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# Ring Protection of Generator with Distributed Generator

**D.Ranganathan*,M.Padmavathi*1,R.Babyshalini*2,S.M.Elakkiya*3**
**PG Student, Gnanamani College of Technology,NH-7, A.K.Samuthiram,Pachal-PO, Namakkal-637 018.Tamilnadu, India.*
**1 Assistant Professor,Gnanamani College of Technology, NH-7, A.K.Samuthiram,Pachal-PO, Namakkal-637 018.*
*Tamilnadu, India,*
**2 Assistant Professor, Gnanamani College of Technology, NH-7, A.K.Samuthiram,Pachal-PO, Namakkal-637 018.*
*Tamilnadu, India.*
**31 Assistant Professor,Gnanamani College of Technology, NH-7, A.K.Samuthiram,Pachal-PO, Namakkal-637 018.*
*Tamilnadu, India,*

***Abstract****—Distributed generation (DG) is the future of energy. This technology allows the bidirectional flow of power within an electrical network. Researchers are faced with many challenges to the accurate implementation of protection schemes for DG-connected distribution network. The schemes designed must satisfy the performance requirements of selectivity, reliability, and sensitivity. Most researchers opine that conventional protection schemes based on over current detection are insufficient to completely and accurately protect a DG-connected distributed power system. There are many challenges that need to be tackled before embarking upon the journey to successfully implement these schemes. This paper summarizes the major challenges which one can encounter while designing protection schemes for DG-connected distribution networks. Some possible solutions from the literature are also mentioned. Moreover, a suggested solution for protecting future active distribution networks is provided. It is expected that this paper will act as a benchmark for future researchers in this field to tackle the challenges related to the protection of active distribution networks.*

***Index Terms—****DC power systems, fault location, microgrid,power system protection.*

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## I. INTRODUCTION

Smart grid is an exciting development of power systems worldwide. It is also one of the scientific and technological innovations in the 21th century [1]. The development mainly lies in the distribution system. Lots of researches are being carried out in the field of smart distribution system around the world.

Meanwhile, more and more electrical equipment, based on electronic products, are consuming direct current (DC), such as LED lamps, mobile phones, liquid crystal monitors, computers, and electric vehicles. Aiming to be more efficient, frequency conversion technology has been widely used in household and industrial loads. These loads can be regarded as indirect DC loads because of the DC link in the converters. At the same time, more and more distributed generators (DGs) are using renewable energy sources and generating DC electricity, such as photovoltaic generator and fuel cell generator. A DC link still exists in other types of DGs, such as micro turbine and wind power system. Hence, it will greatly improve the efficiency and reduce the loss of power conversion by using a DC system to distribute the power. With the rapid development of modern power electronic technology, commutation components are mature enough to work smoothly in DC distribution system.

Besides a number of benefits, there are some technical problems with relay protection of distributed generators. It turned out to be one of the most problematical technical issues since its malfunction could cause serious risk for people and components.

Much more small distributed generation units are nowadays connected to power systems than in the past. Protection requirements should relate to the value of the equipment protected. As such, protection requirements for large units differ from those for smaller units.

Furthermore, the location in the power system at which a generator is connected can create site-specific hazards to the generator as well as to the power system to which it is connected.Generally, generators can be classified as bulk power generators and distributed generators. Both types share many common hazards. Therefore, protection requirements are similar. Smaller generators, common among distributed generators, warrant less sophisticated protection, however, as their cost is significantly less than large units.

Bulk power generators are that interconnect into the bulk power transmission system. Such generators are typically above 20 MVA in size and usually range in the 100 to 1200 MVA size. These generators are often located in power plants that may house one or more generating units. The geographic locations of bulk power plants are selected on the basis of factors such as proximity to fuel supply and load centers, availability of a , and restrictions related to environmental concerns and public acceptance.

An induction generator is simply an induction motor driven above synchronous speed by a prime mover. Induction generators require a source of excitation, which is typically obtained from the power system to which it is connected.

Loss of the power source to the circuit to which an induction generator is connected, therefore, will normally cause the generator to shut down, as its source of excitation is lost. Continued operation of an induction generator is possible after the source to its connected line is removed, however, only if a source of excitation, such as a , exists on the line to which the induction generator remains connected.

To sustain operation in a self-excitation state, the amount of excitation, and load that remains isolated with the induction generator must fall within a suitable range.

This paper proposes a dc bus micro grid fault protection method including backup protection that allows the fault to be detected and isolated without de-energizing the entire system. This is done through the use of a ring bus with overlapping nodes and links controlled by intelligent electronic devices (IEDs). Also proposed is a no iterative, deterministic fault-lo- cation technique using a probe power unit. The information on fault location is extracted from the probe current. The probe power unit can also be used for a pilot test to determine whether the fault is temporary before main CB reclosing to avoid system damage that can be expected when the fault is permanent.

## II. Flow chart

The location of the fault can be identified by the analysis on the return current when the fault is present. The proposed fault- location method using the probe power unit and selection of probe unit components will be described in detail in Section IV. The system will return to normal operation if the fault is cleared, but in case a permanent fault is still detected, the IED will lock out the zone. The IED can identify a permanent fault by the re-closing sequence using the probe power unit. A se- lected number of attempts will be made to reclose. The number of retry depends on the bus configuration and related code. After attempts without success, the IED determines that the fault is permanent and will not allow the breaker to close. A flowchart of the protection logic can be seen in Fig. 1.

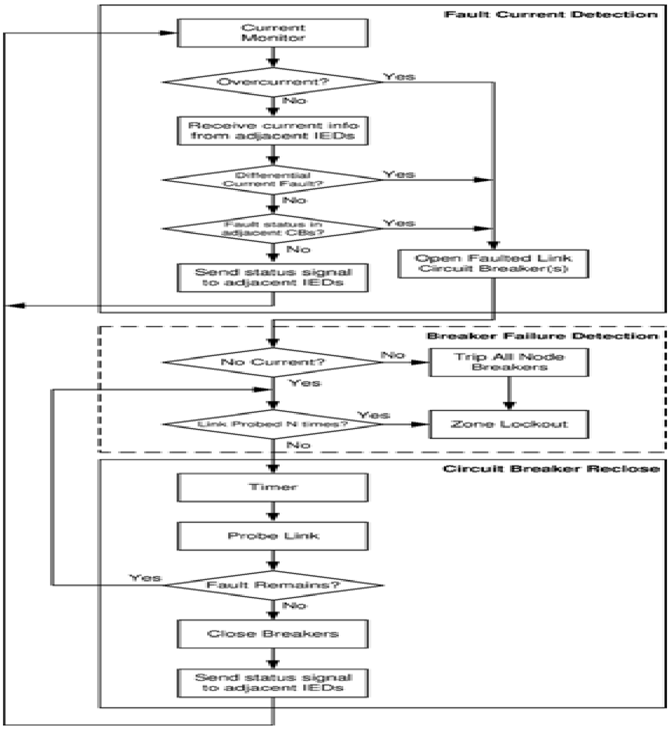

**Fig.1.** Flowchart of the proposed protection algorithm.

## III. EXPERIMENTAL VALIDATION

The proposed fault detection, isolation, and location methods have also been validated on a scaled-down hardware test bed. A 1-mH inductor has been used to implement the 1-km bus seg- ment. The line stray capacitances were neglected. The imple- mented experiment setup has higher resistance (1.3 ) than ex-pected so the current decays too fast. Hence, the probe unit in- ductance $L_P$ was reduced to 67 H to obtain enough frequency and current data for analysis and 100-m line resistance $R_u$ and 1.2- fault resistance $R_f$ were assumed. For the probe unit ca- pacitors $C_P$, 27 F was selected.

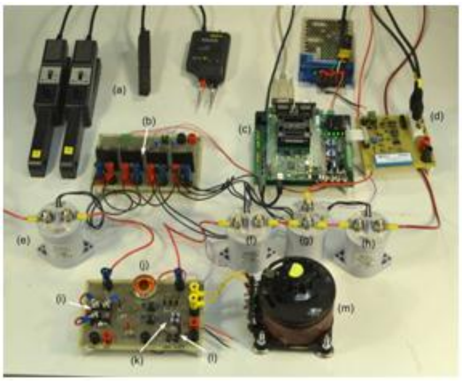

Fig.2. Experiment setup. (a) Current probes. (b) Contactor drivers. (c) DSP control board. (d) Analog signal interface. (e) B83 contactor. (f) B71 contactor.(g) B72 contactor. (h) B73 contactor. (i) Fault IGBT. (j) Line inductor $L_l$ .(k) Probe power unit capacitor $C_P$. (l) DC power switch $S_b$. (m) Probe powerunit inductor $L_P$.

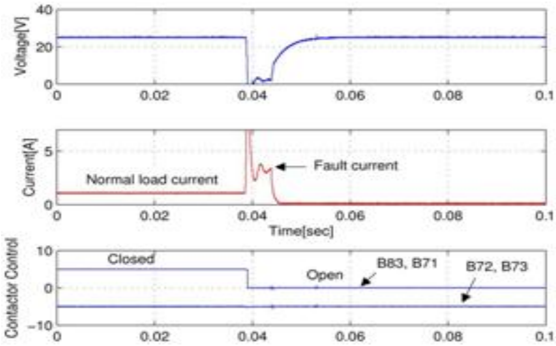

Fig.3. Experiment: Fault is triggered at 0.04 s. (Top) Bus voltage.(Middle) Fault current. (Bottom) Contactor control signals. It can be seenthat the fault current is interrupted and the bus voltage recovers after the fault segment is isolated.

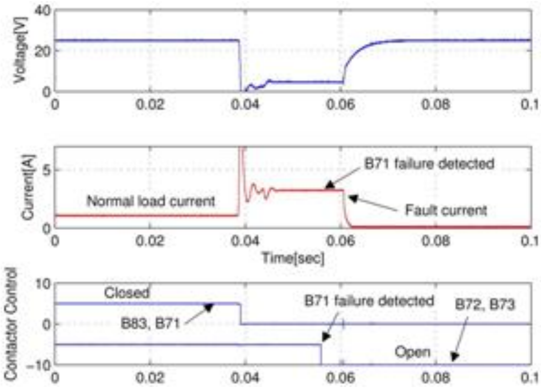

Fig.4. Experiment: Contactor B71 open failure is simulated. (Top) Bus voltage. (Middle) Fault current. (Bottom) Contactor control signals. It can be seen that the fault current keeps flowing after 0.04 s because of the failure of B71. IED opens B73 and B74 after a predefined time to isolate the fault.

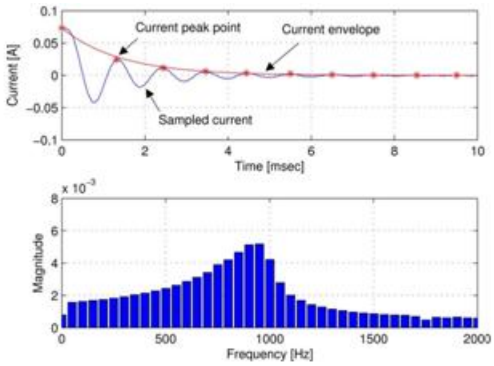

Fig.5. Experiment: (Top) Probe current sampled at 50-kHz frequency. De- tected peak points and the current envelope drawn with the calculated are also shown. (Bottom) Frequency analysis with the FFT algorithm implementedin the DSP-based control board.

The control mode was changed to probing mode from detec- tion mode manually by switch in this experiment. In the fault probing mode, probing power switch is toggled by IED to inject the probe current into the fault circuit. Fig.5 shows the probe current sampled at the falling edge of the probing pulse. The natural frequency of the probe current is 952 Hz and 909 Hz from calculation and measurement, respectively. The FFT routine implemented in the DSP controller [41] detects 950 Hz, which is the closest result because the resolution of FFT analysis is 50 Hz due to 1000-point sampling with 50-kHz frequency. The algorithm estimates the fault location at 1 km with 0.5% error (1.0057 km). The current envelope detection and atten- uation estimation are $\alpha$also implemented and the 1.2- fault resistance Ω was estimated with 9.75% error (1.317 ).

The proposed protection scheme Ω has been successfully vali- dated with a scaled-down hardware testbed. It should, however, be noted that the estimation result is quite sensitive to the ac- curacy of parameters and measurements, especially when thereis not enough information due to the fast decay of the probe current.

## IV. CONCLUSION

Selection of the DG interconnection protective relay is based on several criteria such as power system characteristics, the dynamic response of the generator, the system grounding, the DG transformer connection, etc., as well as the protection policy of the utility and coordination requirements. The interconnection protection IED design can be summarized as follows:
Disconnection of DG plants when no longer operating in parallel with the utility grid,
Protection of the utility grid from damage caused by connection of the DG plants (voltage transients, fault current supplied by DG, reclosing without check sync, etc.).
Protection of the DG plant from damage caused by the utility grid.
Coordination with other protective relays should be made to prevent unnecessary trips.
Possible implications on utility protections must be analysed when a DG is connected, depending on the characteristics of the network, such as the loss of coordination or sensitivity, reclosing coordination, etc. This bus probing method can ensure the proper line status be- fore reclosing and, hence, improves the system reliability and mean time between failure (MTBF) of protective gear. Furthermore, it can be readily applied to ac power systems to eliminate the issues caused by reclosing failure, as well as to identify the fault location. Successful performance of fault detection, isolation, and location has been shown using computer simulations and hardware experiments.

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