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A New Control Strategy Using Grid Interfacing Inverters in 3-Phase Distributed Systems with Power Quality Improvement Techniques

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***Abstract*—** The power quality of grid-connected inverters has drawn a lot of attention with the increased application of distributed power generation systems. The dq transformation based control technique is widely adopted in these systems, due to its excellent tracking performance and low output total harmonic distortion (THD) This will degrade the performance of the system, particularly when the grid frequency varies. This project is concerned with the current control of grid-connected inverters based on a simple frequency-adaptive controller. A grid-tie inverter is desired to behave as a robust voltage source inverter with the high gain in order to improve both the reference voltage tracking and disturbance rejection capabilities. The variations of grid impedance and frequency in distribution networks are some important challenges in the design of grid-converters

***Index Terms*—Finite impulse response (FIR) filter, frequency variation, grid-connected inverter, repetitive control, total har- monic distortion (THD).**

I. INTRODUCTION

Along with the new energy and renewable energy source development, Distributed Power Generation systems (DPGSs) have attracted a lot of interest in the latest years. Moreover, the Pulse Width Modulation (PWM) ,Voltage Source Inverter (VSI) is a key part of the system. To decrease pollution to the grid, the grid-connected VSI should have high output power factor and low output current Total Harmonic Distortion (THD). For both photovoltaic arrays and wind turbines connected to the grid, the allowed maximum current THD is 5%. The most popular current control methods for grid connected inverters are Proportional–Integral (PI) control and Proportional–Resonant (PR) control. The PI control method is usually used in the Synchronous Reference Frame (SRF) and can work well under balanced systems. However, it is not suitable for unbalanced systems, which is common in the DPGS.

The PR control method is popular in the stationary reference frame, because it can eliminate the tracking error while regulating sinusoidal signals.

However, while compensating harmonics, the PR control method has to adopt one regulator for each harmonic frequency. Moreover, in order to maintain good performance, all of the resonant frequencies have to be identical to the grid fundamental and harmonic frequencies, which keep varying in the DPGS. The repetitive control technique, using the internal model principle, can effectively eliminate output steady-state tracking error and minimize THD, as it generates high gains at the fundamental and harmonic frequencies.

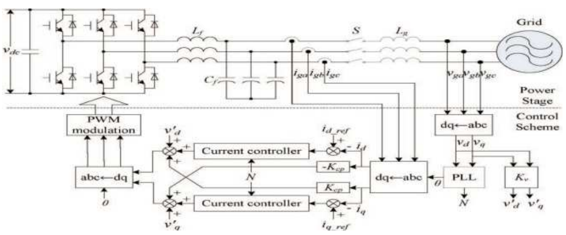


Fig.1. Block diagram of a three-phase grid connected inverter with the improved repetitive control scheme.

To solve the issues mentioned earlier, an improved repetitive control scheme is proposed in this paper. It introduces a special designed finite impulse response (FIR) filter, cascaded with a traditional delay function. The FIR filter replaces the auxiliary function for stabilization, and it has adjustable linear characteristic, which means that its delay time is linear to the frequency, and can be adjusted. The proposed control function can approximate the ideal repetitive control function of any ratio. The improved repetitive control scheme varies the FIR filter according to the varied grid frequency and can maintain its resonant points matching the grid fundamental and harmonic frequencies well. Therefore, the grid-connected VSI using this scheme will have low tracking error and THD.

II. DESCRIPTION OF THE SYSTEM

The current controller includes the improved repetitive control scheme, so that i_d and i_q could track the references i_{d_ref} and i_{q_ref}, where i_d and i_q are transformed from the grid currents i_{ga}, i_{gb}, and i_{gc}. The real and reactive powers injected into the grid are determined by i_{d_ref} and i_{q_ref} and the grid voltages, while the tracking performance and THD of the grid currents are determined by the current controller.

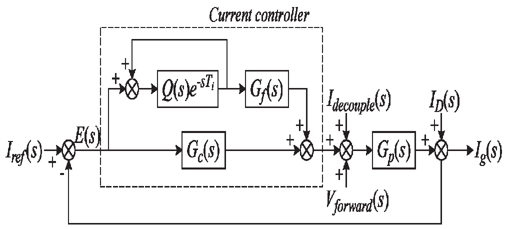


Fig. 2. Block diagram of the improved repetitive control scheme

HARMONICS

The harmonic results due to the operation of power electronic converters. The harmonic voltage and current should be limited to the acceptable level at the point of wind turbine connection to the network. To ensure the harmonic voltage within limit, Each source of harmonic current can allow only a limited contribution, as per the IEC- 61400-36 guideline. The rapid switching gives a large reduction in lower order harmonic current compared to the line commutated converter, but the output current will have high frequency current and can be easily filter-out.

Proportional–integral–derivative controller is a generic control loop feedback mechanism used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an “error” value as the difference between a measured process variable and a desired set point.

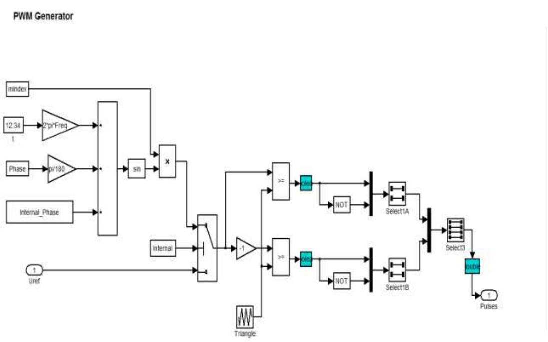
The controller attempts to minimize the error by adjusting the process control inputs.

The PID controller calculation involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D.

Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.

The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, or the power supplied to a heating element.

(a) PWM GENERATER



(b) DC ANALYSIS DESIGN TRADE-OFFS REGULATION AND SOFT-SWITCHIN BOUNDARIES

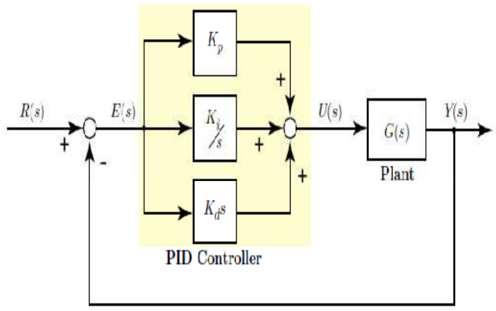
$$i_p(t) = -\frac{V_{Cr}(t_3) - nV_o}{Z_p}\sin\omega(t-t_3)$$

$$D_{loss} = \frac{C_r\left(2nV_o + 2I_{in}Z_p - \sqrt{(I_{in}Z_p + 2nV_o)^2 - (I_{in}Z_p)^2}\right)}{I_{in}T_s}$$

is represented versus the normalized input current . It can be seen that the duty-cycle loss increases with the value of the resonant capacitor, but it always is small.The maximum voltage across the snubber capacitor (which gives the voltage stress across both vstress_on_auxiliary_switch=vCr(t2)max=Iin,maxZp + nVo, and vstress-on-main-switch= vCr(t2)max+ nVo) is given by (3) calculated for the maximum input current. The result is represented

(c) The PID Problem Setup

The standard PID control configuration is as shown. It is also sometimes called the "PID parameter form."



In this configuration, the control signal u (t) is the sum of three terms. Each of these terms is a function of the tracking error e (t) . The term Kp indicates that this term isTHE PROBLEM SETUP 3 proportional to the error. The term Ki/s is an integral term, and the term Kds is a derivative term. Each of the terms works "independently"1 of the other.

We now consider each of the terms, assuming that the others are zero. With Ki = Kd = 0, we simply have u (t) = Kpe (t) . Thus at any instant in time, the control is proportional to the error. It is a function of the present value of the error. The larger the error, the larger the control signal. One way to look at this term is that the farther away from the desired point we are, the harder we try. As we get closer, we don't try quite as hard. If we are right on the target, we stop trying. As can be seen by this analogy, when we are close to the target, the control essentially does nothing. Thus, if the system drifts a bit from the target, the control does almost nothing to bring it back. Thus enters the integral term.
Assuming now that Kp = Kd = 0, we simply have

$$u(t) = K_i \int_0^t e(\tau)\, d\tau$$

$$\dot{x}(t) = \frac{1}{\tau_1}\left(e(t) - x(t)\right), \quad u(t) = K_d \dot{x}(t)$$

where τ 1 limits the bandwidth of the differentiator. In terms of Laplace transform variables, we have

$$\mathcal{L}\{\dot{e}(t)\} = sE(s) \approx \left(\frac{s}{\tau_1 s + 1}\right) E(s)$$

Thus, for τ 1 −small, the approximation is better. This corresponds to the "pole" of the differentiator getting larger. It is common to let

$$\tau_1 = \frac{K_d}{NK_p}$$

where N is typically in the range from 10t o 20. This matter of the differentiator could also be viewed using the Taylor expansion of e (t) . An alternate form of the PID controller is called the "non-interacting form." In this form, we have Ki = Kpτi , and Kd = Kpτ d. In this case, we can factor Kp out of the overall Controller

$$u(t) = K_p\left(e(t) + \frac{1}{\tau_i}\int_0^t e(\tau)\,d\tau + \tau_d\frac{de(t)}{dt}\right)$$

The PID control thus considers past, present and future values of the error in assigning its control value. This partly explains its success in usage

$$u(t) = K_p e_p(t) + K_i\int_0^t e_i(\tau)\,d\tau + K_d\frac{de_d(t}{dt}$$

Where

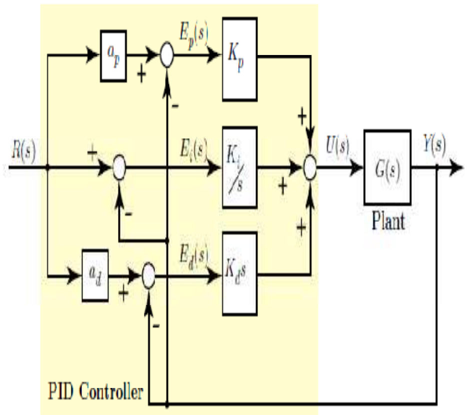
$$e_p = a_p r(t) - y(t), \quad e_i(t) = r(t) - y(t), \quad e_d(t) = a_d r(t) - y(t)$$

where constants ap and ad are as yet undetermined. Each of the terms thus has a different "error" associated with it. Note that when ap = ad = 1, that we have the original PID design. Note also that when r (t) is a piecewise constant signal (only step changes),then for all time (except at the actual step locations), r˙ (t) = 0, and thus,

$$\frac{de_d(t)}{dt} = \frac{d}{dt}(a_d r(t) - y(t)) = -\dot{y}(t)$$

which is independent of r (t) and ad. In general, since y is the output of the plant, it will be a smooth function and thus y˙ will be bounded. It is thus not uncommon to let ad = 0. This eliminates spikes in the term Kd ded(t) dt , without substantially affecting the overall control performance. A block diagram for this is shown. As it appears, it seems much more complicated. However, it is actually not much more complicated

(e) THE PROBLEM SETUP



Consider the system given by the transfer function

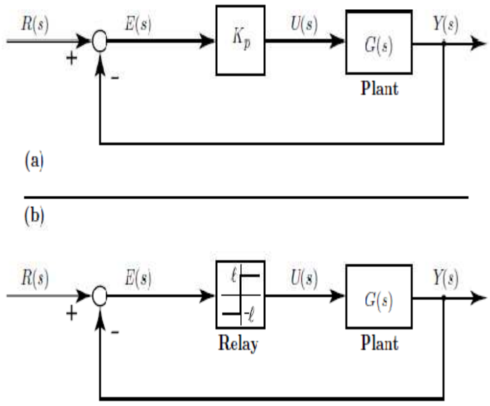
$$G(s) = \frac{20(s+2)}{\left(s+\frac{1}{2}\right)(s^2+s+4)}$$

If we use the (modified) PID controller

$$\begin{aligned} C(s) &= K_p + \frac{K_i}{s} + \frac{K_d s}{\tau_1 s + 1} \\ &= \frac{(K_p\tau_1 + K_d)s^2 + (K_p + K_i\tau_1)s + K_1}{s(\tau_1 s + 1)} \end{aligned}$$

Where

$$K_p = 9, K_i = 4, K_d = 1, \tau_1 = \frac{1}{100}$$



(f) PID CONTROLLER

In the control of dynamic systems, no controller has enjoyed both the success and the failure of the PID control. Of all control design techniques, the PID controller is the most widely used. Over 85% of all dynamic controllers are of the PID variety. There is actually a great variety of types and design methods for the PID controller. What is a PID controller? The acronym PID stands for Proportio-Integro-Differential control. Each of these, the P, the I and the D are terms in a control algorithm, and each has a special purpose. Sometimes certain of the terms are left out because they are not needed in the control design. This is possible to have a PI, PD or just a P control. It is very rare to have a ID control.

(g) IGBT DRIVER

Electronic motor control for various types of motors represents one of the main applications for IGBT drivers today. This application note discusses some of the fundamental concepts needed to obtain the proper IGBT driver for your application. The bridging element between the motor and IGBT driver is normally in the form of a power transistor. This can be a bipolar transistor, Insulated Gate Bipolar Transistor (IGBT). In some small Brushless DC motor or stepper motor applications, the IGBT driver can be used to directly drive the motor. For this application note, though, we are going to assume that a little more voltage and power capability is needed than what the IGBT drivers can handle. The purpose of motor speed control is to control the speed, direction of rotation or position of the motor shaft. This requires that the voltage applied to the motor is modulated in some manner. This is where the power-switching element (bipolar transistor, MOSFET, IGBT) is used. By turning the power-switching elements on and off in a controlled manner, the voltage applied to the motor can be varied in order to vary the speed or position of the motor shaft.

(h) ACTIVE POWER

The active power P depends on the acting values of the voltage V and the strength of the current I and on the cosine , where is the angle of phase displacement between V and I. In an electric circuit of a single-phase alternating current (sinoid), P = VI cos (for a three-phase current, P = VI cos). The effective alue can also be expressed through the strength of the current, the voltage and the active component resistance of the circuit r or its conductivity g according to the formula P = I2 x r = V2 x g. In any electric circuit of sinoidal or nonsinoidal current, the active power of the entire circuit is equal to the sum of the active power of the individual sections of the circuit. The relation between the active power and the full power S is expressed in the equation P = S cos . The unit of measurement of active power is the watt.

(i) REACTIVE POWER

Reactive power flow on the alternating current transmission system is needed to support the transfer of real power over the network. In alternating current circuits energy is stored temporarily in inductive and capacitive elements, which can result in the periodic reversal of the direction of energy flow. The portion of power flow remaining after being averaged over a complete AC waveform is the real power, which is energy that can be used to do work (for example overcome friction in a motor, or heat an element). On the other hand the portion of power flow that is temporarily stored in the form of electric or magnetic fields, due to inductive and capacitive network elements, and returned to source is known as the reactive power.

AC connected devices that store energy in the form of a magnetic field include inductive devices called reactors, which consist of a large coil of wire. When a voltage is initially placed across the coil a magnetic field builds up, and it takes a period of time for the current to reach full value. This causes the current to lag the voltage in phase, and hence these devices are said to absorb reactive power.

(j)GRID TIED CONVERTER CONTROLLER

A phase locked loop (PLL), two measurement system, a current regulation loop, a voltage loop, and a DC link voltage regulator. The PLL is synchronized to the fundamental of the transformer primary voltage to provide the synchronous reference (sinωt and cosωt) required by the abc-qd transformation. The measurement block computes the d-axis and q-axis component of voltage and current by executing an abc-qd transformation in the synchronous reference determined by sinωt and cosωt provided by PLL An outer current regulation loop consisting of an AC voltage regulator and a DC voltage regulator. The output of the AC voltage regulator is the reference current iqref for the current regulator. The output of the DC voltage regulator is the reference current idref for the current regulator. Iq is in quadrature with voltage which control reactive power flow. Id is in phase with voltage which control active power flow An inner current regulation loop consists of a current regulator. The current regulator controls the magnitude and phase of the voltage generated by the PWM converter from the Idref and Iqref reference currents produced respectively by the DC voltage regulator and AC voltage regulator The main function is to operate the converter power switches so as to generate a fundamental output voltage waveform with the demanded magnitude and phase angle in synchronism with the ac system. The main function is to operate the converter power switches so as to generate a fundamental output voltage waveform with the demanded magnitude and phase angle in synchronism with the ac system.

(k) PHASE LOCKED LOOP

Phase Locked Loops (PLL) circuits are used for frequency control. They can be configured as frequency multipliers, demodulators, tracking generators or clock recovery circuits. Each of these applications demands different characteristics but they all use the same basic circuit concept contains a block diagram of a basic PLL frequency multiplier. The operation of this circuit is typical of all phase locked loops. It is basically a feedback control system that controls the phase of a voltage controlled oscillator (VCO).

III MODELLING USIND MATLAB/SIMULINK

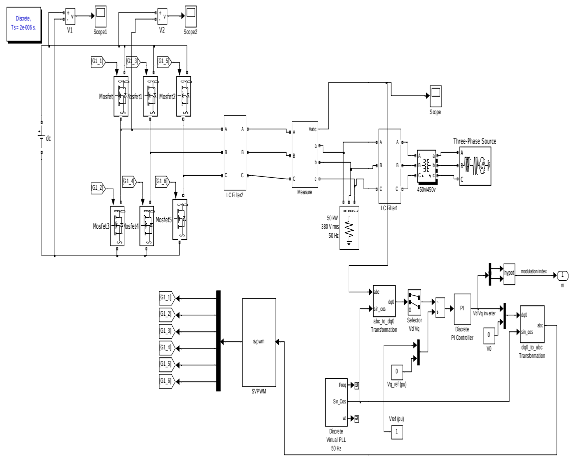


Fig 3: Modelling using Matlab/Simulink

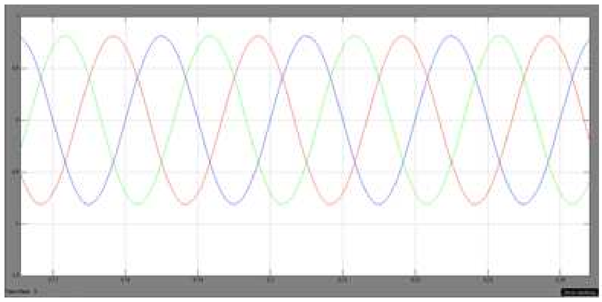
III RESULTS AND DISCUSSION

Simulations using Simulink in MATLAB software are carried out. The maximal step size is 500 ns, and the sampling time is 100 μs. The rated output power is 30 kW, and the output current of each phase is 45 A at rms.

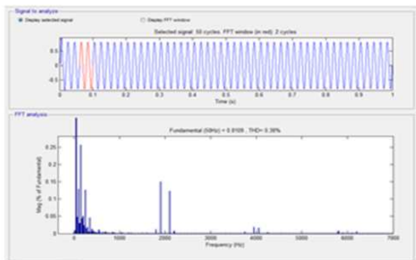
In the SRF, the fundamental currents can be well controlled with the PI regulator, and the repetitive control is used to compensate the harmonics. In order to verify the effectiveness of the proposed repetitive control scheme, the simulation results with the conventional repetitive control are also presented for comparison. The output current and the current tracking error at 49.9-, 50-, and 50.1-Hz grid frequencies are shown in Figs. 5–7, respectively. At the 49.9-Hz grid frequency, the output current THD is 2.53% with the improved repetitive control, compared to 3.84% with the conventional one; at 50 Hz, they are 2.51%. The rated grid frequency is 50 Hz.

SIMULATION RESULTS

GRID TIED VOLTAGE



HARMONICS DISTORTION



THD=0.38%to5%

IV CONCLUSION

In this project, an improved dq transform based control scheme has been proposed. It adopts a new FIR filter design method, which has adjustable linear-phase low-pass characteristics. Moreover, the proposed scheme can approximate the dq control when the ratio of the sampling frequency to the grid frequency varies. The principle of the control scheme and the FIR filter design method have been analyzed. Through simulations and experiments, it is demonstrated theoretically that the improved repetitive control scheme is effective to improve the tracking performance and reduce the harmonic distortion for the grid connected VI systems.

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