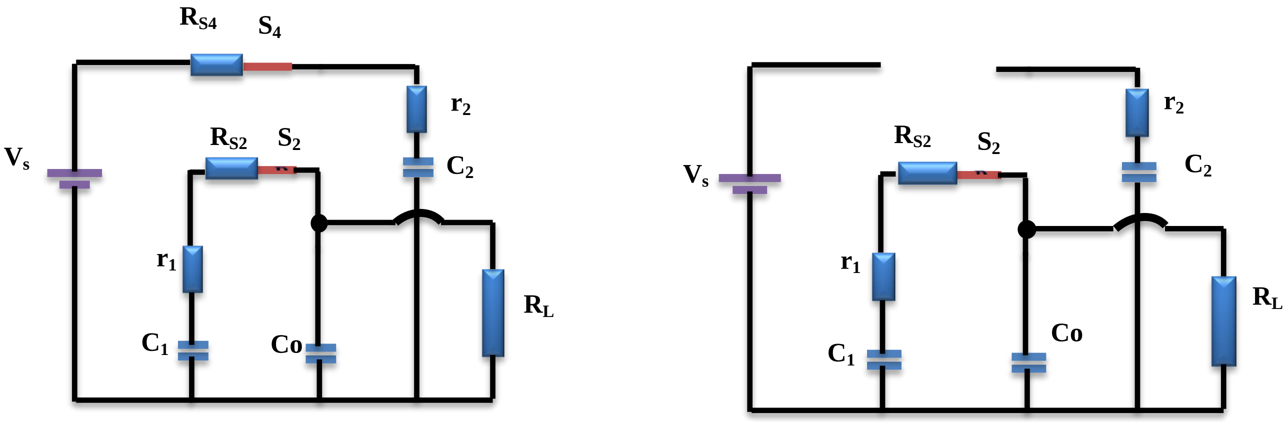
$$d = \frac{T_{on}}{T_s} \qquad (1)$$

As shown in Fig.(3), it results that d is always less than 0.5. If other conversion ratios are wanted, one has to arrange the interval of the states 1 and 3 to obtain a charge of the capacitor $C_1$, respectively $C_2$ at a voltage level slightly greater than the desired output voltage. Therefore, the ratio between $T_{on}$ and $T_s$ i.e. d has to be adjusted correspondingly.

Feedback circuit makes the value of the output voltage is constant value when the load is changed in the circuit of PWM type. The actual voltage is compared with a reference voltage (equal to the desired output voltage), the signal resulting from this operation is used to adjust the timing diagram as in Fig.(3), i.e. by adjusting the timing of the driving signals to the transistors [4].



state 1 state 2



state 3 state 4

Fig.(4): The cyclically topologies of the converter circuit during Ts.

## 2.1 *Analysis of the Converter Circuit*

state-space averaging method is used and applied to the cyclically switching topologies shown in Fig(4), the average state eq.(2) and eq.(3) are obtained[4].

$$\dot{x} = A_{av}.x + B_{av}.u \tag{2}$$

$$y = v_{out} = v_{c_0} \tag{3}$$

Where :

$$x = [v_{c_1} \quad v_{c_2} \quad v_{c_0}]^T$$

$$u = [V_s]$$

$$A_{av} = \begin{bmatrix} -\dfrac{\frac{1}{2}+d}{C_1(R_s+r_{c_1})} & 0 & \dfrac{1}{2C_1(R_s+r_{c_1})} \\ 0 & -\dfrac{\frac{1}{2}+d}{C_2(R_s+r_{c_2})} & \dfrac{1}{2C_2(R_s+r_{c_2})} \\ \dfrac{1}{2C_o(R_s+r_{c_1})} & \dfrac{1}{2C_o(R_s+r_{c_2})} & -\dfrac{1}{2C_o}\left(\dfrac{1}{(R_s+r_{c_1})}+\dfrac{1}{(R_s+r_{c_2})}+\dfrac{2}{R_L}\right. \end{bmatrix}$$

$$B_{av} = \begin{bmatrix} \dfrac{d}{C_1(R_s+r_{c_1})} \\ \dfrac{d}{C_2(R_s+r_{c_2})} \\ 0 \end{bmatrix}$$

$$C_{av} = [0\ 0\ 1\ ]$$

By neglecting the resistance of the output capacitor and all resistances of switches equal to ($R_s$), giving the DC conversion ratio as:

$$y = C(-A^{-1}B)V_s \tag{4}$$

$$\frac{V_{out}}{V_s} = \frac{1}{1+\frac{(R_s+r)}{R_L}(1+\frac{1}{2d})} \tag{5}$$

Where ( $R_s$ )is the switching ( MOSFET ) resistance,( r) is the parasitic resistance of the capacitors $C_1$ respectively $C_2$, $R_L$ is the load resistance.

## 3. Switched –Capacitor Converter Cell With Multistage

Fig.(5): shows the circuit implementation of multistage step down converter cell providing from the input $V_{in}$ to the output load $R_L$ and resulted voltage of $V_o$ .

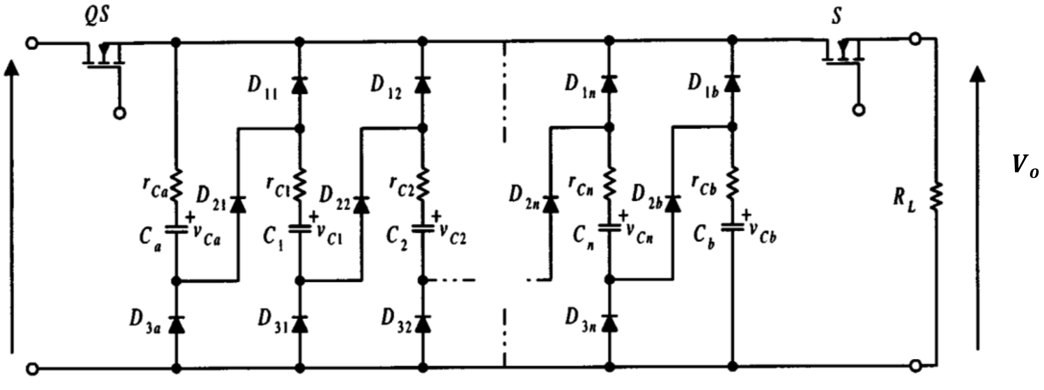


Fig.(5): circuit structure of the switched capacitor converter with multistage[5].

In each cell the number of capacitors limited at (n+2 ) capacitors C, [3(n+1) ] diodes , and 2 MOSFETs. Each capacitor C has capacitance with equivalent series resistance ( ESR ) $r_c$ .Here S is operated as a static switch and QS is operated as a voltage controlled current source. For a MOSFET operating in the saturation region, its static and dynamic characteristics can be shown to be: [5]

$$I_D = K_1(V_{GS} - V_T)^2 \qquad (6)$$

and

$$\hat{i}_D \approx K_2 \hat{v}_{GS} \qquad (7)$$

$$K_2 = 2K_2(V_{GS} - V_T) \qquad (8)$$

Where

| | |
|---|---|
| $I_D$ and $\hat{i}_D$ | static and dynamic drain current. |
| $V_{GS}$ and $\hat{v}_{GS}$ | static and dynamic gate-source voltage. |
| $V_T$ | threshold voltage. |
| $K_1$ | fabrication parameter. |

S and QS are operated alternately in one switching cycle of period $T_s$ , for the same interval of $T_s/2$ with two operating phases. The first phase is the charging phase. All capacitors are charged linearly by a constant current $I_{ch}$ through QS, $D_{21}$, $D_{22}$,……$D_{2n}$ and $D_{2b}$. The magnitude of $I_{ch}$ is determined by the gate - source voltage of QS. Each capacitor will be charged to a voltage slightly higher than $V_o$ in order to compensate for the parasitic resistance and diode voltage drop in the next phase. The second phase is the discharging phase. All capacitors are connected in parallel by $D_{11}$ ,$D_{12}$ ,……$D_{1n}$ ,$D_{1b}$ ,$D_{3a}$, $D_{31}$, $D_{32}$,……..$D_{3n}$ and supplying to $R_L$ through S .

### 3.1 *Realization of the Step-Down Converter*

When the input of two cells are connected together and the output of them together too (connected in parallel form) as shown in Fig.(6), (i.e., cell A and cell B) and operating these cells in antiphase, a step - down DC-DC converter is realized. Where one of these cells operates in the charging phase and the other operates in the discharging phase for example when cell A is in the charging phase, cell B will be in discharging phase and vice versa.

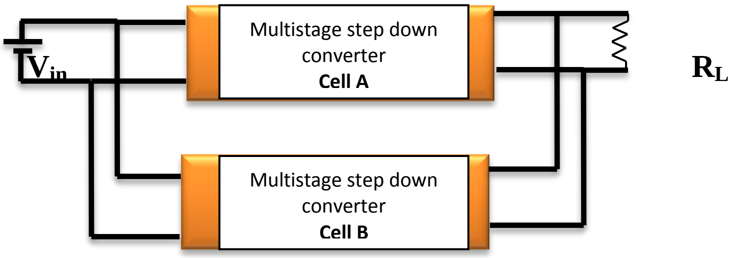


Fig.(6): complete realization of the step-down converter[5].

There are two topologies in one switching cycle. Thus, as shown in Fig.(7). In topology 1, all capacitors in the cell A are linearly charged by the constant current $I_{ch}$ , which is obtained by $QS_A$ . At the end of this topology, all cell-A capacitors will be charged to a voltage value slightly higher than $v_{out}$ in order to avoid and deleting the parasitic losses through the discharging phase in Topology 2. Where the parasitic losses consist of the voltage drops across the on resistance of switches $S(r_T)$, the equivalent series resistance ESR of the capacitors ($r_C$ ) and the diode voltage drop ($r_D$ ). In the same time the capacitors in cell B are connected in parallel form and discharging into the load $R_L$. In topology 2, the operation of cell A and cell B are interchanged. Therefore the input current of the converter equal to the sum of the two cells's current, where: [5]

$$i_{in}=I_{ch} \tag{9}$$

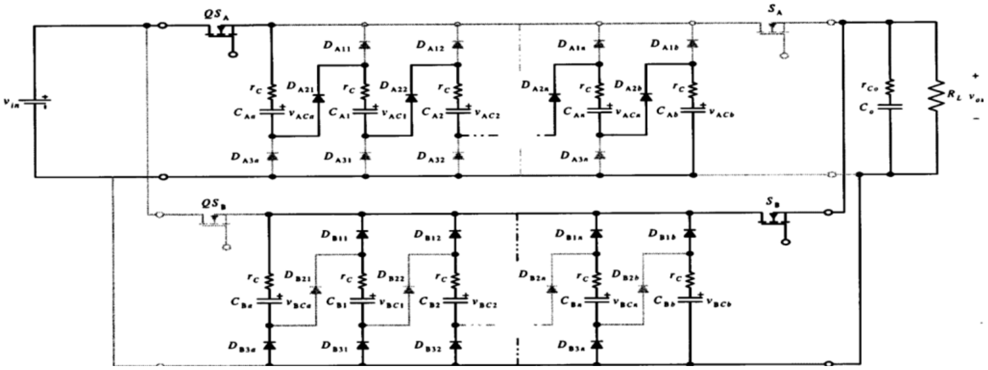


Fig. (7.a): multistage two cells SC converter circuit,$QS_A$ and $S_B$ are on state ( topology 1 ) [5].

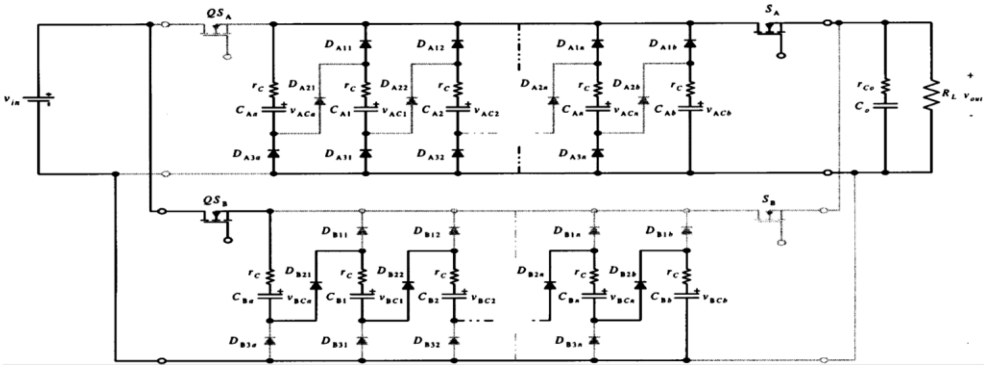


Fig. (7.b): multistage two cells SC converter circuit, $QS_B$ and $S_A$ are on state (topology 2 ) [5].

As the magnitude of $I_{ch}$ is relatively constant, $i_{in}$ is also relatively constant. Compared to the pulse width modulation ( PWM ) switched - capacitor converters, the following observation can be noted.

1) Input current of pulse width modulation ( PWM ) switched - capacitor converter is pulsating with large peak and short duration. The switching devices for capacitor charging are under high current stress. But the input current of current control scheme (CCS) is a constant, as a result the current stress on the switching devices is much reduced and the conducted electromagnetic interference ( EMI ) with the supply network is reduced too.

2) Under light load or low output voltage condition for converters controlled by the PWM technique, the charging time is short and practically hard to implement on the contrary, the duty time of all switching devices in the current – controlled switched – capacitor converter are fixed at Ts/2, which can be easily implemented and will practically improve the regulation capability.

3) The classical ( PWM ) switched capacitor converters which have adjustable voltage conversion ratio are compared with current – controlled converters.Very important difference is in the charging method. The energy loss $E_{loss}$ through charging a capacitor from an initial voltage $v_{c,i}$ to a final voltage $v_{c,f}$ is equal to:[5]

$$E_{loss}=\frac{1}{2}C[\left(v_{in}-v_{C,i}\right)^2-\left(v_{in}-v_{C,f}\right)^2] \qquad (10)$$

$E_{loss}$ is independent of the scheme of charging the capacitors. It is applicable for the current – controlled switched capacitor converter, which is a particular RC circuit. Thus, the conversion efficiency of the converter is same as the classical ones.

### 3.2 *Analysis of the Converter*

Figure (7) shows that two sets of capacitors ($C_A$ and $C_B$ ) including ($C_{Aa}$,$C_{Ab}$,$C_{Ba}$ and $C_{Bb}$ ) and( $C_{A1}$ to $C_{An}$ and $C_{B1}$ to $C_{Bn}$) are defined. A part from the antiphase operations between cell A and cell B capacitors, these sets have the same properties with respect to the charging and discharging process circuits .The value of the capacitor voltage in the same group is the same. Hence, the following simplifications can be made:

$$v_{cAa}=v_{cAb}=v_{cBa}=v_{cBb}=v_{ca}$$

$$v_{cA1}=v_{cA2}=\cdots=v_{cAn}=v_{cB1}=v_{cB2}=\cdots=v_{cBn}=vc$$

A third - order state-space description can be formulated when the state - space averaging analysis method is applied. The averaged state - space matrices can be formulated as following[5]:

$$\dot{x}=A_{av}x+B_{av}u \qquad (11)$$

$$v_{out}=C_{av}x \qquad (12)$$

Where:

$$x=[vc_a \quad vc \quad vc_o]^T$$

$$u = [I_{ch}]$$

$$A_{av} = \begin{bmatrix} -\frac{H_2}{4C\beta} & \frac{H_1}{4C\beta} & \frac{R_L r_y}{4C\beta} \\ \frac{H_1}{2nC\beta} & -\frac{H_3}{2nC\beta} & \frac{R_L r_x}{2nC\beta} \\ \frac{R_L r_y}{2C_O\beta} & \frac{R_L r_x}{2C_O\beta} & -\frac{H_4}{2C_O\beta} \end{bmatrix}$$

$$B_{av} = \begin{bmatrix} \frac{1}{2C} \\ \frac{1}{2C} \\ 0 \end{bmatrix}^T$$

$$C_{av} = \begin{bmatrix} \frac{R_L r_{co} r_y}{\beta} \\ \frac{R_L r_{c0} r_x}{\beta} \\ \frac{R_L(r_T r_x + r_T r_y + r_x r_y)}{\beta} \end{bmatrix}^T$$

$$H_1 = R_L r_{co} + r_{co} r_T + R_L r_T$$

$$H_2 = R_L r_{co} + r_{co} r_T + R_L r_T + r_{co} r_y + R_L r_y$$

$$H_3 = R_L rC_O + rC_O r_T + R_L r_T + r_{co} r_x + R_L r_x$$

$$H_4 = R_{Lr_x} + r_T r_x + R_L r_y + r_T r_y + r_x ry$$

$$\beta = (r_x + r_y)(R_L r_{co} + r_{co} r_T + R_L r_T) + (r_{co} + R_L) r_x ry$$

$$r_x = \frac{(r_D + r_C)}{2}$$

and

$$r_y = \frac{(2r_D + r_C)}{n}$$

### 3.3 *Selection of Capacitor Value*

The value of the capacitor in each cell is chosen by considering the maximum output voltage ripple $\Delta V_{out.max}$. Because all capacitors in the same cell are connected in parallel with $C_0$, therefore equivalent capacitor $C_{eq}$ can be written as:

$$C_{eq} = (n+2)C + C_o = (n+3)C \tag{13}$$

If $C_0$ = C . As the discharging process is fixed at Ts / 2 , C is chosen in such a way that:

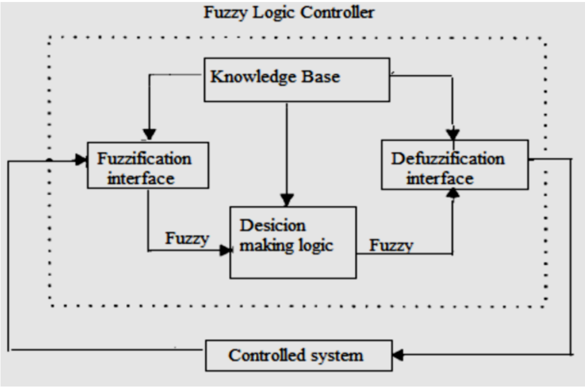
$$\Delta v_{out,max} \geq \frac{I_{out}T_s/2}{C_{eq}} \tag{14}$$

$$\rightarrow C \geq \frac{V_{out}}{2(n+3)R_L f_s \Delta v_{out,max}} \tag{15}$$

Where $f_s$ is the switching frequency.

## 4. Basics of Fuzzy Logic Controllers

A new addition to control theory is Fuzzy logic control ( FLC ). Its design philosophy deviates from all the previous techniques by accommodating expect knowledge in controller design. FLC is one of the most successful applications of fuzzy set theory. Its main properties are the use of linguistic variables rather than numerical variables. Linguistic variables, defined as variables whose values are sentences in a natural language (such as small and large), may be represented by fuzzy sets. FLC's are an attractive choice when precise mathematical formulations are not possible [6].



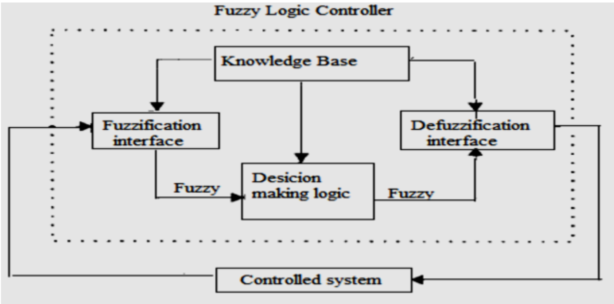


Fig.(8): Basic configuration of FLC[6].

The general structure of an FLC is shown in Fig.(8) and containing four majority components:

1) A fuzzification interface is the part when input data converted into suitable linguistic value.
2) A knowledge base is the part that containing control rule set and data base with the necessary linguistic definitions.
3) A decision making logic is the part where simulating a human decision process, results the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions.
4) A defuzzification interface where a non fuzzy control action yielded from an inferred fuzzy control action.

Design of fuzzy logic or rule based non-linear controller is simple because the proposed mode control function is described by using fuzzy sets and if-then predefined rules rather than cumbersome mathematical equations or larger look-up tables, therefore the development implementation cost is greatly reduced and time minimized and needs less data storage in the form of membership functions and rules. It is adaptive in nature and can also exhibit increased reliability, robustness in the face of changing circuit parameters, saturation effects and external disturbances and so on[6].

## 5. Design and Simulation

This section presents the design and simulation of the switched capacitor DC-DC step down converter with resistive load, A high efficiency switched capacitor step-down DC/DC converter is presented and some important design issues are discussed.

switched capacitor step-down DC-DC converter circuit is designed to produce a 12V regulated output voltage.

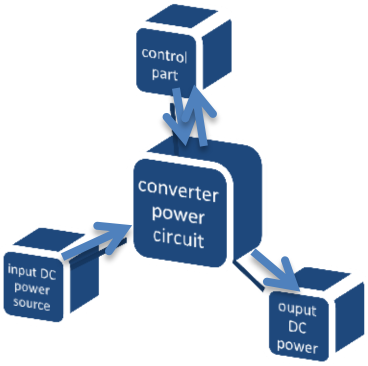


Fig.(9): Block diagram for general dc-dc converter.

Converter circuit with PWM control mode and converter circuit with current control mode are presented. Also a fuzzy controller is used with the current- controlled switched -

capacitor step-down DC-DC converter. A matlab/simlink is used for simulation. The block diagram of the designed system is shown in Fig.(9).

### 5.1 *Design of the PWM Controller*

Fig.(10). shows the PWM control unit that is built using matlab/sumulink. A J.K flip flop is used to obtain a square wave O/P signals to drive the output MOSFET transistors in cell A and B . A pulse width modulated signal is anded with the output of J.K flip flop to obtain driving signals for inputs MOSFET transistors in cell A and B. The complete converter circuit and PWM control unit for 12V output is shown in Fig.(11).

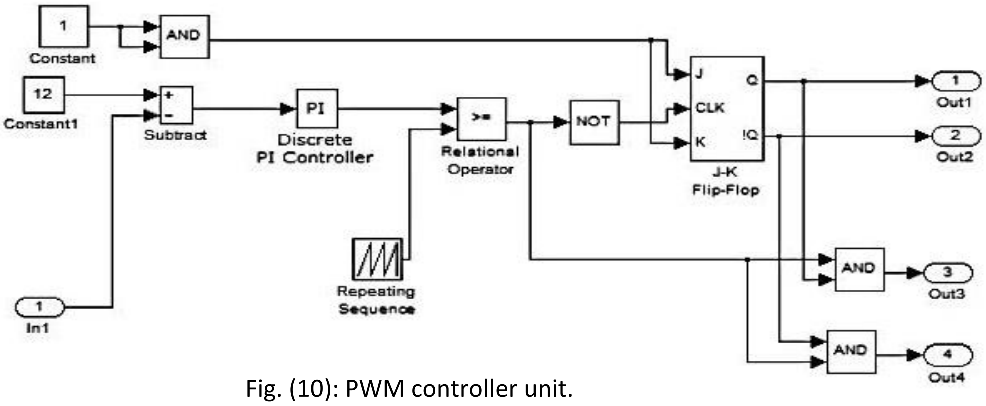


Fig. (10): PWM controller unit.

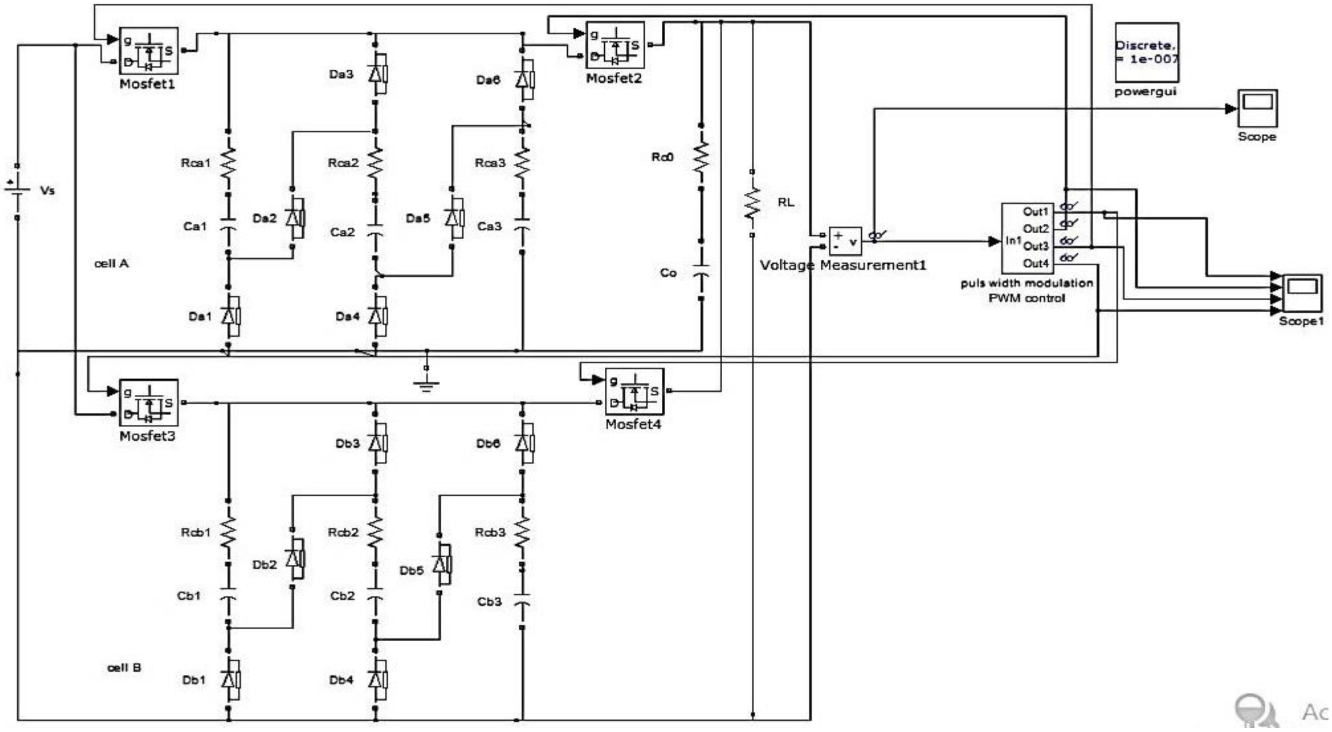


Fig. (11): Switched capacitor converter circuit with PWM controller(12V output )and the output signal for the PWM controller.

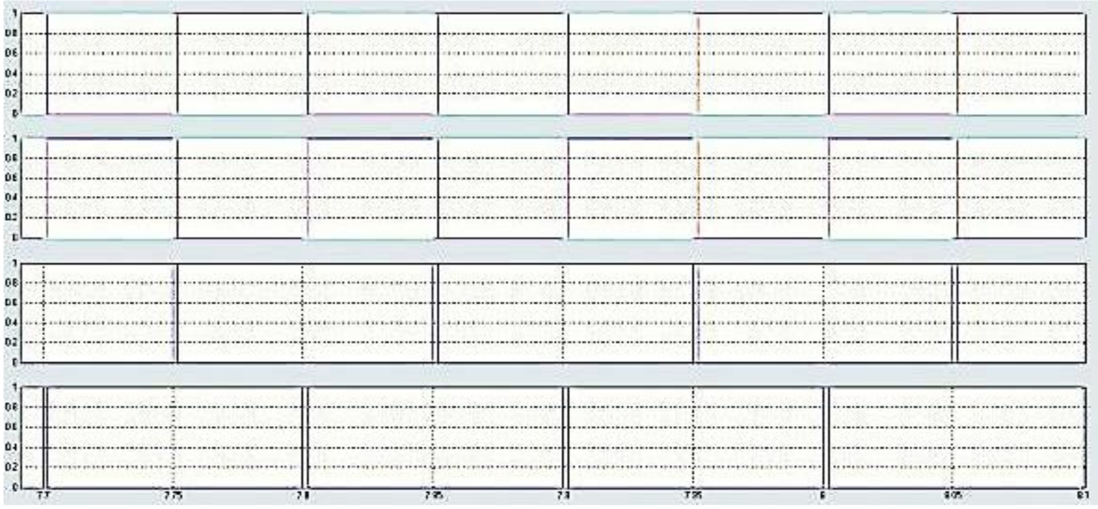


Fig.(12): The output signal of the PWM controller.

### 5.2 *Converter Circuit with Current Control Mode*

The input current of the converter with PWM control is pulsating and causing conducted EMI with the supply network and the charging duration will be short and practically difficult to implement under light load or low output voltage. In order to reduce the current stress on switches, the current control scheme (CCS ) in the charging process has been suggested. Two converter cells are used like with PWM control mode to obtain continuous input current. The basic idea is to drive some MOSFETs into saturation region in order to control the capacitors charging current profile Fig.(13) shows the converter circuit with current mode control that is built using Matlab / Simulink. Equation (6) is used to represent the MOSFET in Matlab/Simulink in order to operate the transistor in current control mode or quasi switched state ( this representation used for capacitors charging only).

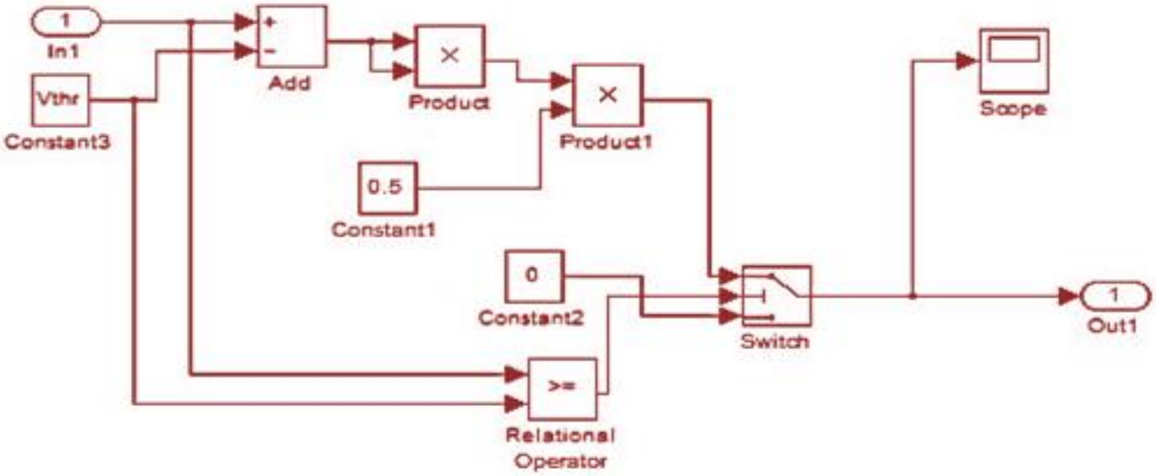


Fig. (13): The transistor drain current equivalent equation.

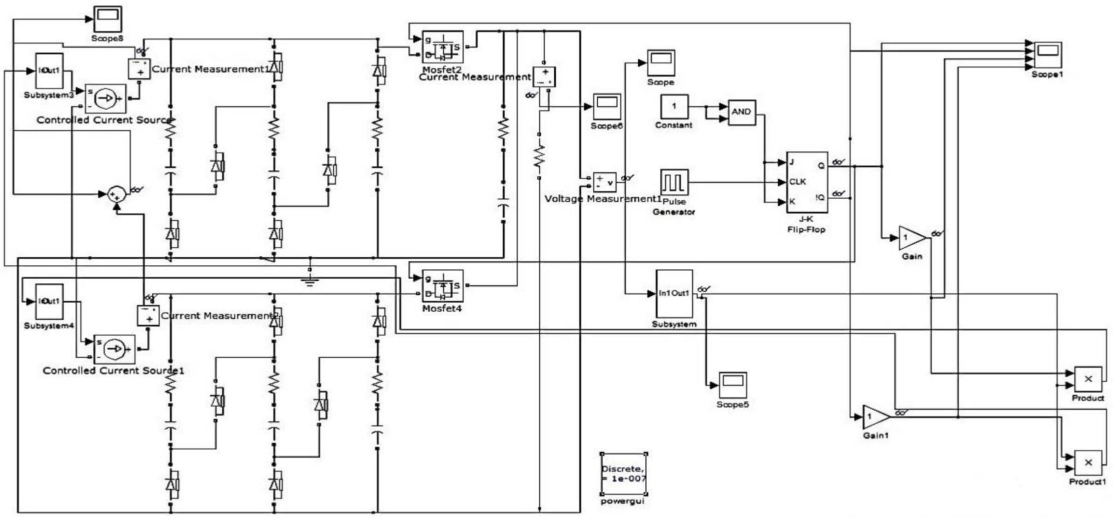


Fig.( 14 ): Switched capacitor convertor circuit with current control mode (12 V ) output.

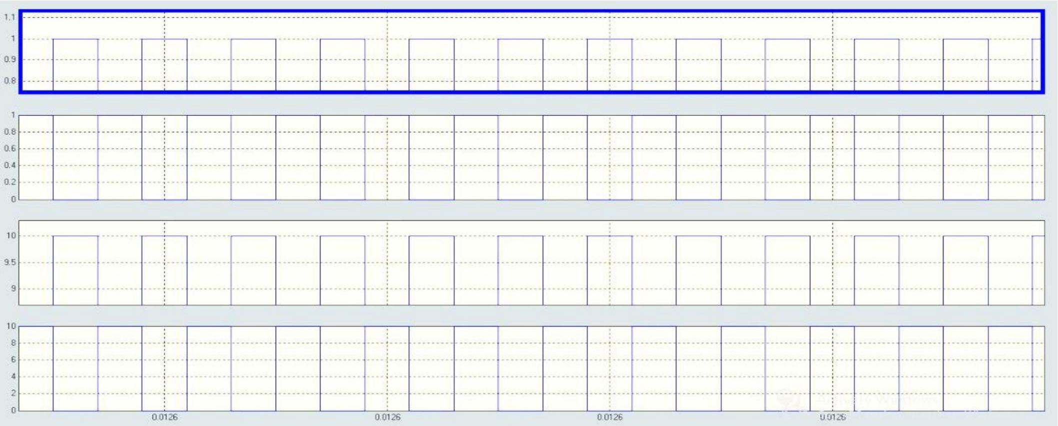


Fig.(15): The output signal of current controller.

### 5.3 *Fuzzy Controller for Current-Controlled Switched-Capacitor Step-Down DC-DC Converter*

Design of fuzzy controllers is based on expert knowledge of the plant instead of a precise mathematical model. There are two inputs for the fuzzy controller. The first input is the error in the output voltage where ADC[k] is the converted digital value of the kth sample of the output voltage of convertor and Ref is the digital value corresponding to the desired output voltage. The second input is the difference between successive errors and is given by

$$e(k) = Ref - ADC(k) \qquad (16)$$

$$ce(k) = e(k) - e(k-1) \qquad (17)$$

The two inputs are multiplied by the scaling factors $G_1$ and $G_2$, respectively, and then fed into the fuzzy controller. The output of the fuzzy controller is the change in the control signal Δu[k], which is scaled by a linear gain $G_3$ and integrated then multipling by $G_4$ to obtain u(k) using integrator with limiter. The scaling factors $G_1$, $G_2$,$G_3$ and $G_4$ can be tuned to obtain a satisfactory response[6]. Fig.(16) shows the fuzzy controller unit.

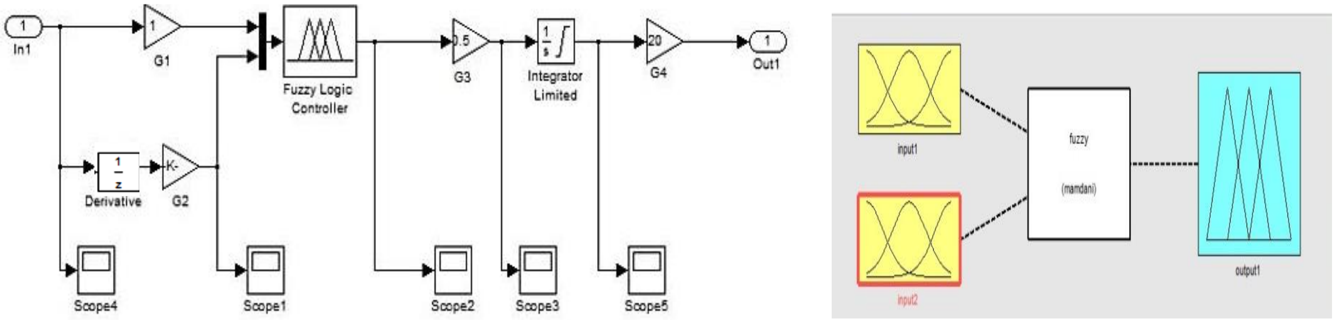


Fig.(16): Fuzzy controller unit and the membership function for e and ce.

In the fuzzy controller unit Fig.(16 ), the fuzzy logic controller consist of the rules made the system operated with a smart form. There are (49) linguistic rules since each input has seven linguistic sets as shown in table(1)[6].

Table ( 1 ): Fuzzy linguistic rules

NB: Negative Big
NM: Negative Medium
NS: Negative Small
Z : Zero
PS: Positive Small
PM: Positive Medium
PB: Positive Big

| ce \ e<br>ce | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| PB | Z | PS | PM | PB | PB | PB | PB |
| PM | NS | Z | PS | PM | PB | PB | PB |
| PS | NM | NS | Z | PS | PM | PB | PB |
| Z | NB | NM | NS | Z | PS | PM | PB |
| NS | NB | NB | NM | NS | Z | PS | PM |
| NM | NB | NB | NB | NM | NS | Z | PS |
| NB | NB | NB | NB | NB | NM | NS | Z |

Figs. (17&18) show the input and output memberships functions respectivly :

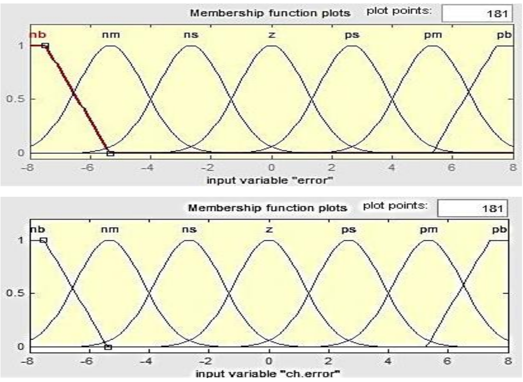


Fig.(17): the input memberships.

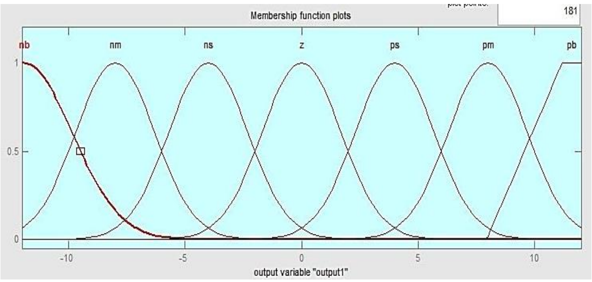


Fig.(18): the output memberships

## 6.Simulation Results

In this section, the converter circuit is simulated using Matlab/ Simulink. The results of simulation for converter with 12V output and different schemes of control (PWM, current control with PI controller and current control with fuzzy controller) are presented.

### 6.1 *Simulation results for the converter with PWM controller*

Simulation is done based on the Simulink model. Firstly the system is operated with input DC voltage ( 48 V) and switching frequency equal to ( 500 kHz). The system produced output DC voltage ( 12 V) and steady state time ( ts = 0.0095 s) ripple voltage ( ripple $_{\mathbf{P\text{-}P}}$ = 0.02) = 0.1665 % from the desirable output value as shown in Fig.(19).

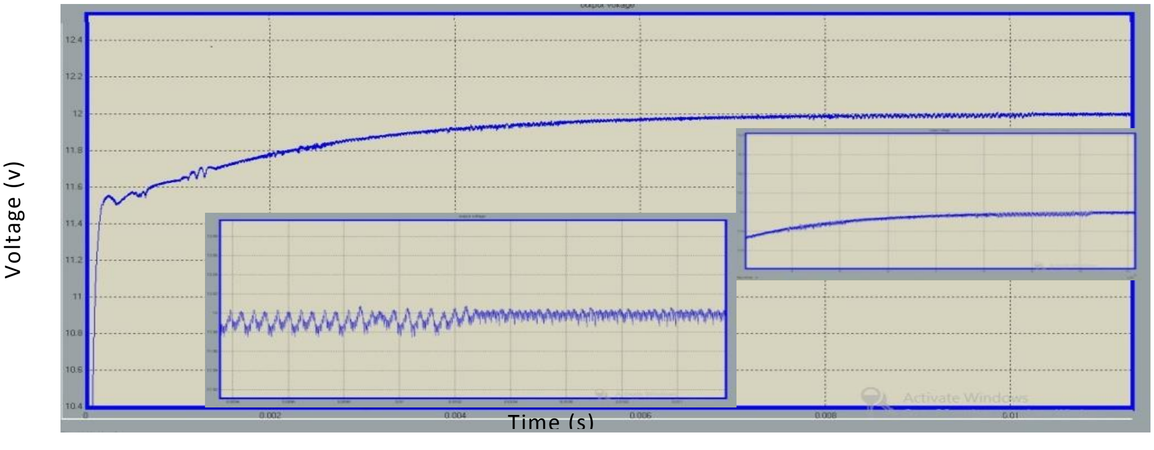
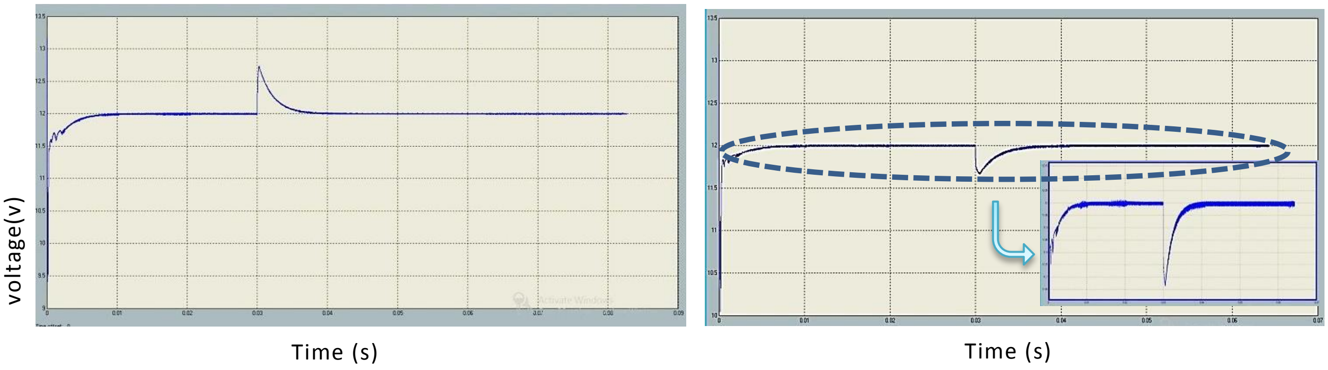


Fig (19) Output voltage for converter with PWM controller

If the sudden change occurred in the load, the following results obtained ,see Fig (19)& Fig (20).



(a) (b)

Fig. (20): Output voltage with change value of the resistance load:
a)load resistance is changed from 2Ω to 4Ω.
b)load resistance is changed from 4Ω to 2Ω.

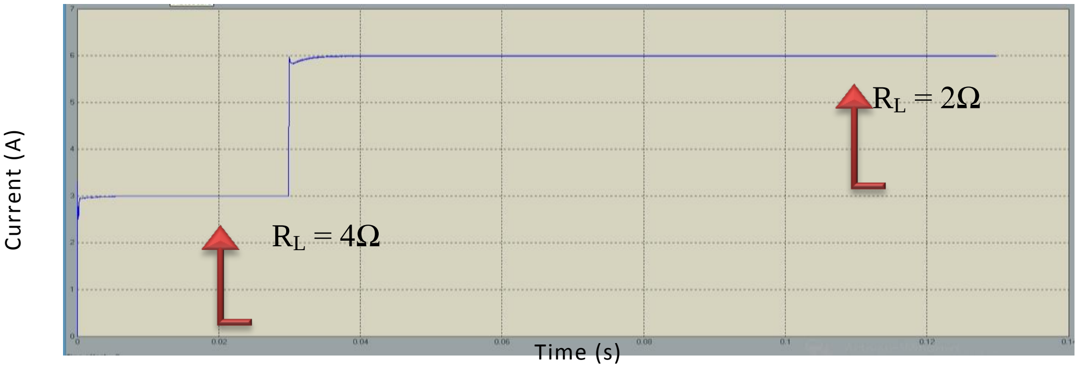


Fig.(21): The output current waveform after the change in the value of load resistance from 4Ω to 2Ω after 0.03s from starting.

The next figure shows the input current waveform appear as a spikes has average value of spike equal to 48A which necessary to calculate the average value of the input current.

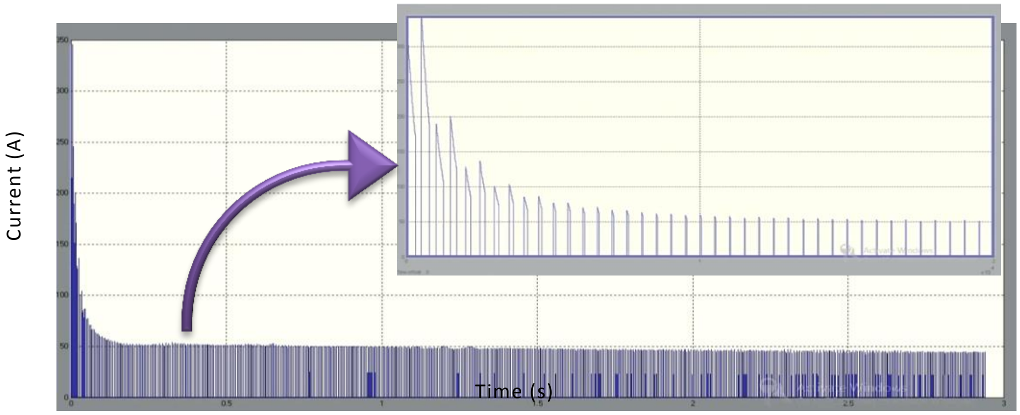


Fig.(22):The input current waveform.

## 6.2 *The Simulation Results of the Converter with Current Control Mode*

In this section, the results of the switched capacitor step down DC-DC converter with current control mode are presented. Two types of voltage controller: proportional integral PI controller and fuzzy controller are used and the obtained results for these two controllers are compared from the point of time response, ripple in the output voltage and disturbance rejection ( load resistance change).

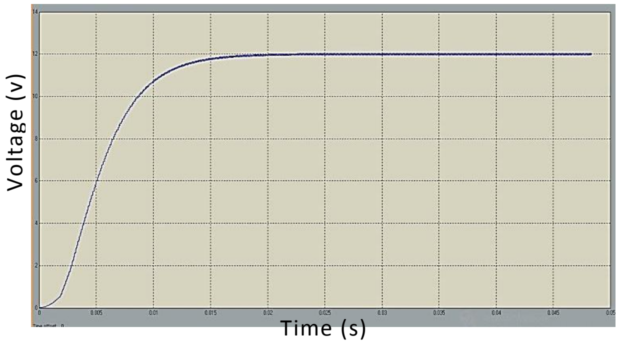


Fig. (23.a): The output voltage with PI controller.

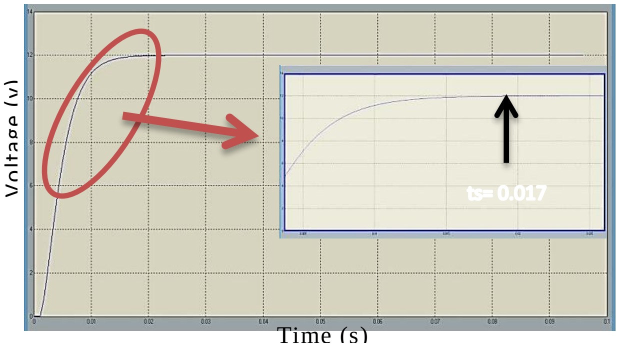


Fig.(23.b): The output voltage with

fuzzy controller.

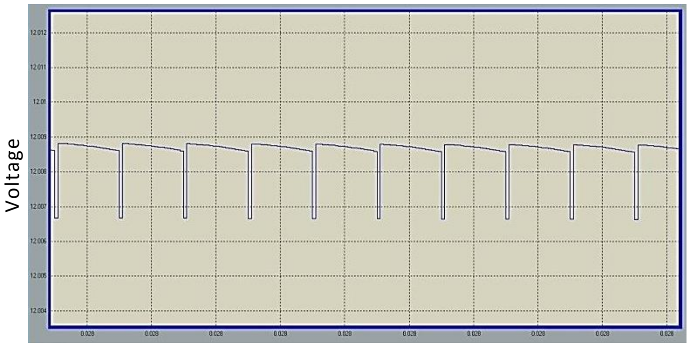


Fig.(24.a): The output ripple with PI controller.

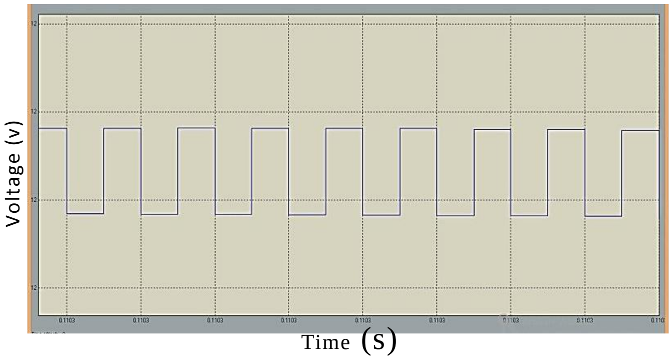
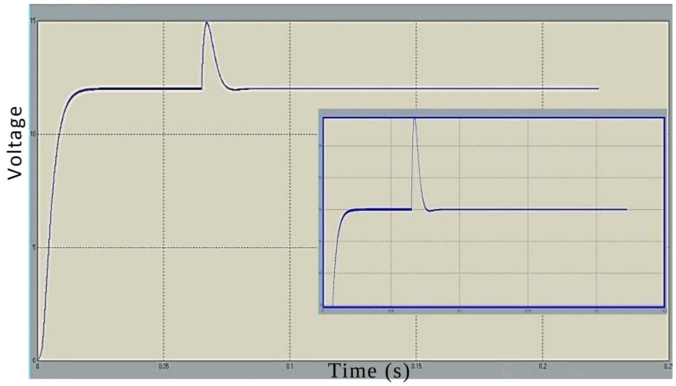


Fig.(24.b): The output ripple with fuzzy controller.



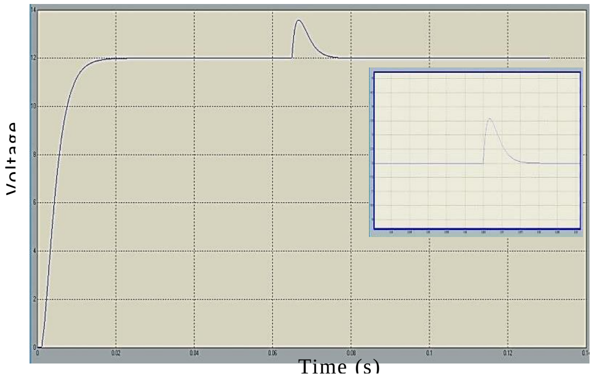
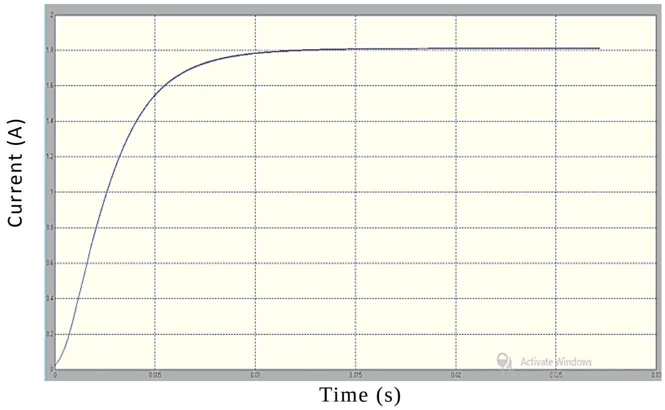


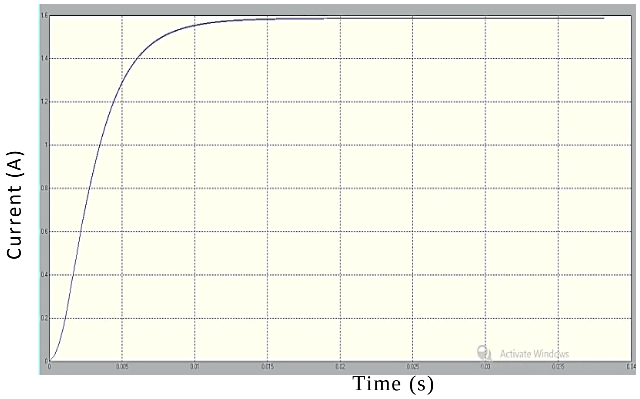
Fig.(25.a): Output voltage waveform for load changed Fig.(25.b): Output voltage waveform

for load changed from 2Ω to 4Ω with PI controller. from 2Ω to 4Ω

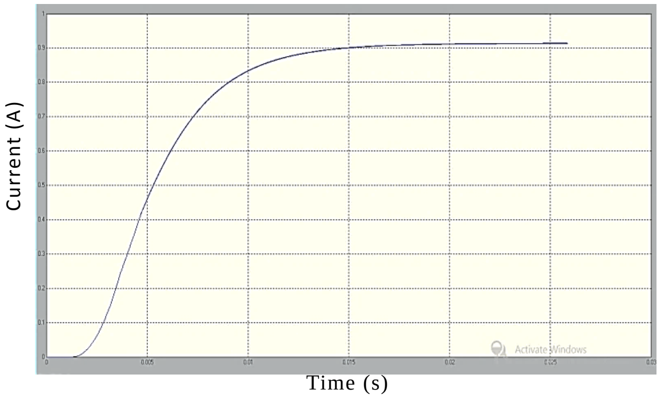
with fuzzy controller.



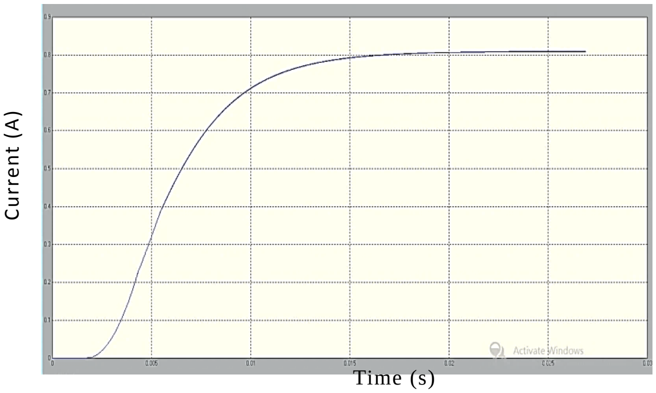
Fig(26.a)Input current waveform with PI controller and 2Ω load resistance.



Fig(26.b)Input current waveform with fuzzy controller and 2Ω load resistance.



Fig(27.a)Input current waveform with PI controller and 4Ω load resistance.



Fig(27.b)Input current waveform with fuzzy controller and 4Ω load resistance.

Table (2) shows the output results obtained from the designed circuits

| Parameter | With PI controller | With fuzzy controller |
|---|---|---|
| Maximum decrease in the output voltage for sudden change load from 4Ω to 2Ω | 3 v | 1.5 v |
| Width of spike ( time to return the voltage to the desirable value) | 0.02 s | 0.015 s |
| The output voltage ripple | 0.0012 v | 0 v |
| Efficiency | (75 – 79 )% | ( 84 – 95)% |
| Maximum increase in the output voltage for sudden change from 2Ωto 4 | 3v | 1.6v |

## 7. Conclusion

In this paper, a multistage current – controlled switched – capacitor ( SC ) step down dc – dc converter is analyzed. A state – space averaging method is applied for analysis. For current control scheme ( CCS ), the converter operates with a good regulation for output voltage and continuous input current waveform resulting in low conduced electromagnetic interference with the supply network by paralleling two converter cells and operated them in antiphase.This suggested converter is compared with the classical PWM switched – capacitor step – down DC-DC converter.The proportional – integral ( PI ) controller is used to control the output voltage at desired value for both techniques ( current controlled and PWM techniques ). In this paper a fuzzy logic controller is proposed as a voltage controller for current – controlled switched capacitor DC-DC converter to produce better performance. A 48 / 12 V, 70 W converter is designed and simulated using Matlab/Simulink. Based on simulation results, the following aspects can be concluded:
the fuzzy controller is used.

## 8.Referances

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