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(54) Title: 4-WIRE 3-PHASE POWER GRID SENSOR FOR MONITORING MINUTE LOAD UNBALANCE AND HARMONIC NOISE

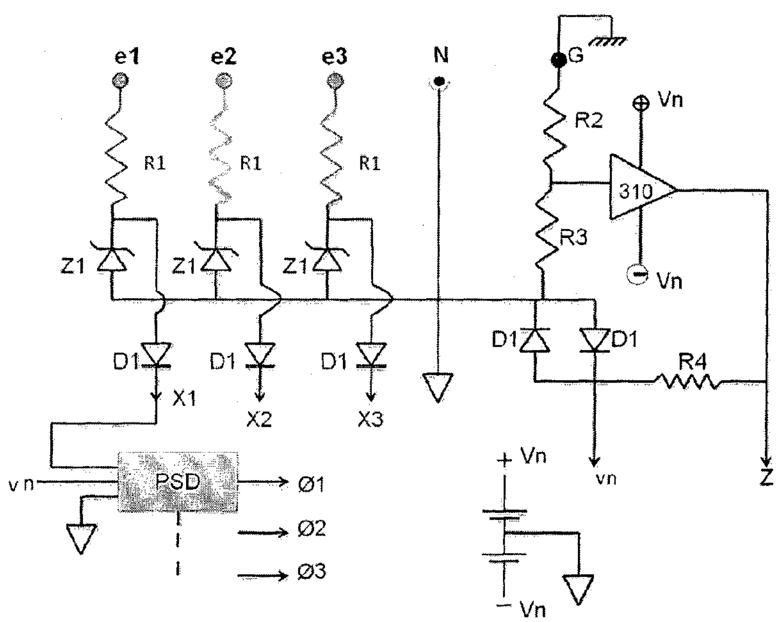

Figure 2

(57) **Abstract**: A sensor system for sensing network parameters of 3-phase power distribution network or power line to interpret neutral failure in said power distribution network or power line comprising means for generating stabilized reference signals synchronized to the three phases of said power distribution network or power line and thereby generating inverting neutral voltage with respect to ground and means for determining electronic attribute related to the neutral voltage. The determined electronic attributes are compared in comparator circuits with their predefined set values to interpret the neutral failure in the power distribution network or the power line. An automatic load switcher is driven by the attributes to restore balance in the distribution network.

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TITLE: A 4-WIRE 3-PHASE POWER DISTRIBUTION NETWORK SENSOR FOR MONITORING MINUTE LOAD UNBALANCE AND HARMONIC NOISE.

FIELD OF THE INVENTION:

The present invention deals with a 3-phase power distribution network sensor. More particularly, the present invention deals with a sensor useful for monitoring load unbalance, harmonic noise and voltage spikes in a 4-wire 3-phase power distribution network. The present invention further deals with a process for manufacturing of the said 3-phase power distribution network sensor. The present invention also discloses a method of protection of a power distribution network against voltage spikes, harmonic noise and fire hazards from neutral failure due to severe load unbalance in 3-phase by involving the said 3-phase power distribution network sensor.

BACKGROUND AND PRIOR ART OF THE INVENTION:

Load unbalance in a 4-wire, 3-phase power distribution network is a common nuisance. This causes wasteful energy in the form of large current in the Neutral wire which is normally rated at lower current capacity. Prolonged high current condition in Neutral wire eventually leads to unpredictable neutral failure, causing severe fire hazards and complete disruption of the voltage distribution among different phases. The phase voltage in the lowest loaded phase increases drastically and triggers a chain reaction of damages in the equipments connected to that phase. Moreover, an unbalanced distribution network causes zero-sequence magnetic flux leakage in the sub-station transformer and becomes a source of electro-magnetic-interference (EMI) which impairs the functioning of sensitive electronic instruments. At the same time, triplens (the 3rd harmonic and higher) of the zero-sequence current enter the Ground from the Neutral at the sub-station transformer and interrupts communication using the Ground. Large harmonics content in the supply due to extensive use of non-linear loads (like SMPS, switched SCR), also causes hike in Neutral current. The existence of current harmonics in power systems increases losses in the lines, decreases the power factor and causes timing errors in sensitive electronic equipment. In all power distribution networks thus load unbalance and harmonics content should be precisely monitored and rectified. Present day market available monitoring systems are based on the concept of simultaneous sensing of voltages and currents at the three phases and also in the neutral wire by employing voltage (VT) and current (CT) transformers over a wide

Dynamic Range (D.R.) with sample rate ~ 16 ksps and all the power grid parameters are computed from the sampled data using a dedicated computer. However, the unit is very costly.

As per records available from MAXIM (www.maxim-ic.com/smartgrid), commercially available instruments employ 8-channel simultaneous sensing ADC (Analog-To-Digital Converter like MAX 11046; price 16 $ USD each) to monitor currents and voltages on the three phases and the neutral. The data is stored in memory for subsequent evaluation of total current, voltage, instantaneous power, active, reactive apparent energy, power factor and analysis of multiple harmonics. Considering a nominal voltage ~ 220 V and a measuring accuracy ~ 0.05% with a over-voltage limit 1.5 KV under fault the D.R. specified is ~ 83 dB (http://www.maxim-ic.com/app-notes/index.mvp/id/4281). The instrument is very costly. A typical base station from Siemens (www.siemens.com) with analyzing software and sensor head costs ~ Rs. 5,00,000/- and each sensor head (www.ekmmetering.com, www.intechopen.com) costs ~Rs. 40,000/-. It is true that such a system will give us all the information about a power grid but there still exists an urgent need for a simpler and cheaper solution to the problems of detection of load unbalance, harmonic noise and voltage spikes in the power system that often leads to neutral failure.

Thus there has been always need for sensory system which will monitor load unbalance, harmonic noise, voltage spikes in a power distribution network with capability of shutting down the distribution block when these parameters exceed a safe limit and most importantly the sensory system should be cheap and simple and can be fabricated with indigenous electronic components.

OBJECT OF THE PRESENT INVENTION:

It is thus the basic object of the present invention is to provide a sensory system which would be adapted to monitor operational parameters of a power distribution network for interpreting operational failure of the power distribution network prior the actual failure and shutting down the power distribution network.

Another important object of the present invention is to provide power distribution network sensor which would be adapted to operate in a 4-wire 3-phase power distribution network for monitoring load unbalance, harmonic noise and voltage spikes in the network and generate a prior alarm much before a neutral failure takes place in the network.

Yet another object of the present invention is to provide a power distribution network sensor which would be adapted to monitor harmonic noise generated due to non-linear loads (SMPS, switched-mode-power-supply) and voltage spikes in power grid and analyze the noise pattern in the power grid to assert the neutral failure before it actually takes place.

A further object of the present invention is to provide a sensing technique which would be adapted to involve phase-sensitive-detection (PSD) technique to detect unbalance in the load and malfunctions in a Distribution Box (DB) within a 3-phase power distribution network.

A still further object of the present invention is to develop fabrication method which would be adapted to construct a reliable and efficient power distribution network sensor for asserting operational failure of the power distribution network prior the actual the actual failure by involving cheap, simple and readily available electronic component.

A still further object of the present invention is to develop fabrication method of a load switcher which coupled with the sensor outputs will automatically switch quanta of ballast load from the maximum loaded phase to the least loaded phase when the imbalance crosses a safe limit.

SUMMARY OF THE INVENTION:

Thus according to the basic aspect in the present invention, there is provided a 3-phase power distribution network sensor for monitoring minute load unbalance comprising

means for generating stabilized reference signals synchronized to the three phases of said power distribution network or power line and generating inverting neutral voltage with respect to ground;

involving said inverting neutral voltage with respect to ground and cooperatively activate means for determining one or more electronic attributes related to the neutral voltage and comparing the said attributes with their predefined set values to monitoring any minute load unbalance in the power distribution network or the power line.

According to another important aspect in the present invention, that said power distribution network sensor for monitoring minute load unbalance comprises means for determining electronic attributes related to the neutral voltage and comparing the said attributes in comparator circuits with their predefined set values to prevent the neutral failure in the power distribution network or the power line.

According to a further aspect in the present invention, said power distribution network sensor for monitoring minute load unbalance comprises

phase sensisitve detection means for detection of phase components of said inverting neutral voltage with respect to ground and its amplification means;

means for precision rectification and generating information about neutral voltage w.r.t. Ground.

means for yielding the harmonics and noise content in the said Neutral voltage w.r.t. Ground and generation of floating signals; and

means for translation of thus obtained electronic attributes with reference to Neutral Point, into Ground-referenced signals to be processed by a central dedicated system; and

comparator circuit means to actuate alarms if any of said comparable attribute value exceeds set value .

According to another aspect in the present power distribution network sensor for monitoring minute load unbalance, the means for determining electronic attributes related to the neutral voltage comprises one or from

precision rectifier and average module for yielding information about root-mean-square (rms) neutral voltage with respect to the ground;

notch-filter followed by precision rectification and averaging module for measuring harmonics and noise content in the neutral voltage with respect to ground.

phase sensitive detection module for detecting the phase components of neutral voltage along the three supply phasors;

According to a further aspect in the present power distribution network sensor, the said precision rectifier and average module is operatively connected with said means for generating inverting neutral voltage for yielding the information proportional to r.m.s. value of the neutral voltage phasor with respect to the ground.

In accordance with another aspect in the present power distribution network sensor, said notch-filter followed by precision rectification and averaging module is operatively connected with said means for generating inverting neutral voltage and to remove fundamental line frequency from inverting neutral voltage by involving said notch-filter and thereby detect the harmonics and noise content of the neutral voltage by involving the precision rectification and averaging module.

According to yet another aspect in the present power distribution network sensor, the means for determining floating signals comprise three independent phase sensitive detection module for each of the supply phasors for measuring of the phase components of neutral voltage along the three supply phasors and to receive signal from the said notch-filter followed by precision diode rectification and averaging module to measure harmonics content in the neutral current

According to another aspect in the present power distribution network sensor, the electronic attribute related to the neutral voltage includes the harmonics and noise content in the neutral voltage, the phase components of neutral voltage along the three supply phasors.

According to a further aspect in the present invention, the present power distribution network sensor is adapted to be disposed in electrical communication with logic circuit having OR gate with resettable latch for sensing load imbalance, harmonics and noise in the power distribution network or the power line and automatically tripping the power distribution network or the power line when the sensory parameters exceed a pre-defined safe limit.

According to a further aspect in the present invention, the present power distribution network sensor comprises signal translator for transforming the said neutral-referenced electrical attributes into ground-referenced signals for converting said signal into its digital equivalent and feeding to a centralized base station to store in memory for further analysis.

In accordance with another aspect in the present invention there is provided a three phase load switcher for switching quanta of loads from most loaded phase to least loaded phase and ensuring efficient control of balanced load sharing comprising

sensor system for sensing network parameters of 3-phase power distribution network or power line adapted for sensing the phase components of neutral voltage along the supply phase of the 3-phase power distribution network or power line involving a 3-phase power distribution network sensor for monitoring minute load unbalance;

Max-Min Logic circuit for placing quanta of ballast loads in the three phases through relay assemblies and automatically switching said ballast loads of the most loaded phase to the least loaded phase when the said sensor system detects the phase components of neutral voltage along the supply phase exceeds a predefined set value;

wherein said relay assemblies are operatively connected with said Max-Min Logic circuit via latch circuit adapted for enabling said relay assemblies only after a delay following the moment of crossing of the phase components of neutral voltage along the supply phase beyond the predefined set value to avoid oscillation in the contacts.

According to a further aspect in the present invention there is provided a method for sensing and monitoring the network parameter by involving the present power distribution network sensor comprising

generating stabilized reference signals synchronized to the three phases of the 3-phase power distribution network or power line;

generating inverse of neutral voltage phasor with respect to ground with proper scaling;

detecting the components of the neutral voltage phasor along the three phases;

detecting the amplitude of neutral voltage;

triggering alarms if any of the components of the neutral voltage phasor value along the three phases exceeds pre-defined set value.

According to yet another aspect in the present invention there is provided a method for automatically shutting down the power distribution network in case of malfunction comprising:

involving 3-phase power distribution network sensor for monitoring minute load unbalance as claimed in anyone of claims 1 to 10;

comparing the electronic attribute related to the neutral voltage with safe limit values in said comparators;

feeding the comparator outputs to a multiple input OR gate with resettable Latch to drive a circuit breaker for automatically tripping or shitting the power distribution network.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS:

Figure 1 illustrates a typical 3-phase power supply system. The system comprises a 3-phase power source at the sub-station (the step-down transformer) and one distribution box (DB). Z_I (I= 1,2,3) represent the individual 3-phase loads connected to the DB. It is obvious that many DBs can be connected to the power source.

Figure 2 illustrates the circuit block diagram indicating the generation of reference signals from the three phases, generation of inverse of neutral voltage with respect to ground (**z**) along with scaled down by R_2,R_3 and phase-sensitive-detection of the components of **z** (Φ_1, Φ_2, Φ_3) along these reference signals. The circuit is essentially referenced to the neutral point (not ground-referenced)

Figure 3 illustrates the circuit block diagram indicating precision rectification of **z** followed by averaging to yield Φ_N which is proportional to the r.m.s. value of the neutral voltage phasor with respect to ground.

Figure 4 illustrates the circuit diagram of the phase-sensitive-detector built around LM565 and LM324 (National Datasheet).

Figure 5 illustrates the circuit diagram of the precision rectifier and averager built around LM324 and D_1.

Figure 6 illustrates the circuit diagram of the passive 50 Hz notch filter (Art of Electronics, Horowitz and Hill).

Figure 7 illustrates the circuit diagram for transforming the signals (Φ_I, Φ_N and Φ_{HN}) from neutral-referenced to ground-referenced signals by the use of opto-isolator 6N136 and LM324.

Figure 8 illustrates a typical circuit configuration to actuate a circuit breaker (CB) if Φ_N, Φ_{HN} and Φ_I 's cross safe limit.

Figure 9 illustrates the actual experimental data of monitoring Φ_N over a span of 50 secs. It is evident that no information about loading in the individual phases can be obtained from this data.

Figure 10 illustrates the actual experimental data of monitoring Φ_I's over the same span. It is evident that information about loading in the individual phases and the unbalance are clearly depicted (explained in the text later).

Figure 11 illustrates a preferred circuit embodiment of the maximum, minimum control line generator.

Figure 12 illustrates a preferred Relay assembly (R.A.) associated with the present invention.

Figure 13 illustrates the detail circuit configuration of an automatic 3 phase load switcher comprising the max-min control line generator and three relay assemblies for three phases , together with a 10 min time lapse delay generator for eliminating oscillation in the relay contacts.

DETAILED DESCRIPTION OF THE INVENTION WITH REFERENCE TO THE ACCOMPANYING FIGURES:

The present invention describes a 4-wire 3-phase power distribution network sensor, useful for monitoring load unbalance, harmonic noise and voltage spikes in a network. The present invention also describes a process for manufacturing of the said 3-phase power distribution network sensor and a method of protection in a 3-phase power distribution network against fire hazards and instrument damage (due to neutral failure), using the said sensor.

The said sensor works on phase-sensitive-detection (PSD) technique to detect unbalance in the load and malfunctions in a Distribution Box (DB) within a 3-phase power distribution network. This sensor also monitors harmonic noise generated due to non-linear loads (SMPS, switched-mode-power-supply) and voltage spikes in power grid. As a general rule the power grid becomes noisy before a massive neutral failure and thus the sensor can give a prior alarm much before a neutral failure actually takes place.

In a feature of the present invention, for efficient monitoring of status of a DB, response time can be programmed in the range of 10 - 100ms, instead of using by cheap analog meters having poor D.R. (~ 24 dB), where the response time is slow (> 1 s).

In another feature of the present invention, a DB can be monitored using the said sensor, by measuring the unbalance information in three phases with large D.R. (~ 100 dB) and fast response time (10 to 360 ms).

In yet another feature of the present invention, the said sensor is capable of detection of small voltage spikes representing noise or switching transients of reactive loads.

In still another feature of the present invention, detection of higher harmonics, specially Triplens, which are additive, generated by unbalanced non-linear loads like SMPS (switched-mode-power-supply) is possible.

In yet another feature of the present invention, it makes possible efficient control of balanced load sharing. As the lowest loaded and highest loaded phases can be easily identified with deep contrast (the phase-locked outputs are of opposite polarity) quanta of loads can be switched between the phases to maintain load balance (manually or by program).

The most promising feature of the present invention is however, the nominal cost and ability to manufacture with indigenous components.

In a feature of the present invention, it describes a method of monitoring a power distribution network, with a sensor for each distribution box, by detecting the phase components of neutral voltage phasor w.r.t. ground voltage, along the three phases of the power supply. Phase-sensitive-detection method, which is also known as lock-in technique has been employed with inherent high dynamic range (> 80 dB) and noise immunity.

Basic principle of detection:

A typical 3-phase power supply system is represented by Figure-1.

e_1 = E sin ωt; e_2 = E sin (ωt + 120°); e_3 = E sin (ωt + 240°)

Z_N = impedance of neutral path << Z_1, Z_2, Z_3 (load in three phases)

e_N = Neutral voltage w.r.t. Ground= $e_{N1} + e_{N2} + e_{N3}$ (components along the three phases)

$$= \frac{e_1 Z_N}{Z_1 + Z_N} + \frac{e_2 Z_N}{Z_2 + Z_N} + \frac{e_3 Z_N}{Z_3 + Z_N}$$

When two phase-locked phasors (same frequency, relative phase= θ) are present at the two inputs of a double- balanced phase detector the dc output of the phase detector is proportional to cos θ .

$e_1 = E_1$ Sin ωt ; $e_2 = E_2$ Sin (ωt + θ) ; Output (dc) = const . E_1 . E_2 . Cos θ

If r_1 , r_2 , r_3 are three reference square waves synchronous to the three voltage phasors of the power grid supply

r_1 = R Sin ωt , r_2 = R Sin (ωt + 120°) , r_3 = R Sin (ωt + 240°) then

phase-sensitive detection between r_1 and e_N yields a dc output Φ_1

Φ_1 = const . R . ($|e_{N1}|$ - $|e_{N2}|$. 0.5 - $|e_{N3}|$. 0.5)

Similarly PSD between r_2 and e_N yields a dc output Φ_2

Φ_2 = const . R . (- $|e_{N1}|$. 0.5 + $|e_{N2}|$ - $|e_{N3}|$. 0.5)

And PSD between r_3 and e_N yields a dc output Φ_3

Φ_3 = const . R . (- $|e_{N1}|$. 0.5 - $|e_{N2}|$. 0.5 + $|e_{N3}|$)

during a balanced load condition $|e_{N1}| = |e_{N2}| = |e_{N3}|$ and $\Phi_I = 0$

In unbalanced condition Φ_I values are a measure of unbalance endowed with inherent high dynamic range (> 80 dB) and noise immunity (characteristics of Lock-in detection).

Design methodology:

1. Generation of amplitude stabilized voltage references of e_1 , e_2 and e_3 .

2. Generation of inverse of neutral voltage w.r.t. Ground, $e_{GN} = -k. e_{NG}$, k= scale factor ; Neutral to Ground isolation ~ 100 MΩ . k = 0.091

3. Detection of phase components of e_{NG} (Φ_1 , Φ_2 , Φ_3) along e_i (i= 1,2,3) employing phase-sensitive-detection with IC LM565 followed by amplification (1/4 LM324).

4. Precision rectification of e_{GN} followed by averaging to yield Φ_N, the information about neutral voltage w.r.t ground.

5. Removal of fundamental line frequency from e_{GN} by a notch-filter followed by precision rectification and averaging to yield the harmonics and noise content Φ_{HN} in the Neutral voltage w.r.t. Ground.

6. Translation of Φ_1, Φ_2, Φ_3, Φ_N ,Φ_{HN}, which are floating signals with reference to Neutral Point, into Ground-referenced signals to be processed by a central dedicated system .

7. Use of suitable comparator circuits to actuate alarms if any of Φ value exceeds set value.

Reference is now invited from the accompanying figure 2, which illustrates the circuit block diagram for the generation of reference signals from the three phases and generation of inverse of neutral voltage with respect to ground (Z). R1-Z1-D1 generates mono-polar, stabilized reference signals (X1, X2, X3) in phase with the three supply voltage phasors $\mathbf{e_1}$, $\mathbf{e_2}$ and $\mathbf{e_3}$. All the signals and the whole circuit including the DC power supplies are floating with respect to Ground and is essentially referenced to NEUTARL point.

Figure 3 which illustrates the circuit block diagram for indicating precision rectification of **z** followed by averaging to yield Φ_N which is proportional to the r.m.s. value of the neutral voltage phasor with respect to ground. As shown in the said figure, **z** is the scaled e_{GN} and is used to measure the neutral voltage after precision rectification and averaging. This is also used to measure the harmonics content in the neutral voltage after filtering in a 50 Hz notch filter followed by precision filtering and averaging (Fig-3). $\mathbf{V_n}$ is the same signal through a diode limiter and is fed to the input of the three PSDs built around three PLL565 ICs. Φ_1 , Φ_2 , Φ_3 thus are measures of the phase components of neutral voltage along the three supply phasors.

Figure 4 depicts the basic phase-sensitive-detector (PSD) for each phase. A first-order filter has been employed with C1 and the internal 3K6 Ω resistor of LM565 and the time constant is on the order of 360 ms. A gain of x2.7 is employed with LM324 (1/4) and P1 is set to bring the PSD output at zero (i.e. at NEUTRL point) with $\mathbf{v_n}$ shorted to NEUTRAL point (i.e. zero) but x signals being connected.

Figure 5 shows a preferred circuit embodiment of the precision rectifier and average used for measuring neutral voltage Φ_N (in Fig-3) and also the harmonics content Φ_{HN}. Herein D1= 1N4148; R5= 10K Ω, 250 mW, 1%; R9= 1K Ω , 250 mW, 1%; R10= 10K Ω, 250 mW, 1%; C2= 470MF, 25 V, electrolytic.

Figure 6 depicts a preferred embodiment of Passive Twin-T (bridged differentiator tunable notch filter); three capacitors are selected to be as identical as possible; resistance on the top must be exactly six times the bottom resistance [15]. The bottom pre-set is adjusted for frequency tuning at 50 Hz. The attenuation of the filter when implemented in the circuit (Fig-3) at 50 Hz is much higher than 60 dB and the transmission at 150 Hz is on the order of 50%. Herein, C3= 0.1 MF, polystyrene, 600V,5%; P2= 50KΩ 10T Preset; R11= 470 KΩ , 250 mW, 1%; P3= 20 KΩ 10T Preset; R12= 1 KΩ ,250 mW, 1%; R13 is parallel combination of 100 KΩ and 150 KΩ

Experimental Data:

Fig-9 and Fig-10 show the experimentally measured data of Φ_N and Φ_I (I=1,2.3) over a period of 50 secs at a specific DB in the electrical power network of IACS by involving 4-channel digital oscilloscope. Fig-9 depicts the change of e_{NG} (neutral voltage w.r.t ground) with time but there is no information of load unbalance in specific phases. However, from Fig-10 we get all the unbalance information. For our circuit design Φ_I value of the most loaded phase is most negative and that for the least loaded phase is most positive. The 3rd phase will have intermediate Φ_I value depending on its loading. In the Fig-10 at the start of the time phase-1 is most loaded and phase-3 is least loaded. However, at time on the order of 25 sec a heavy load is switched in phase-3 and phase-2 becomes the least loaded phase. Phase-1 remains the most loaded phase all the time.

Analysis of the data:

Φ_I is related with e_{NI} by the matrix relation ; $\Phi_I = K2 . A . e_{NI}$ where

$$A = \begin{matrix} 1.0 & -0.5 & -0.5 \\ -0.5 & 1.0 & -0.5 \\ -0.5 & -0.5 & 1.0 \end{matrix} \qquad K2 = \text{scaling factor} = -\text{ve}$$

Interesting features:

At any instant the most loaded Φ_I value will be most negative (depending on the sign of K2 which is negative in our prototype design)

At any instant correspondingly the least loaded Φ_I value will be most positive

For the remaining phase which is loaded in between the Φ_I value will lie in between the two extremes

Φ_I values are unique and indicates the relative loading of the three phases with great precision but A is a Singular matrix (DET A = 0) and analytical solution of e_{NI} from Φ_I values is not possible

This actually represents that individual currents in the three phases can not be determined as addition of balanced currents in the three phases will not change the unbalance criterion. However, it should be noted that in condition of severe unbalance (one phase is heavily loaded in comparison to others) the current in loaded phase can be estimated fairly accurately.

Performance of the device:

1. Φ_N measurement : time constant = 470 ms ; (this can be set at any value by R_9C_2 combination). If Φ_N is the measured output then r.m.s neutral voltage with respect to ground is given by
2. e_{NG} (r.m.s.) = 45 x Φ_N (DC)
3. Φ_I measurement: time constant = 360 ms; (this can be set at any value by adjusting C_1); 1 V r.m.s. sig in @ e_{NG} (in phase) = 1.536 V (DC). Φ_I value has uncertainty of only a few mV (the input offset voltage of LM324 is on the order of 1 mV and the gain in the circuit is 2.7, Fig-4) and considering a power supply of +/- 9 V the dynamic range of unbalance detection is on the order of 80 dB. Further if we consider the fact that this unbalance is in a power distribution network of nominal 240 V AC then the effective dynamic range of the unbalance

measurement is 100 dB. In Fig-8 the spike in Φ_3 approximately corresponds to 0.5 V r.m.s. voltage hike at neutral point due to switching on load in phase-3. Considering $Z_N \sim 160$ m ohm (typically 200 m of 95 Sq mm cable, 150 A per phase), this indicates on the order of 3 A switching transient in phase-3 which may be caused by starting on of some motor.

4. Harmonic detection: In present prototype (the gain in amplifier A is one i.e A is absent, Fig-3) at 3rd harmonic (150 Hz) 1.6 V r.m.s. signal in **eN** triggers the LED. Actually it doesn't mean anything but considering the fact that the dc sig out in the rectifier is in mV scale and sufficient amplification can be given (say ~ 100) so that 16 mV r.m.s. can be easily detected corresponding to 100 mA of 3rd harmonic current in the neutral wire. In actual measurement 1.6 V rms signal at 150 Hz between Ground and Neutral causes about 7 mV (steady) DC output at Φ_{HN} (the noise is less than 0.1 mV with a time constant of 500 ms). Thus with a gain of 100 , the output will be 700 mV and 16 mV rms harmonic can be detectable. However it should be noted that the response of the precision rectifier deviates from linearity at very low value of signal. But the circuit can still be very well used as a limiter to indicate the crossing of the rms value of the harmonics above a certain allowable limit. A simple way to get rid of the non-linearity of the precision rectifier is to place a pre-amplifier (X10) immediately after the notch filter.
5. Voltage spikes: Voltage spikes are generated in the power supply network either from the source (at the sub-station transformer) or from switching reactive loads. These are manifested in the three phases and neutral points as spikes with respect to ground. As spike generation rarely occurs synchronously in all three phases, neutral point always reflects the spikes in the system. In our prototype the noise LED (Fig-3) gets triggered with 8 V, 1 ms pulse in the neutral. Implementation of the gain A (~100, Fig-3) will increase the sensitivity substantially. Normally a spike in the power line has bipolar characteristic and these are easily detected by the half-wave precision rectifier (Fig-5). For better performance regarding harmonics and spike detection a full wave precision rectifier can be used.

Cost-effectiveness: Now we come to the most significant point of this concept of 3-phase power monitoring and that is the incredible low cost of the device. In our prototype we have used a LM310 voltage follower with a 100 M ohm resistor (R2, Fig-2) which are not so cheap. This gives us a 100 M ohm isolation of the neutral to the ground. But considering the fact that the impedance between the neutral and ground is only a few ohms, a cheap voltage transformer (240 VAC to15 VAC , 1.5 W) will serve the purpose as well and still a large number of DBs can be connected with such sensor.

The embodiment of the present invention can be used as a stand-alone unit to monitor the unbalance in load, harmonics and noise in the power line. Coupled with a set of comparators and logic circuits (Fig-8) and actuator, it can safe guard and switch off a DB, if parameters cross safe limit, preventing fire and instrument damage.

It is very easy to implement power management with the sensor of the present invention. As the phase-locked outputs of the least loaded and most loaded phase are of opposite polarity it is easy to switch quanta of loads from the most loaded phase to the least loaded phase and thus ensuring efficient control of balanced load sharing with a conventional load-switcher. There are many concepts of load switching to restore balance in 3-phase power line. One possible method is to place quanta of ballast loads (Z_B) in the three phases through relay assemblies which will automatically switch Z_B of the most loaded phase to the least loaded phase when the Φ_I s will cross the safe limit. This is accomplished by a Max-Min Logic circuit (Fig-11) which will generate six control signals, $\Phi_I$max and $\Phi_I$min (I=1,2,3). At any time there will be only one max and one min line HIGH. As for example, in Fig-10 after 30 sec, $\Phi_1$max and $\Phi_2$min lines will be HIGH. Fig-12 depicts the relay assembly which connects Z_B s to all three phases.

For the R.A. connected to phase-1 the pin connections are given as follows:

Pin 1> Phase-1
Pin 2> Phase-2
Pin 3> Phase-3
Pin 4> $\Phi_3$min
Pin 5> $\Phi_2$min
Pin 6> $\Phi_1$max
Pin 7> Neutral point

Thus the R.A. pin connections for other phases are easily understood. It is to be noted that the $\Phi_I$max and $\Phi_I$min signals must be connected to the R.A.s via a six-bit latch which should be enabled only after a delay following the moment of crossing of the Φ_I values beyond the safe limit to avoid oscillation in the contacts. There should also be sufficient time delay between consecutive strobe of the latch. Conceptually it is possible to make set of ballast loads in the three phases which will be switched consecutively if the first switching does not retrieve the balance. Of course, the first priority loads or the un-interrupted supplies should not be considered as ballast loads.

The detail circuit of the automatic load switcher is depicted in Figure 13. The 6 bit control line data from the Max-Min Logic Circuit is fed to the three relay assemblies via a latch. The three Φ s are fed to three comparators and a OR gate activates when any of the Φ value exceed allowable safe unbalance (analogous to Figure 8). The capacitor C starts charging through R and after a set lapse time (say 10 min) set by another comparator circuit triggers a monostable (M.S. 2, positive edge triggered) to fire a strobe pulse (pulse width 100 ns) to the latch. Thus only if the excess unbalance condition stays for more than 10 min the ballast loads (Z_B) are switched between the phases. This results in reset of the OR gate output and the capacitor C is discharged by a transistor switch activated by the 10 ms pulse from a negative edge triggered monostable (M.S. 1). The circuit eliminates oscillation in the relay contacts. Any excess unbalance condition less than 10 min at a stretch will not cause any switching in the ballast loads.

A set of sensors connected to various DBs in a power distribution network can be easily fed to a base station equipped with a single channel 12 bit ADC and a computer. The input information (5 channels per DB) is de-multiplexed and after A/D conversion can be stored in the computer memory over a long period of time. Thus system troubleshooting will become much simpler. It is evident that the cost of such base station will be substantially cheaper than the present day technology. A typical circuit to convert the neutral referenced signals to ground referenced signals to be fed to the computer is shown in Fig-7. It uses opto-coupler chip and is self explanatory.

Thus it is evident that this technique, though cheap and simple, can provide a complete safeguard from imbalance, harmonics and spikes in a 4-wire 3-phase power line system. It overcomes the limitations of CTs and can be also implemented in very high voltage situations.

We claim

1. A 3-phase power distribution network sensor for monitoring minute load unbalance comprising

means for generating stabilized reference signals synchronized to the three phases of said power distribution network or power line and generating inverting neutral voltage with respect to ground;

involving said inverting neutral voltage with respect to ground and cooperatively activate means for determining one or more electronic attributes related to the neutral voltage and comparing the said attributes with their predefined set values to monitoring any minute load unbalance in the power distribution network or the power line.

2. A power distribution network sensor for monitoring minute load unbalance as claimed in claim 1 comprising

means for determining electronic attributes related to the neutral voltage and comparing the said attributes in comparator circuits with their predefined set values to interpret the neutral failure in the power distribution network or the power line.

3. A power distribution network sensor for monitoring minute load unbalance as claimed in anyone of claims 1 or 2 comprising:

phase sensisitve detection means for detection of phase components of said inverting neutral voltage with respect to ground and its amplification means;

means for precision rectification and generating information about neutral voltage w.r.t. Ground.

means for yielding the harmonics and noise content in the said Neutral voltage w.r.t. Ground and generation of floating signals; and

means for translation of thus obtained electronic attributes with reference to Neutral Point, into Ground-referenced signals to be processed by a central dedicated system; and comparator circuit means to actuate alarms if any of said comparable attribute value exceeds set value .

4. The system as claimed in claim 3, wherein means for determining electronic attributes related to the neutral voltage comprises one or from

precision rectifier and average module for yielding information about the root-mean-square (rms) neutral voltage with respect to the ground;

notch-filter followed by precision rectification and averaging module for measuring harmonics and noise content in the neutral voltage with respect to ground.

phase sensitive detection module for detecting the phase components of neutral voltage along the three supply phasors;

5. The system as claimed in claim 4, wherein said precision rectifier and average module operatively connected with said means for generating inverting neutral voltage adapted for yielding the information proportional to r.m.s. value of the neutral voltage phasor with respect to the ground.

6. The system as claimed in anyone of claims 4 to 5, wherein said notch-filter followed by precision rectification and averaging module operatively connected with said means for generating inverting neutral voltage is adapted to remove fundamental line frequency from inverting neutral voltage by involving said notch-filter and thereby detect the harmonics and noise content the neutral voltage by involving the precision rectification and averaging module.

7. The system as claimed in anyone of claims 4 to 6, wherein means for determining floating signals comprise three independent phase sensitive detection module for each of the supply phasors adapted to receive signal from the said notch-filter followed by precision rectification and averaging module through a diode limiter for measuring of the phase components of neutral voltage along the three supply phasors.

8. The system as claimed in anyone of claims 1 to 7, wherein said electronic attribute related to the neutral voltage includes the harmonics and noise content in the neutral voltage, the phase components of neutral voltage along the three supply phasors.

9. The system as claimed in anyone of claims 1 to 8, adapted to be disposed in electrical communication with logic circuit having OR gate with resettable latch for sensing load, harmonics and noise in the power distribution network or the power line and automatically tripping the power distribution network or the power line when the sensory parameters exceed a pre-defined safe limit.

10. The system as claimed in anyone of claims 1 to 9, comprises signal translator to transform the said neutral-referenced electrical attributes to ground-referenced signals for converting said signal into its digital equivalent and feeding to a centralized base station to store in memory for further analysis.

11. A three phase load switcher for switching quanta of loads from most loaded phase to least loaded phase and ensuring efficient control of balanced load sharing comprises

sensor system for sensing network parameters of 3-phase power distribution network or power line adapted for sensing the phase components of neutral voltage along the supply phase of the 3-phase power distribution network or power line involving a 3-phase power distribution network sensor for monitoring minute load unbalance as claimed in anyone of claims 1 to 10 ;

Max-Min Logic circuit for placing quanta of ballast loads in the three phases through relay assemblies and automatically switching said ballast loads from the most loaded phase to the least loaded phase when the said sensor system detects the phase components of neutral voltage along the supply phase exceeds a predefined set value;

wherein said relay assemblies are operatively connected with said Max-Min Logic circuit via latch circuit adapted for enabling said relay assemblies only after a delay following the moment of crossing of the phase components of neutral voltage along the supply phase beyond the predefined set value to avoid oscillation in the contacts.

12. A method for sensing and monitoring the network parameter by involving the system as claimed in anyone of claims 1 to 10 comprising

generating stabilized reference signals synchronized to the three phases of the 3-phase power distribution network or power line;

generating inverse of neutral voltage phasor with respect to ground with proper scaling;

detecting the components of the neutral voltage phasor along the three phases;

detecting the amplitude of neutral voltage;

triggering alarms if any of the components of the neutral voltage phasor value along the three phases exceeds pre-defined set value.

13. A method for automatically shutting down the power distribution network in case of malfunction comprising:

involving 3-phase power distribution network sensor for monitoring minute load unbalance as claimed in anyone of claims 1 to 10;

comparing the electronic attribute related to the neutral voltage with safe limit values in said comparators;

feeding the comparator outputs to a multiple input OR gate with resettable Latch to drive a circuit breaker for automatically tripping or shitting the power distribution network.

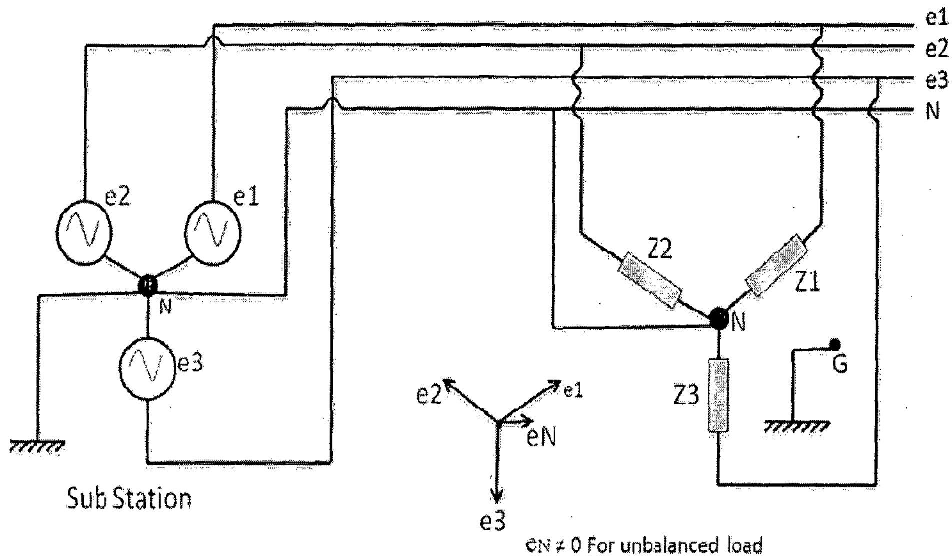

Figure 1

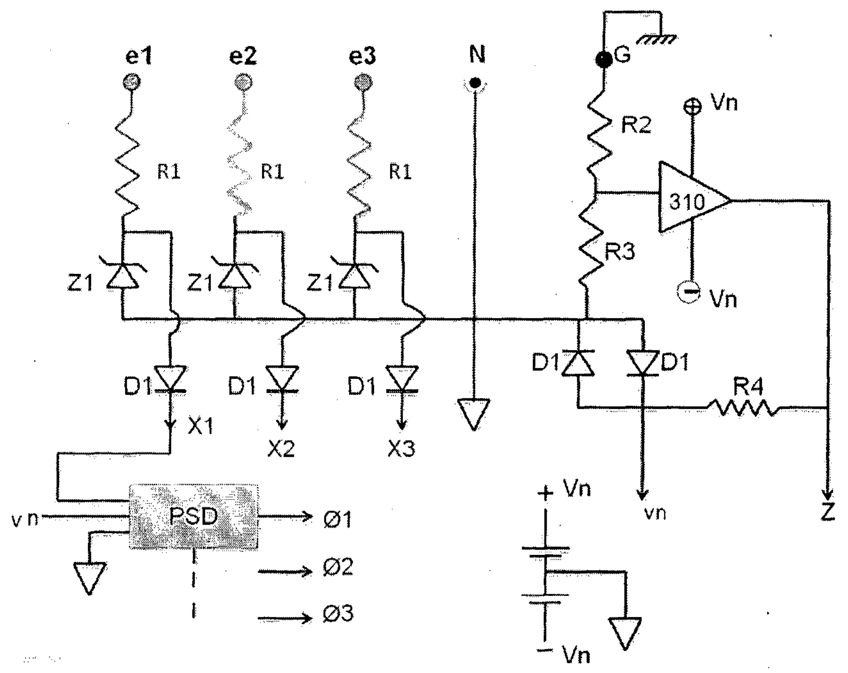

Figure 2

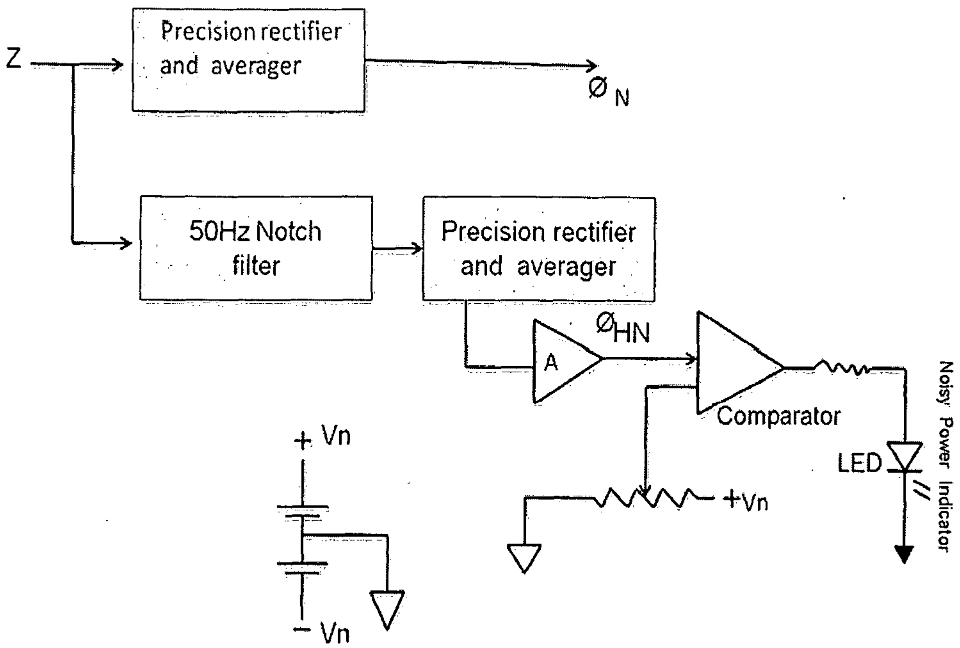

Figure 3

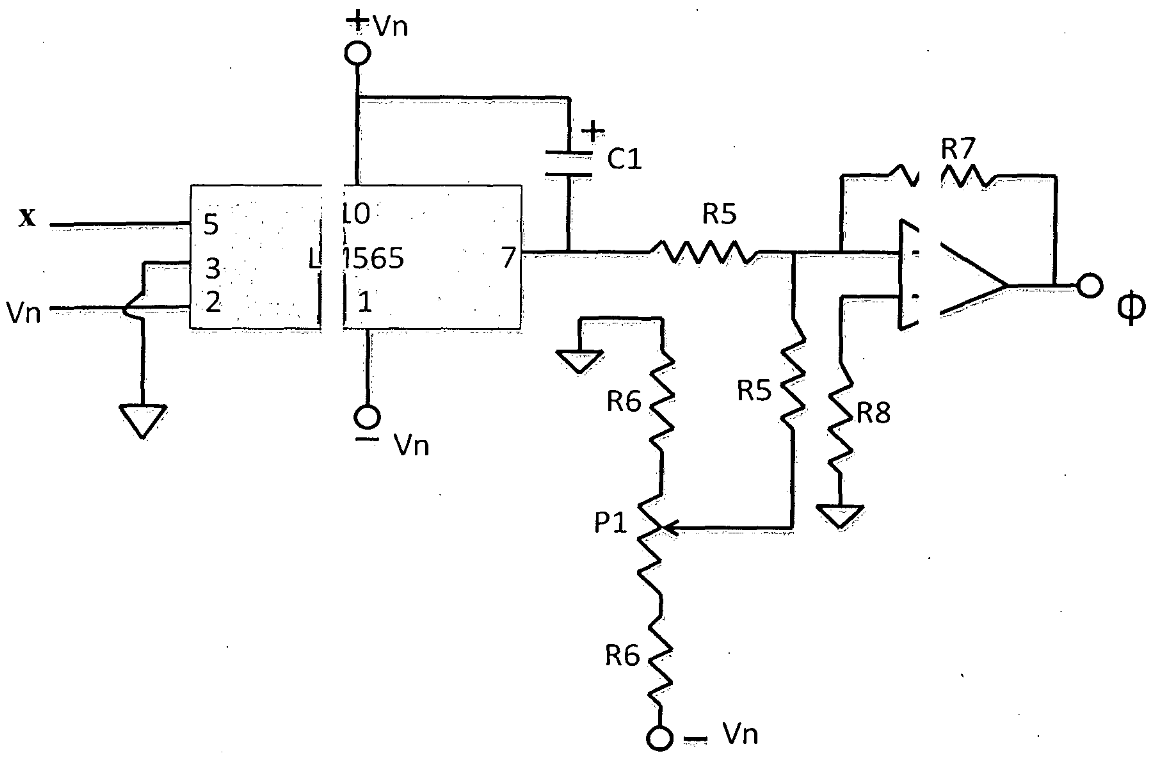

Figure 4

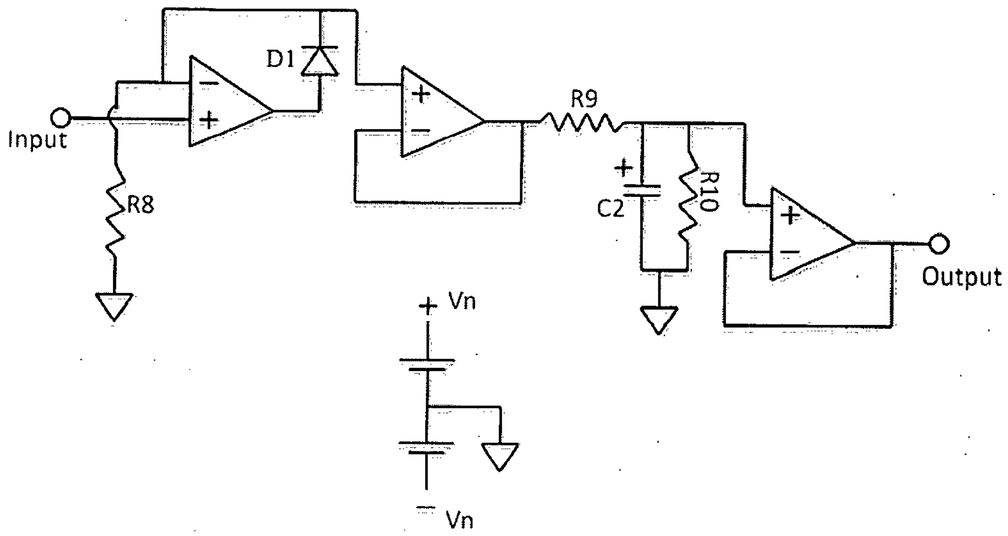

Figure 5

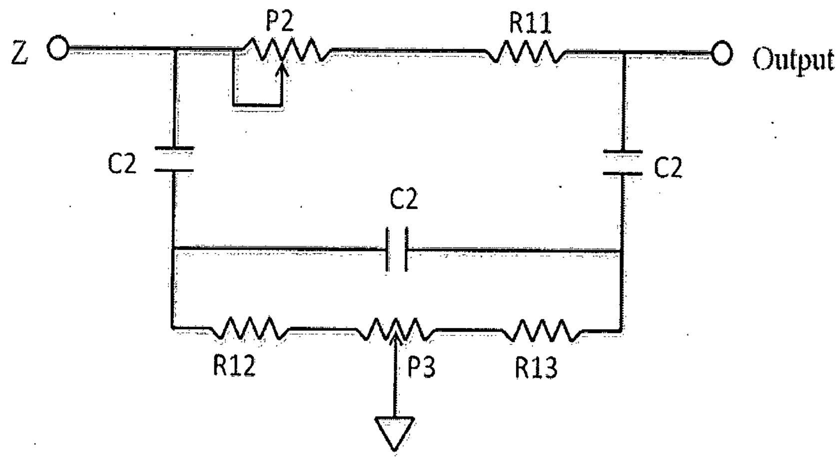

Figure 6

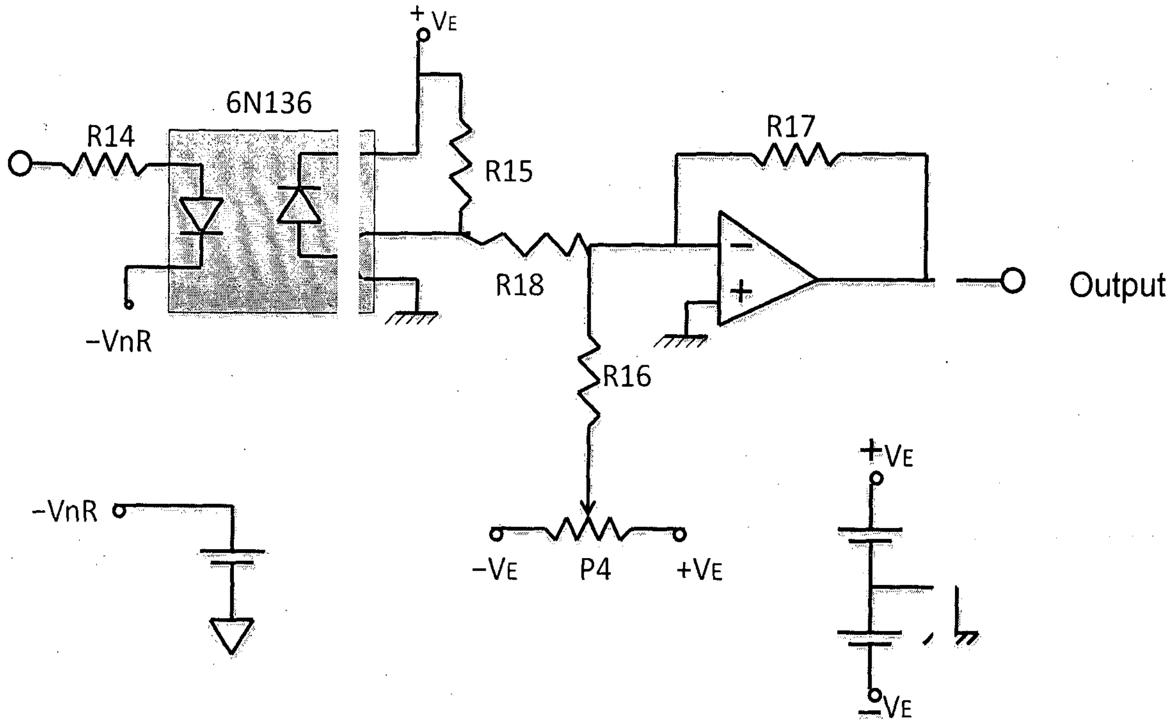

Figure 7

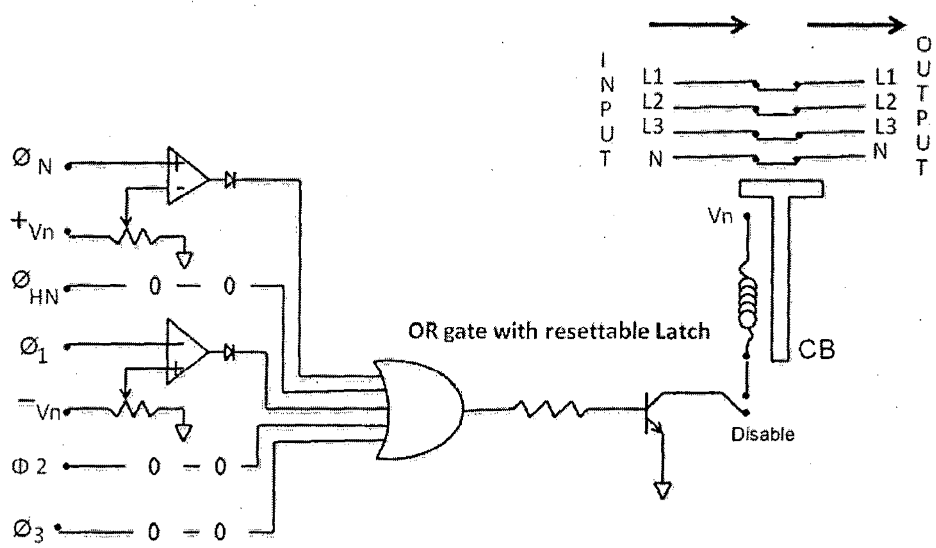

Figure 8

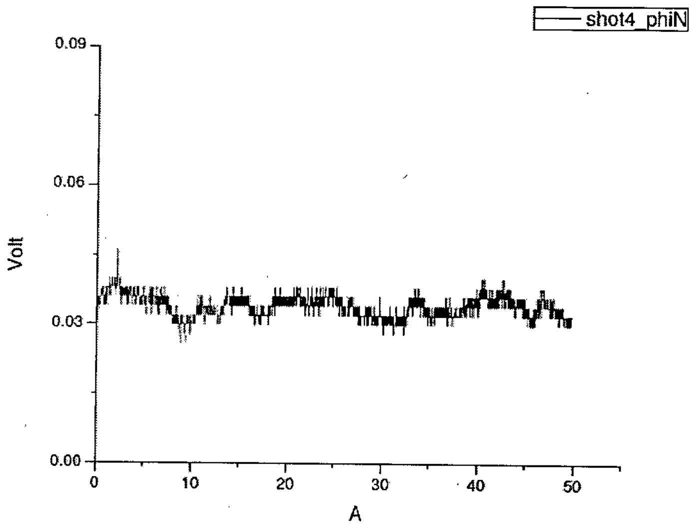

Figure 9

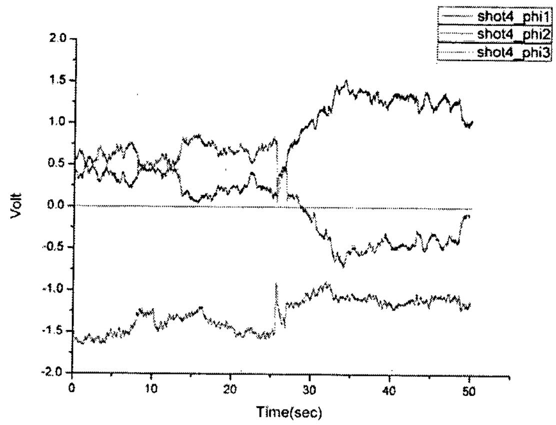

Figure 10

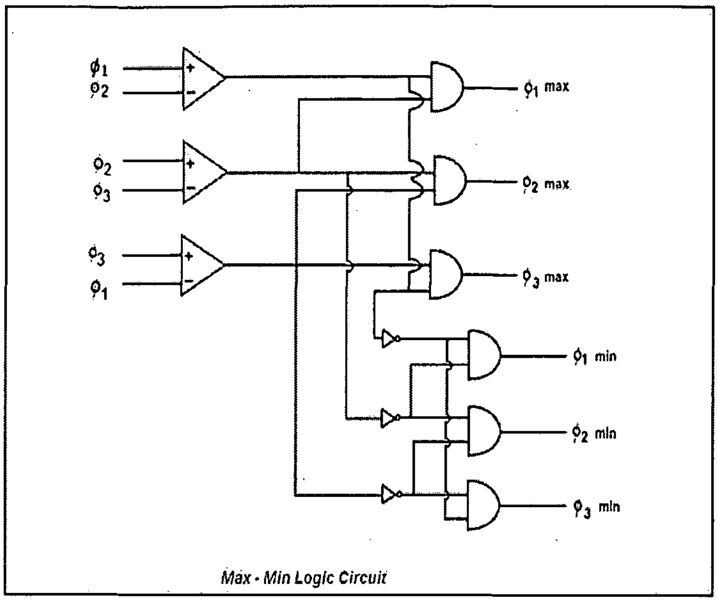

Figure 11

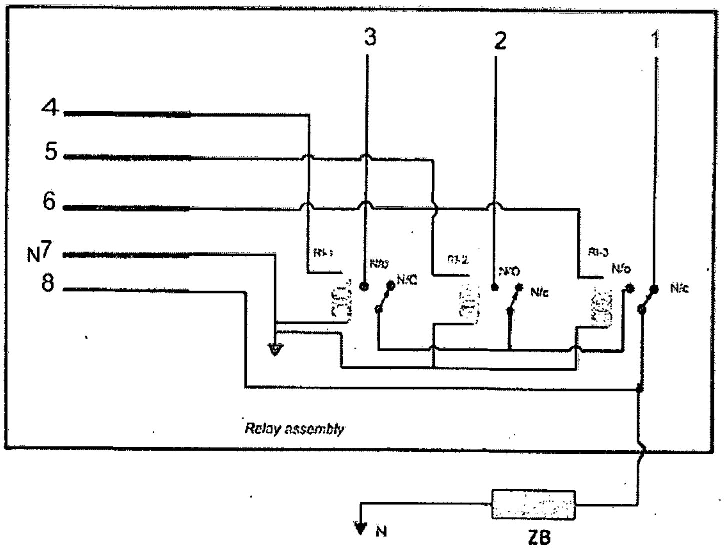

Figure 12

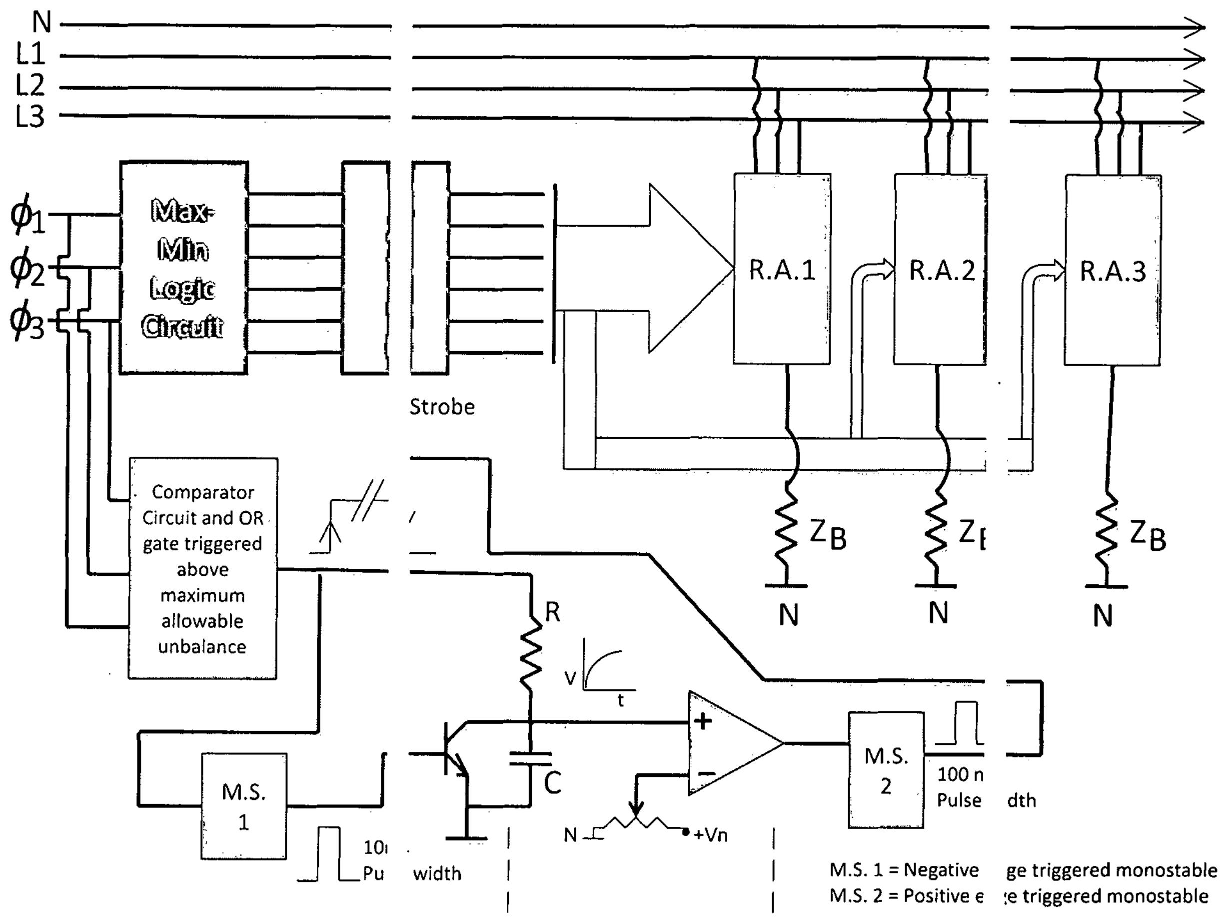
N
L1
L2
L3
ϕ1
ϕ2
ϕ3
Max-Min Logic Circuit
Strobe
R.A.1
R.A.2
R.A.3
ZB
N
Comparator Circuit and OR gate triggered above maximum allowable unbalance
R
V
t
C
M.S. 1
M.S. 2
N
+Vn
100 n
Pulse
dth
width
M.S. 1 = Negative ge triggered monostable
M.S. 2 = Positive e ;e triggered monostable

Figure 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2014/000335

A. CLASSIFICATION OF SUBJECT MATTER
H02J013/00,H02M001/12,G01R031/02 Version=2014.01

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02J,H02M,G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DATABASES: QUESTEL ,IPO INTERNAL DATABASE
SEARCH TERMS: POWER DISTRIBUTION,LOAD UNBALANCE,HARMONICS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005094336(CLEVELAND ANDREW J)05 MAY 2005(2005-05-05) PARAGRAPHS 0008,0014-0018,0031-0032,0035-0036,ABSTRACT	1-12
Y	US 5182547(GRIFFITH DAVID C)26 JANUARY 1993 (1993-01-26) PAGE 1, (PAGE 2-LINES 55-65),(PAGE 3 - LINES 25-35), (PAGE 4 - LINES 20-40), (PAGE 5 - LINES 5-20),ABSTRACT,CLAIMS 1-5	1-12
Y	US 20110130992(KOLWALKAR AMOL RAJARAM, et al)02 june 2011 (2011-06-02) PARAGRAPHS 0002-0003,0009-0010	1-12
Y	US 6577478 (KIM CHEON-YOUN etal) 28 February 2002 (2002-02-28) PARAGRAPHS 0028-0031,0049,ABSTRACT	13
Y	US 4945304(Paul Feron) 31 JULY 1990 (1990-07-21) PAGE 1-LINES 5-10, PAGE 2 -LINES 25-40, PAGE -4-5,CLAIMS 1-5, ABSTRACT	13

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30-09-2014	30-09-2014

Name and mailing address of the ISA/	Authorized officer
Indian Patent Office Plot No.32, Sector 14,Dwarka,New Delhi-110075 Facsimile No.	Sandeep Kumar Telephone No. +91-1125300200

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IN2014/000335

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Invention 1 (Claims 1-12)

A 3-phase power distribution network sensor for monitoring minute load unbalance

Invention 2 (Claim 13)

Automatically shutting down power distribution network in case of malfunction

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IN2014/000335

Citation	Pub.Date	Family	Pub.Date
US 2005094336 A1	05-05-2005	US 2005093376 A1	05-05-2005
		US 7368830 B2	06-05-2008
US 20110130992 A1	02-06-2011	EP 2330430 A1	08-06-2011
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US 4945304 A	31-07-1990	EP 0354841 A1	14-02-1990
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