Voltage sag compensator of a high and precise quality for unbalanced three phase power system

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Abstract

High electronic equipments for demand improvement and efficiency are requested the power superior quality. The compensation system of power quality is processing actively. We propose to a series voltage compensator and control algorithm using pid control in unbalanced three- phase power system, when voltage sag occurs.

1. Introduction

Recently as an industry development, a high technology electronic equipment for a efficiency improvement and rise of the utility factor is required high power quality all of equipment still a medical instrument, home equipment etc and power customers of today industrial society consider the very important subject to power quality so, already it is taken many study and development

Especially power quality is disturbed as very harmful form a moment voltage drop among the factor of voltage source trouble. NPL(National Power Laboratory) of the united states presented measured report at 235 areas of U.S.A and Canada from1990 to1995 and the report showed that 87% of entire voltage source troubles is trouble from voltage sag .

As voltage sag bring about voltage source, the compensation system of sag is processing actively it and the ups which compensates not only sag but swell or high frequency etc is representative. the capacity excellent but it need many maintenances and repair and is not economic in a power-transmission system

So a lot of studies DVR to compensate voltage sag as serial connection in transmission have processed.

DVR has an economic advantage better than ups because of only sag compensation and have an excellent dynamic character. DVR is discussed the control efficiency as that stated.

1. Speed compensation time after sag
2. Steady-sates error reduction
3. Improvement of transient response

The previous studies of voltage compensation proposed algorithm to control dc values throughout the d, q

synchronous coordinate frame of 3-phase source, because it controls easy as reduction from 3-variables to 2-variables.But symmetry parts from most of made 3-phase unbalance voltage source during voltage sag are detected using a vector calculation or the filter. So the control structure is complex.

In this paper we composed a basic theory and control algorithm, simulation and results for compensation voltage sag. It compared the compensation between pid control and pi double control. And we considered dynamic characteristics as important point in system so, proposed compensation using of the pid control.

2. Voltage sag

The voltage sag was given a definition of. IEEE Std. 1159 - 1995 as a temporarily voltage drop from the trouble phenomenon of voltage in a power-transmission and electric power- supply- system. The voltage sag is from 0.5 cycle to 1min in power system that a voltage value is decrease condition inside of 1~0.9 pu by rms value. The voltage sag takes very short time as less than 0.1s to affect to precision production machinery. The compensation system for compensation of Such as sag is satisfied to the next condition.

1. Sag compensates in 1~10cycle time.
2. Voltage drop part compensation up to 5%~35%
3. A compensation inside of a half period of the voltage source frequency
4. Voltage supply of the same period with voltage frequency.

3. The system modeling

The series compensator of sag compensation system operates normally as power-supply which a common using source gives to a load the power through the bypass switch turn off.

And the inverter makes as voltage drop part as a voltage, so between an input voltage and it are the sum as serial through the injection transformer. Finally it is operated to give a regularity voltage at a load.

Figure1 is a composition diagram of the voltage sag compensator.

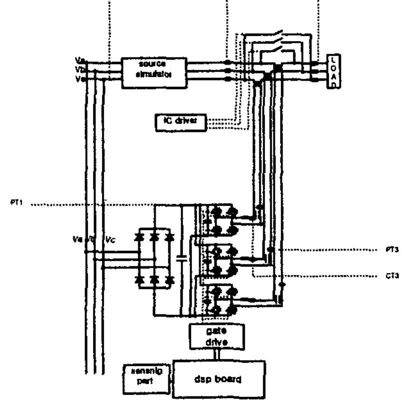

Fig1. The system for voltage sag compensation

A trouble in a power-transmission and electric power-supply- system is 1phase earth troubles, 2phase earth troubles, an each line short, etc. but most of 1 phase earth troubles. Such as this case, a change of the magnitude and phase brings about a load to affect from an unbalance voltage. an unbalance voltage is appeared to positive voltages, negative voltages, zero voltages as same (2-1) by the symmetry coordinate transformation

$$\begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = V_p \begin{bmatrix} \cos(\omega t + |\phi_p) \\ \cos(\omega t + \phi_p - \frac{2\pi}{3}) \\ \cos(\omega t + \phi_p + \frac{2\pi}{3}) \end{bmatrix} + \qquad (2\text{-}1)$$

$$V_n \begin{bmatrix} \cos(\omega t + |\phi_n) \\ \cos(\omega t + \phi_n - \frac{2\pi}{3}) \\ \cos(\omega t + \phi_n + \frac{2\pi}{3}) \end{bmatrix} + V_o \begin{bmatrix} \cos(\omega t + \phi_0) \\ \cos(\omega t + \phi_o) \\ \cos(\omega t + \phi_o) \end{bmatrix}$$

V_p : positive , V_n :negative , V_0 : zero

The symmetry coordinate transformation that it take positive voltages, negative voltages, zero voltages is appeared (2-2).

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad \alpha = e^{j\frac{2\pi}{3}} \qquad (2\text{-}2)$$

The dq synchronous coordinate transform of each other orthogonal between 3 phase- variables at the upper part and 2phase variables uses to a matrix T. .

$$T = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}_n \qquad (2\text{-}3)$$

Using of it, 3 phase- variables are expressed the d, q components as like (2-4)

$$\begin{aligned} e_d^e &= \frac{2}{3}(e_a - \frac{e_b}{2} - \frac{e_c}{2})\cos\theta + \frac{1}{\sqrt{3}}(e_b - e_c)\sin\theta \\ e_q^e &= \frac{2}{3}(e_a - \frac{e_b}{2} - \frac{e_c}{2})\sin\theta - \frac{1}{\sqrt{3}}(e_b - e_c)\cos\theta \end{aligned} \qquad (2\text{-}4)$$

To alter expression for (2-1) from (2-4) , We see the d, q voltages of 3 phase unbalance voltages with same an equation.

$$\begin{aligned} E_d &= E_p \cos\varphi_p + E_n \cos(2\omega t + \varphi_n) \\ E_q &= -E_p \sin\varphi_p + E_n \sin(2\omega t + \varphi_n) \end{aligned} \qquad (2\text{-}5)$$

We are known from (2-5) that the d, q axis about 3 phase unbalance voltages include 2end high frequency ripples of a regularity frequency at dc parts.

The output current of the inverter in the d, q synchronous coordinate frame is showed to (2-6).

$$\begin{aligned} i_{od}^e &= I_{Ld}^e + C_f \frac{dv_{cd}^e}{dt} + \omega C v_{cq}^e \\ i_{oq}^e &= I_{Lq}^e + C_f \frac{dv_{cq}^e}{dt} - \omega C v_{cd}^e \end{aligned} \qquad (2\text{-}6)$$

(2-7) is showed to an expression about the inverter output voltage .

$$\begin{aligned} v_{od}^e &= v_{cd}^e + L_f \frac{di_{od}^e}{dt} + \omega L i_{oq}^e \\ v_{oq}^e &= v_{cq}^e + L_f \frac{di_{oq}^e}{dt} - \omega L i_{od}^e \end{aligned} \qquad (2\text{-}7)$$

A modeling expression from dc voltage of a capacitor at dc link is showed to (2-8).

$$C_{dc} \frac{dV_{dc}}{dt} = S_d i_{od}^e + S_q i_{oq}^e \qquad (2\text{-}8)$$

(2-9) is changed to 3 phase voltage sources as in the d, q synchronous coordinate frame. When a d axis rotates as an angular velocity of $\omega = 2\pi f$, a phase angle to between a d axis and a a axis is showed dc parts because of the same with a phase angle of a voltage source as $\theta = \omega t$. a d axis always coincides (with) a a axis at the stationary coordinate frame, and the theta is became 0 So (2-4) is expressed as (2-9) from $\cos\theta = 1$, $\sin\theta = 0$.

$$\begin{aligned} e_d^e &= \frac{2}{3}(e_a - \frac{e_b}{2} - \frac{e_c}{2}) \\ e_q^e &= -\frac{1}{\sqrt{3}}(e_b - e_c) \end{aligned} \qquad (2\text{-}9)$$

Figure 2 shows to wave-form it's, when 3-phase balanced voltages is converted to each the stationary coordinate frame and synchronous coordinate frame.

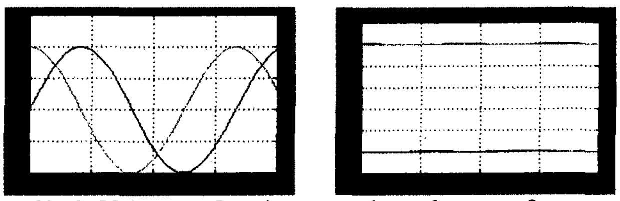

Fig 2. Voltages of stationary and synchronous frames in a case of 3-phase balanced voltages

Because each other a positive voltage and a negative voltage from 3-phase balanced voltages is became the balance, values of d, q transform using the synchronous coordinate frame appear as a fixed dc value. Also a d xis part coincidences a a axis part in the stationary coordinate coordinate frame. A figure 3 shows each a pair coordinate frame when the voltage source is 1 line earth troubles voltage

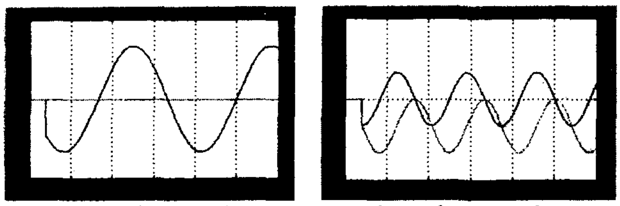

Fig 3 . Voltages of stationary and synchronous frames in a case of 3-phase unbalanced voltages

Because each other a positive voltage and a negative voltage from 3-phase unbalanced voltages is break down the balance, dc value at the synchronous coordinate frame includes the ripple of 120Hz.
PI dual control need a filter for rejection occurred ripples from broken balance of a positive and negative part in unbalanced sources before the control.
It is a case that voltage sag occurs as voltage drop of 1 -phase or 2-phase, almost sources are broken balance.
A time-delay as ripple rejection of 120hz whenever the ripple occurs becomes great to disturb the prompt compensation about equipment of sensitive response. So a performance of pi control has relatively simple, but a delicate control is difficult. And response of steady -state dose not take an excellent result, too.

4. The control algorithm

The controller is found on the voltage control but It must be realized to an output voltage of an ideal sin wave. We proposed the controller that the control loops of an outer voltage for the voltage from capacitors both ends of output voltage and of an inner current for the current from have the double controller. A very useful PI control as control method was used in the system and IP control was used as parallel to support PI control. because of a limited output of the controller, Anti-windup method supported the broken out wind-up situation form error accumulation of integrator. So the entire controller is designed using all of 3-method. figure 4. shows block diagram of proposed PI double control..

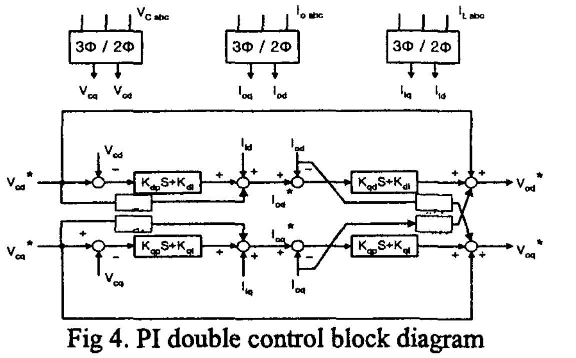

Fig 4. PI double control block diagram

The simulation was transformed all of variables and gains in z-domain. figure 12. shows designed a PI + IP +wind-up discrete controller and result waveforms of the system.

5. Propose of PID control

Proposed pid control is added to differential part effect of transient response capacity from pi control. Differential parts expect to error of forward and control to output of present in advance. Therefore it see improvement of transient response, enable to improve stability of the system. It has to lead drive-toque of the magnitude of ration with error. P control is able to a precise control and I control reduces steady-states errors to give expression to the error of accumulated past events Weak points of a PI control with such as a good point of a PI control be complements, so a PID control is able to performance easy more than a PI dual control.
An applied PID control in the compensation system is used a direct voltage control method about 3-phase without a confused transformation in unbalanced sources
A performance of a PID control using of the system is the control in a discrete domain system throughout the micro-controller. so we transformer from a control function in existing s-domain to z-domain.

$$G(s) = K_d S + K_p + \frac{K_i}{S} \tag{2-10}$$

To substitute (2-10) using $s \Rightarrow \frac{Z-1}{T}$ of forward Euler's method, the trans-function of the presented controller is (2-11).

$$G(z) = \frac{K_d z^2 + (K_p T - 2K_d)z + (K_i T^2 - K_p T + 1)}{zT - T} \tag{2-11}$$

The trans-function of the plant to apply the system is voltage parts of the capacitor, so it is able to appear (2-12).

$$V_c(s) = \frac{\frac{1}{C_f}}{(L_f s + R_f) + \frac{1}{C_f}} V_s(s) \tag{2-12}$$

Also it is able to apply an equation (2-13) throughout z-transformation.

$$N(z) = \frac{T}{L_f C_f (z-1)^2 / T + R_f C_f (z-1) + T} \tag{2-13}$$

The result using a pole-zero cancellation method about a presented two trans-functions is an (2-14).

$$Y(z) = N(z)G(z) = \frac{TW_c}{(z-1)} \tag{2-14}$$

it has a control gain of each Kp, Kd, Ki parts .
In this paper when it took z transformation, forward Euler's method is applied to it, but the result that backward Euler's method is also applied to it is the same trans-function gain.

6. Algorithm to apply PID control

The hardware composed an outline control parts, inverter parts, LC filters, series transformers for a experiment. The control part used TMS320C31 microprocessor of TI instrument and max7000 family and FLEX10K20 of Altera as logic device for a address decoder parts and PWM gating. And it composed the main controller and

sensing circuit board for a sensing detection. The inverter parts composed 3 parts of inverter as arm of 2 units to embody as single bipolar switching method of 3units. It is switching of 10Khz. The LC filters designed to take cut off frequency of around 1Khz, series transformer is tap of 3 pair, so a experiment about effect of turn ratio of series transformer was possible. When a accident of the voltage sag compensator occurs, a bypass switch cuts off its and the system operates voltage sources.
The algorithm for a entire control appears fig 5.

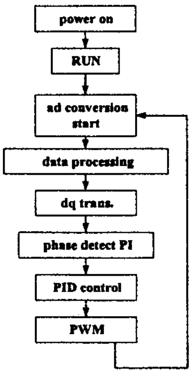

Fig 5. Entire algorithm

Fig 5 appears the algorithm using main program simple as the flowchart.

7. Simulation

we designed the system to see the control performance of the system using simulink of matlab, and simulated to apply a calculated control gain.
Fig 6 is applied the system model PID control using simulink.

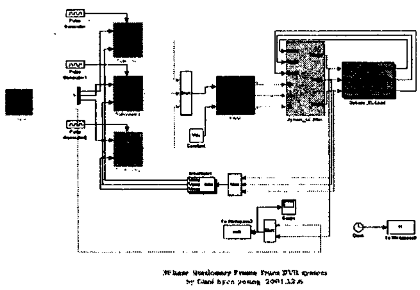

Fig 6. PID system modeling

Fig 7 appears the wave that PI control is the same a modeling system.

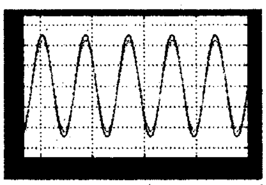

Fig 7. PI simulation result

When it apply 1 line earth-accident of sources, the result that voltage sag occurred at 4.3e-3(s) is became steady-states at 7.7e-3(s), overshoot of transient response is appeared to spark about double. And the steady-states error was about 3%.

Fig 8 appears simulation result of PID control.

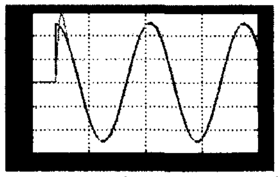

Fig 8. PID simulation result

PID control that voltage sag occur at 4.3e-3(s), it is became steady-states at 6.0e-3(s), the overshoot is appeared to spark 1.2 times much more than the result using PI control.
Fig 9 appears the made voltage compensator as a class 15KVA.

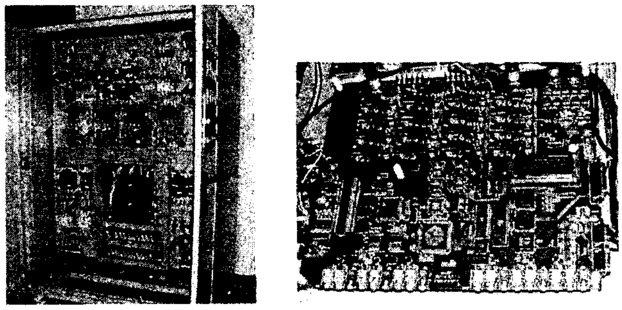

Fig 9. Voltage sag compensator

8. Conclusion

PI control as existing using method of performance for the compensation system of voltage sag is double control shame for the compensation together with current and voltage, also synchronous coordinate frame in unbalanced sources complicated the control to separate positive voltage and negative voltage, stationary coordinate frame must compensate zero-voltage too.
So a great significance about 2 variable control of dq frame has not it.
But the result using PID control at 3 phase was given a little more efficiency result value than PI control.
It is given satisfied result of a rapid compensation condition as important point of the voltage sag system.

9. Reference

[1] M. McGranaghan, D.Mueller, and M. Samotyj, "Voltage Sags in Industrial System." IEEE/IASI & CPS Annual Meeting, 1991,91CH2990-0, pp.18-24
[2] Seung-yo Lee, Seok-woo Han, Hyung-soo Mok, Gyu-Ha Choe, "A Novel Active Series Voltage Compensator with Harmonic Current Compensating Capability" IEEE 1999 International Conference on Power Electronics and Drive System, PEDS'99, July 1999, pp.1054-1059
[3]Md. Abdul Matin, Dariush Divsalar, "Digital State Feedback Control of a 3 phase sinusoidal PWM Inverter." in conf. Rec. IEEE Decision and Control, pp.615-616, 1994
[4]A. Kara, P.Daehler,D.Amhof, H.Gruening, "Power Supply Quality Improvement with a Dynamic voltage Restorer", in Conf. Rec. PESC. pp.248-254,1998
[5]B.J. Kim, J.H. Choi, J.S.Kim, and C.H. Choi "Digital control Scheme of UPS Inverter to Improve the Dynamic Response." in Conf. Rec. KIEE ICPE'95, pp. 184-189, 1995.

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