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Designing a new smart IED for detecting and clearing faults in solar networks

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A B S T R A C T

In recent decades, use of solar systems is developed and it is used in many small applications even in home appliances. DC micro grids with centralized solar generation are widely interested for various power applications due to their advantages over traditional AC power distribution systems with respect to power density and power distribution efficiency. On the other hand, protection of these kind of systems against faults are hard to diagnose. It is difficult to extinguish these arc faults via conventional circuit breakers due to the lack of natural zero-crossing of DC current. To overcome of this problem, this article proposed a new smart relay for detecting and clearing faults in solar networks that can gather data of all elements in grid and transmit data to a central control system in a SCADA system by using IEC61850 standards.

1. Introduction

1.1 Solar Dc microgrid

DC micro grid with centralized solar generation is the simplest, reliable, cost effective, scalable and highly efficient solution to provide access to electricity to people living without access to electricity. In [1], it has been determined that a DC network is better than AC network in the following ways:

- A DC network is more suitable for renewable energy generators, such as photovoltaic panels, fuel cells, and energy storage systems such as batteries, which are DC based.
- DC loads currently represent almost 50% of the whole building consumption, which can be supplied through a DC network.
- The future integration of electric vehicles in the distribution network will increase the consumption of DC devices (batteries) in the buildings.
- DC distribution networks are more efficient than their AC counterparts,
- Since there is no skin effect or reactive power in DC networks.
- Interconnecting and distributing energy through a DC distribution network
- Avoids unnecessary DC/AC and AC/DC conversions which produce losses.

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Moreover, a DC power supply to the DC loads will get rid of the internal AC/DC converters, which will increase the overall efficiency of the distribution network and the device as well. However, the main problem in its implementation is its vulnerability during a fault. This is because of the lack of ability of a converter to withstand against a DC fault, and lack of availability of digital protection devices and standards. These issues must be resolved before the commercialization of an LVDC distribution network [2].

The important dilemma in solar dc micro grid is to detect the faults and after that to eliminate the faulty part as soon as possible to protect other parts of the grid. Many studies focused on this issue and they were successful. In [3] and [4] the author presented a way to detect flash signals in a dc circuit using wavelet transform. Reference [5] describes a recently developed z-source dc circuit breaker that is applicable to the dc micro grid. Therefore, it has the capability to automatically respond to faults and therefore quickly isolate the faulted components.

1.2 IEC

"Communication networks and systems in substations" standard IEC61850 [6] was published in 2002 to 2005. The goal of IEC 61850 is to transform the electricity distribution industry by building more intelligence and more complete automation into power substations. With intelligent electronic devices (IED), it's possible to extend new controls and automation deep into the substation's process layer, thus allowing for real-time monitoring and management from a centralized remote-control hub.

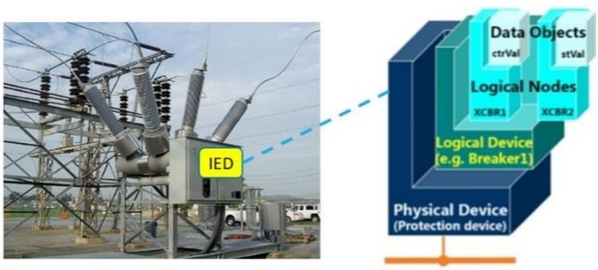

Figure 1 IEC61850 object-oriented protocol used in substation

The IEC 61850 standard stipulates that power substations will use Ethernet switches and embedded computers for data communications and computing all throughout the station, bay, and process levels.

IEC61850 can be used in all system from different manufacturers, because it is compatible and has a wide interoperability.

Figure 2 IEC61850 communication Standard and different IEDs communicating in a gateway

It has a communication standard between all substations; therefore, transmitting data will be easily available with higher speed. It also can be updated when a substation is changed (for example if a new one or more IEDs are added to substation) or developed by sending a description configuration file usually with XML format on that substation [7].

SCL is a description language that configures a substation both before employment at first, or when further IEDs or other equipment is added to the substation.

According to IEC 61850, peer-to-peer communication contains 2 models for transmitting data: GOOSE messages and Sampled measured values (SV).

The benefits of GOOSE model is that the mechanism of messages are very flexible, with high priority and are reliable for the fast transmission of trips commands, alarms, indications and some other substation events.[8]

in this study, a new smart relay has been introduced to overcome this issue. This relay is a kind of IED that is used to gather the data of all Elements by the IEDs located near each element, such as solar panels, or different loads. The measured data is analyzed in IEDs and if the data be over than the upper band of normal range, it will send an alarm and also the data via 61850 messages to be analyzed in central processing unit. benefit of the proposed algorithm is that the central process unit always has the abnormal data that is doubtful for being the fault and also it can request for the data of any IEDs every time. So, the central unit will have the more accurate analyze and the result is more reliable.

2. Goose message

The communication standard of the International Electrotechnical Commission (IEC) 61850 adopts the object-oriented modeling technique and the objects in this standard has meaningful names [9]. Generic object-oriented substation event (GOOSE) is based on a wide range of possible common data organized by a DATA-SET. By using GOOSE messages, you can replace the hard-wired control signal exchange between lEDs for protection purposes, interlocking, time critical and highly reliability.

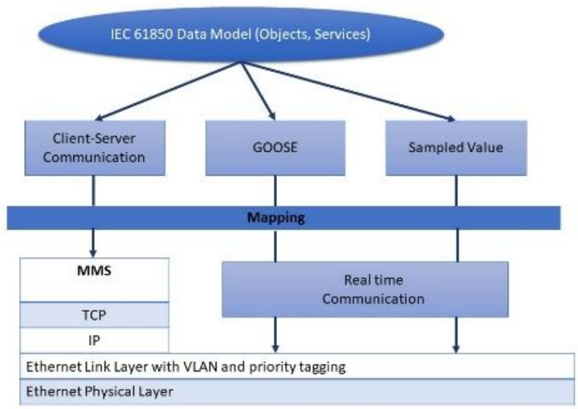

Figure 3 IEC61850 standard and data model

Exchange of information in this model is based on a publisher/subscriber mechanism. It means that the "publisher" writes the values in a local buffer at the sending side; the receiver reads the values from a local buffer at the receiving side. The communication system is responsible to update the local buffers of the "subscribers".

The advantage of IEC61850 GOOSE messages over other communication protocols is that GOOSE messages are directly sent and there are no middle layers between publisher and subscriber. This advantage makes it quick and reduces the possibility of losing data.

In order to protect system from faults, IEC 61850 defines very strict performance requirements. The total time of exchanging data should not exceed 4ms. Another important requirement for the GOOSE message is it's high reliability. there has to be a mechanism to ensure that significant IED can receive the message and operate as expected, especially when an important message such as failure in operation of breakers. In order to achieve a high level of reliability, messages must have enough time to live which is known as “hold time”.

In order to achieve high speed performance and reduce the network traffic during severe fault conditions, the GOOSE message has been designed on the base of the idea to have a single message that conveys all required protection scheme information regarding an individual protection IED. It represents a state machine that reports the status of device in the IED to its peers.

3. Proposed algorithm

In this paper we have processing unit in both inside of each IED and in main processing center And if it meet current over than nominal, IED will send the event to the gateway that all IEDs and also central processing unit can receive this. In addition, local IED will also use the proposed algorithm to trip when the faulty situation didn’t clear in appropriate time. Or when the current meet critical set point, the related IED will send trip command immediately.

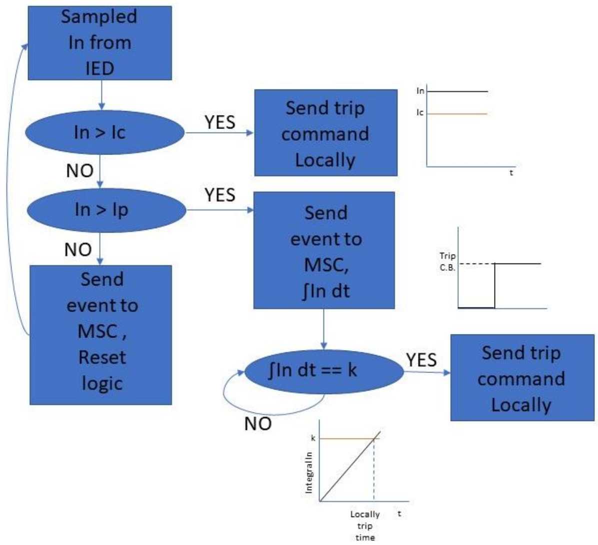

Figure 4 proposed algorithm for fault detecting and clearing in smart IEDs

4. Smart IED

Intelligent electronic devices (IED) are widely used in DC micro grids. In this paper, a smart Relay is designed which can be used in both ac and dc systems. It can measure voltage and current of different parts of systems.

The communication network between IEDs and Master SCADA Center (MSC) uses fiber optic cable that can have kilometers long.

The measured signals and also the transient waveforms can be transmitted to central processing unit in order to analyze data and send trip signal if the fault is occurred.

The process until trip command sending is calculated as the equations below:

ADC sampling delay: $Td_{ADC} = 1\mu s$

Local Process delay: $Td_{LP} = 10\mu s$
Delay: $Td_{ADC} = 1\mu s$
ADC sampling delay: $Td_{ADC} = 1\mu s$
Sum of the times above is equal to 5ms that is acceptable in compare to conventional local relays. But the advantage is that the condition of all parts of system is available in MSC and so the probability of mismatch is very low.

5. Simulation network

The Network that is proposed in this article is shown in figure… and contains 2 solar generators in which they feed two 20kw load and there is a diesel generator that can power the loads in cloudy weather. The model of the photovoltaic (PV) system is based on the configuration presented in [10] and utilizes a boost converter to regulate the panel voltage at 54 V to achieve maximum power transfer.

Table 1 Network parameters

Solar num1,2	*750V, 750V*
Diesel Generator	*700V, 25kw*
Load num1,2	*20kw, 20kw*

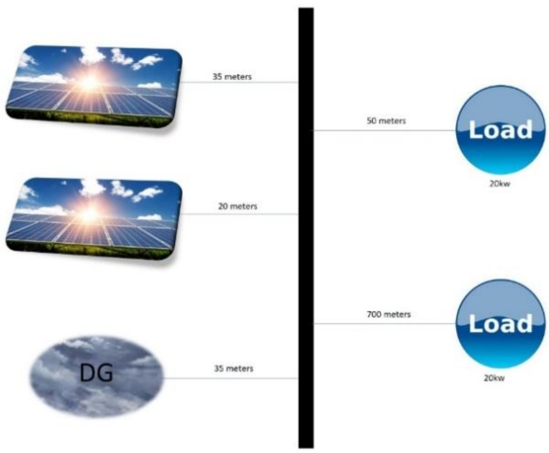

Figure 5 simulated grid

Pole-to-pole faults are simulated in different parts of the network. In figure 6 the fault is occurred near the pv source and in figure 7 fault is near the load. The simulation results are shown in figures below.

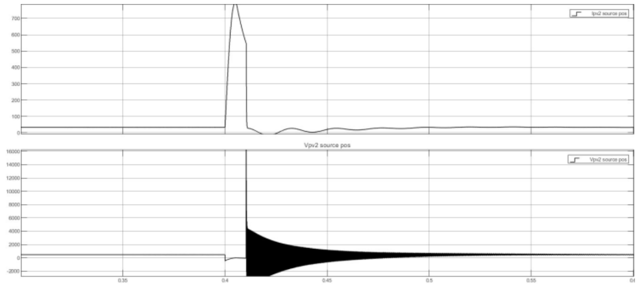

Figure 6 voltage and current in source side when fault is occurred near Solar distributed generators

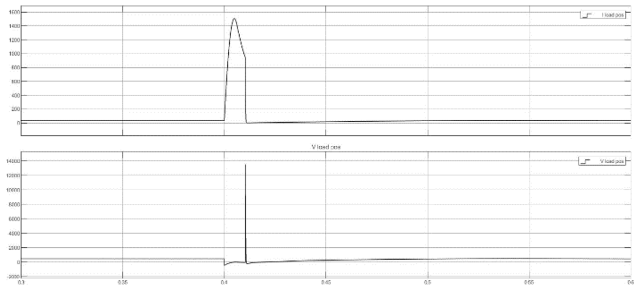

Figure 7 voltage and current in load side when fault is occurred near load at t= 0.4s

6. Designed smart IED

This smart IED is consist of a central processing unit cortex M4 which works in 168MHz frequency that uses a 12bit analog to digital converter with 1milion sample per second.
Considering the high speed of the ADC used in this paper, we used 2 input channels for measuring voltage and current. In voltage measuring unit, each channel is able to measure positive pole to ground and negative pole to ground. It allows the processing unit to recognize either unbalancing or wrong ***pole changing*** faults.

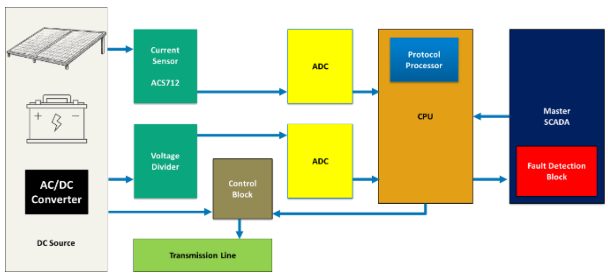

Figure 7 simulated network schematic

Current sensor which is used in this study is ACS712. It uses Hall effect for measuring current in IEDs. Due to the 2kV isolation in output signal, 80KHz bandwidth, low delay about 5µs, powered by 5v and small size, it is the best for using in these IEDs. this system has 66 mV output per each

Ampere. We used ACS712ELCTR-30A-T in this system, therefore, it can measure up to 30mA current. Maximum output voltage is derived from the equation below:

$$V_{out}^{I=30A} = 66 \times 30 \rightarrow V_{Fullscale} = 1980mV$$

So, we use reference voltage of 2.5V for analog to digital converter used in IEDs. due to the 12bit converter and 4096 steps for digital value, measuring accuracy of this system is:

$$Step_{ADC} = \frac{2500mV}{2^{12}} = 0.6103mV$$

$$\frac{66mV}{Step_{ADC}} = 108.14 \rightarrow \frac{1000mA}{108.14} = 9.24mA$$

From the above equation, each digital step is equal to 9.24 mA of output current, and so it is an acceptable accuracy for fault detection. If this ADC be used for bi-directional systems, this accuracy will be half and equal to 18.48mA and it is still a good accuracy for detecting fault in network.

The considerable point of this system is that it can tolerate up to 100A during 100ms. Therefore, we can be sure the data measured by this system is reliable even in transient. The other advantage of the designed system is that it can be used in wide range of temperature from -40 to 85 C.

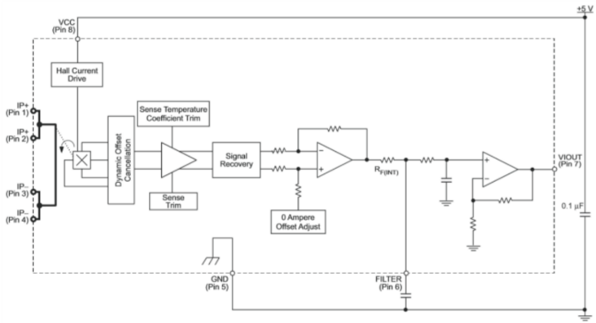

Figure 8 Input current level using ACS712 sensor

Figure10 shows the input voltage level. FB1 to FB4 ferrite beads in series with input power in order to eliminate high frequency noise. Series 50kΩ resistors are used to raise power of the system. TVS diodes are used to protect system from of high voltage impulse. 1kΩ is used for resistor dividing and 2.2nF capacitors are for anti-aliasing. The sampled designed IED is shown in figure11.

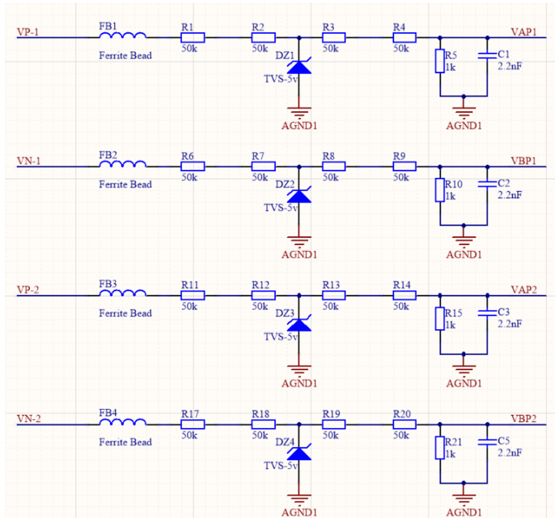

Figure 9 Voltage input level designed. Voltage level has 2 inputs for posetive and negative polarity.

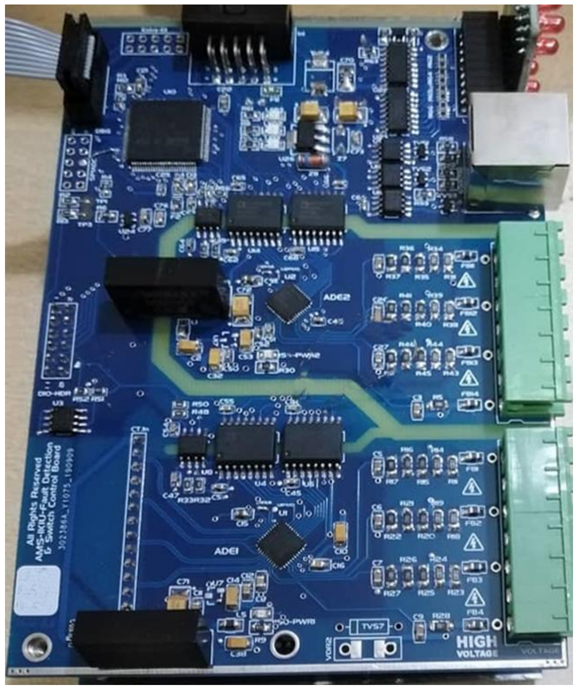

Figure 10 sample IED designed

7. Conclusion

In this paper, a DC microgrid which is powered by solar energy systems is designed. By equipping different parts of this grid with measurement IEDs, voltage and current of all parts of grid is measured and kept in IED registers, and also it is transmitted to a central processing unit with GOOSE messages introduced in IEC61850 standard unsolicited or by requesting from SCADA Master. Central processing unit will detect the fault if occurred by analyzing signal and data which is received from IEDs and will send trip signal in order to eliminate the faulty part from the whole system. The related results are analyzed in MATLAB Simulink of this grid and a sample smart IED board is implemented.

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