

Micro Grid Architecture for Line Fault Detection and Isolation

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Abstract: One of the major problems power grids system face today is the inability to continuously deliver power at the consumer side. The main reason for this is the occurrence of faults and its long term persistence within the system. This persistence of faults causes the cascading failure of the system, thereby adversely affecting the connected loads. Traditional methods of fault isolation cause the shutdown of power to a large area to maintain the system stability. Today, localization of faults and its isolation is done manually. Therefore, a localized fault recovery mechanism is very essential to maintain the system's stability after the occurrence of a fault. In this paper, we have developed fast fault detection and isolation mechanism for single phase to neutral line fault in a three phase islanded micro grid scenario. The fault detection and isolation during the islanded operation mode of a micro grid is very critical, since bidirectional power flow is present. The fault detection mechanism we developed can detect and isolate the fault within a few milliseconds and localize the fault within a two second delay for both in single and bi-directional power flow scenarios. The proposed system is capable of locating the exact faulted segment with the aid of the communication network integrated into the power grid. The implemented system was tested with different ranges of fault current and the analysis showed that the proposed system could localize the fault with less than a two second delay.

1 INTRODUCTION

The frequency of fault occurrence of the secondary distribution grid as compared to the primary side is considerably high. Most of the faults in a power system results in a huge variation of electrical parameters which will badly affect the operation of the loads. In today's distribution grid, whenever a fault occurs in any part of the distribution grid, that fault should be isolated from the distribution transformer. This condition causes a long term power cut in majority of the grid.

A micro grid is a small scale distribution network, which is designed to provide power for a local community. Whenever an abnormal condition occurs in the main grid, the micro grid can work in island mode. During the islanded mode of operation, power sharing is present within the micro grid. The power flow within the network is bidirectional, which is based on the power demand. In order to develop a fault detection mechanism in an island micro grid scenario, the direction of power flow should also be known.

In this paper, we proposed a three phase micro grid system. This micro grid system includes smart

homes, which can act like a power supplier as well as a consumer, and intelligent modules which are present at each distribution pole. Most of the fault detection and isolation mechanisms, which had proposed previously in other works for a micro grid system, were mainly in DC system. In most of the previous work, fault detection and isolation mechanism for micro grid system has done in the DC system. Furthermore, most of the works used ring type architecture for this DC micro grid system. In this paper, we considered the AC micro grid system with radial architecture. By considering this system, we developed and implemented an automatic fault detection, isolation and fast fault localization mechanism.

The rest of the paper is structured as follows: Section 2 presents the related works, section 3 explains the proposed system architecture, section 4 gives the fault detection and isolation method, section 5 gives the fault localization method, section 6 gives the hardware design, section 7 gives the hardware implementation, section 8 gives the experimentation and analysis and section 9 gives the conclusion.

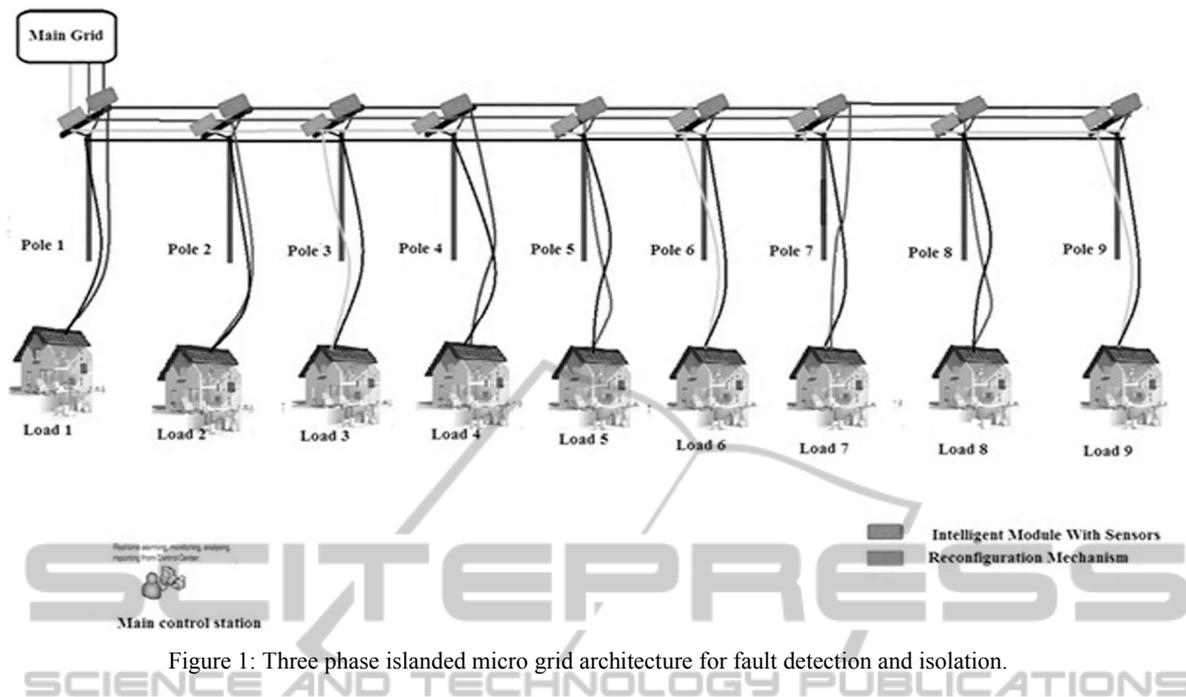


Figure 1: Three phase islanded micro grid architecture for fault detection and isolation.

2 RELATED WORK

A fault protection and isolation scheme for a DC micro grid system was proposed in (Jae-Do and Jared, 2013). In this scheme, the authors used the current sensor to detect and isolate the fault with the help of a master and slave controller, which is associated with every segment of this loop type micro grid system. But in the island mode of operation, the protection schemes for the micro grid system may be entirely different from the traditional protection scheme since bidirectional power flow is present. Different types of fault which occur at three phase distribution system were compared in (Cheraghi and Goodarz, 2011). The simulation depicted that the magnitude of the fault current varies widely for different types of fault in a three phase system. In order to develop a protection scheme for this system, knowledge about this huge fault current was vital. An overview of the existing protection schemes for the micro grid was given in (Buigues, 2013). The protection scheme for a micro grid should be tolerable to the dynamic topological change due to changes in the connection and disconnection of generators, load centres, storage system and other switches.

A fault current detection method by analyzing the current conditions at different relay locations did in (Sanaye-Pasand and Khorashadi-Zadeh, 2003).

Whenever a fault occurs at the transmission line, the current at each the relay location was subject to change. The principle of variation of the current sensor before and after the fault incidence was used for fault detection and its classification in this work.

An over current protection for a micro grid system with the help IED has been proposed in (Voima, Kauhaniemi and Laaksonen, 2011). According to them, a new over current protection scheme is needed for a micro grid system when it is operating islanded mode since the change in the operating condition from grid connected mode to islanded mode causes a drastic change in the distribution network parameters. Detection of a fault is done in this paper with the help of the telecommunication communication system in association with IEDs.

An approach of using wireless sensor networks to power grid monitoring was given in (Fateh, Govindarasu and Ajjarapu, 2013). According to this paper, even though the bandwidth and latency was the main bottlenecks for using wireless sensor networks in a smart grid scenario, proper design of the network could make wireless sensor networks the best solution for power grid monitoring. The authors used a hierarchical wireless sensor network in this paper. Different communication technologies and its requirements which are applicable in a smart grid scenario were addressed in (Fateh, Govindarasu and Ajjarapu, 2013).

Analysis of different communication technologies gave in this paper with different communication requirements like latency, reliability, frequency and security. Study of wireless sensor network for smart grid monitoring application gave in (Gungor and Hancke, 2010). The authors did an experimental study of WSN at different power grid scenario and found that it can meet most of the communication requirements needed for smart grid communication.

3 MICROGRID ARCHITECTURE FOR FAULT DETECTION AND ISOLATION

In this work we considered a three phase micro grid, which operates in islanded mode. Each smart home in this system had the capability to generate power from a renewable energy resource and stored it. In order to maintained the system self sustaining, the extra power generated within the system could share among the load centres according to the power demand. This sharing of power between the loads was vital since the micro grid was not connected to the regular power grid source. The system architecture of the proposed system is given in Figure1.

In the figure 1, the micro grid has nine distribution poles named as Pole 1, Pole 2 ... Pole 9 and each distribution pole is connected to each smart home. In this work we considered only single phase loads which were equally distributed along three phases. We assumed that every load had a renewable energy source and it will act both as a load and generator. The extra power produced can also be stored. The smart meter which was present at each smart home can continuously monitor the bidirectional power flows into the home as well as away from the home. Since a three phase distribution grid was considered in this work, the distribution pole will have three power lines. In order to monitor the three phase lines, we needed to use three intelligent modules at each distribution pole. If we have only had one intelligent module to monitor the three phase lines, failure of this intelligent module could cause the three phase lines unobservable. Thus, intelligent modules for each phase line would improve the robustness of the system. At each distribution pole, the breakers associated with an intelligent module. A control station associated with the micro grid to control and take decision according to data of the system.

4 FAULT DETECTION AND ISOLATION METHOD

Power sharing is one of the key features of the proposed micro grid system. Faults which may occur in this three phase micro grid could cause the system to unbalance and prevent the power sharing. Therefore, a fault detection and isolation mechanism is very essential for the continuous operation of the system. In this work, only the single line to neutral fault was considered since 95 % of the fault occurs within a three phase system was this type of fault.

Each distribution pole was associated with three intelligent modules for each phase line. Each intelligent device was connected to a current sensor, voltage sensor, circuit breaker, communication module and a micro controller unit. These sensors along with circuit breakers and communication modules were connected to the micro controller. The block diagram of an intelligent device is shown in Figure 2. Current sensors and voltage sensors continuously monitored the current and voltage condition at each phase line. The processor unit at each intelligent device continuously checked whether the current values exceeded the allowable lower and upper threshold limit. If the current sensor value had exceeded the threshold limits, the circuit breaker present at that phase line opened the circuit.

5 FAULT LOCALIZATION METHOD

After the fault detection and isolation the intelligent device continuously sent the sensed current value to its neighbouring distribution pole's intelligent device. Whenever an intelligent device received a message from its neighbour, it compared the received value with its own sensed value. Each intelligent device took one of the two decisions after this comparison.

- a. If the difference in current values of the adjacent intelligent module was not a high value, then no fault occurred between the two poles and the status of the breaker was closed condition.
- b. If the difference in current values of the adjacent intelligent module was a high value then a fault occurred between the two poles and it opened the breaker associated with that phase line.

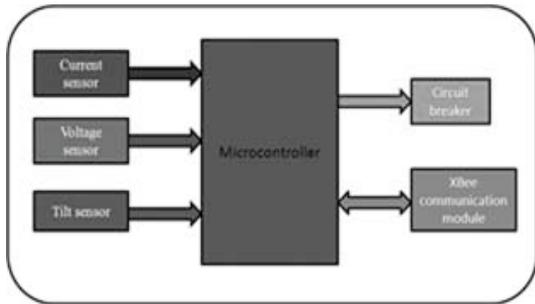


Figure 2: Block diagram of intelligent device.

Thus the breaker associated with the exact fault location opened and the other breaker remained in the closed. This helped to exactly locate the fault within this islanded micro grid. The main advantage of this localized fault isolation was that it avoids the entire system shut down during faulted condition. Besides, the other part of the distribution grid remained in stable condition.

After localization of fault, the intelligent module sent the information about fault location and the new status of breaker condition to the control station. The fault detection and isolation resulted in the formation of two nano grids. These two nano grids could be a power demanded region or power balanced region. To change the power demanded region to a power balanced region, the power re-routing mechanisms could be introduced in future.

6 HARDWARE DESIGN

Fault detection and isolation had an important role for maintain the stability of the proposed micro grid system. A segment of the proposed micro grid system with automatic fault detection and isolation mechanism in a single phase system was implemented in our laboratory. In this work, two intelligent modules which were to be present at each distribution pole have developed. Hardware architecture of an intelligent module gave in Figure 3.

Whenever a fault occurred, the current and voltage value changed. Therefore, in our system we used these parameters to determine the fault condition. Even though the fault was detected from the current value, we also monitored the change in voltage in our system. According to (Rebekah Hren Brian, 2011) the voltage drop for feeders should not exceed 2% and the voltage drop for branch circuit should not exceed 3%, for efficient operation. In our system, the voltage was continuously monitored to ensure its variation has limited in this range.

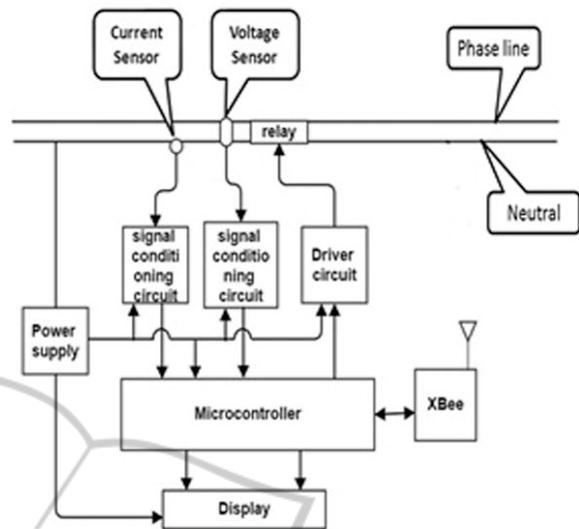


Figure 3: Hardware architecture of an intelligent module.

Since the short circuit current due to single phase to neutral line fault was very high, we have generated a scaled down version of this high fault current in this system to ensure the safety. The current sensor used to monitor the over current should have had the capability to tolerate our scaled down version of over current. The current sensor with good resolution would have increased the accuracy of measurement. A transformer, which can provide good isolation was calibrated in the voltage range of 44V to 240V and used as a voltage sensor in this system since the RMS voltage used was 240V. Consider figure 3. A signal conditioning circuit was used in association with these sensors to manipulate the sensor output in such a way that it met the requirements for the next stage for future processing. Since the output voltage range of the current sensor was very small, we needed to amplify this voltage to a range which could be easily detectable by the micro controller. For that we used a signal condition circuit with the selected current sensor. This would also improve the resolution of the sensor. Since the output voltage of the current sensor was in an AC voltage range of 0-6V, we needed to manipulate the signal in such a way that it could be given to the micro controller unit. We needed a micro controller unit of ADC resolution of atleast 10 bit with good operating speed. We selected PIC as our micro controller unit since its ADC can provide required resolution and have a wide operating voltage range of 2V to 5.5V. Besides, it had a program memory of 8Kbytes and data memory of 368bytes and had a good operating range of 20 MHz.

In the hardware implementation, we used relay module for fault isolation. The relay module needed

for our system should have good ampere range so that it could be controlled easily. In this system we selected a relay with 30A current range with an operation voltage of 12V DC. A communication module was needed to implement the localization of fault. The intelligent module was present at every distribution pole and the distance between these distributions poles were 40-60 meter. Therefore, our communication module should have had a communication range greater than this distance and should have operated in unlicensed frequency band. In order to power up the entire module from the main supply, a step down transformer was needed. Since the circuits in this intelligent module needed a voltage of 0- 5V, we used a step down transformer of 230 V to 6V and then the required voltage was taken through regulators.

Each intelligent module had a current sensor and a voltage sensor. These sensors continuously monitored the current and the voltage condition of the power line. The sensors were connected to the micro controller unit through a signal conditioning circuit. There was a circuit breaker connected with the power line which helped to isolate the line when anomalous conditions occurred. Operation of the relay was controlled by the processor unit with the help of a driver circuit. The XBee module present at each intelligent module helped to communicate with the neighbouring unit so that the intelligent module could exactly locate the faulted part of the grid. There was a display associated with the micro controller unit. It indicated the current and voltage condition of the line continuously. The power supply module associated with this system took power directly from the line and made it suitable and available for all the circuits present within each individual intelligent module.

7 HARDWARE IMPLEMENTATION

We developed two intelligent modules in this hardware. These modules were connected to a power supply line and were tested with different load conditions.

We used an ACS 714 current sensor with a maximum current rating of 5A and a sensor transformer with a voltage rating of 30-300V with a current rating of 500mA. The micro controller unit used in this module was PIC16F877A since it met all the requirements for this design. An XBee module with 2.4GHz frequency with 0dBm power

output was used in this project for wireless communication (Rhidolabz, 2014).

The two intelligent modules were developed and connected with the power line. Whenever we simulated a faulted current within this system, the two modules sensed the faulted current and immediately tripped and communicated together and exactly isolated the faulted part. After detecting the faulted section, it isolated this part and maintained the system's stability.

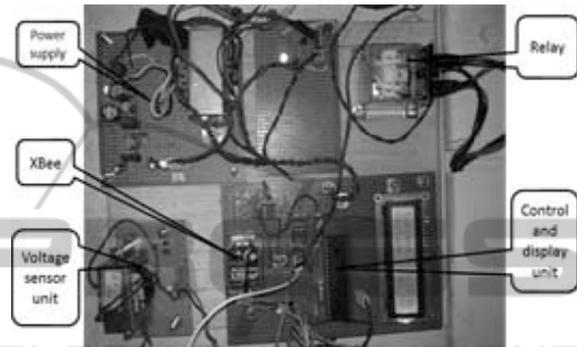


Figure 4: Hardware implementation of intelligent module.

8 EXPERIMENTATION AND ANALYSIS

We have tested the system with resistive and inductive loads.

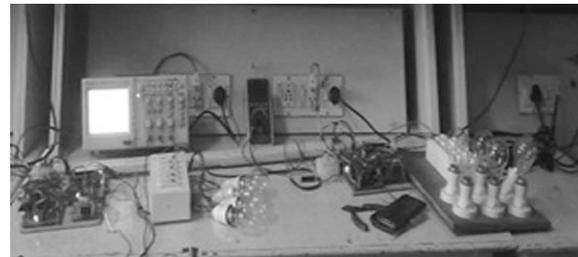


Figure 5: Integrated system.

In this test we have generated different scaled down fault current and observe tripping time variation. Test has done with both resistive and inductive loads. Table 1 and table 2 show the fault current test of intelligent module I with resistive loads and inductive loads respectively.

Table 3 and 4 gave the fault current test of intelligent module II with resistive and inductive loads respectively. From the fault current test we found that our system could locate the fault at different over current conditions with almost the same delay.

Table 1: Fault current test of intelligent module I with resistive loads.

Fault Current (in %)	Fault localization time (sec)
115	1.15
163	1.06
190	1.16
211	1.05
238.3	1.15

Table 2: Fault current test of intelligent module I with inductive loads.

Fault Current (in %)	Fault localization time (sec)
133	1.19
195	1.15

Table 3: Fault current test of intelligent module II with resistive loads.

Fault Current (in %)	Fault localization time (sec)
116	1.01
133	1.02
163.33	1.02
200	1.1

Table 4: Fault current test of intelligent module II with inductive loads.

Fault Current (in %)	Fault localization time (sec)
133	1.12
195	1.28

9 CONCLUSIONS

Three phase micro grid architecture capable of automatic fault detection and isolation mechanism was proposed in this paper. The bidirectional power flow inside the islanded micro grid made the fault detection mechanism more challenging. A fault detection mechanism developed in this work could detect and isolate the fault and make the remaining part of the grid in a balanced condition. The proposed system was tested with different fault current conditions and the results showed that the proposed system could localize the fault within a 2 second delay. Even though a single phase to neutral fault was very common in a three phase distribution power system, other types of faults and its occurrence was also important. Automatic fault detection and localization of fault could not make the system balanced. New approaches to power re-

establishment after fault detection and isolation could also be done as future work.

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