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Load Bus Symmetrical Fault Analysis in Microgrid System

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Abstract
In this paper an attempt has been taken to detect grounded and ungrounded symmetrical fault in a solar energy fed micro grid system. At first a 400 KW microgrid model with an average model based inverter unit has been modeled. The output of the inverter units feeds to conventional grid as well as load units. Inverter output terminal currents have been monitored. DC components, total harmonic distortion and wavelet decomposition based few statistical parameters have been analyzed at normal load condition as well as grounded and ungrounded symmetrical fault at load bus. Then comparative study has been made which has shown significant difference in harmonic distortion and wavelet decomposition based statistical parameter that may be useful in diagnosis of such fault.

Keywords:
Grounded symmetrical fault, ungrounded symmetrical fault, DC component, total harmonic distortion, wavelet analysis

1. Introduction

In recent years, number of solar based microgrid systems has increased to meet the ever increasing green energy demand. Synchronism and fault diagnosis are two important aspects to deal with microgrid. A lot of survey and research work are going on using the current signature analysis in this matter [1]-[4].

Quality of voltage source converter based microgrid operation [2] has been observed. Performance of low voltage microgrid distribution networks connected with power electronics system has been studied in [3]. Xin Wang et al has done smart power grid synchronization with fault tolerant nonlinear estimation [4], where modeling and simulation have demonstrated using fault tolerant extended Kalman filter (FTEKF) to provide better voltage synchronization results than the extended Kalman filter (EKF). Gilmanur Rashid et al (2015) has enhanced transient stability of doubly fed induction machine-based wind generator using bridge-type fault current limiter [5] in microgrid to provide better power quality; where effectiveness of the BFCL and series dynamic braking resistor (SDBR) have been compared. Modeling of doubly fed induction generator wind turbine systems has been introduced subject to recurring symmetrical grid faults [6]. Performance of the doubly fed induction generator (DFIG) used in wind turbine system has been studied under recurring symmetrical grid faults [7] , where modeling and simulations were carried out using an IEEE 30-bus power system and medium-scale micro-distribution systems. Mathematical morphology-based islanding detection has been shown for distributed generation [8]. GPS - based control framework has been modeled for accurate current sharing and power quality improvement in Microgrids [9]. Symmetrical and asymmetrical low-voltage ride through of doubly-fed induction generator coupled with wind turbines has been modeled using gate controlled series capacitor [10]. Rashad et al (2016) has presented described control methodology of inverter used in standalone micro-grid system [11]. Novel harmonic mitigation method [12] has been introduced for power distribution network in minigrid. New virtual harmonic impedance scheme has been introduced for harmonic power sharing in an islanded microgrid [13]. Virtual damping flux-based LVRT Control has been used for DFIG-Based Wind Turbine [14] with a 2-MW DFIG in MATLAB/Simulink environment to provide smooth electromagnetic torque and to minimize different grid faults. Adaptive neuro-fuzzy controlled-flywheel energy storage system has been introduced [15] for transient stability enhancement. Useful mathematical tools have been described for harmonics assessment [16] that have been found very effective in fault assessment [17].

However very few works are found on harmonics assessment based microgrid based power system. This has motivated to work on harmonic assessment based fault detection in microgrid system. Attempt has been taken to model a micro grid then to perform FFT based harmonics assessment for fault diagnosis in microgrid system. Harmonic distortion has been monitored for fault diagnosis in [18 – [19]. In this paper extended work of [18-19] by introducing dc component measurement and wavelet analysis has been presented.

2. System Architecture of Micro Grid

A 400KW solar PV Array based average model micro grid system has been modeled as shown in Fig.1. The output of Parallel connected PV arrays have been fed to three phase average model inverter through charge controller and in Inverter unit average model based VSC having 3 bridge arms has been considered. Total 64 strings have been used in each PV array and total 5 numbers of series connected modules are used in each string having following parameters: Maximum power - 315.072W, Cells per module - 86, Open circuit voltage - 64.6 volts, Short circuit current - 6.14 A, voltage – 54.7 volts and current –5.76 A during maximum power point, temperature coefficient of "-0.27269" %/deg.C and "0.061694" %/deg.C during open circuit voltage and short circuit current, Light-generated current of 6.1461 A, Diode saturation current of 6.5043×10^{-12} A, Diode ideality factor of0.9507, Shunt and Series resistance are 430.0559 ohms and 0.43042 ohms respectively. Output of the Inverter is fed to star/delta type three phase transformer of 400KVA, 260V/25KV, 60Hz. Transformer secondary feeds power to load Bus (BUS-2), which is also connected with conventional 120kV, 2500 MVA grid through a 3 - phase 400KVA, 260V/25KV, 60Hz star/delta transformer.

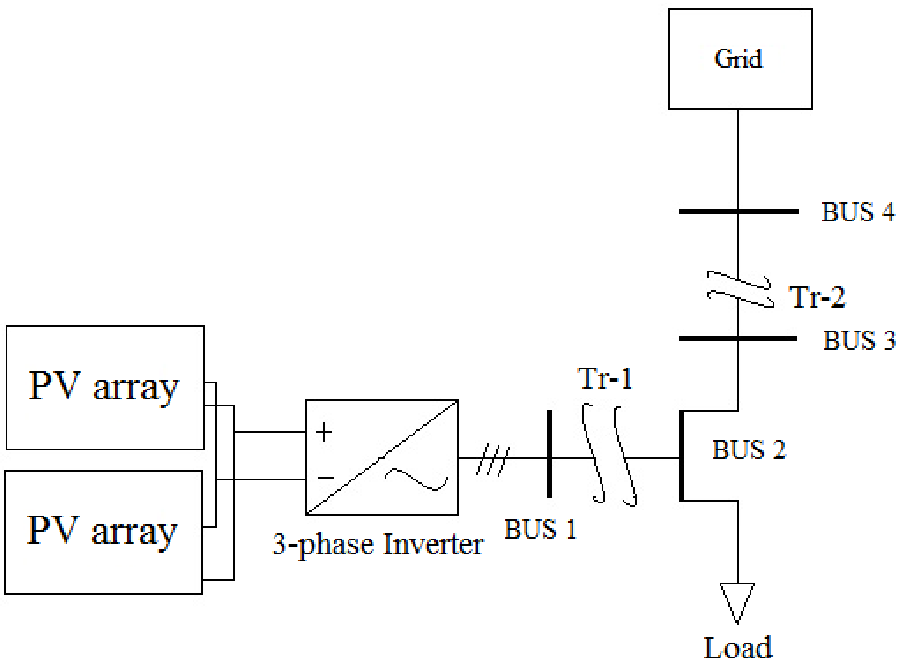

Fig. 1 Layout of solar PV array based average modeled microgrid system

3. Analysis of DC Component

In this work, the average model solar PV array based microgrid system has been described and continuous symmetrical fault at load bus (Bus 2) considered for computer simulation of model shown in Fig. 1. To measure the output inverter currents of each phase, three different current measurement units have connected. Each phase currents have been captured by using the current measurement units. Under normal condition, ungrounded symmetrical fault (LLL) and grounded symmetrical fault (LLLG), the waveform of individual phase currents have been monitored and analyzed by Fast Fourier Transform (FFT). Here the DC components have been measured by monitoring the FFT spectrums.

Table 1

Values of DC components of current signals for phase –A, B and C during nornal, LLL and LLLG measured at inverter output terminal

Phase	Normal	LLL	LLLG
A	0.2347	12.5	13.75
B	24.12	24.23	26.11
C	24.35	36.74	39.86

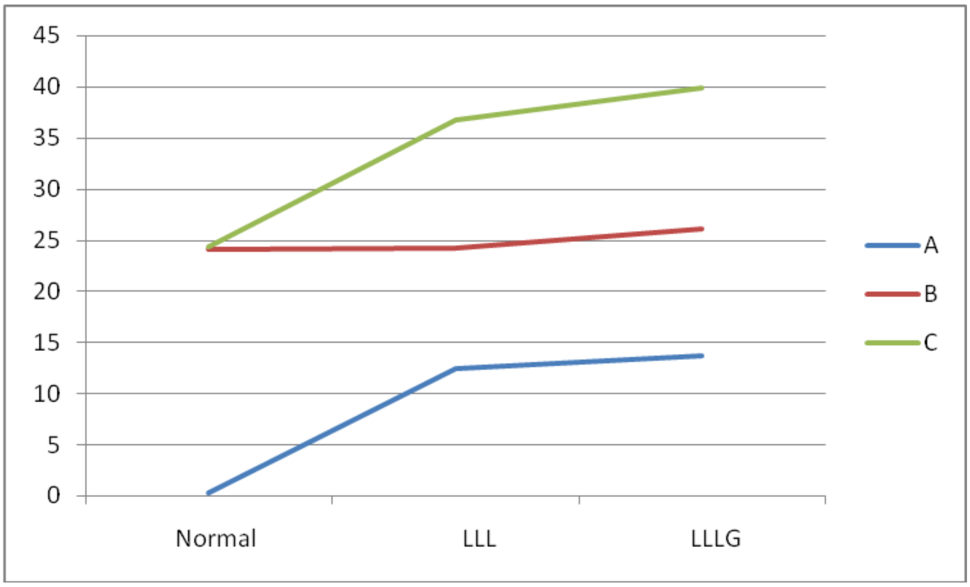

Fig. 2 Variation of DC components of current signals for phase – A, B and C during nornal, LLL and LLLG measured at inverter output terminal

The Fig. 2 shows the variations of DC components for phase –A, B and C under normal, LLL and LLLG fault conditions . During normal condition DC component values for phase –B and C are same but for phase –A, it shows lesser magnitude than that of phase –B and C.
However, for LLL fault condition the DC magnititudes have increased as compare to the normal condition for all phases.The rates of increase of magnitude for phase-A and C are more than phase –B. Magnitude of phase –B is greater than of phase –A but magnitude of phase – C is highest compared to other two.
The magnitudes during LLLG fault condition for phase –A, B and C have increased slightly than LLL fault condition. Here also magnitude of phase –B is greater than of phase –A but magnitude of phase – C is highest compared to other two like LLL fault condition.

4. Analysis of Harmonics Distortion

FFT spectrums at different conditions are compared in [18]-[19]. Comparison shows significant changes in FFT spectrums of symmetrical fault conditions from that of normal condition. Also FFT spectrums at LLLG fault differ from FFT spectrums at LLL fault. After, FFT based spectrum comparison; THD values obtained at different conditions are compared. Maximum THD values at normal condition which reduces drastically at symmetrical fault condition. THD at LLLG and THD at LLL are found much closed to each other; however THD is found minimum at LLL fault condition as shown in Fig. 3.

Table 2

Total Harmonic Distortion of line currents at Phase–A, B and C during normal, LLL and LLLG fault conditions

THD (%)	Normal	LLL	LLLG
Phase-A	26.46	11.76	11.82
Phase-B	22.03	9.89	9.81
Phase-C	24.67	9.81	9.4

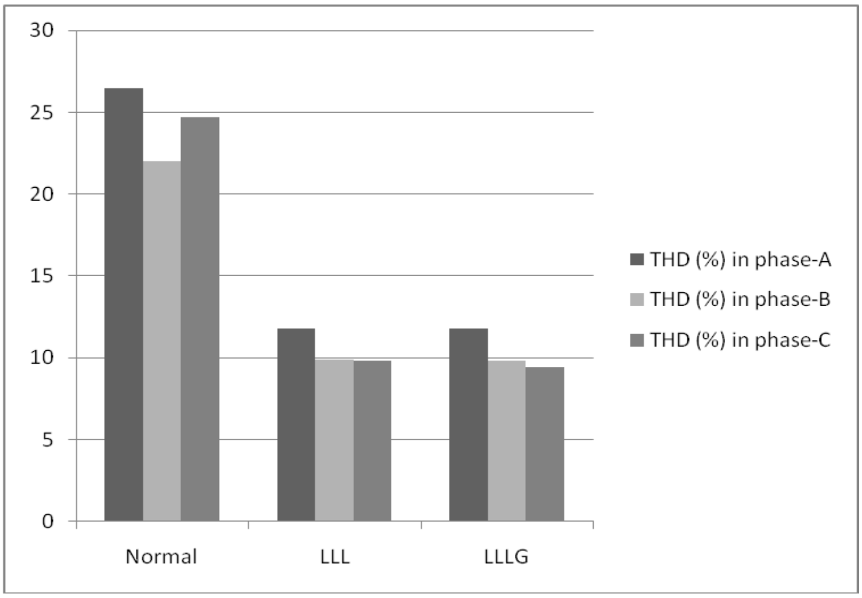

Fig. 3 Total Harmonics Distortion at normal, LLL and LLLG fault conditions [19]

The Fig. 3 shows the Total Harmonic Distortion(THD) for phase –A, B and C under normal, LLL and LLLG fault conditions . THD at normal condition comparetively greater than that of LLL and LLLG fault onditions. During normal condition THD at phase –C is higher than phase – B and phase –A is highest compare to other two phases. At LLL fault condition the THD have decreased as compare to the normal condition for all phases.The THD for phase –B and C are almost same and phase –A is maximum for LLL fault condition. Under LLLG fault condition THD have decreased as compare to the normal condition for all phases, however, THDs are at LLL and LLLG fault conditions are almost similar.The main advantage of THD analysis is that, the symetrical faults (LLL and LLLG) can easily be identifed by comparing with the normal condition. However, the main dwrwback of this THD analysis is that the specific type of symetrical faults can not be identified easily by this technique.

5. Analysis of DWT based skewness assessment

The drawback of THD analysis has been overcome by introducing Discrete Wavelet Transformation (DWT) based diagnosis technique for identifying the symmetrical faults in microgrids. Flow diagram of DWT based skewness assessment has been shown in Fig.4 where first current signals of inverter output have been captured. Then wavelet decomposition has been carried out for current signals of all phases. Due to discrete nature of the signals, the Discrete Wavelet Transformation has been used for determination of approximate and detail co-efficients from DWT level 1 to 9. The skewness values of approximate co-efficients (SA) and detailed co-efficients (SD) during normal, LLL and LLLG fault conditions have been presented in Table 2 and Table 3.

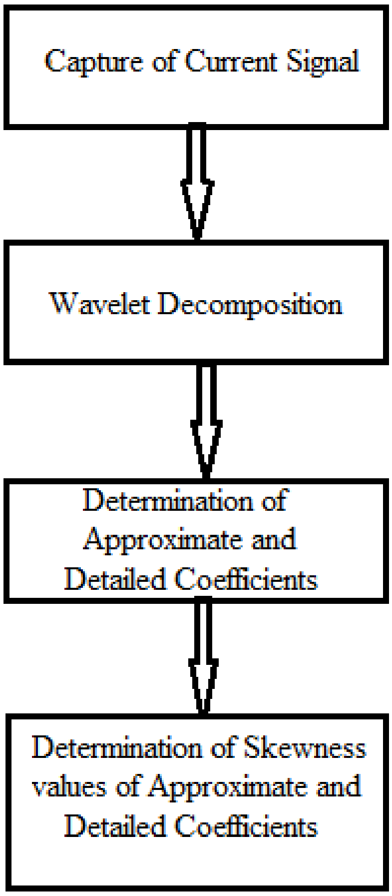

Fig. 4 Flow diagram of Wavelet analysis

Table 3

Skewness values of approximate co-efficients at Normal, LLL and LLLG fault conditions

DWT Level	SA_N	SA_LLL	SA_LLLG
1	-0.00049	-0.00073	0.00051
2	-0.00049	-0.00071	0.000519
3	-0.00049	-0.00049	0.000603
4	-0.00055	-0.00056	0.000678
5	-0.00054	-0.00084	0.001057
6	-0.00015	0.000524	-0.01293
7	1.584857	1.611494	-1.61812
8	2.236017	2.234001	-1.93272
9	2.787768	2.807118	-3.36569

Table 4

Skewness values of detailed coefficients at Normal, LLL and LLLG fault conditions

DWT Level	SD_N	SD_LLL	SD_LLLG
1	-3.3088	-0.26753	-1.75815
2	-0.37391	-0.01306	-0.1219
3	0.032195	-0.00335	-0.01451
4	0.025761	0.065788	0.012421
5	0.005616	0.003041	0.000796
6	-0.01207	-0.01281	0.006567
7	-0.00174	-0.00012	-0.0247
8	-1.46528	-1.51754	2.115801
9	-0.33417	-0.3346	0.385852

At various DWT Levels the skewness values of approximate co-efficients (SA) have changed as shown in Fig. 5. The SA values from DWT level 1 to 6 are almost same under normal, LLL and LLLG fault conditions. Thereafter, SA values from DWT level 6 to DWT level 9 during normal condition and LLL fault conditions have increased but SA values have decreased for LLLG fault condition.

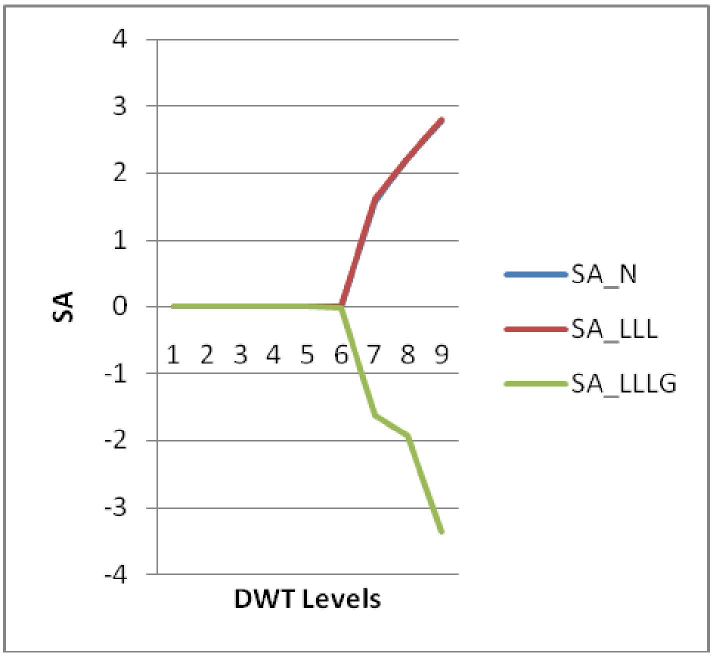

Fig. 5 SA versus DWT Levels

At various DWT Levels the skewness values of detailed co-efficients (SD) have changed as shown in Fig. 6. The SD values from DWT level 1 to 3 are totally different for normal, LLL and

LLLG fault conditions, SD values for LLL and LLLG fault conditions are higher compare to normal condition and among the two faults the SD values are higher for LLL fault. Thereafter SD values from DWT level 3 to DWT level 7 are almost same for conditions. At DWT level 8 the SD values for LLLG fault condition are then the normal and LLL fault condition.

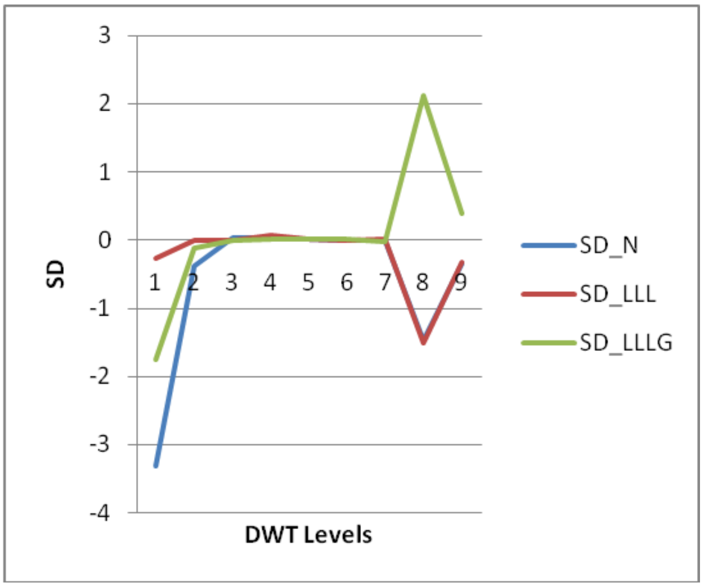

Fig. 6 SD versus DWT Levels

SA, as observed from Fig. 5 cannot discriminate three state of operation viz. normal, LLL fault and LLLG fault. But SD as observed in Fig.6 is clearly distinguishing normal condition, LLL fault and LLLG fault at DWT level 1; therefore, may be chosen for symmetrical fault diagnosis.

6. Conclusion

Grounded and ungrounded symmetrical faults have been detected from inverter terminal end in a microgrid. Current signals of normal and fault conditions have been studied. DC components present in the signals have been measured and then harmonic distortion of the current signals at normal and fault conditions have been determined. THD has been found different for normal and symmetrical fault condition. However, it could not differentiate type of the symmetrical fault whether it is grounded or ungrounded. To overcome this limitation, wavelet decomposition has been performed and skewness of approximate and detailed coefficients has been determined for all three phases both at normal condition fault conditions. Skewness of detailed coefficients shows distinct difference for grounded and ungrounded faults. The result may be useful for grounded and ungrounded symmetrical fault diagnosis with may be extended for diagnosis of unsymmetrical faults also.

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