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Control Method for Improving the Voltage Utilization Factor of Multilevel Inverters Considering Co-Generation System Voltage Fluctuation

S. Narasimha, M. Sushama

Abstract— Given the threat of diminution of fossil fuels and several environmental concerns, cogeneration systems using natural energy and fuel cells have begin widespread. In such systems, the generated power is converted into a DC voltage, stored in batteries, and then converted into an AC voltage by inverters. The generated power is often unsteady and large voltage fluctuations. In an attempt to improve efficiency and decrease costs, a simple control method for improving the voltage utilization factor of multilevel inverter. This paper describes a control method which combined feed back control of output voltage with the improvement on voltage utilization factor that the superposition ratio is controlled in the three phase multilevel inverter application to smart grid/co-generations. The aim of this control method is to realize improvement on the controllability and absorption of the fluctuation of the DC voltage by superimposing the moderate third harmonic wave. It is applied to the multilevel inverter, and the operation principle and features are explicated, By simulation/MATLAB.

Key words- Multilevel inverter; improvement of voltage utilization factor; feedback control; DC-link voltage; Co-generation.

I. INTRODUCTION

As one solvent for the problem of environmental deterioration and energy shortage, co-generation system using natural energy and fuel cell widely spread. The electric power generated from these systems is converted to AC voltage by the inverter, after it is stored as DC electric power in the battery. In case of the system of power generation using natural energy and fuel cell, comparatively large fluctuation is generated at the DC voltage [3]. As this counter measure, improvement of voltage utilization factor by the superposition of the third harmonic wave was applied in order to absorb this fluctuation [1]. The feed back control of output voltage was applied for the stabilization of output voltage. In addition, the output voltage in the ideal modulation without the distortion was obtained by controlling superposition ratio of third harmonic wave with the fluctuation of DC voltage. As a circuit converted into AC power from DC power, the multilevel inverter circuit was applied considering the reduction in switching component and capacity an expansion. The multilevel inverter is possible to reduce lower harmonic wave and switching component by outputting many voltage levels [2]. However, many switching devices and DC power source are necessary. It is possible to output stabilizing AC voltage by the bsorption of the fluctuation of DC voltage.

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And it will be possible to reduce the capacity of the DC capacitor [2][3]. In this paper, the new control method which introduced the control of superposition ratio of third harmonic wave into output voltage feedback control and improvement on voltage utilization factor is proposed. It is applied to the multilevel inverter, and the operation principle and features are explained. Block diagram of co-generation systems is an explained in Fig(10) which including Solar, Wind and fuel cells system .The fluctuated inputs are converted to stable output by using Multilevel inverter. By simulation the validity of proposed control has been confirmed.

II. CIRCUIT CONFIGURATION

The main circuit configuration is shown in Fig. 1. This circuit is an ordinary three-phase 5level inverter composed of 12 IGBTs, 6 diodes, and 2 DC sources. With *E* denoting the voltage of one DC source, the output provides five levels of line voltage, namely $\pm 2E$, $\pm E$, 0. In addition, pulse width modulation is applied in order to reduce harmonic components. With more voltage levels, the content of switching components is reduced, and the generation of harmful harmonics is suppressed.

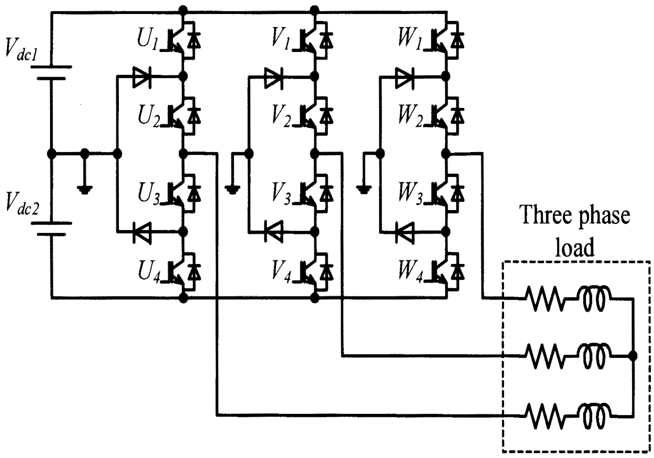

Fig. 1 Circuit Configuration

III. CONTROL METHOD

In the proposed control method, the basic PWM control block used conventionally for multilevel inverters is supplemented by output voltage feedback and improvement of the voltage utilization factor. Assuming the use of a general-purpose digital control system, we aimed at the minimizing individual phase control in order to simplify control processing. A block diagram of the proposed control method is shown in Fig. 2, and detailed explanations are given below.

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A. Improvement of Voltage Utilization Factor [1, 2, 4]

There is a known method for improving the utilization factor of the output voltage by superimposing a third harmonic on every phase signal of a three-phase inverter. In this study, we describe the application of this method to a multilevel inverter. In addition, we introduce variable superposition ratio control, so that the superposition ratio of the third harmonic can be adjusted to the DC voltage fluctuation. The input signal of proportional integrator PI_1 reflects the control state of output voltage, and its value is employed for calculation of the appropriate superposition ratio of the third harmonic. When the DC voltage is sufficient to output the rated voltage of 440V, the input signal of PI_1 is zero, and the output of LIM1 is below V_{tri}. Therefore, the input of PI_2 becomes negative. As a result, the output of LIM_2 is zero, and the superposition amount is likewise zero. On the other hand, when the DC voltage is deficient, the output LIM_1 is limited byV_{tri}, and the input of PI_2 becomes positive. As a result, the output of LIM_2 is somewhere between 0 and V*out, and the superposition amount is adjusted to the deficit of the DC voltage. The superposition ratio ∝ is obtained by dividing the output value by $6V^*_{out}$, and the superposition signal is generated by applying the ratio to the sine wave of the third harmonic. The signal is added to the three-phase sine wave reference multiplied by (1 + ∝) in order to calculate the output V_{out} of PI_1. As a result, the following phase signals are obtained:

$$V^*_R = V_{pi}[(1+\propto)\sin\theta + \propto \sin 3\theta]$$

$$V^*_Y = V_{pi}[(1+\propto)\sin(\theta - \tfrac{2}{3}\Pi) + \propto \sin 3\theta]$$

$$V^*_B = V_{pi}[(1+\propto)\sin(\theta + \tfrac{2}{3}\Pi) + \propto \sin 3\theta]$$

……………………………………………..………. (1)

B. Output Voltage Tracking Control [1]

Two phase output line voltages V_{RY} and V_{BR} are taken into the Simulation the following can be obtained from the fundamental equations for a three-phase three-wire system, and from the relationship between the line voltages and phase voltages:

$$\mathbf{V_{RY}+V_{YB}+V_{BR}=0}$$

$$\mathbf{V_{RY} = V_{BN} - V_{YN}}$$
$$\mathbf{V_{YB} = V_{YN} - V_{BN}}$$
$$\mathbf{V_{BR} = V_{BN} - V_{RN}} \quad \text{……………………..……………………..(2)}$$

Therefore,

$$\mathbf{V_{BN}} = 1/3(\mathbf{V_{RY}} - \mathbf{V_{BR}})$$
$$\mathbf{V_{YN}} = 1/3(\mathbf{V_{YB}} - \mathbf{V_{RY}})$$
$$\mathbf{V_{BN}} = 1/3(\mathbf{V_{BR}} - \mathbf{V_{YB}}) \text{…………………….………. (3)}$$

Three phase voltages V_{RN}, V_{YN} and V_{BN} are converted into two-phase AC voltages $V\propto$ and $V\beta$ by using the following:

$$\begin{bmatrix} V\propto \\ V\beta \end{bmatrix} = \frac{\sqrt{3}}{2} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{RN} \\ V_{YN} \\ V_{BN} \end{bmatrix}$$

………………………………………………..……….. (4)

Now the magnitude V_{out} of the resultant output vector is calculated as follows:

$$V_{out} = \sqrt{|\dot{V}_\alpha|^2 + |\dot{V}_\beta|^2} \text{ …………………………………..…. (5)}$$

The magnitude Vout corresponds to the effective value of the output line voltage, which is a DC value in the case of a three-phase balanced voltage without fluctuation. Therefore, tracking control of the output voltage can be implemented by maintaining this value at a stable level. The difference between the output voltage references V*out and the resultant vector magnitude Vout is given to the proportional integrator, and the DC voltage compensation on V_{pi} is calculated. A coefficient related to the superposition ratio α is applied to this value, and then a sinusoidal reference is obtained by multiplying by a three-phase sine Wave with amplitude of one. The advantage of this system is obtaining the fixed control characteristic, when the AC voltage of any frequency is output, because the signal input to the proportional integrator is the instant DC voltage which does not depend on the frequency of the output Voltage. That is, the method can be applied to variable speed drive of electric motors and to other cases when a variable-frequency source is required.

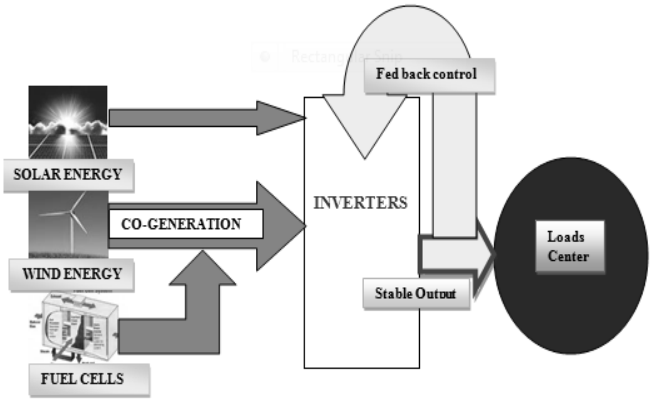

Fig. 10 Block Diagram of Co-Generation System Integration

C. PWM Control [5]

As shown in Fig 2, after output voltage tracking and Improvement of the voltage utilization factor, the three phase signals V^*_R V^*_Y, and V^*_B are compared to two triangular carrier waves with positive and negative offsets. The PWM signals thus generated are passed through control circuit. Then fed to 12 IGBTs as gate signals.

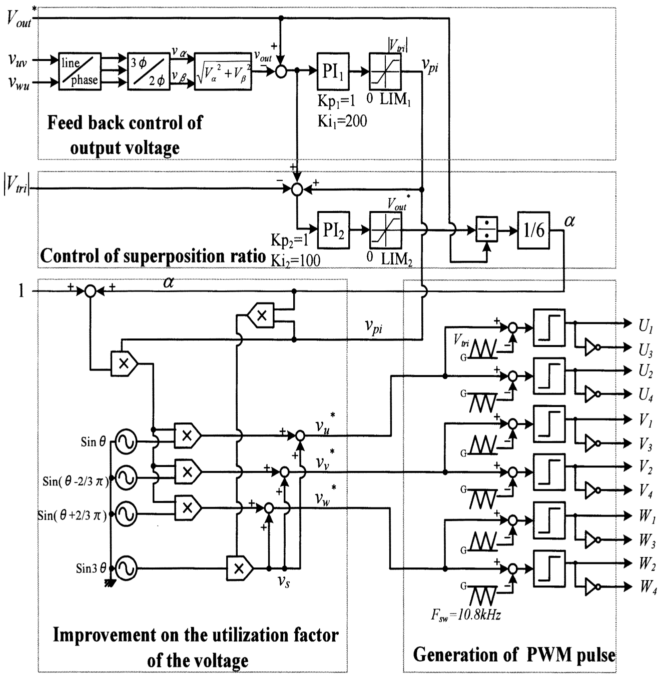

Fig. 2 Control Block Diagram

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IV. SIMULATION RESULTS

The simulation was carried out by the circuit shown in fig.3 in order to verify the validity of this control method in steady state. The LC filter was connected with output side of each phase of the multilevel inverter circuit, and the resistance was used as a load. Was the feedback control method, in order to detect the voltage after the LC filter, and the line voltage between R-Y phase and B-R phase were fed back. Simulation result for DC voltage fluctuation is shown in fig.7 and Fig 8. This shows the waveform of signal wave, superposition wave and output line voltage as DC voltage is made to lower from 440V to 396V, and 400V. This assumes the case in which the voltage of the battery lowers by the change of the load. With the lowering of DC voltage, the signal wave composed of fundamental wave component and third harmonic wave increases in the range which does not exceed lpu. The output voltage is fixedly controlled of 440Vrms regardless of the lowering of DC voltage. The distortion ratio of output voltage in considering to 25th order harmonic wave was 0.88. The Fig 4. Shows the simulation of control method diagram ,In this method the input voltage fluctuations are by superposition of third harmonic wave applied to inverter, The output voltages are stable even input voltages are fluctuating nature. The Fig 5.shows the simulation diagram of cascade connection of 7level inverter. Sub block of each Phase as shown in Fig 6. It is in series connection. From fig.7 can prove that the input DC voltages in three phase are 396volts in each phase, correspondingly output voltages are stable at 440V. Fig7 (a) input DC voltage for R phase 396V, fig7(b) input DC voltage for Y phase, Fig7(c) input DC voltage for B phase correspondingly 396V, 396V. From fig7 (d) prove that, the stable output voltage of multilevel inverter and from input voltage 14% is improved.

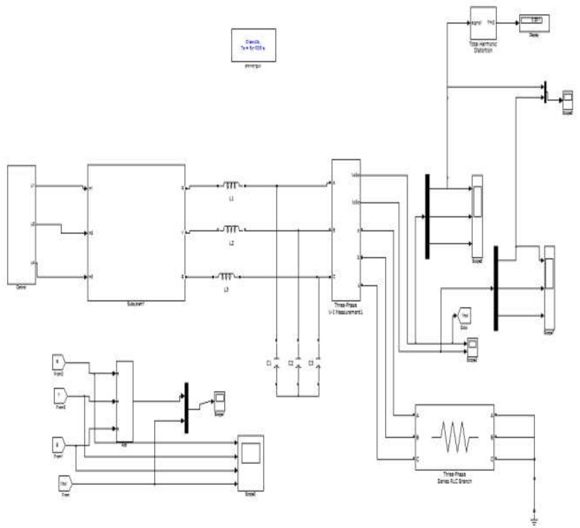

Fig. 3 Simulation Block Diagram of 7 Level Inverter with Cascade Connection

From fig.8 can prove that the input DC voltages in three phase are fluctuating nature, even though output voltages are stable. (1) The R-phase have 390V/DC shown in fig 8(a). (2) The Y-phase have 440V/DC input shown in fig 8(b). (3) The B-phase have 450V/DC input shown in fig 8(c). Correspondingly output voltages is stable at 440V /3phase /AC output of multilevel inverter show in fig8(d). With THD=0.88% up 25cycle as shown in fig 9.

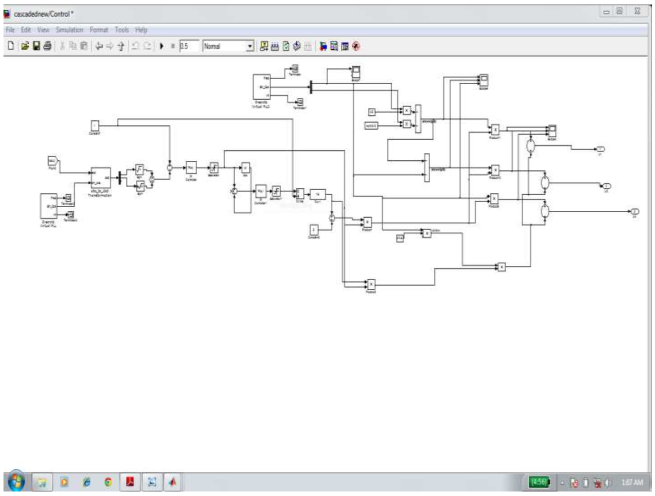

Fig. 4 Simulation of Control Block

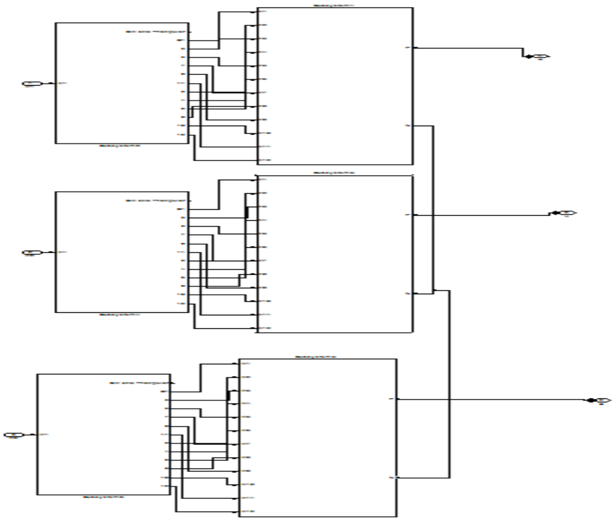

Fig. 5 Simulation Cascade Connection of 7 Level Inverter

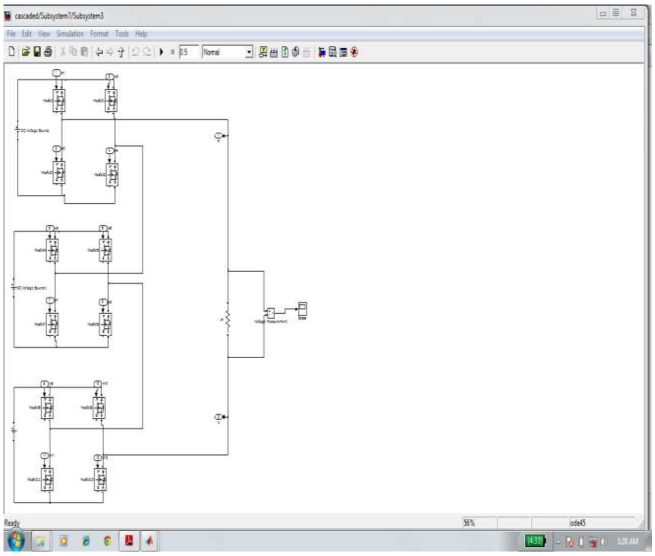

Fig. 6 Subsystem of Cascade Connection of 7 Level Inverter

The method for reducing the voltage ripple instead of the smoothing capacitor was examined by superposition of third harmonic wave. The circuit for the simulation is shown in fig. 3. The three-phase AC voltage is used as a power supply, and it is converted into DC voltage by the diode rectifier. Film capacitor of small capacity was used as a capacitor for the smoothness in order to attempt the electrolytic capacitor-less.

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The voltage ripple was generated from about 390V to 450V. The third harmonic wave was superimposed by the response to the fluctuation of the DC voltage in a moment, and the line voltage became sine wave including the distortion of 14%. The effect of voltage utilization improvement is illustrated in Fig 8. Specifically, the diagram shows the measured DC voltage required in order to obtain an output voltage with an effective value of 440 V. The output voltage waveforms were observed after smoothening by the LC filter (0.4mH, 40μF).

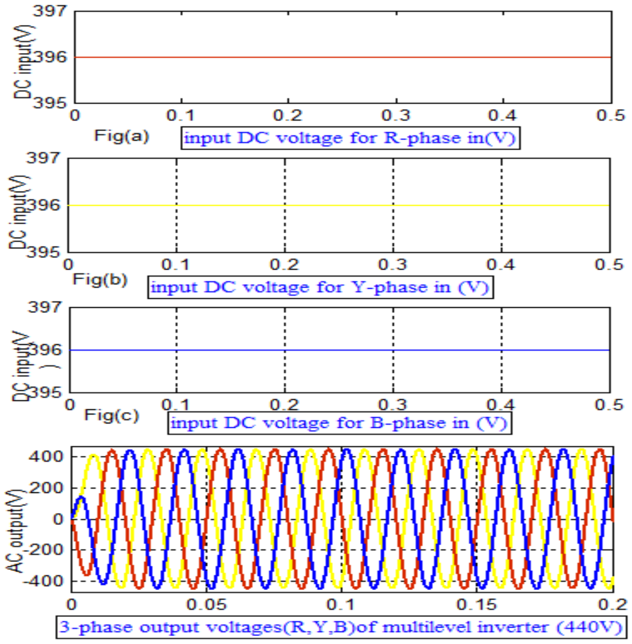

Fig. 7 Multilevel Inverter Input (DC396V, in Each Phase) and Fig (d), Output Voltages (R, Y, B) 440V/AC

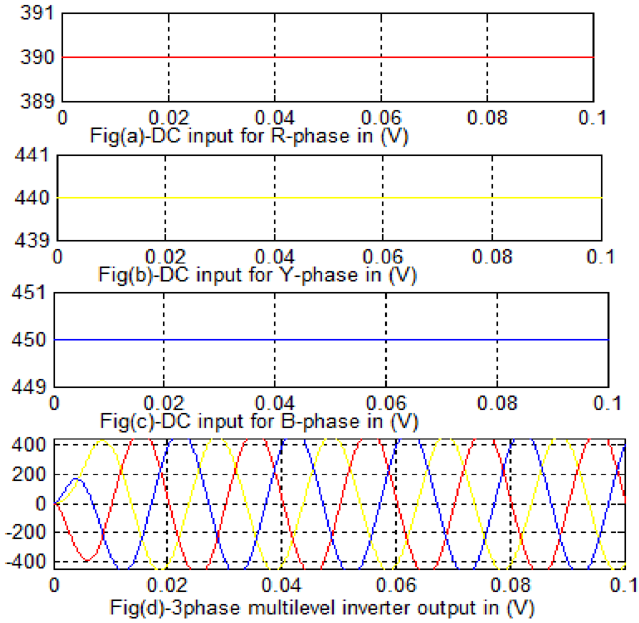

Fig. 8 Multilevel Inverter Input (DC/390V, 440V, 450V , in Each Phase Correspondingly R,Y,B Phases and Output Voltages (R,Y, B) 440V/AC

V. CONCLUSIONS

In this paper, the simple control method which combined the improvement on voltage utilization factor through the superposition of third harmonic wave with voltage feedback control was proposed, and it was applied to the multilevel inverter. Features of this control are to control the superposition ratio with the fluctuation of the DC voltage. For deficiency and excess of DC voltage, it was obtaining a stable AC voltage from a DC source with strong voltage fluctuation by simulation. The improvement in the control performance is considered, and reduction of the capacity of the common-mode filter and electrolytic capacitor -less of the DC link will be examined. In this paper we confirmed the absorption of DC voltage fluctuations of about 15% was examined, 7Level cascade connection multilevel inverters with SPWM. Which contain Less harmonic distortion i.e., THD=0.88%only. In the future, we intend to focus on further reduction of output voltage distortion and improvement of the voltage control characteristics for unbalanced loads.

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