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Surveying multi cellular convertors controllers in power systems

Reyhaneh Chamyan[1] , Abolfazl Varani Farahani[2]

[1,2,] *Department of Electrical Engineering, Shahid Beheshti University, Tehran Iran*

Abstract

Multi-cellular convertors have interesting and versatile applications in the field of electricity and power. Two main types of multilevel converters based on floating capacitors include floating capacitor multi-cellular convertors and stack multi-cell. The first controller shows transient state based on average model and appropriate response and second controller functions based on a Lyapunov function and at the same time controls load currency and capacitor voltage at any Kumutasion (consecutive change) that leads to good performance in stable state. In this paper we design an observer to estimate capacitor voltage according to incorporate behavioral converter. A compound observer is designed based on collecting detailed information from separate switching system modes. Also this paper proposes a method for calculating capacitor voltage stability and load current. Finally, it shows controller effect and observer and proposed model for these three convertor using simulation.

Keywords: multi-cellular exchanger; switching; average model; combined observer; linearization feedback

Introduction

Multi-cellular convertors have interesting and versatile applications in the field of electricity and power. A major reason about this is increase of output voltage and its frequency. Main advantages of proposed convertor in comparison with accumulated multi-cellular convertors and FCM is duality RMS and output voltage level that as a result of this, frequency range of output voltage is improved and middle point of dc source is disappeared. This issue occurs in case of adding two switch with low frequency to FCM convertor and in the case of capacitors stability and switches with high frequency, grading capacitors

voltage and switches and switches with high frequency during a full cycle. First part of this paper discusses about multi-cellular convertors application in power systems. Second part of the article is dedicated to designing controller to ensure load current configuration and a proper distribution of passing voltage from each cell. In this regard two initiatives have been proposed, one is based on average model (for an appropriate transient state response) and the other is based on a Lyapanof function which is proper for controlling convertor switch with no need to modulation technique. Then discussed about observer design to estimate capacitors voltage regard to convertor compound behavior where that only load current is measured. Third part of proposed linearization feedback surveys convertor stability. Simulations reveal control and observer and proposed method effects for three-cell converter [1]. Also, these two MLD methods has been studied for buck-boost converter using Haysdl [2]. In this regard using linear piecewise approximations, nonlinear terms problem in mode equations is solved [3].special attention have been paid to newest and best application programs of these convertors such as press machine, conveyer belt and continuous power flow controllers [4]. Multi-cellular convertor is modeled based on a combination of p primary cells [5]. Current flows from source E toward different swatches outputs. Showed convertor has a combined structure that dealing with discrete variables (switching).

Note that due to presence of capacitances and inductances continues variables (like current and voltage) will emerge two. The important point is that because of standard industrial production, it is necessary to ensure a balanced distribution of capacitors voltage. According to agreements status, source voltage of j-th capacitor $j=\{1,2,...,p-1\}$ will be like $V_{cj,ref}=j\frac{E}{p}$. Dynamic convertor with a load includes a resistor R and inductor L with following differential equations:

$$\dot{I}=-\frac{R}{L}I+\frac{E}{L}S_p-\sum_{j=1}^{p-1}\frac{V_{cj}}{L}\left(S_{j+1}-S_j\right) \quad (1)$$

$$\dot{V_{cj}}=\frac{1}{cj}(S_{j+1}-S_j)\ ,\ j=1,2,\ldots,p-1 \quad (2)$$

In that formula, I is the load current, ، V_{cj} is the j-th capacitor, Cj is the capacity of capacitance, E is the Power supply voltage. Each embedded cell is controlled by binary signal $S_j=\{0,1\}$. $S_j=1$ Signal means that upper switch of j-th cell is on and lower switch of j is off and it means that upper switch is off and lower switch is on. Discrete input control $q=\{q_1,q_2,...,q_p\}$ of switches is as follow:

$$\begin{cases}q_j=S_{j+1}-S_j\\ q_p=S_p\end{cases}\qquad j=1,2,\ldots,p-1 \quad (3)$$

Suppose that only load current (I) can be measured (means the output is current y=I).system can be defined as follow:

$$\dot{I} = -\frac{R}{L}I + \frac{E}{L}q_p - \sum_{j=1}^{p-1}\frac{V_{cj}}{L}q_j \quad (4)$$

$$\dot{V}_{cj} = \frac{1}{cj}q \quad (5)$$

$$Y = I \quad (6)$$

We use compound systems. So we describe the system as below:

$$\dot{x}(t) = A_{\sigma(t)}x(t) + B_{\sigma(t)}u(t),\ t \neq \{t_k\},\ u(t) = E \quad (7)$$

$$x(t_k) = F_{\sigma(t_k^-)}x(t_k^-) \quad (8)$$

$$y(t) = C_{\sigma(t)}x(t) \quad (9)$$

Switching signal of $\sigma : R \to \{1, 2, ..., 2^P\}$ is a fixed piece and a Continuous function that its value changes with time changing of tk. at each t time, takes the convertor mode. Suppose that limited numbers of time switching in each limited interior exist (it means Xenon phenomenon won't be exist).

2. Materials and methods

Controller target is finding the qi extensive control input and $j = \{1, 2, ..., p\}$ so that multi-cellular converter ensures that:

I. Setting load current I to the nearest possible amount with constant and desired (I-Iref error goes to be zero) current.

II. Distribution of equal passing capacitors voltage from each cell (it means $V_{cj} - V_{cj,ref}$ goes to zero).

So proposed control will be designed to configure output current and obtain appropriate level of voltages in convertor output and capacitors terminal to configure output current. Two controllers are proposed in [6]. One is based on pulse with modulation and implementing desired response in transient mode and the second is based on Lyapanof function to direct control of upper converter switch without need to modulation technique.

2.1. Width pulse modulation strategy (PWM)[*]

The goal of this continues load current strategy and passing capacitors voltage from each embedded cell. PWM strategy is based on average model. This idea produces binary signal p with differential phase of $\frac{2\pi}{p}$. P fire cycles are comparing and let the load current and near capacitors voltage to desired amount become stable. In this regard, some studies by maintaining limiting Fluctuations and load current stable errors and internal proposed errors are introduced. Here controlling method have been applied separately [7]. Three PI controllers are dedicated to each internal voltage (V_{c1}، V_{c2} and load current I).that are represented by α_1، α_2 و α_3 variables. They are calculated using a similar method of [8] for each embedded cell.

2.2. Binary control strategy based in Lyapanof Function

Consider the shared Lyapanof function:

$$V = \frac{L(I - I_{ref})^2}{2} + \sum_{j=1}^{p-1} \frac{c_j (V_{cj} - V_{cj,ref})^2}{2} \qquad (10)$$

As there is no Jump, positive V, is continues and its value is zero for $I = I_{ref}$ and $V_{cj} = V_{cj,ref}$ and j=1,2,…,p-1. So we show that:

$$\dot{V} = (I - I_{ref})(-RI + ES_P) - (I - I_{ref}) \left(\sum_{j=1}^{p-1} V_{cj}(S_{j+1} - S_j)\right) + \sum_{j=1}^{p-1} V_{cj} - V_{cj,ref})I(S_{j+1} - S_j) \qquad (11)$$

Suppose that:

$$A_j = -(I - I_{ref})V_{cj} + (V_{cj} - V_{cj,ref})I$$

So equation (11) is becomes as follow:

$$\dot{V} = (I - I_{ref})(-RI + ES_P) - \sum_{j=1}^{p-1} A_j (S_j - S_{j+1}) \qquad (12)$$

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[*] Pulse-Width-Modulation

We can infer a status feedback control law by defining switching sequence of this shared Lyapanof function.

So we have the following equation under the controlling law:

$$S_p = \frac{1 - f\,(I - I_{ref})}{2} \quad (13)$$

$$S_j = \frac{1 + g(A_j)}{2},\ \forall j = 1,2,...,p-1 \quad (14)$$

$$f\,(I - I_{ref}) = \begin{cases} 1 & if \quad I - I_{ref} \rangle 0 \\ -1 & if \quad I - I_{ref} \langle 0 \\ Sign(A_{p-1}) & if \quad I - I_{ref} = 0 \end{cases} \quad (15)$$

$$g(A_j) = \begin{cases} 1 & if \quad A_j \rangle 0 \\ -1 & if \quad A_j \langle 0 \\ -Sign(A_j) & if \quad A_j = 0 \end{cases} \quad (16)$$

3. Design and analysis

3.1. Observer analysis

This part is dedicated to analysis of capacitors voltage Vcj and measuring I current and acknowledgement of q controlling input order.

Classic method: based on the existing system (12.7a-12.7c) in [7] we can see that there are some switching mode of x which are not visible. For example if Vcj capacitors voltage are not completely visible, so x order matrix is not complete order.

Geometric method: concept of being visible of Z is proposed in [9] that considers visibility of some class and compound systems.

$(\sigma^i, u^i, y^i, x^i)$ Set in $[t_0, t_f)$ domain defines a path in [7] that suggests that it is visible in $[t_0, t_f)$, if this equity occurs $(\sigma^1, u^1, y^1, x^1) = (\sigma^2, u^2, y^2, x^2)$, system (12.7a-12.7) in [7] switch signal σ(t) corresponds to a node which its value differs in the moment. Switching time is t_k that in it k mode transfers to k+1 [7].

3.2. Designing compound observer

In this part, a compound observer is designed to estimate, multi-cellular capacitors voltage only by measuring I current. This observer collects detailed information from initial modes of system switching.

Resetting method at each switching time is obtained based on detailed observer and some inverse formulas. This system is resistance if:

$$N^{m}_{k-N} = \{0\}\ ,\ \forall k \geq N+1$$

Using theorem of (4-2), compound observer is described as follow:

$$\dot{\hat{x}}(t) = A_k \hat{x}(t) + B_k u(t)\ , t \in [t_{k-1}, t_k) \quad (17)$$

$$\hat{x}(t_k) = \hat{x}(t_k^-) - \xi_k(t_k^-) \quad (18)$$

First status of $\hat{x}(t_0)$ is selected equal to zero. Applied Reset method with each switching time, is based on Sliding mode observer component. Coefficient Vector kξ is used to correct detailed mode information using Sliding mode observer component to coefficient zero error $\tilde{x} = \hat{x} + x$. Proposed method in [10] is defined to calculate kξ. A observer is designed to estimate visible test $\tilde{x}$ at time t_k^- . We define z^k matrix. So in domain of $[t_{k-1}, t_k)$ we can show that:

$$z^k = (z^k)^T \tilde{x}\ , Z^k \in R^{l_k} \quad (19)$$

$$w^k = (w^k)^T \tilde{x}\ , W^k \in R^{p-l_k} \quad (20)$$

$$S_k = (Z_k)^T A_k (Z_k)^{-T}\ , S_k \in R^{l_k \times l_k} \quad (21)$$

$$R_k = C_k (Z_k)^{-T}\ , R_k \in R^{1 \times l_k} \quad (22)$$

That (S_k, R_k) is visible. Sliding mode observer component is obtained using following equation

$$\dot{\hat{Z}}^k(t) = S_k \hat{Z}^k(t) + \bar{G}_k^{-1} v_k(t)\ ,\ \forall t \in [t_{k-1}, t_k) \quad (23)$$

$$\hat{Z}^k(t_{k-1}) = 0 \quad (24)$$

Coefficients are as (25.12) equations of [7]. Derived sliding mode is defined as a dynamic in (26-12) of [7].

Using Sliding mode observer (24.12) with terms of (25-12) in [7], α_1 and M_k constants can be estimated well. Mode estimate error $\tilde{z}^k(t) = \hat{z}^k(t) + z^k(t)$ at the limited time goes to zero. Due to the (12.23) in

[7], visible mode of error system is as (12.8a-12.8c) in [7]. Using this Conversion $\varsigma^k = \bar{G}_k z^k$ and [11], observer is as follow:

$$\dot{\varsigma}^k = \bar{s}^k \hat{\varsigma}^k + \nu_k \qquad (25)$$

Observer error stability produces $\hat{\varsigma}^k - \varsigma^k$ in a limited time. We can conclude from Using Change coordinates $\varsigma^k = \bar{G}_k z^k$ that Sliding mode observer (24.12) in [7] with corrected terms of (25.12) in [7] observer error $\tilde{z}^k$ in limited time of T* goes toward zero. Detailed mode information is collected to apply using an estimate of error. This estimate for current time of transition matrix is

$$\psi_i^j = \prod_{l=j}^{i+1} (e^{A_l \tau_l}) \qquad (26)$$

Is used and $\psi_i^i = I$. Based on [10] we define Θ_i^k matrix, Θ_i^k matrix in (12.23) in [7] is used to filter invisible component of applied estimated mode after transferred in t_k^- time. Then we can use Ω_k vector in [7] and information of $[t_{k-N-1}, t_k)$ term of resetting to $\xi_k(t_k^-)$ is defined in [7].

4. Simulation

To show the result of control design, a comparative study between PWM feedback, binary control and observer is presented [7]. Using a simulation of a 3 cell convertor about RL load and its features using all three strategies is as follow.

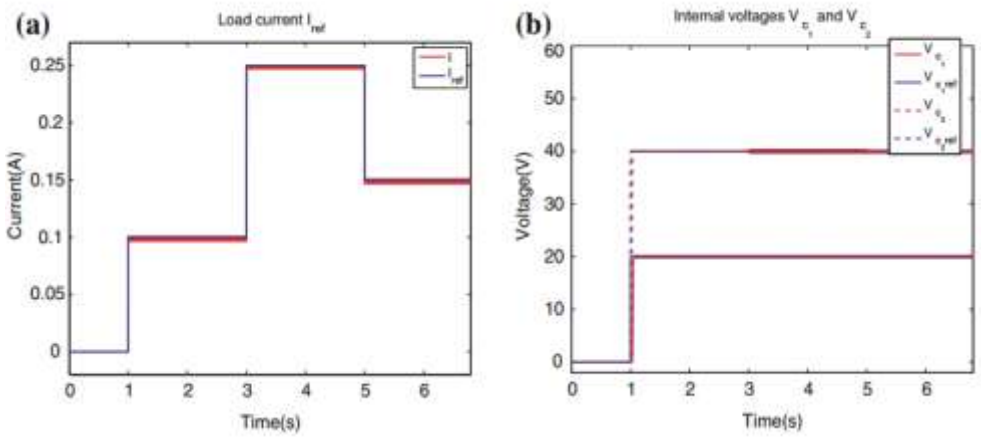


Fig1. Simulation of results of PWM strategy control

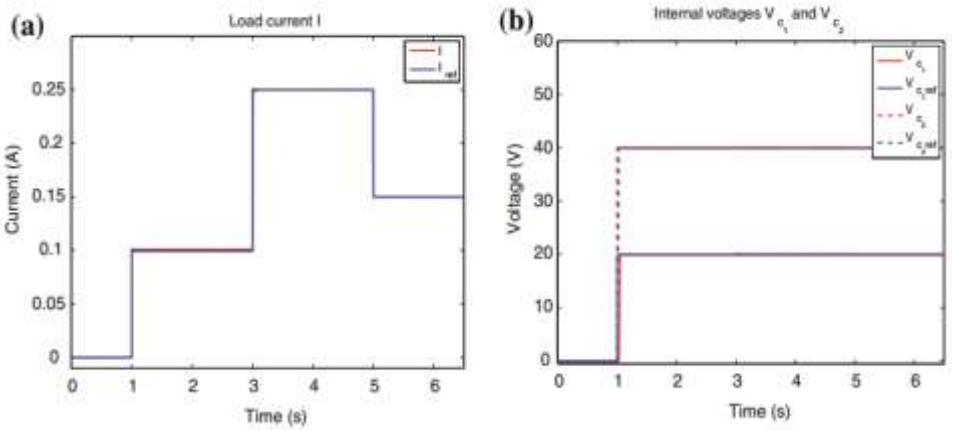


Fig2. Simulation results of binary control strategy

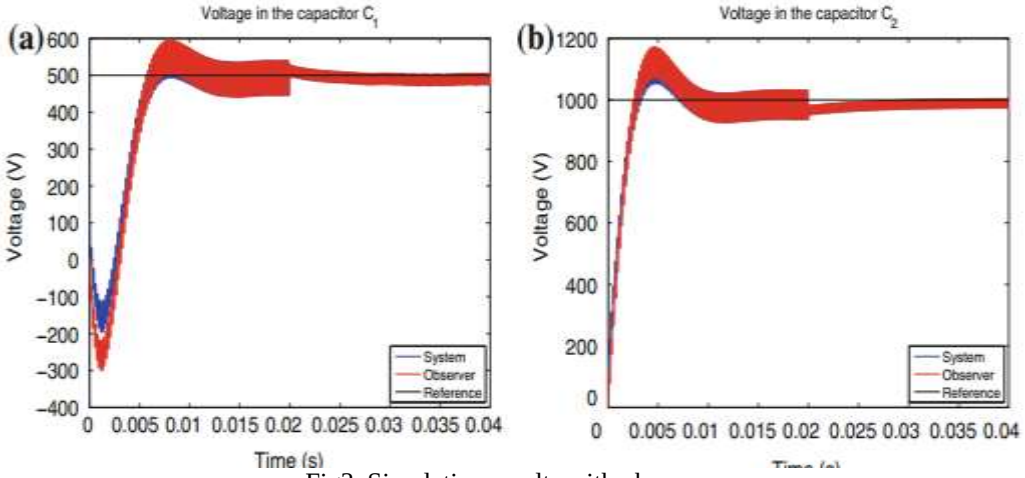


Fig3. Simulation results with observer

Simulation results for $E=1500V$ ，$L=1mH$ ，$C_1=C_2=40\mu F, R=10\Omega$ are defined below. At first stage we should study the tracking discussion. We set a test cycle with below features as a reference $I_{ref}=100A, t=0ms$

$I_{ref}=80A, t=10ms$

$I_{ref}=120A, t=30ms$

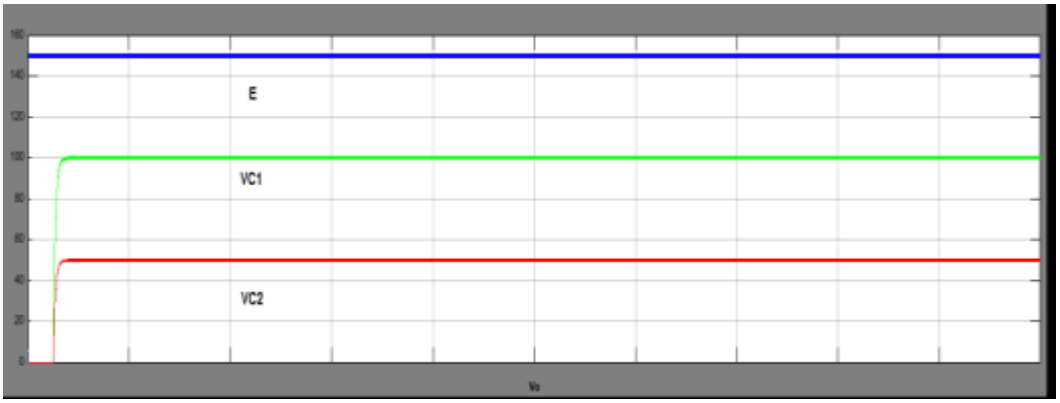


Fig4. C_1,C_2 Capacitors voltage

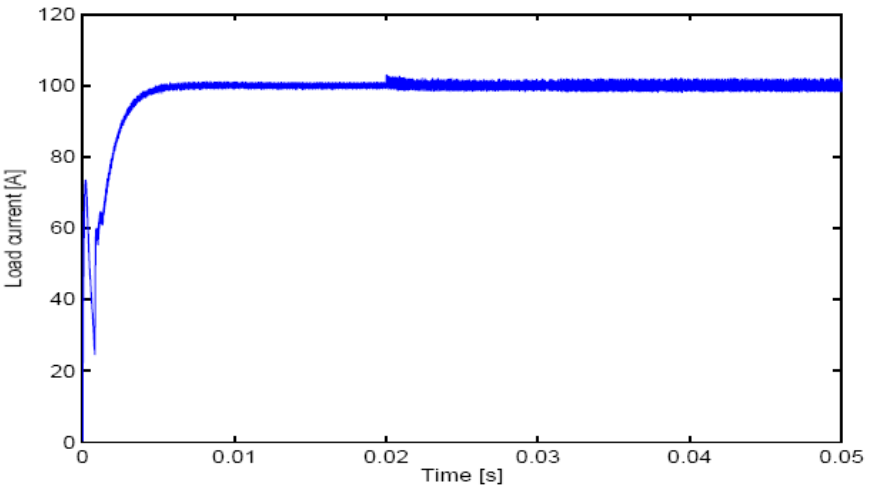


Fig5. Inducer current per change

5. Conclusion

In this paper, first of all, application and effect of multi-cellular convertors in power systems have been described. Then using two controllers for voltage control and converter current and an observer for estimating converter voltages have been studied. Finally, a proposed control method has been developed that shows its simulation effects. Regarding simulation results, it was shown that floating capacitance voltages and flow of errorless reference signals static is followed and at second stage, resistance test is Linearized. For this reason, at the moment of t=20ms, resistance load have been doubled. Also regarding fig 5 as you can see, this system have the capability of removing external noises and controlling parameters changes and considered control is resistant.

6. References

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