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Measurement of Instantaneous Active and Reactive Power with SRF Theory

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Abstract: - The advancements in power electronics has contributed towards development of power quality improvement devices. These devices include active filters, static VAR compensator, DVRs, UPQC, STATCOM etc. For the control of these devices, a common requirement is measurement of instantaneous voltage, current and power in appropriate frame of reference. For ease of control of three phase circuits, the three phase quantities are converter into three phase quantities using transformation. In this paper, a synchronous reference frame (SRF) theory often known as dq theory is deployed for measurement of instantaneous active and reactive power. By transforming three-phase voltages and currents into a rotating dq0 coordinate system aligned with the voltage vector, time-varying AC quantities are converted into steady DC components, simplifying power computation. The methodology employs Clark (α-β) and Park (dq0) transformations to derive instantaneous active power (P) and reactive power (Q) via direct relationships with the d- and q-axis currents. In this paper MATLAB simulation results are presented and the simulation results are validated with hardware prototype model.

Keywords: active power, reactive power, SRF theory, instantaneous power

I. Introduction

In modern power systems, accurate and real-time measurement of instantaneous active and reactive power is critical for efficient energy management, grid stability, and the control of power electronic converters [1]. Traditional methods of power measurement, which often rely on averaging techniques or steady-state assumptions, struggle to address the dynamic and nonlinear behavior of modern electrical networks, especially under unbalanced loads, harmonic distortions, or rapidly varying conditions [2].

The dq (direct-quadrature) theory, also known as the Synchronous Reference Frame (SRF) method, provides a robust mathematical framework to overcome these challenges. By transforming three-phase voltages and currents into a rotating reference frame synchronized with the grid frequency, this approach simplifies the analysis of time-varying AC quantities into DC-like signals [3]. The dq transformation decouples active and reactive power components, enabling instantaneous computation and precise control even in distorted or transient operating conditions [4].

The methodology involves two key steps of Clarke Transformation and Park Transformation. The Clarke transform converts three-phase (abc) quantities into a stationary αβ reference frame whereas, Park Transform converts the αβ components into the synchronous dq frame aligned with the grid voltage vector. In the dq domain, instantaneous active power (pp) and reactive power (qq) are derived directly from the product of the transformed voltage and current components. These values inherently filter out oscillatory terms caused by imbalances or harmonics, allowing for real-time extraction of average power through low-pass filtering [5].

The power quality improvement devices require precise measurement of instantaneous active and reactive power. These precise instantaneous values are required for control strategies for minimizing harmonics and dynamic compensation [6]. The AC electrical measuring instruments are calibrated for indicating the root mean square (RMS) value whereas the DC measuring instruments indicated the average value. Hence, for a power quality improvement device, like STATCOM or active filters, which are deployed for mitigating harmonics, these average and RMS values are hardly useful [14]. The control signals for these devices are obtained from instantaneous values of voltage and current. These devices processes instantaneous voltage and current to evaluate instantaneous active and reactive power component as well as power loos component which is indicative of harmonics [10].

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II. INSTANTANEOUS POWER MEASUREMENT WITH SRF THEORY

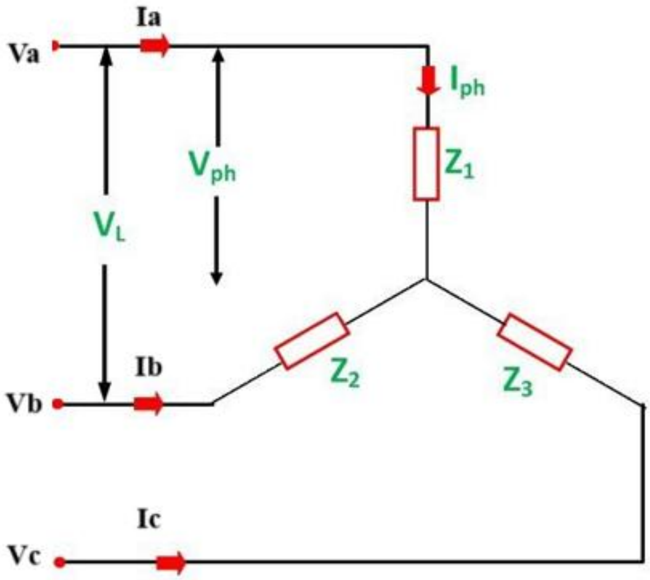

Fig 1: Three phase load driven by three phase source

For instantaneous power measurement in three phase AC circuit of Fig 1, the SRF theory procedure performs following steps [7, 8]

At first, the three phase voltages (Va, Vb, Vc) and currents (Ia, Ib, Ic) are converted from abc reference frame to αβ reference frame using Clarke's transform as given in equation (1) and (2) for voltages and equation (3) and (4) for currents

Voltages

$$V_\alpha = \frac{2}{3}\left(V_a - \frac{1}{2}V_b - \frac{1}{2}V_c\right) \quad (1)$$

$$V_\beta = \frac{\sqrt{3}}{3}(V_b - V_c) \quad (2)$$

Currents

$$I_\alpha = \frac{2}{3}\left(I_a - \frac{1}{2}I_b - \frac{1}{2}I_c\right) \quad (3)$$

$$I_\beta = \frac{\sqrt{3}}{3}(I_b - I_c) \quad (4)$$

These αβ components are rotated to synchronous reference frame by using the grid angle θ

Voltages

$$V_d = V_\alpha \cos\theta + V_\beta \sin\theta \quad (5)$$

$$V_q = -V_\alpha \sin\theta + V_\beta \cos\theta \quad (6)$$

Currents

$$I_d = I_\alpha \cos\theta + I_\beta \sin\theta \quad (7)$$

$$I_q = -I_\alpha \sin\theta + I_\beta \cos\theta \quad (8)$$

The value of instantaneous active and reactive power in dq reference frame is computed as,

$$p = \frac{3}{2}\left(V_d I_d + V_q I_q\right) \quad (9)$$

$$q = \frac{3}{2}\left(V_d I_q - V_q I_d\right) \quad (10)$$

The factor 3/2 ensures the power invariance for Clarke's transform 2/3 scaling

III. Experimental Setup and Results

A. MATLAB Simulation

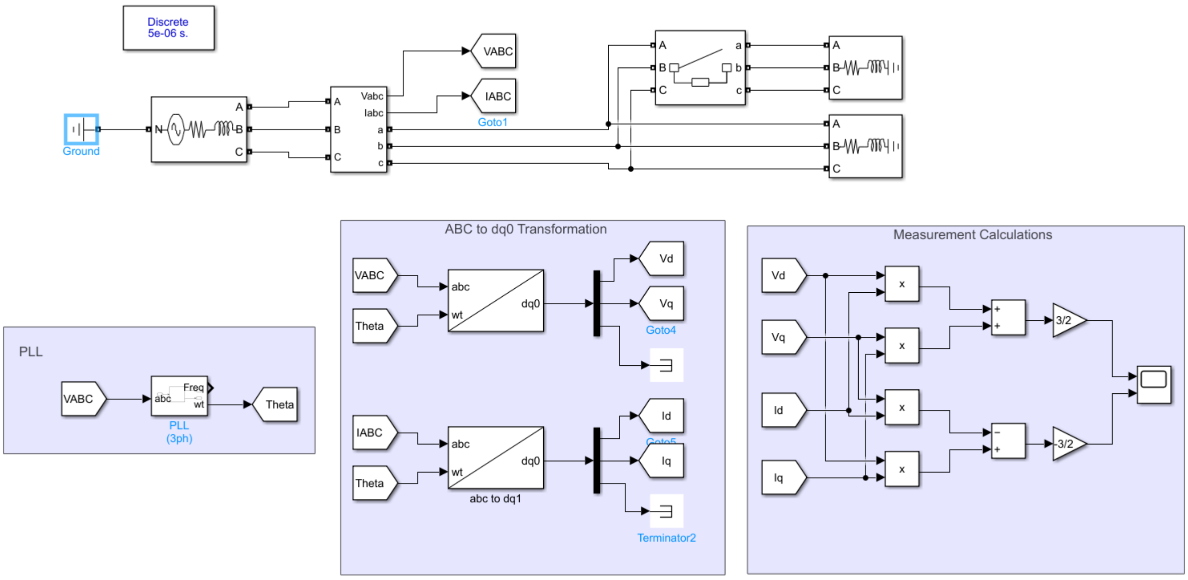

Fig 2: MATLAB Model

The MATLAB Simulink model of three phase instantaneous power measurement system is shown in Fig 2. The details specifications of the system are mentioned in table 1. The system consists of a three phase source of 415V feeding RL load. The contribution of the total load is 20kW active power and 2kVAR reactive power. A circuit breaker is used to add load in the circuit at desired time instance.

Table 1: System Specifications

Source	415V 50Hz
Load 1 and load 2 (each)	Active power: 10kW Reactive power: 10kVAR
Unbalancing load	Active power: 5kW Reactive power: 5kVAR
Load type	Balanced load
Switching device	Circuit breaker
Switching instance	0.5 second
Current sensor	ACS 712
Voltage sensor	ZMPT101b

The system shown in Fig 2 is executed for a period of 1 second. During this interval, a load change is applied at time instance 0.5 second with the help of a circuit breaker. The waveforms of three phase current and voltage are seen in Fig 3(a) and 4(a) respectively. The zoomed portion of these waveforms around to load change instance are seen in Fig 3(b) and 4 (b) respectively.

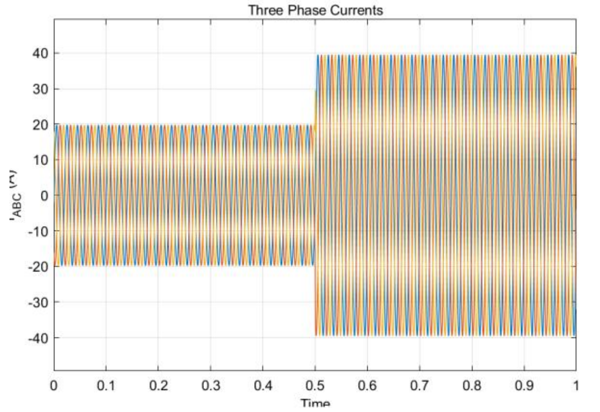

Fig 3 (a): current waveforms

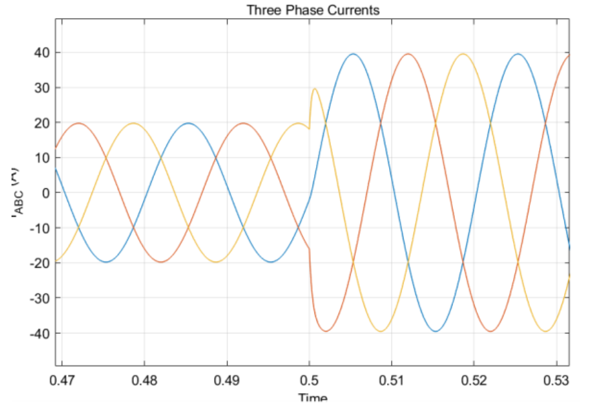

Fig 3(b): zoomed view of current waveforms

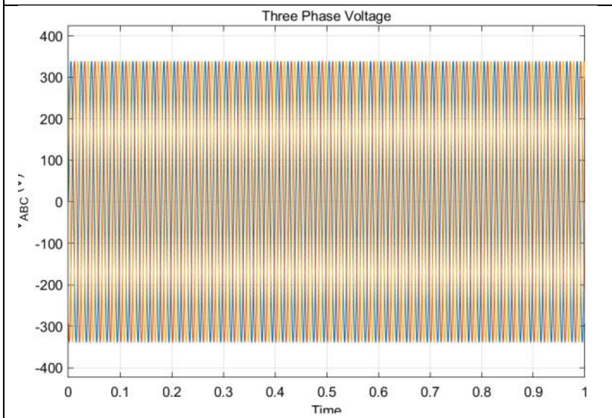

Fig 4(a); Voltage waveforms

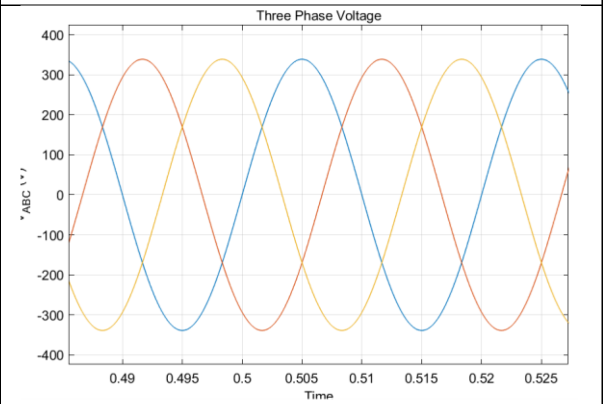

Fig 4(b): zoomed view of voltage waveform

The graph of instantaneous active and reactive power measured, are illustrated in Fig 5. During the time interval 0 – 0.5 seconds, only load 1 was active which is reflected in the graph with active power of 10kW and reactive power of 1kVAR. After the load change, the total active power measured is 20kW and total reactive power is 2kVAR. These Figs are exactly identical with the system specifications.

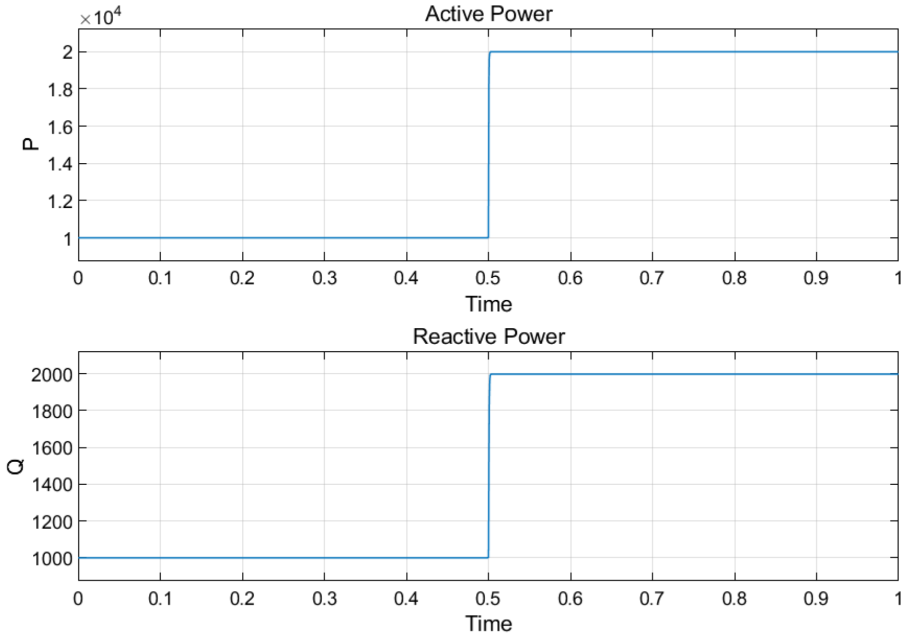

Fig 5: active and reactive power

In the same system when a single phase load is added at time instance 0.5 second instead of adding balanced load, the graph of measured active and reactive power is shown in Fig 6. In this Fig it can be noted that the unbalancing of three phase circuit has caused the resultant power to be oscillating at a rate twice the grid frequency.

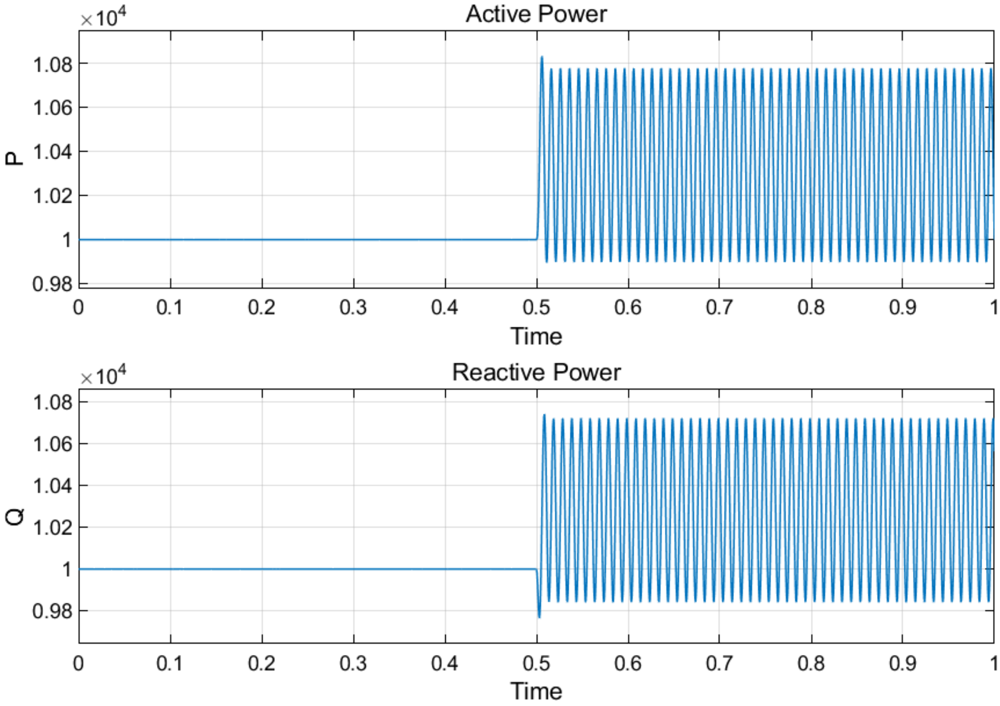

Fig 6: active and reactive power under unbalance condition

B. Experimental Setup

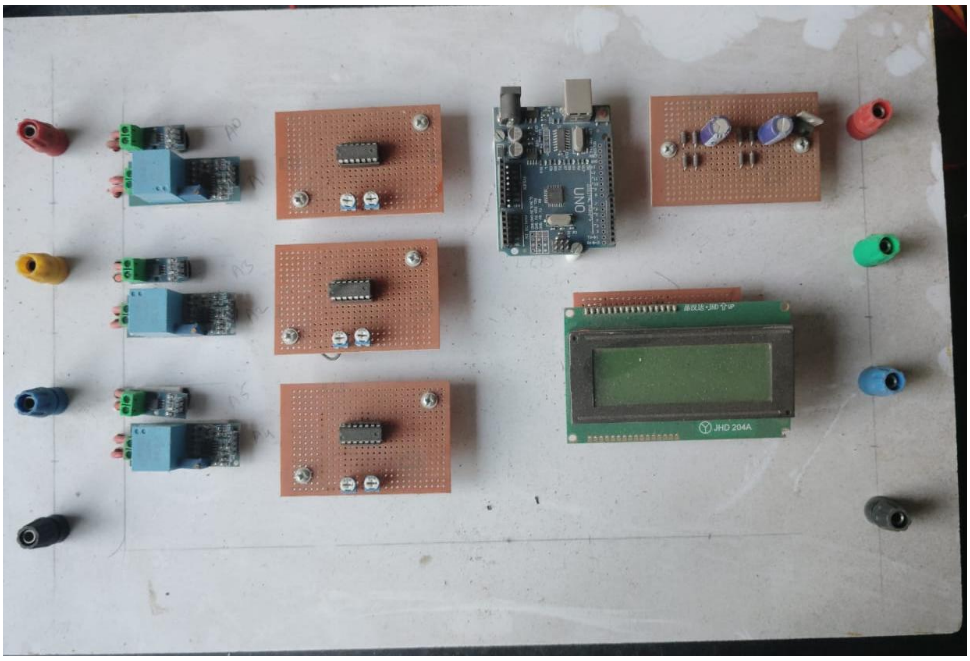

Fig 7: Experimental setup for instantaneous power measurement

A hardware model for instantaneous power measurement in three-phase AC circuits using Arduino and SRF theory involves integrating voltage and current sensors (ZMPT101B for voltage and ACS712 for current) to capture phase voltages and currents, which are conditioned via signal scaling, filtering, and offset adjustment to fit Arduino's 0–5V analog input range. The Arduino samples these signals at a fixed rate and processes them using SRF theory: first applying the Clarke transformation to convert three-phase quantities into αβ0 coordinates, then the Park transformation to rotate these into a grid-synchronized dq0 reference frame using a software-based phase-locked loop (PLL) to track the grid frequency. The grid frequency is also determined in first iteration with zero crossinf detectors based frequency measurement. In the dq0 frame, instantaneous active power (p) and reactive power (q) are calculated from equation (9) and equation (10) respectively. Results are displayed on an LCD/OLED, while challenges such as noise mitigation (via filtering), synchronization accuracy, and Arduino's limited ADC resolution (10-bit) are addressed through calibration. This setup enables practical applications like load monitoring and power quality analysis, though higher precision systems may require advanced microcontrollers. The photograph of developed hardware is shown in Fig 7.

IV. CONCLUSION

The application of SRF theory in measuring instantaneous power in three-phase AC circuits offers a robust and efficient methodology for modern power system analysis. By transforming three-phase voltages and currents into a rotating reference frame synchronized with the grid frequency (dq0 coordinates), SRF theory converts time-varying AC quantities into steady-state DC components under balanced conditions. This transformation enables the direct and instantaneous computation of active and reactive power, with the d-axis representing active power and the q-axis representing reactive power, thereby decoupling their control for enhanced real-time regulation. The SRF approach excels in simplifying control strategies for applications such as active power filters, grid-tied inverters, and renewable energy systems, where precise instantaneous power measurement is critical. Its ability to streamline filtering and control processes by processing DC-like quantities in the dq0 frame underscores its practicality in dynamic environments.

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