Wavelet Based Multi-Terminal Transmission Line Protection with MicroGrid

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Abstract: - This paper introduces a novel protection scheme for protecting multi-terminal transmission system combined with microgrid comprises of wind, solar, fuel cell energy sources.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 and transmission system. Protection must respond to both utility grid and microgrid faults. The major challenges are a protection system for microgrid which must respond to main grid as well as microgrid faults. After the microgrid is model is developed and it is connected to an equivalent multi terminal transmission system. Wavelet Multi Resolution Analysis is used for detection, classification and location of faults on multi terminal transmission system as well as microgrid resources.The proposed algorithm is tested and it is proved for the detection, classification of faults on transmission system with microgrid 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

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.

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.

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. In this paper, the validation of wavelet based fault location methods are performed on a multi terminal transmission system with microgrid comprises wind, solar and fuel cell energy sources. After the microgrid model is developed, it is connected to an equivalent transmission system. A fault is simulated on the transmission line so that the fault location algorithm can be applied to detect the fault as well as location estimation with the existence of microgrid. The scheme is tested for different types of faults with varying fault incidence angles and fault resistances using typical transmission line model.

2. Technical challenges in micro grid 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 of the issues related to a protection of microgrids and distribution grids with a large penetration of distributed energy resources. 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]. 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. 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].

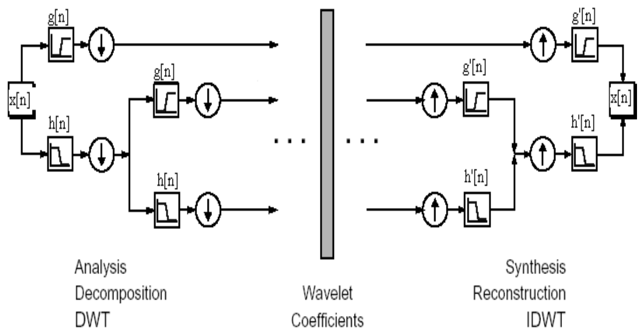

Fig 1.Analysis of signal using wavelet transforms

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 Wavelet transform 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.

4. Modelling of Hybrid Micro Grid connected to utility Grid

Non-conventional energy resources, such as solar PV, fuel cell 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. The proposed system model is described in Figure2.

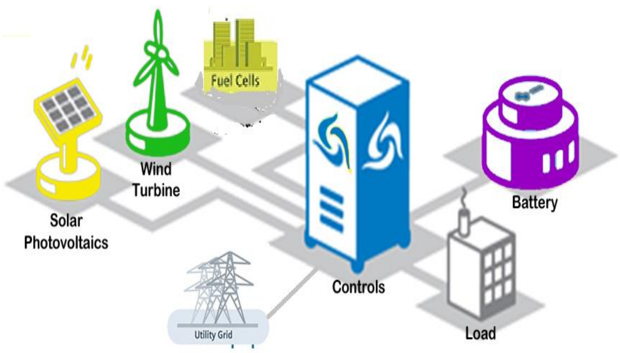

Fig 2: Microgrid connected energy resources to utility grid

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.

$I = I_{ph} - I_D$ (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.

$\lambda = \omega_m R/V$ (2)

$P = 1/2 C_P \rho V^3_w AW$ (3)

ω_m = 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 (m2).

ρ = Density of Air (kg/m3).

5. Micro Grid Fault Analysis with System Modelling

In micro grid, fault analysis can be categorizing mainly two types 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 microgrid 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 modes 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].

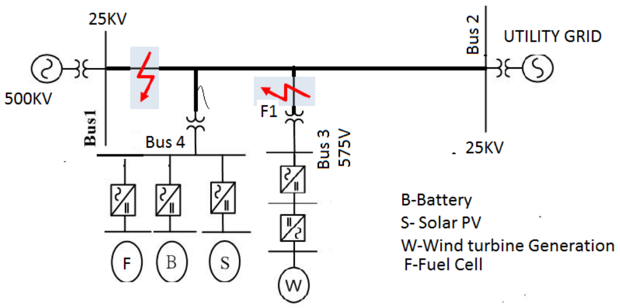

Fig 3. Single line diagram for microgrid connected to utility grid

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.Figure 3. Represents the Single line diagram for microgrid connected to utility grid

6. Result analysis

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.

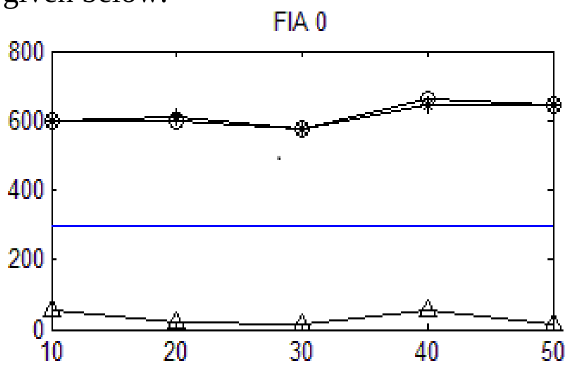

Fig 4. Variation of fault index from Bus1 at LL Fault on Phase AB for transmission line at Fault Inception Angle 0^0

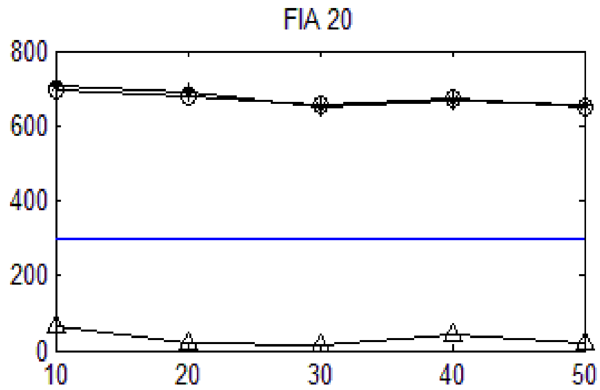

Fig 5.Variation of fault index from Bus1 at LL Fault on Phase AB for transmission line at Fault Inception Angle 20^0.

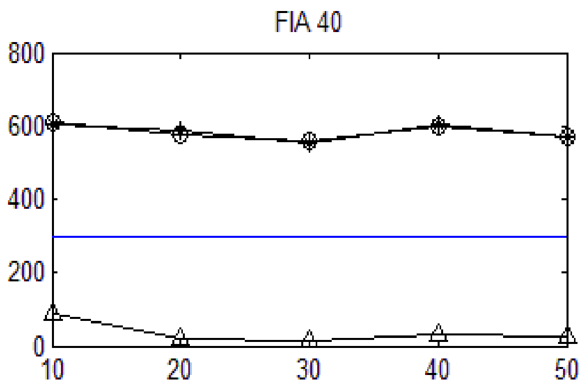

Fig 6. Variation of fault index from Bus1 at LL Fault on Phase AB for transmission line at Fault Inception Angle 40^0.

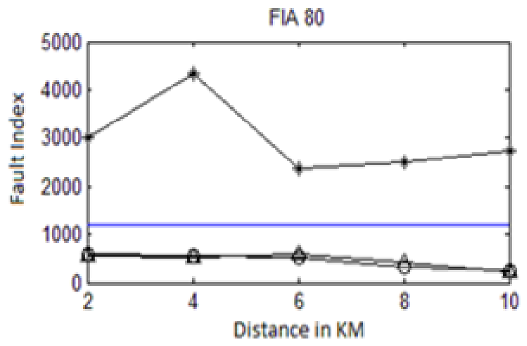

Fig7. Variation of fault index from Bus2 at LG Fault on Phase AG for transmission line at Fault Inception Angle 80^0.

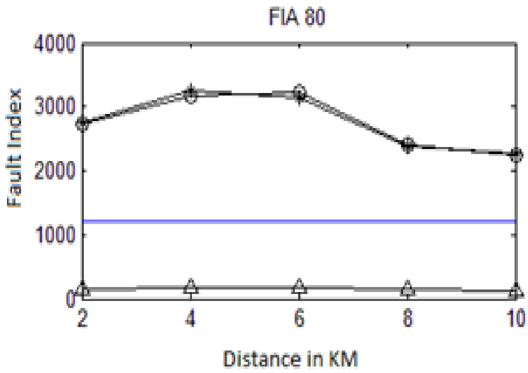

Fig8. Variation of fault index from Bus2 at LLG Fault on Phase ABCG for transmission line at Fault Inception Angle 80^0.

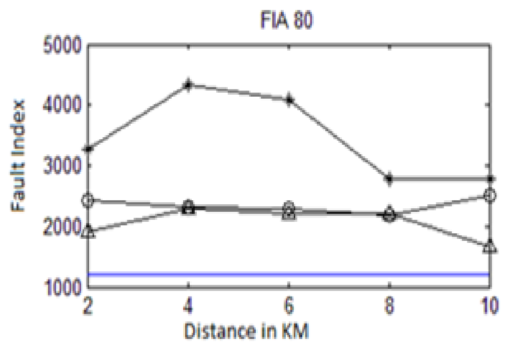

Fig9. Variation of fault index from Bus2 at LLLG Fault on Phase ABCG for transmission line at Fault Inception Angle 80^0.

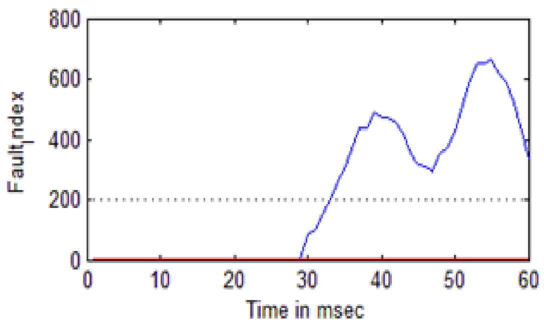

Fig 10: Detection of LG fault at wind generation

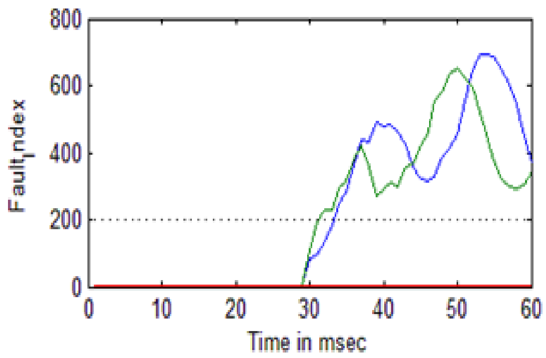

Fig 11: Detection of LLG at wind generation

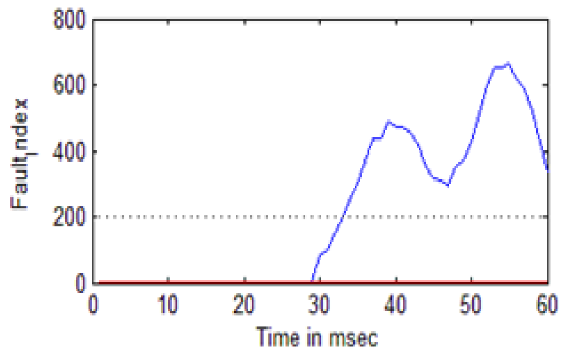

Fig 12 Detection of LG fault at PV generation

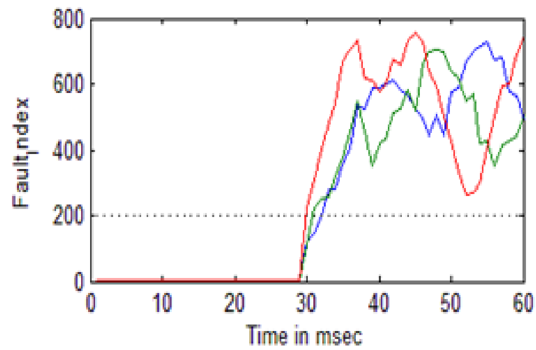

Fig13 Detection of LLLG fault at PV generation.

Figures 4-6 illustrates the variation of fault index for transmission system at fault inception angle 0^0, 20^0, 40^0 LL Fault on Phase AB on Bus1.
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 10-11 shows the Detection of fault with LG, fault currents and LLG Faults at wind generator on Phase ABG.
Figures 12-13 Shows the Detection of fault at PV generation with LG,LLG and LLLG Faults on Phase ABCG

7. Conclusions

This paper describes an innovative technique based on wavelet multi resolution analysis is used to detection, discrimination and location of the fault in the multi terminal transmission system with microgrid comprising of solar, wind turbine, and fuel cell generation. The test system is created and simulated using the power system block set with SIMULINK software. The proposed protection scheme tested and found to be fast, reliable and accurate for LG, LL, LLG, LLL and LLLG types of faults on transmission lines irrespective of fault impedance, inception angle and location of the fault.

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