The two signals, Vi(t) and vi'(t) are a pair of orthogonal function. If they are sent to two separate multipliers and squared, equations (10) can be derived.

Equation (10)

$$v_{01}(t) = KV_P^2 sin^2(\omega t)$$
$$v_{02} \;\; = KV_P^2 cos^2(\omega t)$$

Equation (11)

Where K is the multiplication factor of the multipliers. Due to the characteristic of orthogonal function it v01(t) and v02(t) is easy to obtain the square of the input voltage peak value by adding equations (9) and (10).

$$v_{0a} = v_{01}(t) + v_{02}(t) = KV_P^2(sin^2(\omega t) + cos^2(\omega t) = KV_P^2$$

Equation (12)

In order to measure the peak value, the signal v0a(t) is fed to a square root circuit. Then the output of the square root circuit is given by equation (12).

$$v_0(t) = K_1 V_P$$

Where K1 is the multiplication factor of the square root circuit. when the multiplication factors of the multiplier and the square root circuit are selected properly, the value of constant K1 can be set as 1. The output voltage of the detector is equal to the peak value of the input voltage. Because the detector is based on the concept of an orthogonal function pair, it is called orthogonal detector [17] [18].

D. Missing voltage evaluation method

The Missing Voltage can be used to see the real time variation of the waveform from the ideal and the actual severity of the event. It is also capable to give more accurate indication of the duration of voltage sag/swell/interruption as well as the start and the end of event. The Missing Voltage Technique is defined as the difference between the desired instantaneous voltage and the actual instantaneous value. The desired voltage can be easily obtained by taking the pre-event voltage and extrapolating this out during the event which is similar to the way a phase-locked loop (PLL) operates. A PLL is a control loop incorporating a voltage control oscillator and phase sensitive detector in order to lock a given signal to stable reference frequency. Therefore, the desired voltage waveform will be known as PLL waveform (VPLL(t)) and it will be locked in magnitude, frequency, and phase angle to the pre-event voltage waveform [19] [20].

$$v_{pll}(t) = Asin(\omega t - \emptyset_a)$$
$$v_{sag}(t) = Bsin(\omega t - \emptyset_b)$$

$$m(t) = Rsin(\omega t - \emptyset)$$

Equation (13)

with m(t) gives the instantaneous deviation of equation (15).

$$R = \sqrt{A^2 + B^2 - 2ABcos(\emptyset_a - \emptyset_b)}$$

Equation (14)

And

$$tan\emptyset = \frac{Asin\emptyset_a - Bsin\emptyset_b}{Acos\emptyset_a - Bsin\emptyset_b}$$

This method seems to be shown to be superior to the RMS method for sag analysis where phase angle jumps occur. It relies on the assumption that the system frequency is constant during the sag. Since the technique requires the RMS method to determine the amplitude of the pre-sag and sag voltages and, respectively. This method is suitable for sag analysis rather than detection but since its style need RMS it shows that the method is too long and fastidious [19] [20].

II. Simulation Models

For simulation purpose, electrical power distribution model is designed and the single-line diagram of the distribution model is shown in Figure 1. Using SimPowerSystem library of Simulink®, this model is simulated by applying various type of loads commonly seen in industries and faults like short circuit fault, heavy load, normal load, non-linear load (Power converter, efficient bulb lighting, etc.), and capacitor bank. The electrical power distribution model consists of a 25-kV voltage source and 50 Hz fundamental frequency. Each power quality events simulated for 10 cycles and a sampling frequency of 10 kHz. When single-line to ground fault is applied to bus 1 then, voltage sag and interruption are caused on faulty phase and voltage swell is caused on healthy phase. It is known that voltage sag, swell and interruption are also caused by switching on a heavy load but for simulation purpose we will target on faulty. Table 2 shows the specifications of the power distribution system used in the simulation. The performance study of sample system is carried out for detection and characterization of voltage due to power system faults. It is assumed that a fault has occurred at position short circuit fault, on the primary side of distribution transformer T2, and the fault lasted for 4 cycles from t = 0:045 to 0:125 seconds.

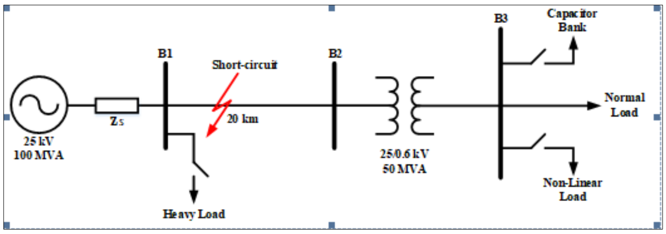

Figure 1. Single-Line diagram of the power distribution system

Table II. SPECIFICATION OF THE POWER DISTRIBUTION SYSTEM