Wavelet Based Transient Fault Detection and Analysis of Microgrid Connected Power System

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Abstract: - Microgrids comprise low voltage distribution systems with distributed energy resources and controllable loads which can operate connected to the medium voltage grid or islanded in a controlled coordinated way. Microgrids provide clear economic and environmental benefits for end-customers, utilities and society. However, their implementation poses great technical challenges, such as a protection of microgrid. Protection must respond to both utility grid and microgrid faults. If the fault is on the utility grid, the desired response may be to isolate the microgrid from the main utility as rapidly as necessary to protect the microgrid loads. If the fault is within the microgrid, the protection coordinator isolates the smallest possible section of the microgrid to eliminate the fault. In order to cope with the bi-directional energy flow due to large numbers of micro sources new protection schemes are required. This paper presents microgrid protection system using digital relaying and satellite communication is based on wavelet detailed coefficients of Bior 1.5 mother wavelet. The proposed algorithm is proved for the detection, classification of faults on microgrid connected power systems which is almost independent of fault impedance, fault inception angle and fault distance of feeder line.

Key-Words: - Microgrid protection, inverter-interfaced microgrids, islanded microgrid.

1. Introduction

Power systems currently undergo considerable change in operating requirements – mainly as a result of deregulation and due to an increasing amount of distributed energy resources. In many cases distributed energy resources include different technologies that allow generation in micro sources and some of them take advantage of renewable energy resources such as solar, wind or hydro energy. Having micro-sources close to the load has the advantage of reducing transmission losses as well as preventing network congestions and also consumers, utilities and society, such as:

- improved energy efficiency,
- minimized overall energy consumption,
- reduced greenhouse gases and pollutant emissions,
- improved service quality and reliability,
- cost efficient electricity infrastructure replacement.

During the last decade, the concept of microgrid has emerged as a remarkable way of integrating sustainable energy sources in the electric network. Its main benefits lie in that it supplies power locally, reduces grid investment due to lower network capacity requirements, reduces operation costs and losses, reduces the peak load and increases reliability [1]. However, along with these benefits, microgrids have also raised a number of challenges, amongst them the issue of protection [2]. There are two main issues the microgrid has to address with regard to its protection [3]: Firstly, the determination of the time when it should be islanded from the main grid in response to abnormal conditions that the utility may experience; secondly, the provision of properly coordinated and reliable protection system so that it can reliably trip in the event of a fault within it.

In the past decades, the development of fault diagnosis for the power system has progressed with the applications of wavelet transform. However, the work rarely mention about the location of fault on multi terminal. Wavelet transform analyzes transient voltage and current signals associated with faults both in frequency and time domain. In this paper, Wavelet Multi Resolution Analysis is used for detection, classification and location of faults on transmission lines. Detail D1 coefficients of current signals using Bior1.5 wavelets are used to detect, classify and location of fault.

2. Technical Challenges in Microgrid Protection

One of the major challenges is a protection system for microgrid which must respond to main grid as well as microgrid faults. In the first case the protection system should isolate the microgrid from the main grid as rapidly as necessary to protect the microgrid loads. In the second case the protection system should isolate the smallest part of the microgrid as early as possible to clear the fault in the system. Some issues related to a protection of microgrids and distribution grids with a large penetration of distributed energy resources have been addressed in recent publications Basically, there are two main issues, first is related to a number of installed units in the microgrid and second is related to an availability of a sufficient level of short-circuit current in the islanded operating mode of microgrid since this level may substantially drop down after a disconnection from a stiff main grid. The short circuit current calculations for radial feeders with distributed energy resources and observed that short-circuit currents which are used in over-current protection relays depend on a connection point and a feed-in power from distributed energy resources. Because of these directions and amplitudes of short circuit currents will vary according to the system abnormalities. In fact, operating conditions of microgrid are constantly changing because of the intermittent micro-sources like wind and solar and periodic load variation. Also a network topology can be regularly changed aimed at loss minimization or achievement of other economic or operational targets. In addition controllable islands of different size and content can be formed as a result of faults in the main grid or inside a microgrid.

In such circumstances a loss of relay coordination may happen and generic over-current protection with a single setting group may become inadequate, i.e. it will not guarantee a selective operation for all possible faults. Therefore, it is essential to ensure that settings chosen for over-current protection relays take into account a grid topology and changes in location, type and amount of generation. Otherwise, unwanted operation or failure to operate when required may occur. In order to cope with bi-directional power flows and low short-circuit current levels in microgrids dominated by micro-sources with power electronic interfaces a new protection philosophy is required, where setting parameters of relays must be checked/updated periodically to ensure that they are still appropriate. This report presents a novel adaptive microgrid protection [4,5] concept using advanced communication system[6], real-time measurements and data from off-line short circuit analysis. This concept is based on an adaptation of protection relay settings with regard to a microgrid topology, generation and load status. A segmentation of microgrid, i.e. a creation of multiple islands or sub-microgrids must be supported by micro-source and load controllers. In these circumstances problems related to selectivity and sensitivity of protection system may arise.

The microgrid concept has to face a number of challenges in several fields, not only from the protection point of view, but also from the control and dispatch perspective [7]. Nevertheless, due to their specific characteristics and operation, microgrid protection systems have to deal with new technical challenges [5, 6]:

Generation systems in both medium voltage (MV) and low voltage (LV) systems, making power flow bidirectional;

- Two operational modes: grid connected and islanded/stand-alone;
- Topological changes in LV network due to connection/disconnection of generators, storage systems and loads;
- Intermittence in the generation of several micro sources connected in the microgrid;
- Increasing penetration of rotating machines, which may cause fault currents that exceed equipment ratings.
- Insufficient level of short-circuit current in the islanding operation mode, due to power-electronics interfaced distributed generation (DG);
- Reduction in the permissible tripping times when faults occur in MV and LV systems, in order to maintain the stability of the microgrid;
- Nuisance tripping of protection due to faults on adjacent feeders

3. Wavelet Analysis

Wavelet Transform (WT) is a linear transformation much like the Fourier transform, however with one important difference: it allows time localization of different frequency components of a given signal. So, it is a mathematical technique used in signal analysis. Wavelet analysis is particularly efficient where the signal being analyzed has transients or discontinuities, e.g., the post fault voltage/current waveform. In wavelet transform, the analyzing functions, which are called Wavelets, will adjust their time width to their frequency in such a way that, higher frequency wavelets will be very narrow and lower frequency ones will be boarder. Wavelet transform is a tool that cuts up data or functions or operators into different frequency components, and then studies each component with a resolution matched to its scale [12].

The Discrete Wavelet Transform is easier to implement than Continuous Wavelet Transform is computed by changing the scale of the analysis window and shifting the window in time or multiplying the signal and the information of interest is often a combination of features that are most speedy. This requires the use of analysis methods sufficiently in which it is versatile to handle signals in terms of their localization of time-frequency. Frequency based analysis has been common since Fourier's time. These results in a very wide frequency spectrum in the analysis of transients Fourier techniques cannot simultaneously achieve good localization in both time and frequency resolution for a transient waves. The main advantage of WT over Fourier Transform is that the size of analysis window varies in proportion to the frequency analysis at which WT can offer a better compromise in terms of localization.

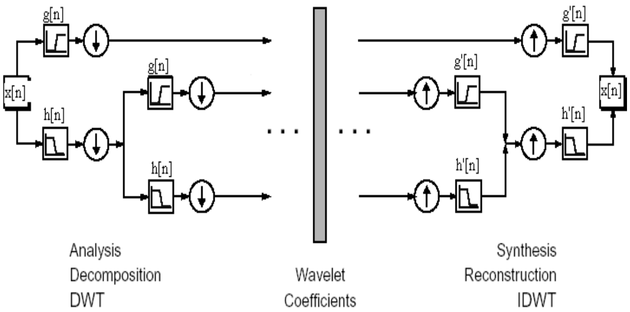

Fig 1.Analysis of signal using wavelet transforms

The wavelet transform decomposes transients into a series of wavelet components having each of which corresponds to a time domain signal that covers a specific octave frequency band containing more detailed information. Such wavelet components appear to be useful for detecting and classifying the sources of surges [12]. Hence, the WT is feasible and practical for analyzing power system transients and disturbances [13].

Power transmission line protection is one of the most important concerns for the power utilities set of basic functions called Wavelets, are used to decompose the signal in various frequency bands, which are obtained from a mother wavelet by dilation and translation [14]. Hence the amplitude and incidence of each frequency can be found precisely.

Given, a function f(t), its continuous wavelet transform(WT) be calculated as follows:

$$WT(a,b) = \frac{1}{\sqrt{a}} \int x(t) g\left(\frac{t-b}{a}\right) dt$$

Where a and b are the scaling (dilation) and translation (time shift) constants respectively, and ψ is the wavelet function which may not be real as assumed in the above equation for simplicity.

The selection of mother wavelet is based on the type of application. In the following section a novel method of detection and classification of faults using Multi Resolution Analysis of the transient currents associated with the fault is discussed [14].

4. Microgrid Fault Analysis with System Modelling

In micro grid fault analysis can be categorize mainly two type, one of the fault in main grid and other is in micro grid considered as internal and external faults. External fault could be in MV bus or distribution transformer and internal fault could be in LV feeder or LV consumer. As micro grid need to operate in both island and grid connected mode there have challenge in micro grid protection system with conventional protection strategy [11]. The major micro grid protection problem is related to large difference between fault current in main grid connected and islanded mode.

Also there have sensitivity and selection problem due to different fault current in different scenario [10]. But it is essential to have high sensitive to faults and selectively isolate/sectionalize in the case of DGs with low fault current level. As conventional protection system doesn't offer solution for all micro grid protection challenge, but it needs advanced protection strategy. The protection scheme must ensure that safe operation of the micro grid in both mode of operation, that is the grid connected mode and island mode. Due to contribution of host grid in grid connected mode fault currents are large. This allows to employment of conventional over current relay, but the fact is that due to existence of distributed resources the protection coordination may be compromised [15].

5. Modelling of Hybrid Microgrid System Connected to Utility Grid

Non-conventional energy resources, such as solar PV and wind energy have attracted energy sectors to generate power that interconnected at point of common coupling to the main power grid with an aim to improve reliability in power supply against the load demand. Both wind and solar, is unsystematic in nature and dependence on climatic changes. Fortunately, the problems can moderately overcome by integrating the resources to form a hybrid Microgrid system, strength of one source overcome the limitation of the other source. The energy resources connected to the Microgrid to allocate the shortage power as per conditional demands. However, the interfacing of Microgrid with these energy resources lead to several power quality and islanding problems which must be detected, analyzed and mitigated effectively.

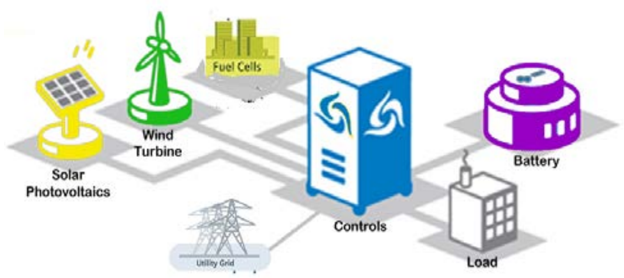

Figure 2. Micro Grid Connected Energy Resources to utility Grid

Photovoltaic (PV) system refers to an array of cells containing a solar photovoltaic material that converts solar radiation into direct current electricity. The DC is carried through wiring to an inverter which converts the current to AC so it can be connected to main grid [8].Maximum power obtaining from solar has directly related to solar irradiance intensity and temperature. Several photovoltaic cells connected in series, which is a PV module. The output current is equal to difference of light generated current to diode current.

$$I = I_{ph} - I_D \tag{1}$$

I_D = Current of the diode
I = Cell output current and voltage.
I_{ph} = Light generated current.

The wind turbine acts as a prime mover to a connected DC generator. Pulse Width Modulation (PWM) is used to obtain three phase AC voltage from the output of DC generator [9]. Wind turbine extracts maximum kinetic energy from the wind, which strikes rotor blade. The power coefficient Cp is a measure of how much the energy extracted by the turbine. CP may be expressed as a function of the Tip Speed Ratio (TSR) given by equation.

$$\lambda = \omega_m R/V \tag{2}$$

$$P = 1/2 C_P \rho V_w^3 AW \tag{3}$$

ωm = mechanical angular rotor speed of the wind turbine.
P = Power (W).
Cp = Power coefficient.
V_w = Wind velocity (m/s).
A = Swept area of rotor disc (m^2).
ρ = Density of Air (kg/m^3).

6. System Modelling and result Analysis

A 60km length transmission line is considered in between Bus1 and Bus2 as test case in this paper. At 10km distance of the transmission line at bus3 formulated with wind energy source of capacity 9MVA, 575V through a transformer of 575V/25KV is connected. A bus4 formulated with battery, solar PV and Fuel cell energy source of capacity 400KVA connected through transformer of 575V/25KV. Using the power system block set (PSB) and the SIMULINK software, the test system is simulated. The test system single line diagram is shown in Fig.3.

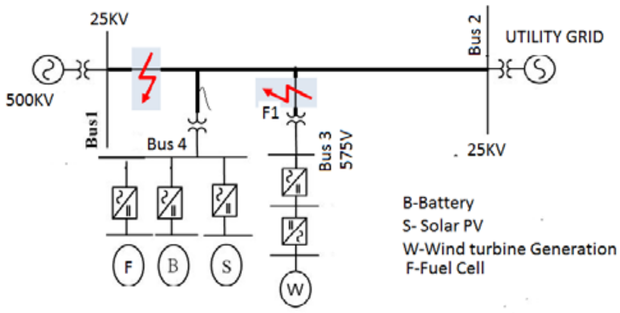

Figure3: Single line diagram for microgrid connected to utility grid.

The three phase currents of the local terminal are analyzed with Bior.1.5 mother wavelet to obtain the detail coefficients over a moving window of half cycle length. The detail coefficients are calculated from the Bus1, Bus 2, Bus3 and Bus4 to obtain effective D1 coefficients (D1E). The Fault Index (If1) of each phase is then calculated.

The results are plotted for different faults are given below. Figures 4-6 illustrates the variation of fault index for transmission system at fault inception angle 40^0 with LG, LL, LLG and LLLG Faults on Phase ABCG on Bus1.

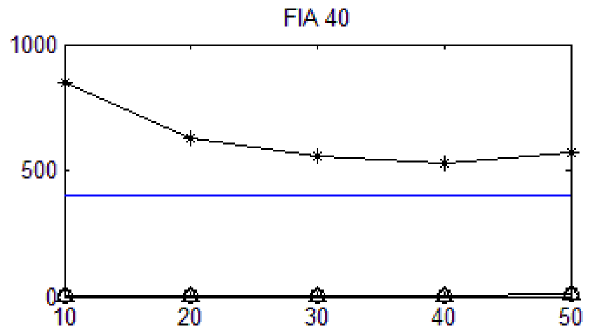

Fig 4. Variation of fault index from Bus1 at LG Fault on Phase AG for transmission line at Fault Inception Angle 40^0.

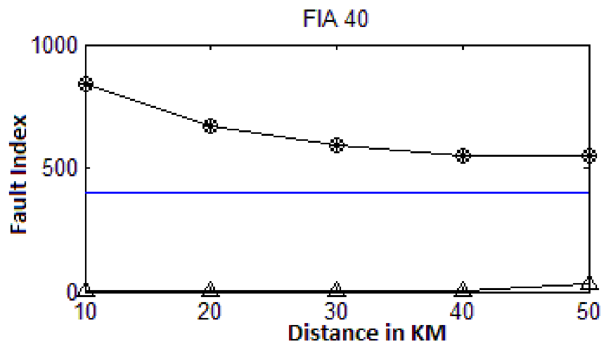

Fig 5.Variation of fault index from Bus1 at LL Fault on Phase AB for transmission line at Fault Inception Angle 40^0.

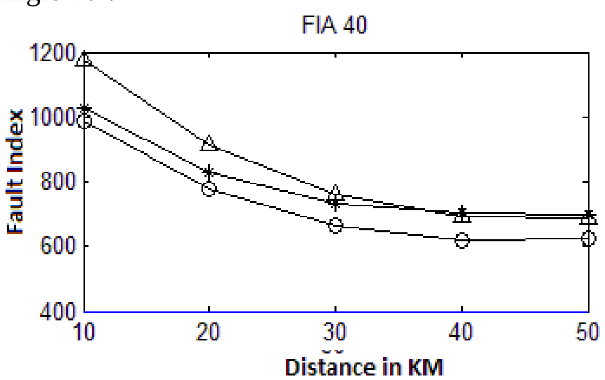

Fig 6. Variation of fault index from Bus1 at LLLG Fault on Phase ABCG for transmission line at Fault Inception Angle 40^0

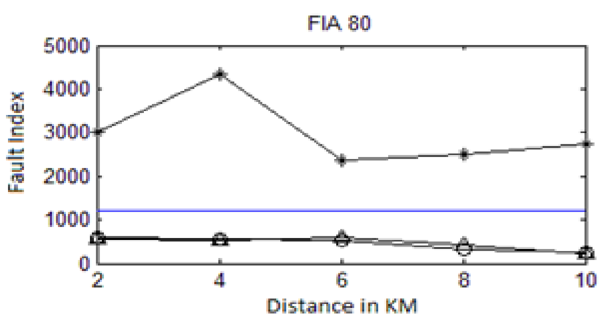

Fig 7.Variation of fault index from Bus2 at LG Fault on Phase AG for transmission line at Fault Inception Angle 80^0.

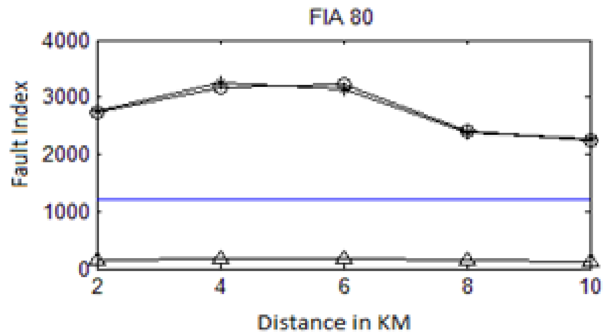

Fig 8.Variation of fault index from Bus2 at LL Fault on Phase AB for transmission line at Fault Inception Angle 80^0.

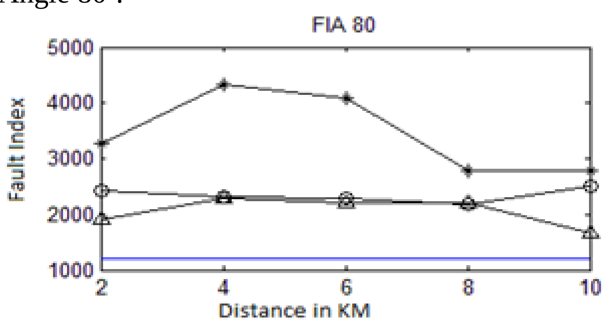

Fig 9.Variation of fault index from Bus2 at LL Fault on Phase AB for transmission line at Fault Inception Angle 80^0.

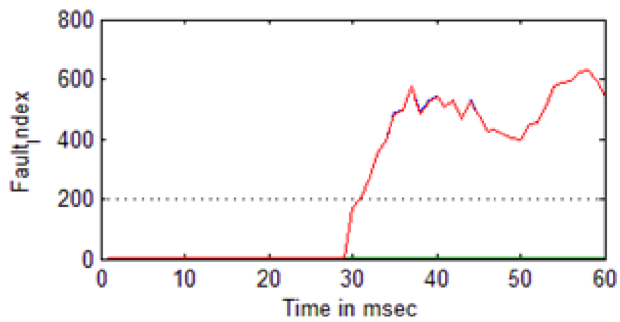

Fig 10 Detection of LG fault at wind generation.

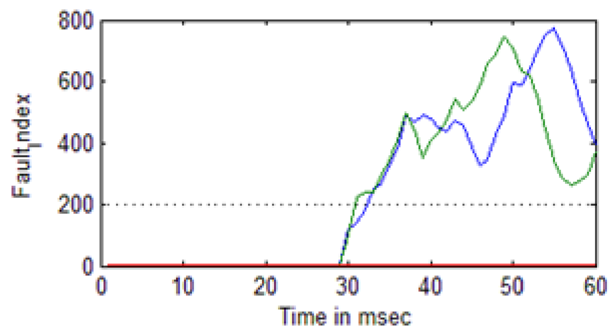

Fig 11 Detection of LLG fault at wind generation

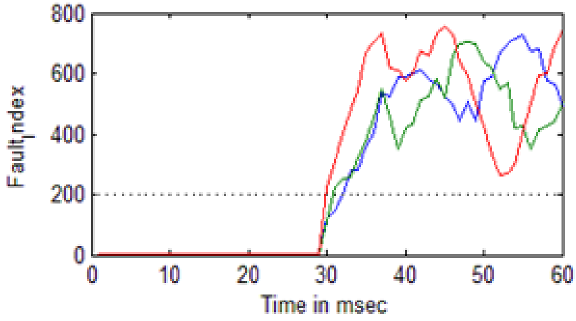

Fig 12 Detection of LLLG fault at wind generation

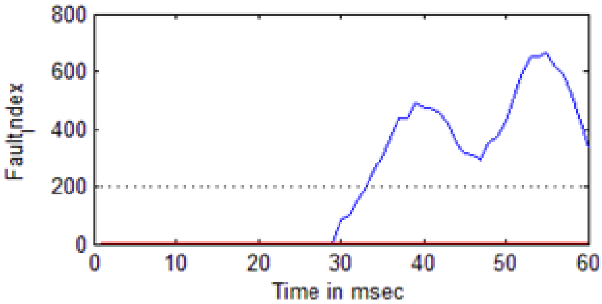

Fig 13 Detection of LG fault at PV generation

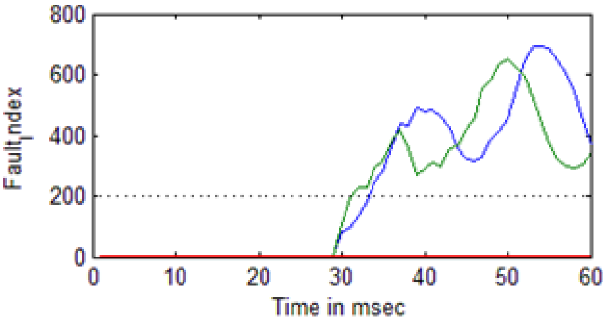

Fig 14 Detection of LLG fault at PV generation

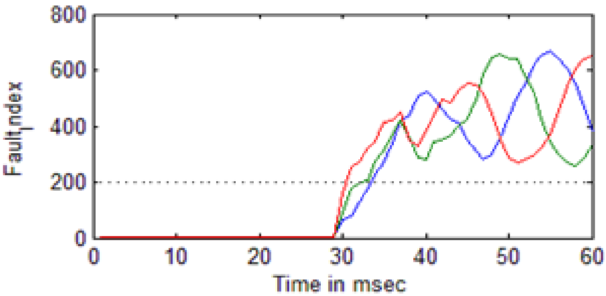

Fig 15 Detection of LLLG fault at PV generation

Figures 7-9 illustrates the variation of fault index for transmission system at fault inception angle 80^0 with LG, LL, LLG and LLLG Faults on Phase ABCG on Bus2.

Figures 9-12 Shows the Detection of LLG fault at Wind turbine generation with LG, LL, LLG and LLLG Faults on Phase ABCG.

Figures 13-15 Shows the Detection of LLG fault at PV generation with LG, LL, LLG and LLLG Faults on Phase ABCG.

7. Conclusions

The protection scheme must ensure that safe operation of the micro grid in both mode of operation, that is the grid connected mode and island mode. Due to contribution of host grid in grid connected mode fault currents are large. The determination of the time when it is islanded from the main grid in response to abnormal conditions. The provision of properly coordinated and reliable protection system so that it can reliably trip in the event of a fault within it. In this paper, the test system is created and simulated using the power system block set with SIMULINK software. Wavelet Multi Resolution Analysis is used for detection, classification and location of faults on transmission lines. Detail D1 coefficients of current signals using Bior1.5 wavelets are used to detect, classify of fault. The proposed protection scheme is found to be fast, reliable and accurate for various types of faults on transmission lines with microgrid containing battery, PV cell, fuel cell and wind turbine generation.

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