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STUDY OF MATRIX CONVERTER BASED UNIFIED POWER FLOW CONTROLLER APPLIED PI-D CONTROLLER

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Abstract

In this paper, the Unified Power Flow Controller (UPFC) using a matrix converter is studied. It is an adaptation of an approximate differentiation type PI-D controller. By setting appropriately the values of the gain controller, it is possible to stabilise the power of the transmission line by controlling the UPFC by a matrix converter. The matrix converter is a power conversion circuit that can convert an arbitrary phase and amplitude of the AC power directly to AC power. The principle of creating a switching pattern that adopts a Direct Duty ratio Pulse Width Modulation (DDPWM) scheme. The UPFC is a stationary device to adjust the grid voltage for controlling the power flow is inserted into the power system, and controls the transmission power according to the load variations. This is intended to stabilise the power system. Verification is done by simulation using MATLAB/Simulink for the validity of this proposed method.

Keywords: Matrix converter, Unified power flow controller, Direct duty ratio PWM, Approximate differentiation PI-D controller.

1. Introduction

In recent years, highly reliable and stable power supply system is achieved international, especially in Japan. With the entry of Independent Power Producer (IPP), the introduction of small-scale distributed power using natural energy IPP and deregulation of power, there is a possibility that the power flow is complicated and the power transmission system is overloaded locally.

Nomenclatures

$d_{A1,2}$	Duty ratio value in each switching pattern
K_D	Differential gain value
K_I	Integral gain value
K_P	Proportional gain value
l	Time constant
MD	Medium Input voltage, V
MN	Minimum Input voltage, V
$M_{p,q}$	Modulation rate in each of the axis
MX	Maximum Input voltage, V
n	Percentage of T_1 for T_s
T_1	Time period, s
T_2	Time period, s
$T_{A1,2,3,4}$	A-phase output terminal
T_s	Switching period, s
v_{OA}	Integration of the output voltage
v_{OA}^*	A-phase output voltage command
$\bar{v}_{OA}$	Averaged value of v_{OA}
$v_{sa,b,c}$	Input voltage in each phase

As transmission control system uses power electronics technology to avoid these problems. Therefore, to achieve effective use of the existing power transmission system, the Flexible AC Transmission System (FACTS) concept has been proposed [1, 2]. The UPFC acts as one of FACTS devices, thereby improving stability and strain transmission power control by adjusting the phase and amplitude of the electric lines [3].

However, problems such as the loss of conversion and small capacity of the power converter that compensates for the power stage must be resolved. So, the matrix converter is adapted as a power converter [4]. Matrix converter is able to convert the AC power to AC power directly. Comparing with the back to back converter, which connected converter and inverter with a electrolytic capacitor, there is a merit of improving conversion efficiency and miniaturisation is possible because electrolytic capacitors are not required [5-8].

We use the direct duty ratio pulse width modulation (DDPWM) [9]. DDPWM synthesize the duty ratio value directly from the desired output voltage and have some advantages that relatively easy implementation and decrease the switching loss compared some other switching methods. To accommodate fast changes in the load as the controller and performs stabilisation, the approximate differentiation type PI-D controller with a low pass filter is designed. The simulation results using MATLAB/Simulink have shown the validity of the proposed methods.

2. Proposed Method

The stabilisation of the power system by UPFC when the load current is varied is as shown in Fig. 1.

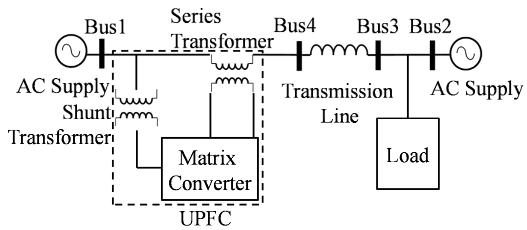

Fig. 1. Diagram of a Power System Inserted the UPFC.

The load is to simulate a location that requires power plants, homes and buildings. The variety of the current supplied to the load must be always stable, but demands for power with time. A method of keeping a stable power of Bus 3 is proposed where even the value of the load is changing rapidly, the UPFC can give out a fast response, by adjusting the power of Bus 4.

The need of security of the power of the UPFC is because there is a need to convert alternating current to direct power to security department. So, the matrix converter had been adapted. Its advantage is that it can be miniaturised and conversion efficiency is improved when using the matrix converter.

A block diagram of an electric power system is inserted the UPFC is shown in Fig. 2. Switching pattern is created by using DDPWM scheme.

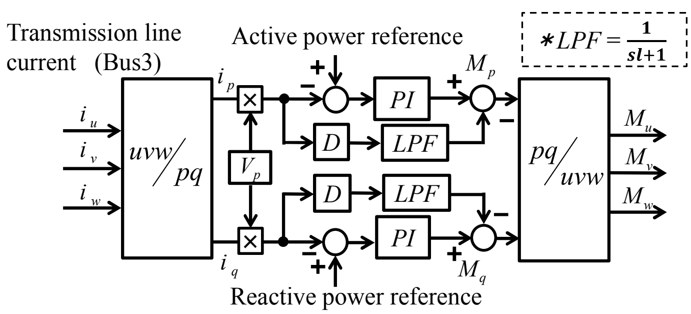

Fig. 2. Diagram of Controller Block.

In order to obtain the robustness of the UPFC system and high-speed response, its control is performed by using the model of instantaneous power *pq*. First, the *pq* converts the three-phase alternating current, which is the output of the matrix converter and is considered as an instantaneous reactive current and instantaneous active current. Then, by adding the line voltage, it is considered as instantaneous reactive power and instantaneous active power.

To give a command value for the power to perform the PI-D control, control of the current is done by making an inverse transformation *pq*. Finally, it is converted into three-phase alternating current again, to determine the duty ratio by using this value.

PID controller is employed to the proposed system because it is widely used in many industrial applications to obtain the desired response. Simple PI type controller and its controller gains design method was proposed by authors [7], but in some cases more robust against the load change is demanded so PID type controller was also considered [8]. In this paper, an approximate differentiation type PI-D controller is composed of the PI controller and this controller and low pass filter is applied to the differential. By setting the appropriate gain value for the control unit to control the UPFC, it is possible to stabilise the grid.

3. Direct Duty Ratio PWM (DDPWM)

The method of DDPWM is shown below. For this paper, only one out of the three phases is shown here. Two other phases are also determined in a similar manner. First, as shown in Fig. 3, the phases have been divided into intermediate phase, the minimum phase voltage of the power supply. The intermediate phase is the switching pattern II whereas the value of the switching pattern I is positive if the value is negative. Using these phases to create a switching pattern, when switching is done, the result is as shown in Fig. 4, when the switching pattern is at I. The switching period T_S is divided into T_1 and T_2. T_1 is defined as n = T_1/T_S here. Divided into T_{A1}, T_{A2}, T_{A3}, T_{A4} in switching cycle further, switching of the input voltage *MN*, *MX*, *MX*, *MD* is performed to output in each section. Figure 5 shows the output voltage at this time.

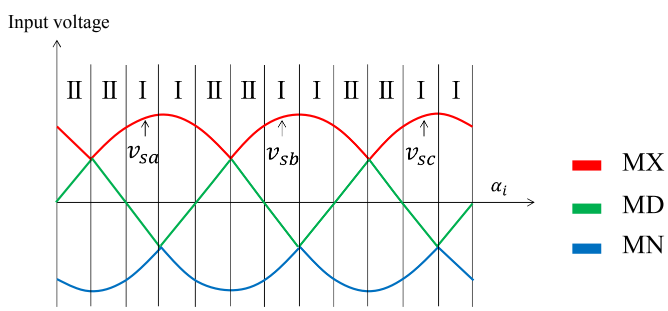

Fig. 3. *MX*, *MD*, *MN* and Switching Pattern I, II.

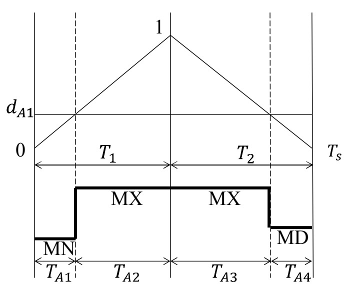

Fig. 4. Output A-Phase Switching State in Switching Pattern-I.

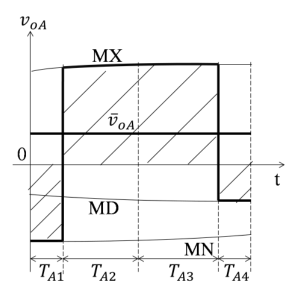

Fig. 5. Output A-Phase Voltage Synthesis in Switching Pattern-I.

where $\bar{v}_{OA}$ is the average voltage. Section T_{A1} to T_{A4} can be obtained in the next section as in Eqs. (1).

$$T_{A1} = d_{A1} \cdot n \cdot T_s$$
$$T_{A2} = (1 - d_{A1}) \cdot n \cdot T_s$$
$$T_{A3} = (1 - d_{A1}) \cdot (1 - n) \cdot T_s$$
$$T_{A4} = d_{A1} \cdot (1 - n) \cdot T_s \quad (1)$$

Here, the section of each of the $T_{A1} \sim T_{A4}$ is in a very small range, the voltage may be a constant in the interval. Therefore, the integral value of the output voltage of the switching period v_{OA} between T_S is given by Eq. (2).

$$\int_0^{T_s} v_{OA}\, d_t \cong T_{A1} \cdot MN + (T_{A2} + T_{A3}) \cdot MX + T_{A4} \cdot MD \quad (2)$$

Equations (1) and (2) wherein the average value of the voltage $\bar{v}_{OA}$ is as shown in Eq. (3).

$$\bar{v}_{OA} = \frac{1}{T_s} \int_0^{T_s} v_{OA}\, d_t \cong d_{A1} \cdot (n \cdot MN - n \cdot MD + MD - MX) + MX \quad (3)$$

Therefore, by using the voltage command value v_{OA}^* and n the maximum phase of the input voltage, intermediate phase and the minimum phase, the duty ratio of d_{A1} for A-phase is determined by the following equation. Therefore, by using the voltage command value v_{OA}^* and n the maximum phase of the input voltage, intermediate phase and the minimum phase, the duty ratio of d_{A1} for A-phase is determined by Eq. (4).

$$d_{A1} = \frac{1}{n \cdot MN - n \cdot MD + MD - MX} (v_{OA}{}^* - MX) \quad (4)$$

It is possible in the same manner, to determine the duty ratio even in switching pattern II. Equation (5) shows the switching pattern corresponding to Figs. 6 and 7.

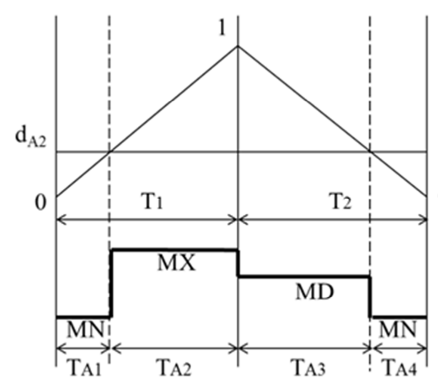

Fig. 6. Output A-phase Switching State in Switching Pattern-II.

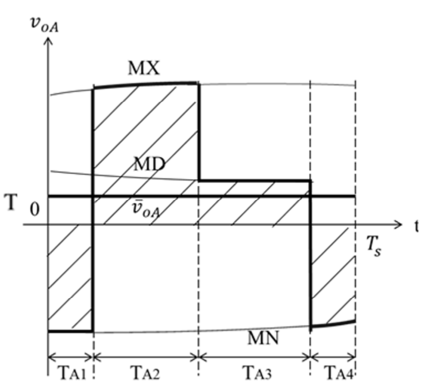

Fig. 7. Output A-Phase Voltage Synthesis in Switching Pattern-II.

$$d_{A2} = \frac{v_{OA}{}^{*} - (n \cdot MX - n \cdot MD + MD)}{MN - n \cdot MX - MD + n \cdot MD} \quad (5)$$

Accordingly, the switching pattern for each duty ratio d_A of the A-phase is determined by Eq. (6).

$$d_A = \begin{cases} \dfrac{v_{OA}{}^{*} - MX}{n \cdot MN - n \cdot MD + MD - MX} & Pattern\ I \\ \dfrac{v_{OA}{}^{*} - (n \cdot MX - n \cdot MD + MD}{MN - n \cdot MX - MD + n \cdot MD} & Pattern\ II \end{cases} \quad (6)$$

4. Approximate Differentiation Type PI-D Controller

It is designed to approximate differentiation type PI-D controller in this study, it has been used a simple PI controller first. The gain values have been determined by trial and error, and these were $K_P = 10$, $K_I = 100$. Instantaneous reactive and active power are as shown in Fig. 8. The enlarged view is also shown in Fig. 9. The command value of the instantaneous active power is 1500 [VA] and of the instantaneous reactive power is 0 [VA].

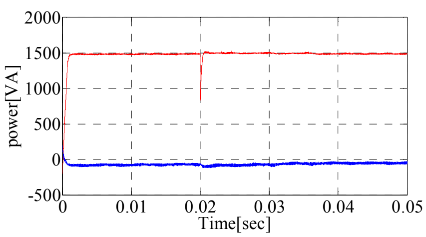

Fig. 8. Instantaneous Power (K_P=10, K_I=100).

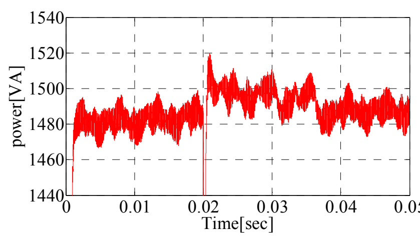

Fig. 9. Enlarged View (K_P=10, K_I=100).

It has not been possible from Fig. 8, the instantaneous reactive power to follow the command value. The instantaneous power takes long time to settle the steady state when the load change occurs in 0.02 s from enlarged view. Therefore, it is necessary to modify the controller and gain values to enhance stability; an approximate differentiation type PI-D controller is designed. By using this controller, without differentiation settings directly, derivative action is to function only on the control variables, and a low pass filter is applied to the differential, thus rapid changes is seen stepwise and less sensitive to the noise component it is strongly against. These gain values are determined by trial and error again, and these were set to $K_P = 40$, $K_I = 400$, $K_D = 0.3$, and time constant is 0.12. Instantaneous active and reactive power is as shown in Fig. 10. The enlarged view is also shown in Fig. 11. From Fig. 10, it is able to follow the command value both instantaneous active and reactive power by using the approximate differentiation type PI-D controller. It can be seen from the enlarged view; it is able to stably keep the active power even when the load change occurs. So this controller is adapted in this study.

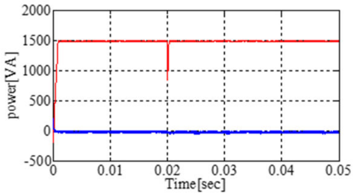

Fig. 10. Instantaneous Power (K_P=40, K_I=400, K_D=0.3).

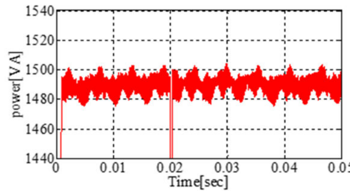

Fig. 11. Enlarged View (K_P=40, K_I=400, K_D=0.3).

5. Results and Discussions

These simulations according to the proposed method, is carried out by MATLAB/Simulink, the simulation was performed by varying load conditions as shown in Table 1. The result is shown in the Figs. 12-17. The parameter of the control block is shown in Table 2.

Table. 1. Value of *RLC* Load.

	Time [s]	0~0.02	0.02~0.04	0.04~0.05
RLC	*R*[W]	200	400	200
load	*L*[var]		200	
value	*C*[var]	0	300	0

Table. 2. Parameter of Control Block.

Reference (active)	Value	0.5[p.u.]
Reference (reactive)	Value	0
	K_P	40
PI-D Controller	K_I	400
(active and reactive)	K_D	0.3
	l	0.12

Figures 12 and 13 respectively indicates a modulation rate of the reactive component and active component.

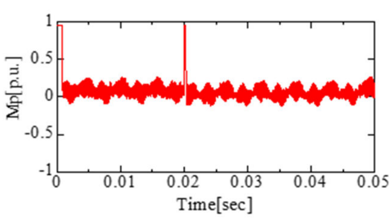

Fig. 12. Instantaneous Power (K_P=10, K_I=100).

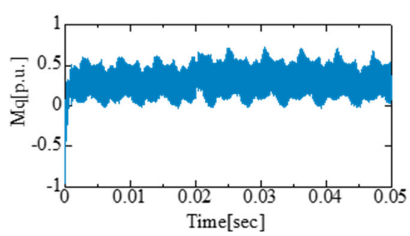

Fig. 13. Enlarged View (K_P=10, K_I=100).

Figures 14 and 15 show the voltage and current of Bus 4 which is the output of the matrix converter. The voltage and current of Bus 3 is a system that is to undergo stabilisation is shown in Figs. 16 and 17.

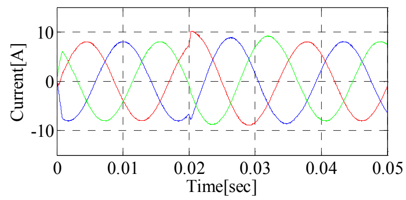

Fig. 14. Bus 4 Current.

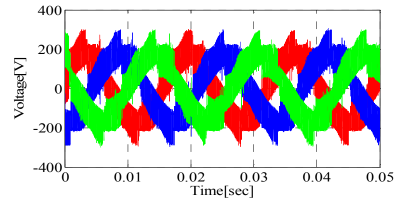

Fig. 15. Bus 4 Voltage.

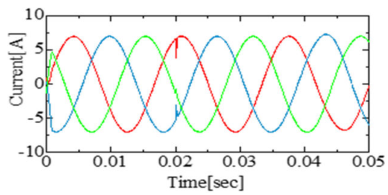

Fig. 16. Bus 3 Current.

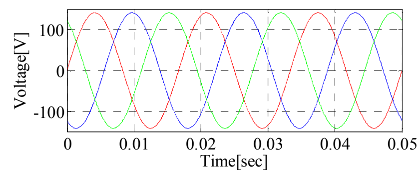

Fig. 17. Bus 3 Voltage.

It is found that the output of the matrix converter is changed from Fig. 14, with varying value of the load. From Fig. 16, the power of the system that is intended to be stabilised when changing the value of the load is changed momentarily. It can be seen that both the phase and amplitude is back to its regulated value instantly. Having said that, it can be seen that in Figs. 14 and 16, changing the value of the load are controlled by the UPFC power of the system so as to maintain a stable value. The instantaneous power of Bus3 is shown in Fig. 18. It is found that the power of the system is stabilised by UPFC from the waveform. Therefore, the gain value set from these results is appropriate and it was possible to control the power of the system.

6. Conclusions

In this paper, it has been described that the UPFC can be used onto the PV derivative type PI-D control using a matrix converter. The controller is designed successfully from the simulation results that are built as a simulation model. The system also revealed the effectiveness and feasibility of the PV derivative type PI-D control of the UPFC matrix converter based as had been proposed. The simulation results show the validity of the proposed controller. Furthermore, it can be studied using the actual simulation for further understanding in the future.

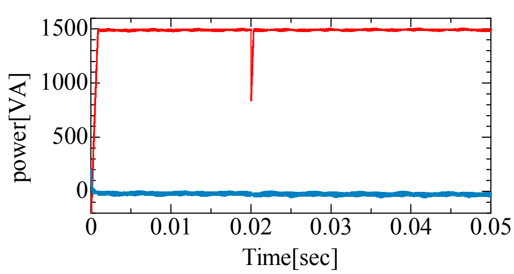

Fig. 18. Instantaneous Powers of Bus 3.

Acknowledgement

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