High precision Automatic Voltage Regulator by using series transformer

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Abstract

Now there are two types Non-contact compensation AC automatic voltage regulator (A.V.R). One is transformer compensation regulator, whose principle is the combination of multiple compensation transformers, do the compensation by turning on and off the connections of the transformer through the multi-full bridge circuit. This method removed the mechanical drive and contacts, which increases the life and the dynamic performance of the A.V.R. However, the compensation is multilevel, and it needs many compensation transformers and switches, the circuit is complex, the compensation precision is low. Another type is PWM switch AC regulator, whose principle is getting the AC voltage from the input, then induce the AC compensation voltage through commutating and high frequency PWM transforming, and phase tracking. Here the compensation is step-less, the compensation precision is high, and the response is fast. But the circuit is complex, and it needs an inverse compensation transformer, which is difficult to realize high-power applications. In this paper, it shows an Automatic Voltage Regulator which use high frequency PWM inverter do compensation. This A.V.R has the function as the custom-power, which make the performance of the power supply in a high level.

1. Introduction

An ac automatic voltage regulator can provide a well-regulated voltage source, and is becoming more and more important due to the rapid decrease in the quality of power systems. Generally, there are many different structures to implement an A.V.R, including a conventional transformer with mechanical or electrical tap changer, an adjustable transformer driven by motor, a saturated reactor, a regulative series transformer controlled by a dc-to-ac inverter which is supplied by a diode rectifier or a switching mode rectifier, a high-frequency ac-to-ac electronic transformer with or without a high-frequency transformer, and so on. The adjustable transformer or saturated reactor-based A.V.R has some disadvantages, including the use of bulky transformers and/or a slower response than switching-based structures. In contrast to this, the high-frequency switching-based A.V.R has the merit of a smaller size as it uses high-frequency switching technology. However, it normally allows only unidirectional ability of voltage regulating (voltage sag or voltage swell), and it is not suitable for a large-scale system. Thus, the regulative series transformer controlled by a dc-to-ac inverter seems to be a good choice as it manages only the fluctuation part of the source voltage, and has a smaller size than the topology that is processing the full-load power. Fig. 1 shows the circuit configuration of this type of A.V.R.

The AVR which is showed in this paper can be used to deal with both directions of voltage regulation, and it has merits including a higher switching efficiency, a simple circuit structure, and a simple control algorithm.

2. Automatic Voltage Regulator using high frequency PWM inverter

The Principle circuit of Non-contact compensation AC Power Supply using PWM high frequency inverter is shown in Fig.1, in which the compensation voltage is produced by full-bridge inverter, and the inverter uses high frequency SPWM modulation. The output voltage of the single phase full-bridge inverter \( u_0 \) goes through the transformer \( T_c \), which transforms \( u_0 \) to compensation voltage \( u_C \) and output it in the secondary winding of \( T_c \). The secondary winding of transformer \( T_c \) is in series in the main circuit to compensate the commercial power, and make sure the output voltage \( u_o \) is stable. In the circuit the filter is low-pass filter, which is used to filtering the high frequency harmonic wave of the output. The PWM controller can use single-chip to produce and control the PWM signal, and control the switches of the inverter. The voltage sensor is used to detect the input and output voltage.

The resistance of the transformer secondary winding and internal resistance of commercial power make up of line impedance \( Z \), and \( u_r \) is reference voltage, the control circuit is showed in Fig.2, so following the control principle in Fig.2, if use
Voltage band load voltage inverter proportional to the changes of commercial power voltage and load voltage.

Assuming that there is no harmonic in commercial power voltage, commercial power input power factor is cosψ=1, so:

\[ u_o = \sqrt{2} U_s \sin \omega t - \sqrt{2} Z L_f \sin \omega t - \xi M U_{d} \sin \omega t \]

(5)

Using the low-pass filter in the circuit filtering the high frequency harmonic of the \( u_o \), the above formula is:

\[ u_o = \sqrt{2} U_s \sin \omega t - \sqrt{2} Z L_f \sin \omega t - \xi M U_{d} \sin \omega t \]

(6)

Substituting the value of M in formula (1) and \( \xi = \frac{r}{r_2} \) to the formula (6);

\[ u_o = \sqrt{2} U_s \sin \omega t - \sqrt{2} Z L_f \sin \omega t - \sqrt{2}(U_s - Z L_f - U_f) \sin \omega t = \sqrt{2} U_s \sin \omega t \]

This AC regulator has 6 operative modes:

1. \( u_o > u_k + Z L_i \), \( u_{co} = u_k - Z L_i - u_e \) this time output voltage \( u_e = u_k + (u_k - Z L_i - u_e) \)
2. \( u_e < u_k + Z L_i \), \( u_{co} = u_k - Z L_i - u_e \) The output voltage \( u_k = u_k - u_k - Z L_i - u_e \) =u_k
3. \( u_k = u_e \), this time \( u_k = Z L_i \) output voltage \( u_k = u_k - Z L_i = u_k \)
4. No-load (i=0), \( u_e > u_k \), \( u_{co} = u_k - u_e \), output voltage \( u_k = u_k - (u_k - u_e) = u_e \)
5. No-load (is=0), \( u_k < u_k \), \( u_{co} = -u_k + u_e \), output voltage \( u_k = u_k + (-u_k + u_e) = u_e \)
6. No-load (i=0), \( u_k = u_k \), \( u_{co} = 0 \), no compensation.

When the commercial power voltage \( u_k \) or the load changes, the output voltage of the SPWM high frequency inverter which is modulated by the instantaneous value of \( (u_k - u_k - Z L_i) \) can compensate the changes of the output voltage \( u_k \) and keep \( u_k = u_k \).

2.3 The compensation for the harmonic in the commercial power voltage

Assuming the value of the commercial power is unchanged, but
it contains harmonic
\[ \sqrt{\sum_{n=2}^{\infty} U_{sn} \sin \omega t} \]

That is
\[ u_2 = \sqrt{2U_1} \sin \omega t + \sum_{n=2}^{\infty} U_{sn} \sin n \omega t, \quad u_{n1} = u_0 \]

In order to simplify the derivation, let \( i_s = 0 \), the voltage of modulation wave is:
\[ u_s - Z_o u_o = \sqrt{2U_1} \sin \omega t + \sum_{n=2}^{\infty} U_{sn} \sin n \omega t - \sqrt{2U_1} \sin \omega t \]
\[ = \sum_{n=2}^{\infty} U_{sn} \sin n \omega t \] (7)

Modulation ratio: \( M_n = \frac{U_{sn}}{u_o} \), the compensation voltage \( u_{co} \) is:
\[ u_{co} = \sum_{n=2}^{\infty} \frac{2U_1}{\pi} \frac{\sin n \omega t}{m^2} \left( 1 - \frac{1}{m^2} \right) \frac{1}{n^2} = \frac{F_n(M_n \pi)}{m} \]
\[ \cos m \pi \sin [(m + n \pi) \sin \pi t] \] (8)

Substituting the value of \( u_s \), is and \( u_{co} \) into the formula (4), use low pass filter filtering the higher frequency harmonic, and substitute \( M_n = \frac{U_{sn}}{u_o} \), \( \frac{U_{sn}}{u_0} = \frac{U_1}{u_0} = \frac{U_1}{u_0} \) into \( u_{co} \)
\[ u_{co} = \sqrt{2U_1} \sin \omega t + \sum_{n=2}^{\infty} \sqrt{2U_1} \sin n \omega t - \sum_{n=2}^{\infty} \sqrt{2U_1} \sin n \omega t \]
\[ = \sqrt{2U_1} \sin \omega t \] (9)

From equation (9), it can be known: when the commercial power \( u_o \) contains harmonic, the SPWM high frequency inverter output voltage \( u_{co} \) which use the instantaneous value of \( (u_o - u_0 - Z_0) \) as modulation wave can compensate the harmonic in \( u_o \) in particular the low harmonic.

Furthermore from the physical perspective, because the control circuit do comparison of the instantaneous value of the commercial power and sine wave reference voltage, and use the difference of these two values as modulation wave do compensation, the commercial power \( u_o \) is sine wave, when \( u_o > u_0 \), it is negative compensation, that is \( u_o - u_{co} \), when \( u_o < u_0 \), it is positive compensation, that is \( u_0 - u_{co} \). When the commercial power contains harmonic which contain flickering and sharp pulse, \( u_o > u_0 \) part is negative compensation, and \( u_0 > u_o \) part is positive compensation. The sketch map of the compensation principle is Fig.4. From Fig.4, it can be known: when the commercial power wave changes, which can be compensated by PWM inverter theoretically.

The value change of \( u_o \), the harmonic or flickering and sharp pulse, which can be compensated by instantaneous value of the SPWM inverter and the waveform of output voltage \( u_o \) after compensation, is close to stability power supply.

3. Simulation results

Fig.5 and Fig.6 are the voltage waveforms before and after compensation. Through these two waveforms it can be known: the THD of the waveform before compensation in Fig.5 is large and there is dissymmetry in the fundamental wave. The waveform after compensation is a perfect sine wave, and the dissymmetry is eliminated.

Conclusion

Through the simulation and experiment it shows that this ac regulator using PWM inverter can compensate voltage changes of the commercial power and it also compensate the harmonic wave and the flickering, which can improve the power quality. It is a promising AC stabilized-voltage power.

Reference