Embedded System Based Multi-Source Leakage Current Protection for Low and Medium Voltage Applications

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Abstract - *Now a day, battery Inverters and diesel generators are most commonly used backup source in almost every residential and commercial building. The backup inverters are connected between source and load to protecting sensitive loads against incoming supply disturbance like voltage dips. This system may be cost effective solution for protection of highly sensitive loads. If the main supply fails, the inverters are automatically turned ON and thus maintaining the supply in the system. The inverter circuits are provided with protection such as protection from over current, over voltage etc. in order to protect the inverter circuit, but there is no leakage protection. RCCB which is connected to the mains is the commonly used protective device to protect the humans from hazardous shock occurring due to leakage current or other unhealthy conditions occurs in the system. Even these protective devices are available, there exist a problem that is, if a short circuit or any other unhealthy conditions occurs in the system after supply fails and inverter is in action, the user who comes in contact with the circuit can get hazardous shock because the RCCB fails to do its duty. This project aims at developing such an RCCB which will comes into an action even if any fault occurs in the system after main supply fails and backup inverter is in action. A micro controller based residual current circuit breaker is proposed here which can detect any fault in any condition. The proposed hardware architecture and sensors form a low-cost and reliable control unit.*

1. INTRODUCTION

DC/AC power converters (inverters) are used today mainly in uninterruptible power supply systems, AC motor drives, induction heating and renewable energy source systems. Their function is to convert a DC input voltage to an AC output voltage of desired amplitude and frequency. The inverter specifications are the input and output voltage range, the output voltage frequency and the maximum output power. An inverter is required to always operate within its strict specifications, since the inverter may supply power to sensitive and expensive equipment, fail-safely in case of malfunction, since inverters are often used in harsh environments to electronics, for example, outdoors in case of renewable energy applications with wide temperature and humidity variations and record the inverter state and inform the supplied equipment and/or the operator about the cause of failure. As we know that a short circuit in an electrical circuit allows a current to travel along an unintended path with no or very low electrical impedance. This results in an excessive amount of current flowing into the circuit. Short circuit is the one of the major problem that leads to damage of equipment and potential injury for person who is in contact with the equipment. Inverters are the most commonly used backup source. These inverters are provided with over current, over voltage protection.

Considering the inverter protection, the designers usually employ special protection devices and control circuits. The most common form of over current protection is fusing [1], but this method is not always effective because fuses have relatively slow response-time, so additional protective equipment is required, such as crowbar circuits or a di/dt limiting inductance. The DC supply and load-side transients can be suppressed with filters, which have the disadvantage of increasing the inverter power losses, cost and weight.

Current source inverters (CSI) have an inherent over current protection capability, since proper design of the DC link inductance can provide protection against overload conditions [2]. Voltage source inverters (VSI) include an LC filter at the output stage thus, in case of an output short circuit condition; the filter inductance limits the output current rising rate [3]. In both preceding cases, the high inductance value leads to inverter size and power losses increase.

In motor drive applications, the inverters are usually protected only from overloading conditions, using either intrusive current sensing techniques, which measure the DC input current or the load current [5–7] or special motor control algorithm techniques [8–10]. However, the above methods do not fully detect all possible fault conditions, e.g. a DC link capacitor short circuit [11].

The advance of the microcontroller technology has led to the implementation of digital control techniques for controlling and monitoring inverters. The use of a Kalman filter for monitoring the magnitude and frequency of a UPS output voltage is proposed in Ref. [12]. Although this method has the advantage of integration of a number of control functions in a single chip, it is not adequate for protection of the inverter from many kinds of faults. If this method is extended to monitor more critical signals, then the system response becomes not fast enough to protect the inverter, while the use of a faster microcontroller or a digital signal processor (DSP) increases the system cost.
Still these protections are provided with the equipment the chance of getting shock to the person whose come in contact with the faulty system when main supply fails and back up is in action is very high. RCCB which is a commonly used protective device to protect the humans from hazardous shock occurring due to leakage current or if any other fault conditions occurs in the system. Now the situation changes and arise a question that what happens to the person who comes in contact with the unhealthy supply system even after supply fails and inverter is in action and RCCB fails to do its duty. This situation is a bitter one and in order to solve the above stated situation, a micro controller based Residual Current Circuit Breaker that comes into action if any fault occurs after the main supply fails and inverter is in action is proposed. This RCCB is able to detect faults under any condition and works properly and thus saves the life of person who comes in contact with unhealthy system.

2 CONVENTIONAL LEAKAGE PROTECTION DEVICES

2.1 Earth Leakage Circuit Breaker

ELCB is a molded case circuit breaker used in a low-voltage AC electrical circuit to provide electric shock protection and prevent fires from current leakages. ELCB is called a "Circuit-breaker incorporating residual current protection" (IEC60947-2) or a "Residual current operated circuit breaker" (IEC61009-1). It is also referred to as a "Ground-fault circuit-interrupter" (UL943). Fig.1 shows the model of a market available ELCB.
There are two types of ELCB, a current-operated type and a voltage operated type. In terms of ELCB structure, the product is defined as a "device with integrated ground fault detector, tripping device and switch mechanism in an insulated body, and automatically shuts off the electric current in the event of a ground fault". The low-voltage electrical circuit is originally a non-grounding circuit. However, after it became possible to use an alternating current to reduce a high-voltage to a low voltage with a transformer, the risk of contact of high and low voltages and the risk of double ground faults increased. Subsequently, the use of grounded systems became main stream. Of course, there are still some non-grounding circuits, but most are grounded circuits. In Japan and the United States, priority has been placed on preventing fires from ground faults. Most protective grounding systems reduce the voltage and ground the device frame. Conversely in Europe, 220 V voltage systems are used in homes, so there has been an interest in ELCB from an early stage. The initial ELCB was a voltage-operated type, and the protection range was small there were many disadvantages in the use, etc. Today, most units adopt the current operating type.

Awareness toward electric shock injuries and short-circuit fires has increased in view of saving human life and assets. In addition, places requiring installation of ELCB has increased for legal reasons. Conventionally, electric shocks were prevented only with protective grounding work. While this was effective, it was found to be insufficient when stricter conditions were considered.

Generally, fires caused by electrical leaks occur when the insulation sheath of the wire is damaged, and the electricity flows through the structure's metal body resulting in heating or spark discharge. In residential homes, it is essential to provide protection against earth leakage accidents caused when the metal truss contacts a stable or when the wire sheath is damaged in an earthquake, etc. If the ground fault occur is small, the risk of fires is small. However, if not repaired, the fault could develop and cause a fire. The size of the ground fault current that causes a fire differs according to various conditions, but is said to be several Amperes.

The earth leakage alarm method is effective if it is in the constant monitor state. However, when using the protective grounding method or insulating transformer method, the ground fault current cannot be detected, and thus sufficient protection against earth leakage fires cannot be anticipated.

Another type of hazard is arc accidents. There are many cases of arc accidents in load centers, distribution panels, bus wires, control centers and cables that resulted in serious damage. Arc ground fault accidents cannot be prevented with just an over current breaker. In other words, the arc short-circuit limits the short-circuit current with the arc resistor and prevents the over current protector from functioning or taking a long time to function. Even in indirect arc accidents, there are cases when the over current breaker does not function even through the damage is sequentially increases. Thus, an arc accident protection device is required in addition to the over current breaker. The arc ground fault current can extend over the range of several Amperes to several 1000A, so protection using the earth leakage breaker method is the most appropriate.

While the operations of ELCB caused by the intended faults, such as earth leakage, electric shock and ground fault, are considered to be normal operations, the operations caused by other factors, such as surge and induction, are unnecessary operations (nuisance operations or nuisance trips).

When the current sensitivity of ELCB is too high for the normal leakage current of a circuit, ELCB operates unnecessarily. This trouble is caused by improper selection of current sensitivity. In most cases, circuit leakage current is caused by earth floating capacitance of electric wire. However, some electric furnaces and sheathed heaters decrease in insulation resistance at high temperatures although they have sufficient insulation resistance at low temperatures, and it may take time to reveal the cause of the operation. In addition to the leakage current in the steady state, the transient leakage current at the switching or start may activate ELCB. The transient leakage at the start is caused through the capacitance to the winding frame because the potential distribution on the winding at the start differs from that during operation.

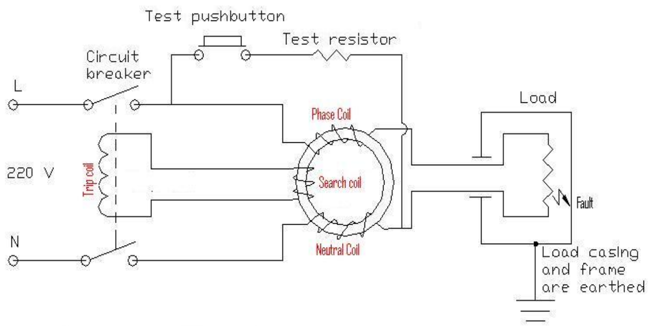

Fig.1. Circuit diagram of ELCB

2.2 Residual Current Circuit Breaker

A Residual Current Circuit Breakers is another different class of circuit breakers. A Residual Current Circuit Breaker (RCCB) is essentially a current sensing device used to protect a low voltage circuit in case of a fault. It contains a switch device that switches off whenever a fault occurs in the connected circuit. Residual Current Circuit Breakers are aimed at protecting an individual from the risks of electrical shocks, electrocution and fires that are caused due to faulty wiring or earth faults. RCCB is particularly useful in situations where there is a sudden earth fault occurring in the circuit.

For example, a person accidentally comes in contact with an open live wire in the circuit. In such situation, in absence of an RCCB in the circuit, an earth fault may occur and the person is at the risk of receiving an electrical shock. However, if the same circuit is protected with RCCB, it will trip the circuit in fraction of a second thus preventing the person from receiving an electrical shock. Therefore, it is a good and safe practice to install RCCB in an electrical circuit.

As explained above, RCCB is meant for protection from earth faults and associated risk to human life such as electrical shocks. The underlying fundamental principle behind operation of RCCB is that in ideal situations the current flowing in to the circuit through live (hot) wire should be same as the returning current from the neutral. In case of an earth fault, the current finds a passage to earth through accidental means (such as accidental contact with an open wire etc.). As a result the returning current from neutral is reduced. This differential in the current is also known as “Residual Current”. RCCB is designed such way that it continuously senses and compares for difference (residual current value) in current values between the live and neutral wires. Any small change in the current value on account of such event would trigger the RCCB to trip off the circuit.

There are two types of RCCB available in the market. One is the 2 pole RCCB which is used in case of a single phase supply that involves only a live and neutral wire. It is as displayed in fig.2. It contains two ends where the live and neutral wires are connected. A Rotary switch is used to switch the RCCB back to ON or OFF positions. A test button helps to periodically test the RCCB functionality. The other one is 4 pole RCCB which is used in cases of a three phase supply connection involving three phase wires and a neutral. It is as displayed in figure 4. It consists of two ends where the three phases and neutral wire are connected. Besides this it is similar in construction and operation as 2 Pole RCCB.

As per studies, a person is able to sustain electrical shocks only to the magnitude of 30 mA. Thus, RCCBs in low voltage protection are designed such a way that they will trip off the circuit even for small change in residual current value of up to 30 mA. The response time is usually within 40ms, thus ensuring that the person is fully protected from electrical shocks at all times. Higher values of 300mA are used in cases where a protection from fire hazard is sought. This is useful in places where a lot of flammable material is stored.

Residual current operated circuit-breakers normally have an instantaneous release. This means that a series connection of such residual current operated circuit-breakers with the aim to provide selective tripping will not operate correctly when a fault occurs. To achieve selectivity when RCCBs are connected in series, the devices connected in series must be graded both with regard to the release time as well as with regard to the rated fault current. Selective RCCBs have a tripping delay.

Thus RCCB is an essential protective device in your electrical circuit that helps to prevent electrical hazards in cases of earth faults. A properly set RCCB will ensure that there is no fatal injury caused to human being in case of an accidental touch to live wires.

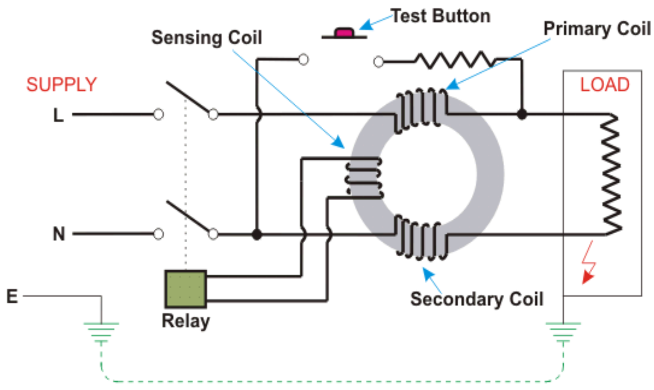

Fig. 2. Circuit diagram of RCCB

comes into action when main supply fails due to unhealthy situation. At that time this section measures the current for inverter side load only.

If a fault occurs in the main supply this module isolates the unhealthy system and trips the inverter output too at the same time, thereby reducing the chances of occurrence of fault in the inverter load side and thus protects the contact person from hazardous shock. Also in this work an over current and leakage current protections are provided. For these protections current sensors are provided which works under the control of a microcontroller. Both main and backup sources are provided with these sensors. They measure the current in phase and neutral side at the same time. If the measured current differs by 30mA suddenly all the relays comes into action and isolates the unhealthy system and thus saves the life of the person who comes in contact with the faulty backup system or supply system when backup is active or inactive respectively.

3 PROPOSED METHOD

In an ordinary residential wiring, the neutral conductor is provided in looped manner to use for both main and backup supply. In this case, ELCB/RCCB works properly for main supply faulty conditions but its fails to do its work for the case such as if an unhealthy condition occurs when the backup source is in action. It is not advisable to use the present market available ELCBs/RCCBs separately for both main and backup sources, since the return current varies because of the common looped neutral wiring and due to this unwanted tripping occurs. Fig.3 represents the block diagram of the proposed system.

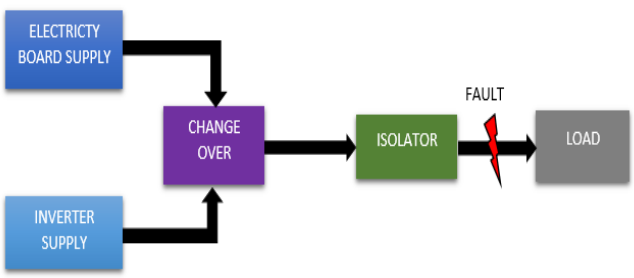

Fig.3. Block diagram of Proposed Method

In this work, a protective module is used which consists of two sections, both works similar to the RCCBs/ELCBs. One of the section is used for the measurement of current for whole system like power load, inverter load etc. in normal healthy condition of the system. The other section which

4 EXPERIMENTAL RESULT

The hardware is implemented and is tested with the normal single phase supply voltage and an artificial fault is provided to the main and backup source respectively. When the system is tested with normal market available ELCB/RCCB with an artificial fault in the main source, the ELCB trips and isolate the unhealthy system which indicates the proper working of ELCB/RCCB. But when artificial faults is given to both main and backup sources, the ELCB/RCCB trips and isolate only the main source and the person comes in contact with inverter output load gets mere shock.

Later the protective device is replaced with the proposed protective module and the same fault condition is applied to both sources. It can be seen that the proposed protective module trips both main source and inverter output at the same time and thus keeps the inverter load current to zero. Thus it saves the contact person life during a fault occurrence in both main and backup source at the same time.

5 CONCLUSION

A low-cost, real-time control unit has been developed, which can effectively protect and monitor a DC/AC converter (inverter) as well as the supply system. The system is designed to assure that the inverter output voltage drops to zero (fail-safely) in case of improper operation such as fault occurrence. The system design is based on a high performance microcontroller. The proposed system can be incorporated with any load system in the residential buildings. The system monitors the current in each and every time and trips the system wholly when unhealthy condition occurs in the system. Thereby saving the life the person comes in contact with the main system or backup system. Also the proposed system is highly reliable and cost effective method of protection than the other type protective devices available in the market

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