CONSIDERATIONS ON POWER LINE ROUTER BY USING MATRIX CONVERTER

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A power line router has been proposed the power flow control when clustered photovoltaic system (PV) is connected with utility. Back-to-Back (BTB that means AC/DC/AC converter) and matrix converter are thought as the power line router. This paper proposes a concept of power line router which is composed of a matrix converter. The matrix converter is based on direct power conversion without any intermediate DC power stage in order to obtain longer life and smaller size than conventional BTB system. Simulation with PSIM ver.6.1 shows active and reactive power flow is controlled independently by matrix converter.

Keywords: matrix converter, virtual indirect method, power line router, Autonomy-Enhanced PV Cluster

INTRODUCTION

The installation of PV has been expanding according to "PV2030 roadmap" in Japan. Generally, distribution voltage and fluctuation become large because of total installation of PV increase. Thus, it has been said that installation of conventional PV system connected with utility has upper limitation. For this matter, the project Autonomy-Enhanced PV clusters (AE-PVC) is proposed [1]. In AE-PVC, as the power flow is normally closed in the community, it is not necessary to synchronize with an external utility. AE-PVC configuration is shown in Fig.1. Electricity is generated by customer's PV, and the electricity that is not used is stored in the AC battery station. If PV could not generate power, the power is supplied by AC battery station. Voltage and frequency inside community are fixed. The electric power of the AC battery station is thought to be insufficient to long time insolation shortage or season change. It is necessary to supply the electric power only of the determine quantity and time from the external utility to prepare for such a low-speed change. At this time, internal community and external utility is asynchronous and it has possibility of different frequency. In addition, inter-community connection is needed when two or more communities are implemented as shown in Fig. 2. In this case, it is required that power flow direction is changed by the speed of PV system generation. In AE-PVC, power line router to supply the controllable electricity is proposed. Proposed power line router should satisfy the independent control of active power and reactive power flow in asynchronous and a different frequency at utility and community or inter-community.

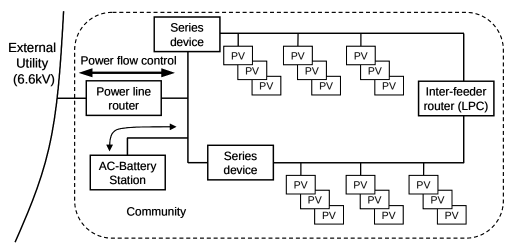

Fig. 1. Community image of AE-PVC.

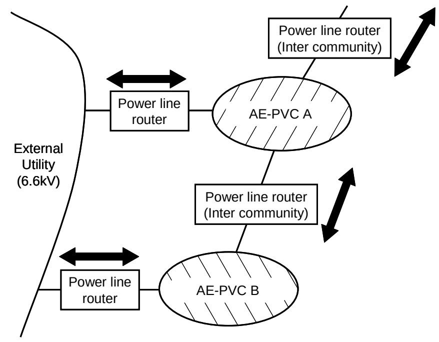

Fig. 2. Overview of AE-PVC.

POWER LINE ROUTER

BTB system and matrix converter using power electronics are considered as a power line router. BTB system needs intermediate DC link capacitors. On the contrary, matrix converter does not need any DC link capacitors and has some advantages such as longevity and miniaturization. Generally, matrix converter is used for driving motor load. In this study, matrix converter is proposed as a power line router from abovementioned reasons. Matrix converter circuit configuration is shown in Fig. 3.

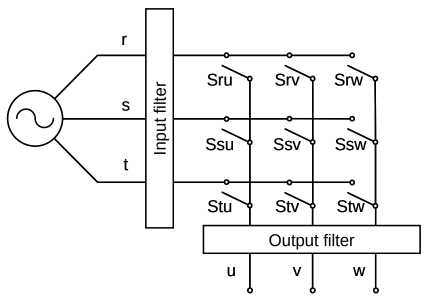

Fig. 3. Matrix converter circuit configuration.

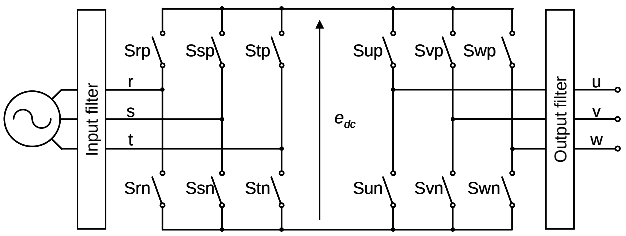

Fig. 4. BTB circuit.

MATRIX CONVERTER CONTROL METHOD

Matrix converter virtual indirect control

In Fig. 3, the relation between input voltage and output voltage can be expressed in eq. (1).

$$\begin{bmatrix} v_u \\ v_v \\ v_w \end{bmatrix} = \begin{bmatrix} s_{ru} & s_{su} & s_{tu} \\ s_{rv} & s_{sv} & s_{tv} \\ s_{rw} & s_{sw} & s_{tw} \end{bmatrix} \begin{bmatrix} v_r \\ v_s \\ v_t \end{bmatrix} \tag{1}$$

s_{mn} is the switching function of switch s_{mn}. The suffix *m* means *r*, *s*, *t*, and *n* means *u*, *v*, *w*, respectively. s_{mn} equals to "1" when switch s_{mn} turned on, and s_{mn} equals to "0" when s_{mn} turned off. In matrix converter, it must be $s_{mn} + s_{mn} + s_{mn} = 1$ to prevent short circuit of input voltage source and open circuit of output reactive load current. Fig. 4 shows the main circuit of BTB system (the left side six switches are PWM rectifier and right side six switches are PWM inverter). The same as eq. (1), the relation between input voltage and output voltage can be expressed in eq. (2).

$$\begin{bmatrix} v_u \\ v_v \\ v_w \end{bmatrix} = \begin{bmatrix} s_{up} & s_{un} \\ s_{vp} & s_{vn} \\ s_{wp} & s_{wn} \end{bmatrix} \begin{bmatrix} s_{rp} & s_{sp} & s_{tp} \\ s_{rn} & s_{sn} & s_{tn} \end{bmatrix} \begin{bmatrix} v_r \\ v_s \\ v_t \end{bmatrix} \tag{2}$$

Switching functions in eq. (2), it must be $s_{rk} + s_{sk} + s_{tk} = 1$ and $s_{kp} + s_{kn} = 1$ to prevent short circuit of input voltage source and open circuit of output reactive load current. The suffix *k* means *p*, *n*, in the rectifier side, *u*, *v*, *w* in the inverter side. Generally, if the ideal switching function can be obtained from different topology converters, the waveforms of the input current and the output voltage in different topology converters become exactly the same. Thus, it can be summarized that PWM pulses of the matrix converter is expressed in eq. (3).

$$\begin{bmatrix} s_{ru} & s_{su} & s_{tu} \\ s_{rv} & s_{sv} & s_{tv} \\ s_{rw} & s_{sw} & s_{tw} \end{bmatrix} = \begin{bmatrix} s_{up} & s_{un} \\ s_{vp} & s_{vn} \\ s_{wp} & s_{wn} \end{bmatrix} \begin{bmatrix} s_{rp} & s_{sp} & s_{tp} \\ s_{rn} & s_{sn} & s_{tn} \end{bmatrix} \tag{3}$$

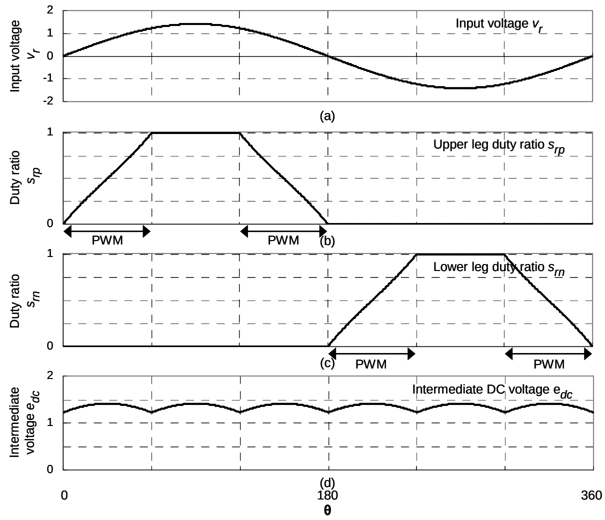

Fig.5 . Virtual current mode rectifier duty and e_{dc}.

The eq. (3) only consists of switching functions ("0" or "1"). Thus, it is easy to calculate by a digital logic hardware and it consists of "AND" gate and "OR" gate. This method consists of virtual rectifier control, virtual inverter control, and PWM pulse pattern conversion. Thus, it can be controlled complex matrix converter

Virtual rectifier control

Input voltage and the virtual rectifier PWM duty (r phase) are shown in Fig. 5. The virtual rectifier switches only operate 240 degree on one period as shown in Fig. 5 (b) and (c). In this rectifier pulse pattern, the intermediate DC voltage e_{dc} includes voltage ripple as shown in Fig. (d).

Virtual inverter control

Duty ratio is a percentage of on-time in triangle waveform period. Thus, numerical multiplication of duty ratio is not always equates to logical "AND" gate calculation. The logical multiplication result of inverter duty D=0.5 for rectifier pulse s_{rp} with the same triangle waveform is shown in Fig. 6.

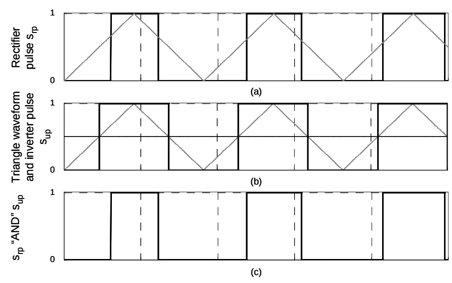

Fig.6 . Relation between rectifier and inverter pulse.

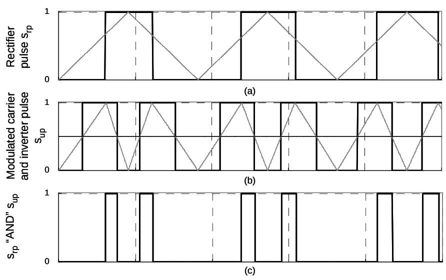

Fig. 7. Relation between rectifier and inverter pulse by using modulated triangle waveform.

It is confirmed that calculation result (c) doesn't become the half of (a). Thus, there is a special triangular modification to solve this problem [2]. In this method, the triangular carrier slope is controlled by converter duty ratio as shown in Fig.7. It is confirmed that calculation result (c) equals to the half of (a). The virtual inverter makes possible to control like the conventional inverter by using modulated triangle waveform.

CURRENT COMMUTATION

Fig.8 shows the circuit of two phase to single phase matrix converter, representing the first two switches in the matrix converter shown in Fig. 3. In steady state, both switch s_{A1} and s_{A2} are on state and both switch s_{B1} and s_{B2} are off. The next steady state switched s_B and switch s_A are off at the same time. Here, both s_A and s_B do not turn on or off simultaneously, open circuit and short circuit occur. In this study, "2-step swithing strategy" as a kind of several multi-step commutation strategies is used to solve this problem [3]. In this method, only the device which carries the current (switch s_{A1} and s_{B1} in this case) is gated at any given time. So, switch s_{A2} and s_{B2} are not used at above description. In this state, turn on of switch s_{B1} is delayed time t_0 from turn off of switch s_A, as shown in Fig. 9. The input voltage sources v_A and v_B are not open. Output current direction is needed in this method. Fortunately, input and output current are controlled in the proposed power line router system as shown in Fig. 10. The controller has output current feedback signal to control output current. Therefore, it doesn't occur any problem.

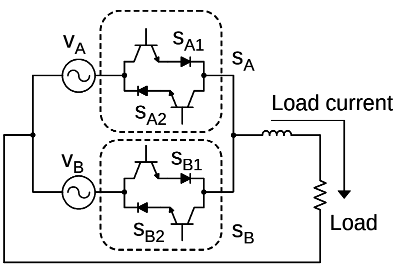

Fig. 8. Two-phase to single phase matrix converter.

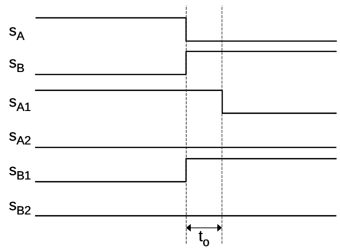

Fig. 9. Timing diagram of two-step commutation.

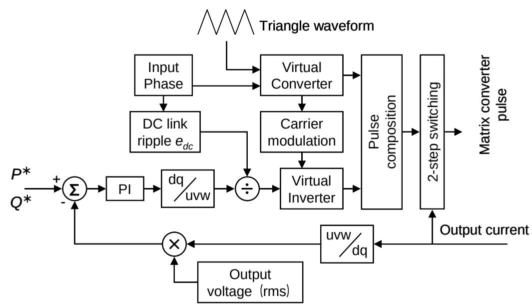

Fig. 10. Block diagram of power line router system.

Table 1. Circuit parameter for simulation

Line impedance	0.025+j0.339 Ohm	L3	600 uH
Triangle waveform	10.5 kHz	C1	10 uF
L1	35 uH	C2	4 uF
L2	250 uH		

SIMULATION AND RESULT

Fig.11 shows the router system configuration in AE-PVC. In this power line router simulation, voltage and frequency of the input community side A and the output community side B are fixed by the ideal AC battery station. Each community is simulated by three-phase voltage source and line impedance. Each frequency is different that two or more introductions of AE-PVC and extreme case are assumed. Therefore, this situation is asynchronous and the frequency is different. Circuit parameter is shown in Table.1.

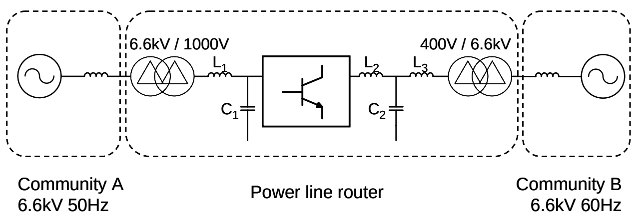

Fig. 11. Router system configuration.

Fig.12 shows the steady-state waveforms of each voltage and current at active power flow control P*=100kW and reactive power flow control Q*=0kVar with constant. It is verified that the power line router provides sinusoidal current with high power factor on different frequency connection. The reverse power flow case (P*=-100kW, Q*=0kVar) is shown in Fig.13. Waveforms (b) and (d) are anti-phase from both (a) and (c).

Fig. 14 shows the power flow direction changing from P=100 kW to -100 kW from 0.5 [s] to 1 [s], and reactive power flow is fixed to 0 kVar. Thus, power flow direction change is verified in this simulation.

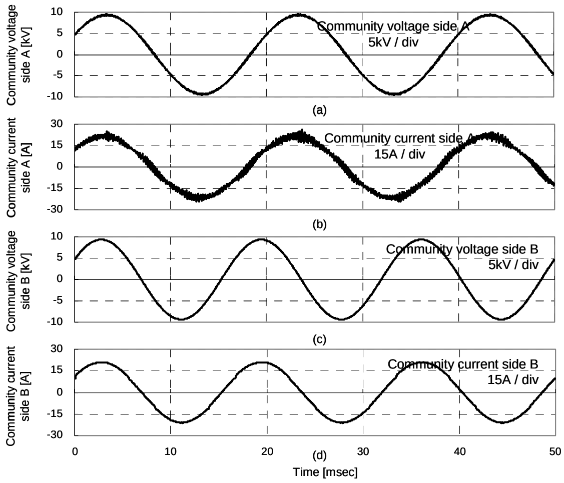

Fig. 12. Waveforms of forward power P*=100kW.

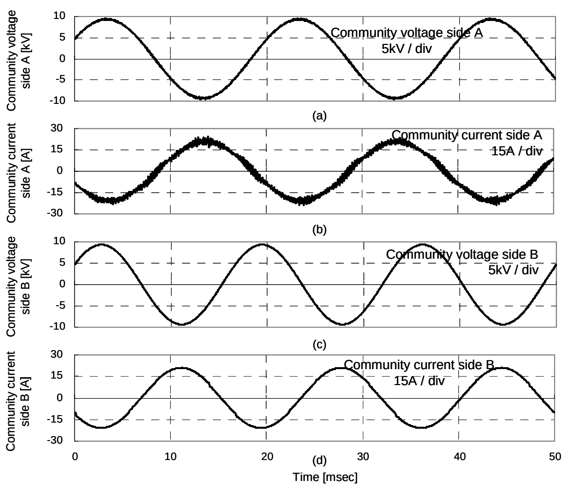

Fig. 13. Waveforms of reversal power P*= -100kW.

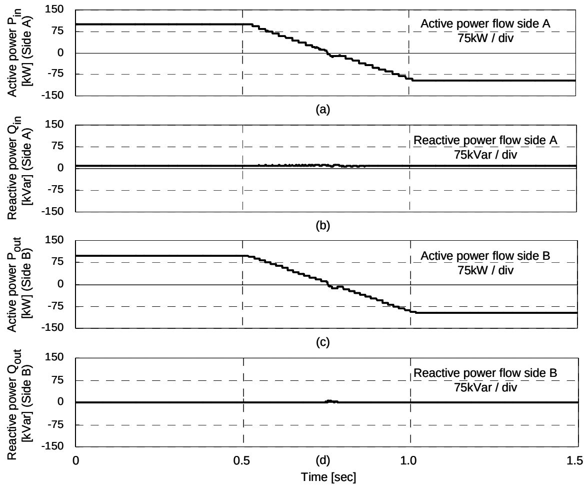

Fig. 14. Independent control of active and reactive power flow and power flow direction change.

CONCLUSION

This paper proposes application of matrix converter based on virtual indirect method to power line router on AE-PVC. An independent control of active and reactive power flow and power flow direction change are shown in the simulations. Thus, it is confirmed that the controls of power line router can be satisfied in the AE-PVC.

Acknowledgement

This study has been carried out as a part of “Autonomy-Enhanced PV Cluster” project founded by New Energy and Industrial Technology Organization (NEDO). The authors wish to thank them for their support.

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