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Faults Detection and Isolation in Wind Energy System using Digital Protection

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Modern power system is highly penetrated with the green energy comprised of solar, wind and mini hydro power plants all over the power grid. Fault analysis and protection plays a dominant role for avoiding the islanding, partial blackout or complete blackout of the power system. Wind plant was designed and with Asynchronous Generator with self excitation equipped with a STATCOM. Fault analysis have been performed in this plant with all kinds of faults such as three phase fault, LG fault, LL fault and LLG faults. Type and location of faults have been detected with the help of identification of low voltages and huge currents in appropriate bus and phase of the system. The wind system is simulated with two cases, case1 with detection of fault and without protection and case2 is with detection and digital protection with isolation of fault. The simulation results have been proven that the digital protection scheme is most powerful in restoring the system with immediate isolation of fault from the rest of the wind energy system.

1. Introduction

The modern age requires huge amount of power, which can be met by the high penetration of the green energy generation with wind and solar power plants. This article focuses on wind power equipped with the asynchronous generator with self excitation. The wind power plant is designed for feeding remote loads in the villages and thandas of the Indian continental, where there is no availability of the power supply either D.C or A.C. Hence asynchronous Generator is embedded in the wind plant as a power generator, which does not need any power supply except reactive power supporting equipment. In this article wind plant is developed with self excited asynchronous generator with capacitor bank and Static Synchronous Compensator (STATCOM). Fault analysis plays a major role in modern power system, which has been equipped with huge amounts of green energy such as solar, wind and mini hydro power plants. Diagnosis of both symmetrical faults and unsymmetrical faults viz. three phase fault, LG fault, LL fault and LLG faults. The faults are identified with the waveforms of both phase voltages and phase currents of the system at different parts of the system. The digital protection is quite essential and used to isolate the fault from the healthy part of the power system in order to restore the system.

The developed system have been simulated with two different cases, case I is identification of faults with the use of phase voltages and phase currents at various locations of wind power plant and case 2 with isolation of fault with the use of digital protection.

- Designed and developed wind power plant model for remote loads with Asynchronous Generator with capacitor bank in the self excited mode without any additional electrical supply or grid.
- Performed fault analysis at different locations of wind power plant with three phase fault, LG fault, LL fault and LLG faults
- Isolated the faulty section from the healthy part of the system to restore the WES to its normal state with the use of digital protection.

Organization of the article:

Section II describes the main system which comprising of the wind power plant, asynchronous generator, STATCOM and power quality compensation equipment. Section III discusses the simulation models of wind plant with STATCOM and power quality compensators and subsequent part describes the FFT analysis with THD values for both of these cases. Lastly comparative analysis of power plant without and with harmonic compensators have been performed with wave forms, tabular forms and bar graphs.

2. MATERIALS AND METHODS

In this section the developed components of the wind power plant, FACTS devices and their mathematical models, design and development for mitigation voltage harmonics including the development of filters have been discussed.

II.1. WIND POWER PLANT

Wind Power Plant with asynchronous generator with a capacitor bank and STATCOM has been illustrated in Fig.1 depicts the Wind Power Plant with asynchronous generator with STATCOM and the equations 1 to 4 describe the mathematical modelling of the wind plant.

$$P_w \quad \frac{1}{2}\left(C_p(\lambda, \beta) A V^3\right) \tag{1}$$

$$C_p = 0.22\left(\frac{116}{x} - 0.4\beta - 5\right)e^{\frac{-12.5}{x}} \tag{2}$$

$$\frac{1}{x} = \frac{1}{(\lambda - 0.08\beta)} - \frac{0.035}{(1+\beta^3)} \tag{3}$$

$$\lambda = \frac{wR}{v} \tag{4}$$

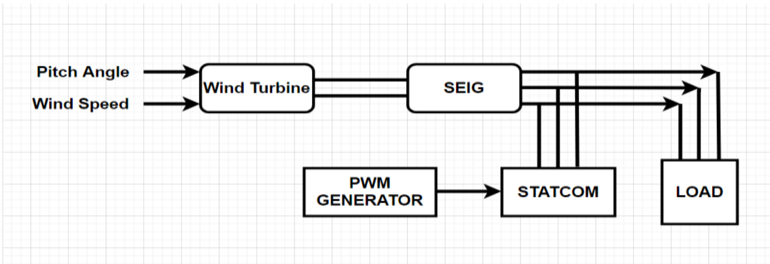

Fig.1 Wind Power Plant with Self Excited Induction Generator with STATCOM

II.2. ASYNCHRONOUS GENERATOR

Asynchronous generator equations have been described below and it is operating in negative torque-slip region [7] and [9]. Equations 4 to 8 describes the mathematical modeling of the Asynchronous Generator used as self excited wind generator.

Stator Side Equations

$$V^a_{abcs} = r_s \left(i^a_{abcs}\right) + \frac{d\lambda^a_{abcs}}{dt} \qquad (5)$$

$$\lambda^a_{abcs} = \left(L_s + M\right)\left(i^a_{abcs}\right) + L_{sr}(i^a_{abcr}) \qquad (6)$$

Rotor side Equations

$$0 = r_r \left(i^a_{abcr}\right) + \frac{d\lambda^a_{abcr}}{dt} \qquad (7)$$

$$\lambda^a_{abcr} = \left(L_r + M\right)\left(i^a_{abcs}\right) + L_{sr}(i^a_{abcs}) \qquad (8)$$

II.3 STATCOM

STATCOM is a shunt connected device which employs IGBT as depicted in Fig.2, which is basically fast acting switching device in order to improve stability of power system. The Fig.3depicts the V-I Characteristics of STATCOM VI characteristics depicts that the STATCOM [1] to [5].

Mathematical Modelling of DSTATCOM

The equations for active power, reactive power of STATCOM are as follows; Consider V_t = system terminal voltage

V_{st} = STATCOM output voltage

X_L = Inductive reactance

V_c = DC capacitor voltage

$$P = \frac{V_t V_c}{X_L} \sin sin\, \alpha \qquad (1)$$

$$Q = \frac{V_t V_t}{X_L} - \frac{V_t V_c}{X_L} \cos cos\, \alpha \qquad (2)$$

The equation of DSTATCOM DC side can be given as;

The mathematical equations of DSTATCOM can be expressed as;

L = series inductance

R = series resistance

i_{ac}, i_{bc}, i_{cc} are output currents of DSTATCOM

V_{ac}, V_{bc}, V_{cc} are output voltages of DSTATCOM

V_{ta}, V_{tb}, V_{tc} are terminal voltages

$$L\frac{di}{dt} = Ri_{ac} + V_{ac} - V_{at} \quad (3)$$

$$L\frac{di}{dt} = Ri_{bc} + V_{bc} - V_{bt} \quad (4)$$

$$L\frac{di}{dt} = Ri_{cc} + V_{cc} - V_{ct} \quad (5)$$

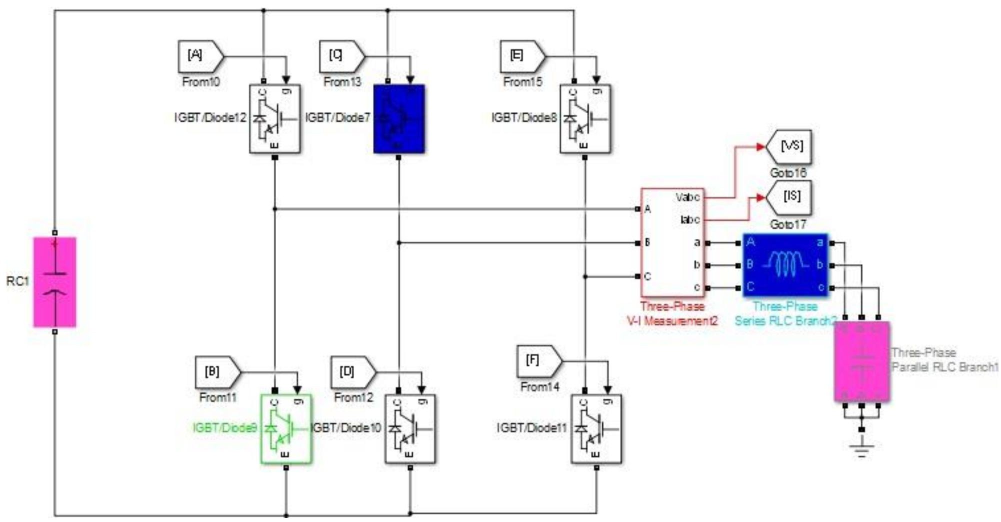

Fig.2 STATCOM Power Circuit

3. RESULTS, ANALYSIS AND DISCUSSION

The wind plant have been designed and simulated with a capacitor bank and STATCOM along with harmonic compensators. The developed wind power plant with STATCOM fed asynchronous generator have been illustrated by the below Fig. 4 and is also equipped with faults and digital protection. The developed system was designed for feeding the remote loads in villages and thandas of Indian continental without any power supply. This system is simulated for two cases, case I is identification of faults with the use of phase voltages and phase currents at various locations of wind power plant and case 2 with isolation of fault with the use of digital protection and these results have been presented in this article with phase voltages and phase currents and Fig.3 depicts the Simulink diagram of wind power plant with self excited induction generator with STATCOM and faults.

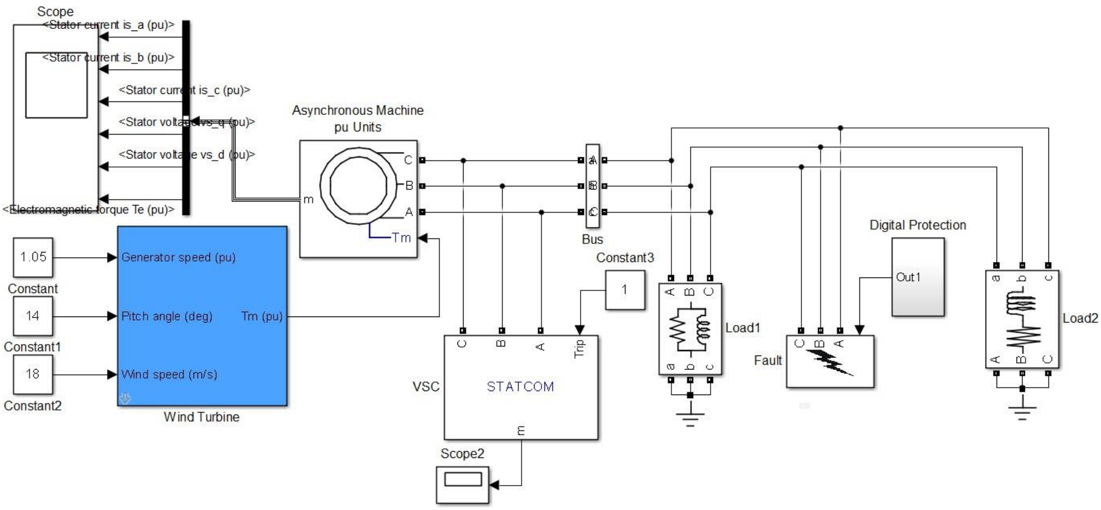

Fig.3 Simulink diagram of Wind Power Plant with Self Excited Induction Generator with STATCOM and faults

The following section of this chapter discusses the case study and results of WES fault analysis and isolation with digital protection.

Three phase fault analysis: Detection and isolation

Fig.4-6 illustrates the detection of three phase fault with under voltage relay in phase R, phase Y, phase B of WES, subsequently Fig.7 illustrates the Detection of fault with over current relay for a three phase fault in WES. Fig.8 illustrates the phase R Voltage with Isolation of three phase fault with digital protection, Fig.9 depicts the phase Y Voltage with Isolation of three phase fault with digital protection and Fig.10 detects the Phase B Voltage with Isolation of three phase fault with digital protection. Fig.11-13 shows the Phase R,Y and B phase currents with Isolation of three phase fault with digital protection.

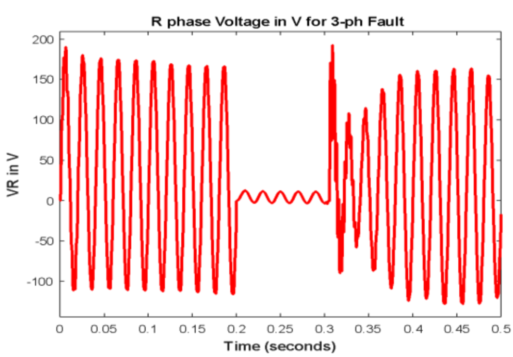

Fig.4 Detection of fault with under voltage relay in phase R for a three phase fault

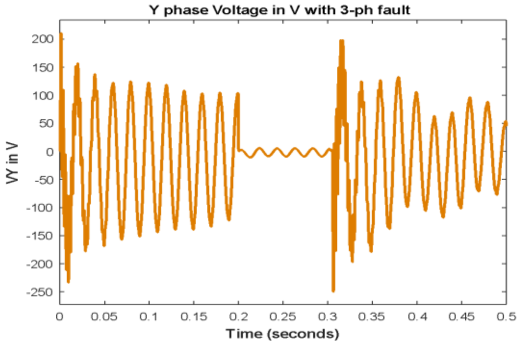

Fig.5 Detection of fault with under voltage relay in phase Y for a three phase fault

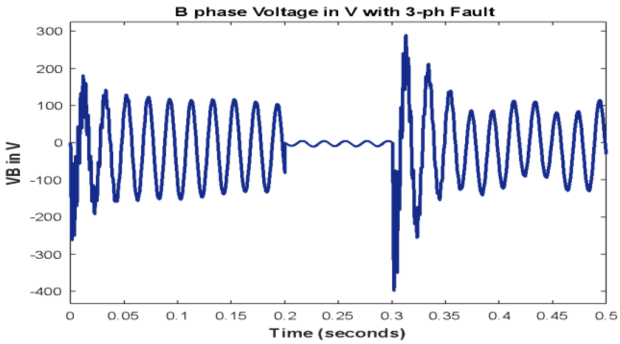

Fig.6 Detection of fault with under voltage relay in phase B for a three phase fault

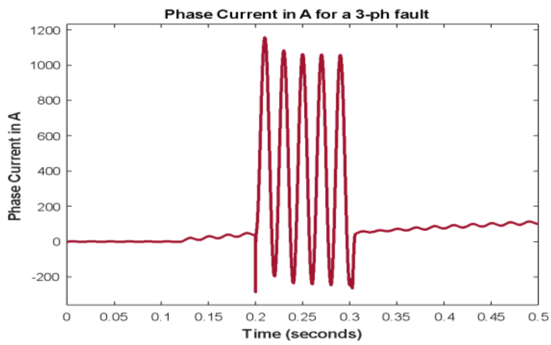

Fig.7 Detection of fault with over current relay in all phases for a three phase fault

Fault clearance with digital protection

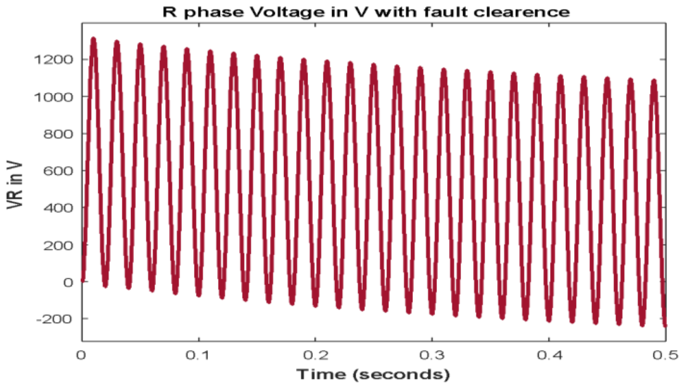

Fig.8 Phase R Voltage with Isolation of three phase fault with digital protection

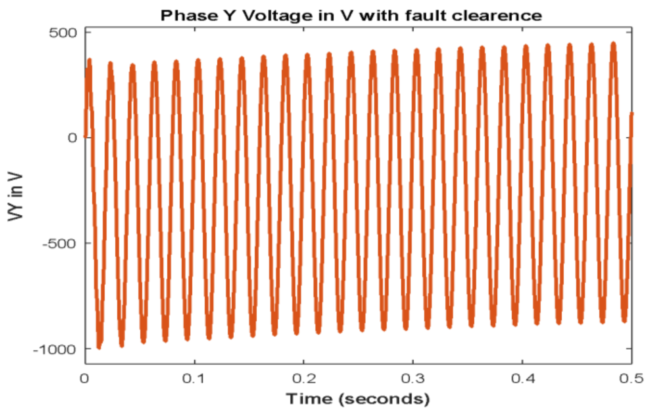

Fig.9 Phase Y Voltage with Isolation of three phase fault with digital protection

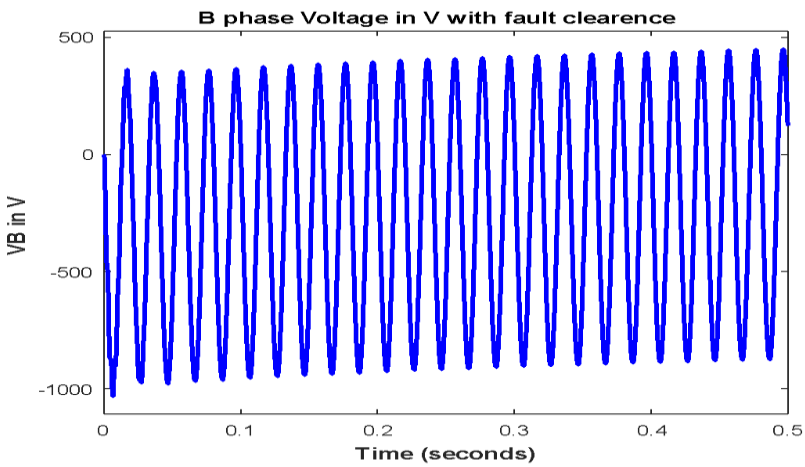

Fig.10 Phase B Voltage with Isolation of three phase fault with digital protection

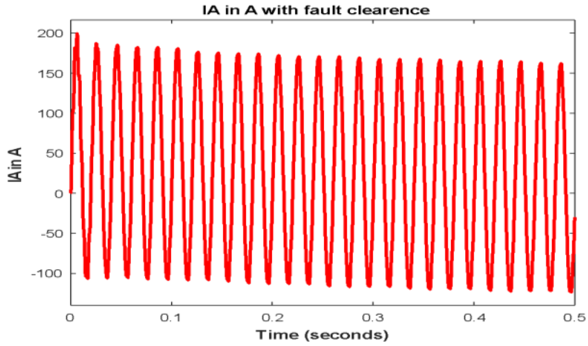

Fig.11 Phase R Current with Isolation of three phase fault with digital protection

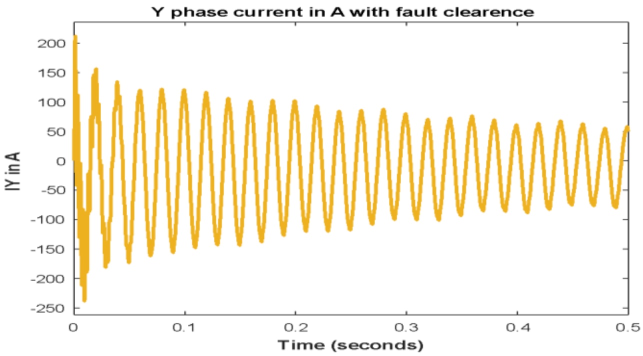

Fig.12 Phase Y Current with Isolation of three phase fault with digital protection

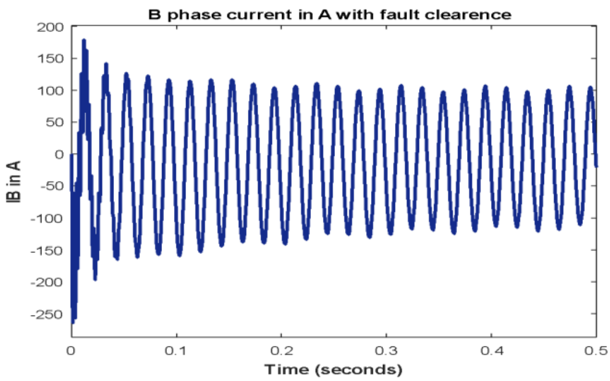

Fig.13 Phase B Current with Isolation of three phase fault with digital protection

LG Fault Analysis: Detection and isolation

The following section signifies the detection of LG fault with under voltage and over current relays and its isolation for restoring the system to its normal state. Fig.14 shows the detection of fault with under voltage relay in phase R for an LG fault, Fig.15 illustrates the detection of fault with over voltage relay in phase Y for an LG fault, Fig.16 shows the detection of fault with over voltage relay in phase B for an LG fault. Fig.17 shows the detection of fault with over current relay in phase R for an LG fault, Fig.18 depicts the phase R voltage with Isolation of LG fault with digital protection and Fig.19 illustrating the phase Y voltage with Isolation of LG fault with digital protection and Fig.20 shows the phase B voltage with Isolation of LG fault with digital protection. Fig.21 illustrate the phase R current with Isolation of LG fault with digital protection, Fig.22 depicts the phase Y current with Isolation of LG fault with digital protection, Fig.23 shows the phase B current with Isolation of LG fault with digital protection.

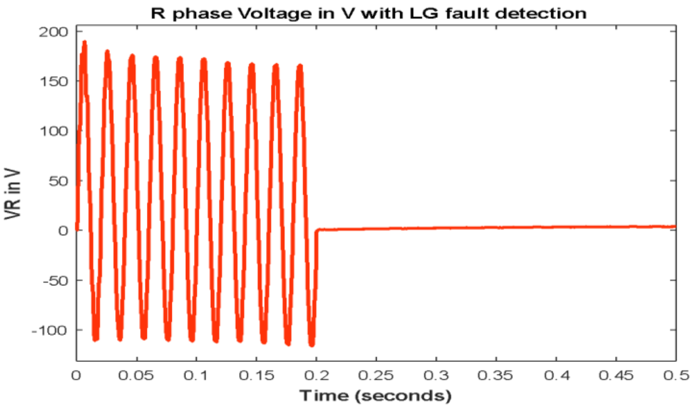

Fig.14 Detection of fault with under voltage relay in phase R for an LG fault

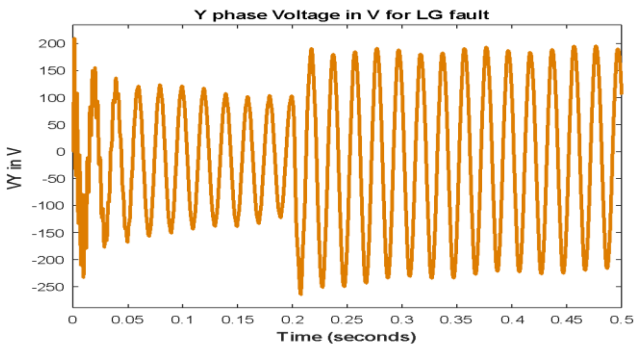

Fig.15 Detection of fault with over voltage relay in phase Y for an LG fault

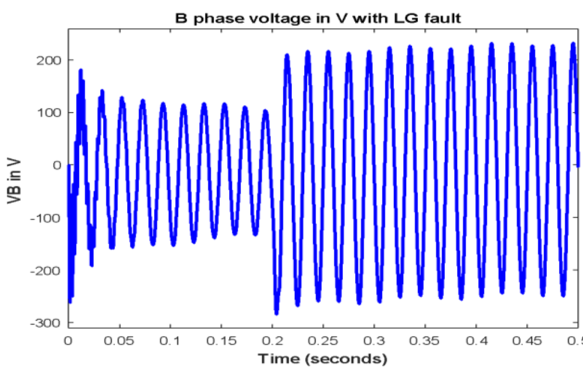

Fig.16 Detection of fault with over voltage relay in phase B for an LG fault

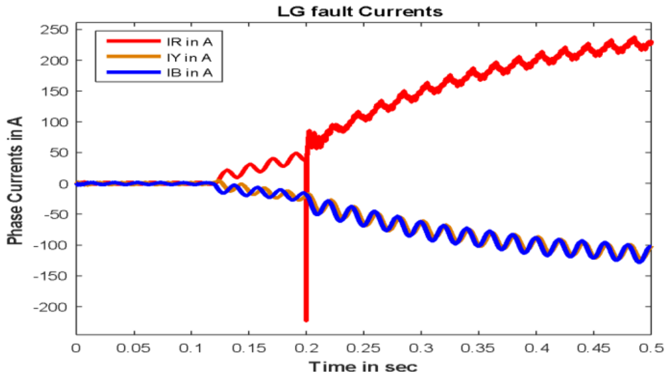

Fig.17 Detection of fault with over current relay in phase R for an LG fault

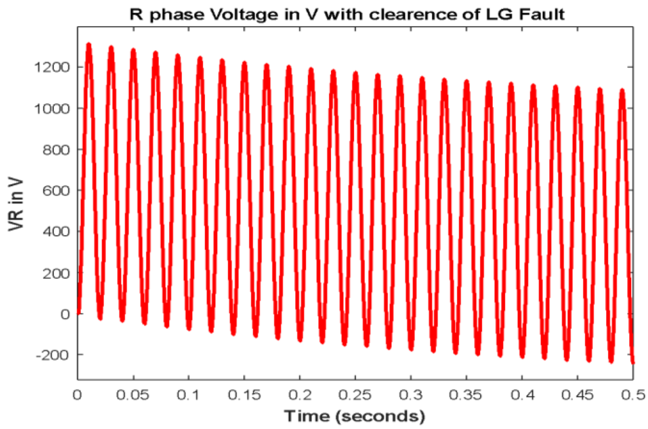

Fig.18 Phase R voltage with Isolation of LG fault with digital protection

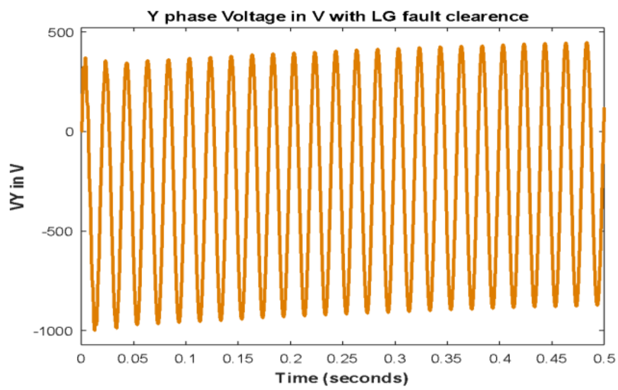

Fig.19 Phase Y voltage with Isolation of LG fault with digital protection

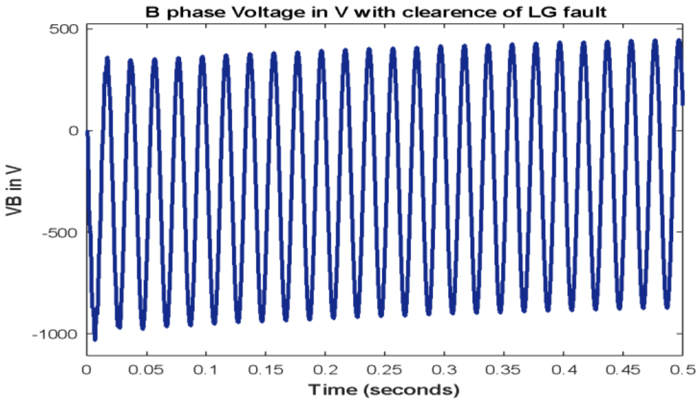

Fig.20 Phase B voltage with Isolation of LG fault with digital protection

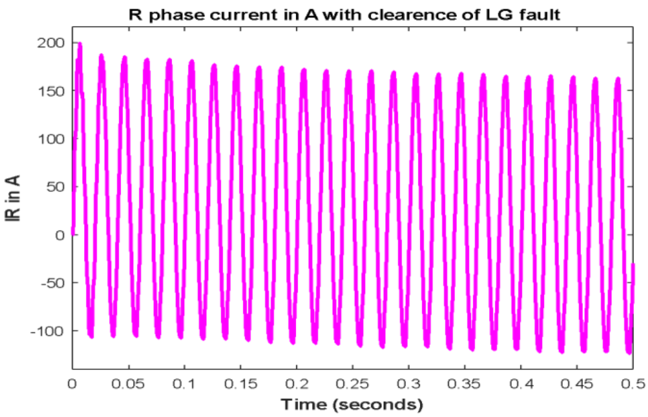

Fig.21 Phase R current with Isolation of LG fault with digital protection

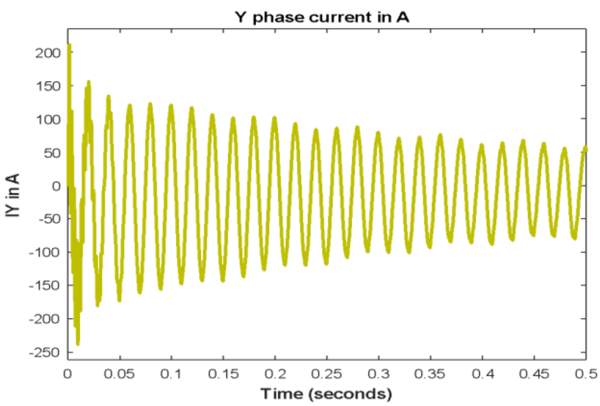

Fig.22 Phase Y current with Isolation of LG fault with digital protection

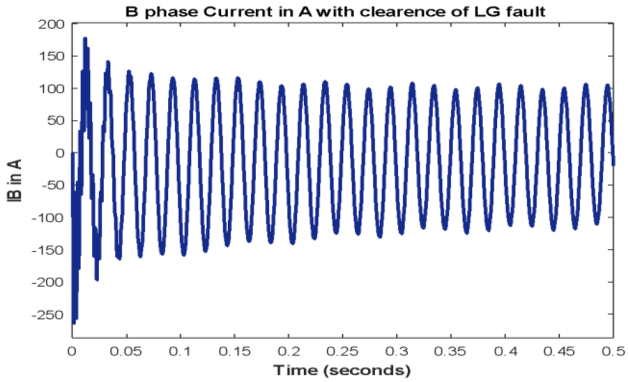

Fig.23 Phase B current with Isolation of LG fault with digital protection

LL fault analysis

LL fault analysis: Detection and isolation

The following section signifies the detection of LL fault with under voltage and over current relays and its isolation for restoring the system to its normal state. Fig.24-26 shows the phase R, Phase Y, Phase B voltages with under voltage relay for LL fault. Fig.27 illustrates the phase R Current with over current relay for LL fault with digital protection, Fig.28 shows the phase Y Current for LL fault and Fig.29 illustrates the phase B Current with over current relay for LL fault. Fig.30 depicts the phase R Voltage with clearance of LL fault with digital protection, Fig.31 illustrates the phase Y Voltage with clearance of LL fault with digital protection and Fig.32 shows the phase B Voltage with clearance of LL fault with digital protection. Fig.33 shows the phase R Current with clearance of LL fault with digital protection, Fig.34 illustrates the phase Y Current with clearance of LL fault with digital protection and Fig.35 depicts the phase B Current with clearance of LL fault with digital protection.

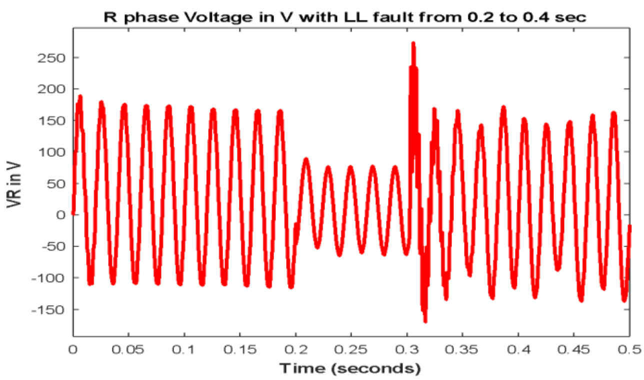

Fig.24 Phase R Voltage with under voltage relay for LL fault with digital protection

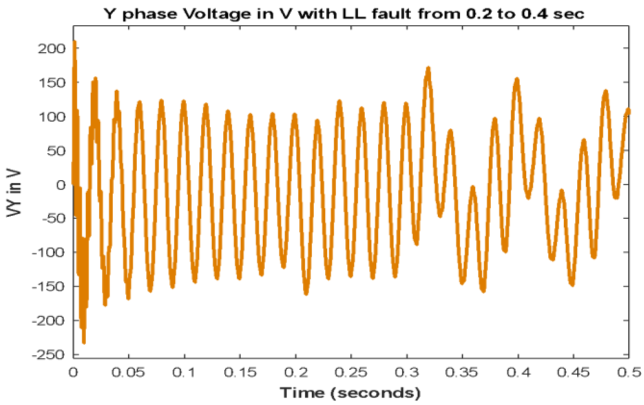

Fig.25 Phase Y Voltage with under voltage relay for LL fault with digital protection

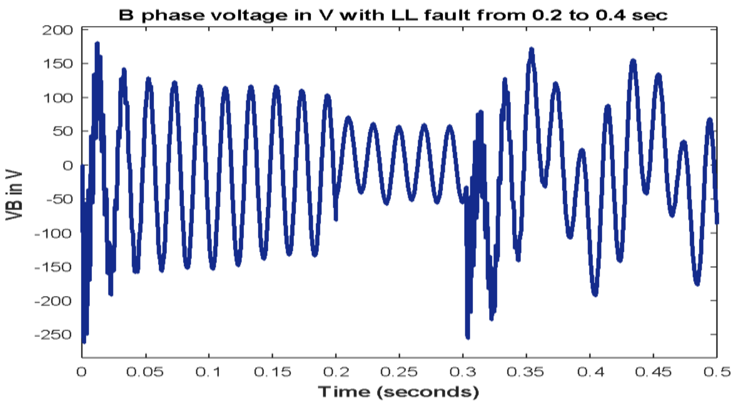

Fig.26 Phase B Voltage with under voltage relay for LL fault with digital protection

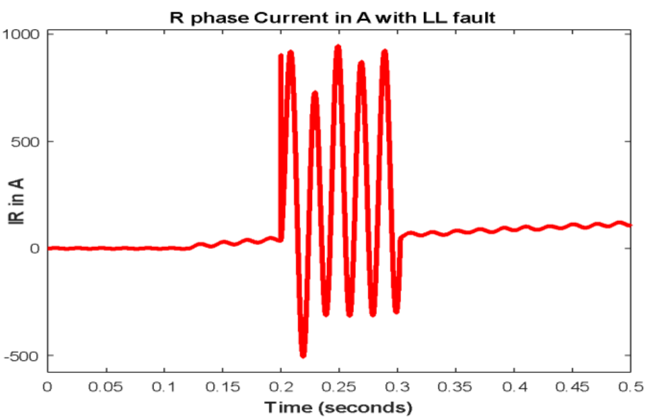

Fig.27 Phase R Current with over current relay for LL fault with digital protection

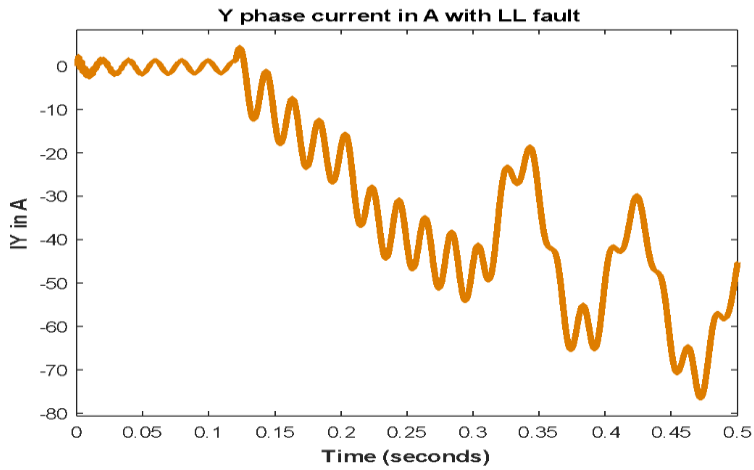

Fig.28 Phase Y Current for LL fault

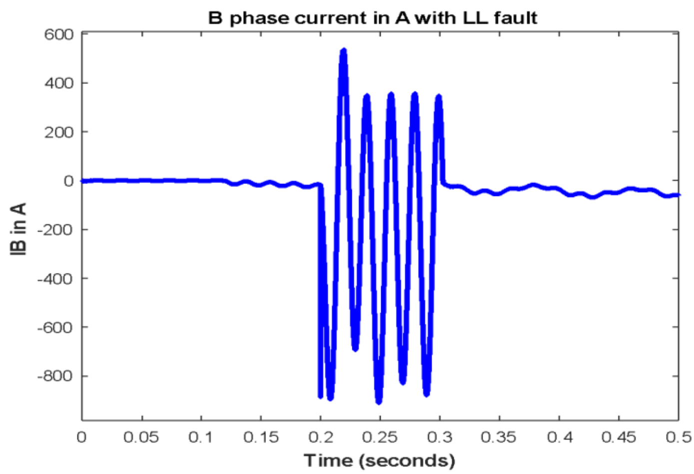

Fig.29 Phase B Current with over current relay for LL fault

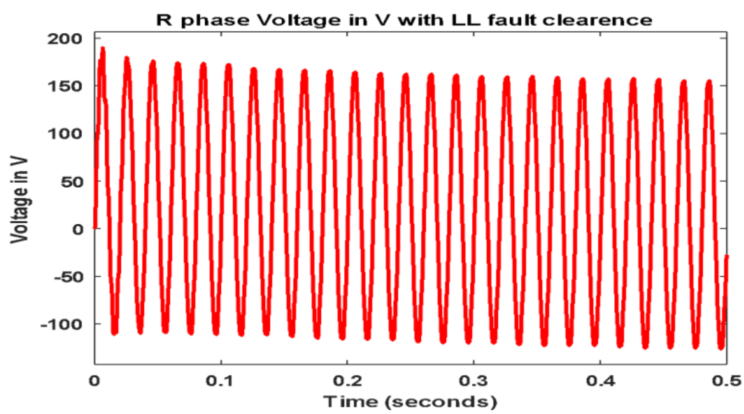

Fig.30 Phase R Voltage with clearance of LL fault with digital protection

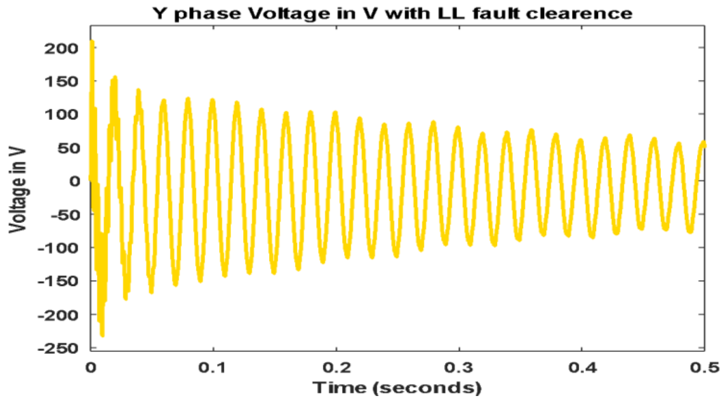

Fig.31 Phase Y Voltage with clearance of LL fault with digital protection

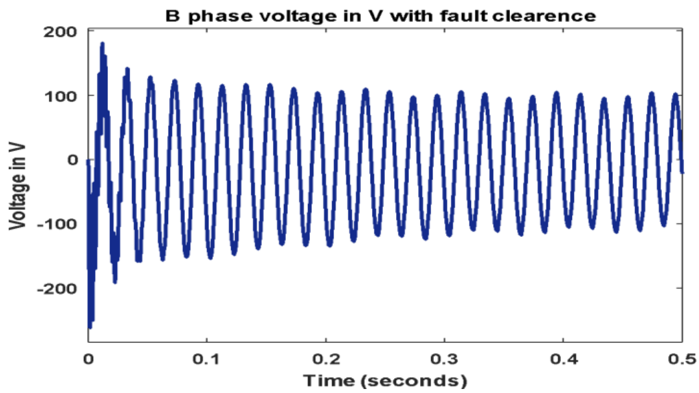

Fig.32 Phase B Voltage with clearance of LL fault with digital protection

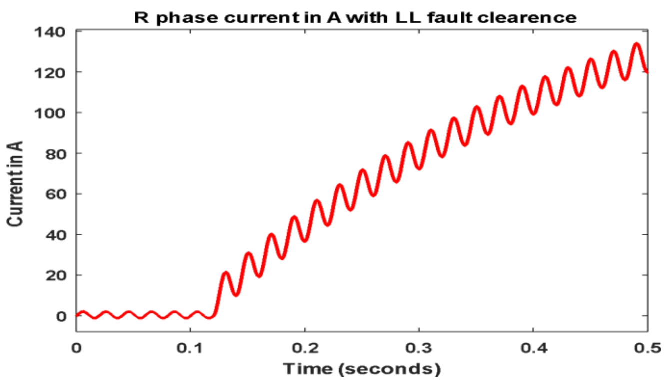

Fig.33 Phase R Current with clearance of LL fault with digital protection

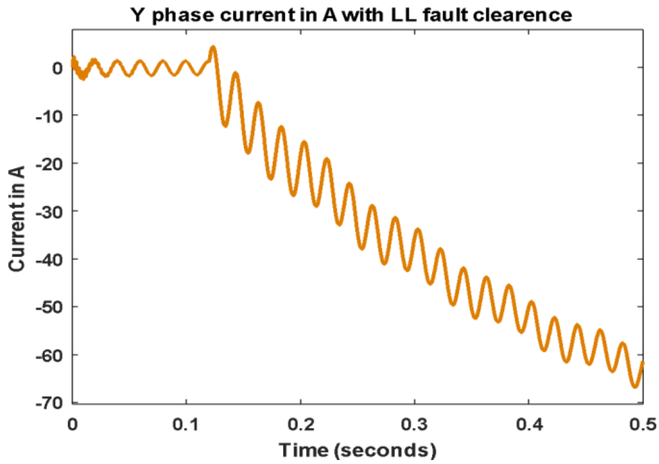

Fig.34 Phase Y Current with clearance of LL fault with digital protection

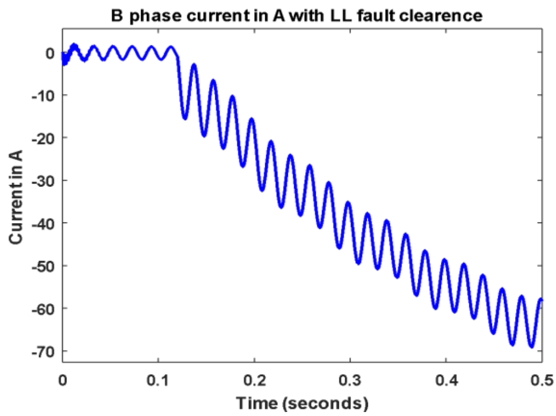

Fig.35 Phase B Current with clearance of LL fault with digital protection

LLG Fault Analysis: Detection and isolation

The following section signifies the detection of LL fault with under voltage and over current relays and its isolation for restoring the system to its normal state. Fig.36 illustrates the phase R Voltage with under voltage relay for LLG fault, Fig.37 shows the phase Y Voltage for LLG fault and Fig.38 illustrates the phase B Voltage with under voltage relay for LLG fault. Fig.39 illustrates the phase R Current with over current relay for LLG fault, Fig.40 shows the phase Y Current for LLG fault and Fig.41 depicts the phase B Current with over current relay for LLG fault. Fig.42 illustrates the phase R Voltage with clearance of LLG fault with digital protection, Fig.43 depicts the phase Y Voltage with clearance of LLG fault with digital protection and the Fig.44 shows the phase B Voltage with clearance of LLG fault with digital protection

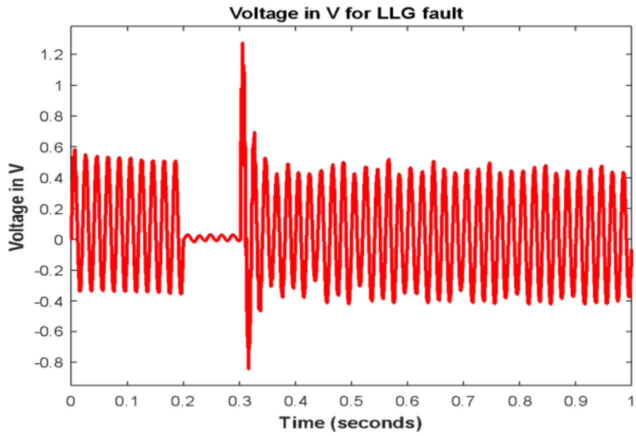

Fig.36 Phase R Voltage with under voltage relay for LLG fault

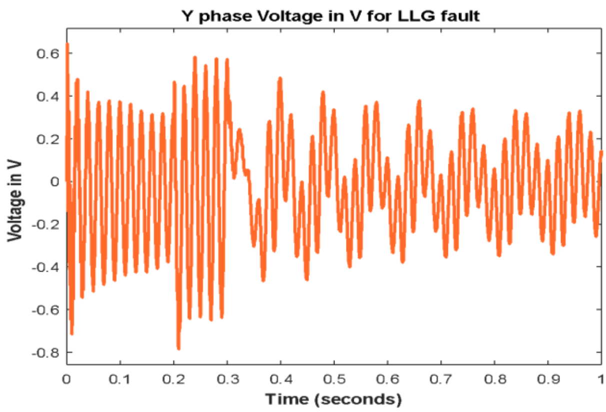

Fig.37 Phase Y Voltage for LLG fault

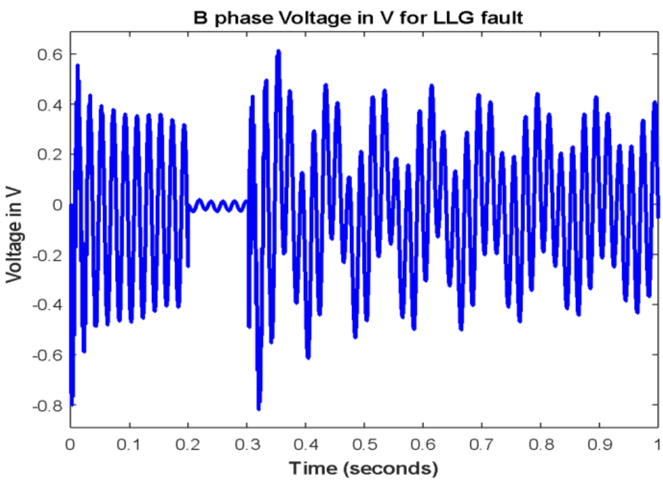

Fig.38 Phase B Voltage with under voltage relay for LLG fault

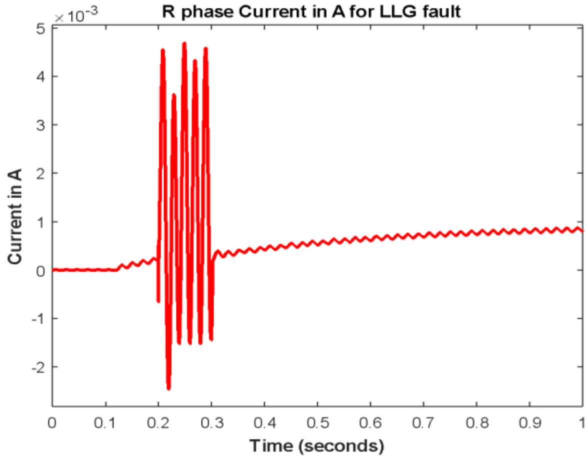

Fig.39 Phase R Current with over current relay for LLG fault

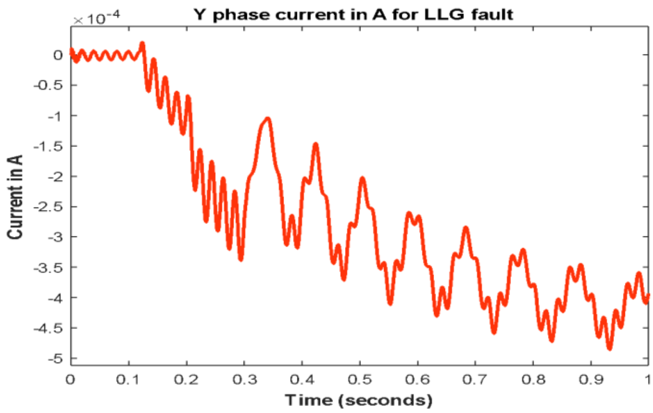

Fig.40 Phase Y Current for LLG fault

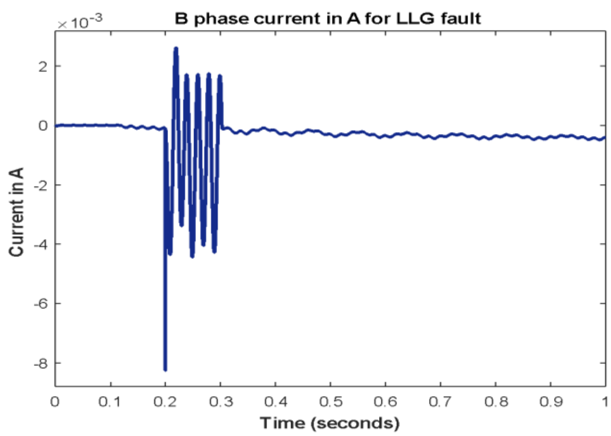

Fig.41 Phase B Current with over current relay for LLG fault

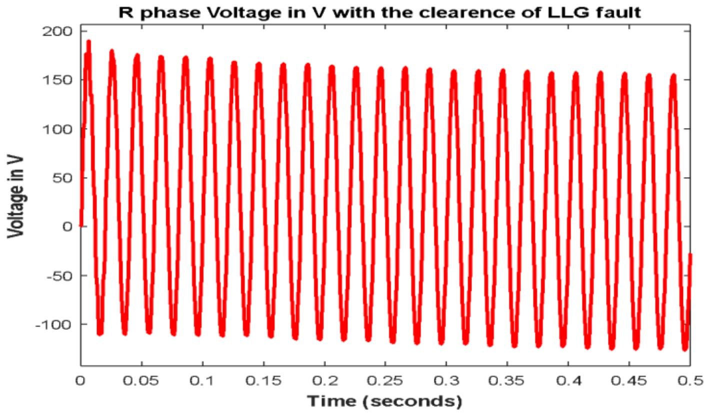

Fig.42 Phase R Voltage with clearance of LLG fault with digital protection

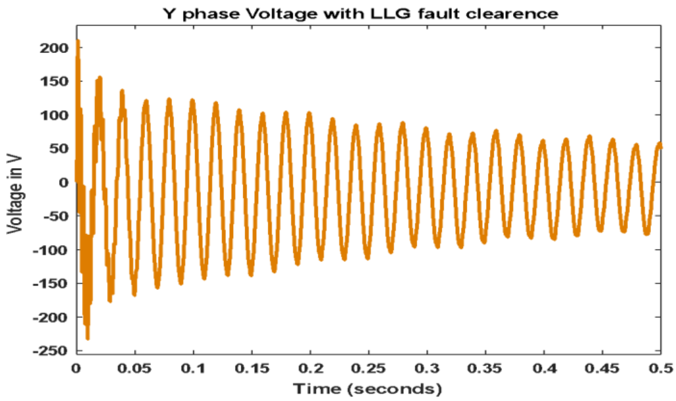

Fig.43 Phase Y Voltage with clearance of LLG fault with digital protection

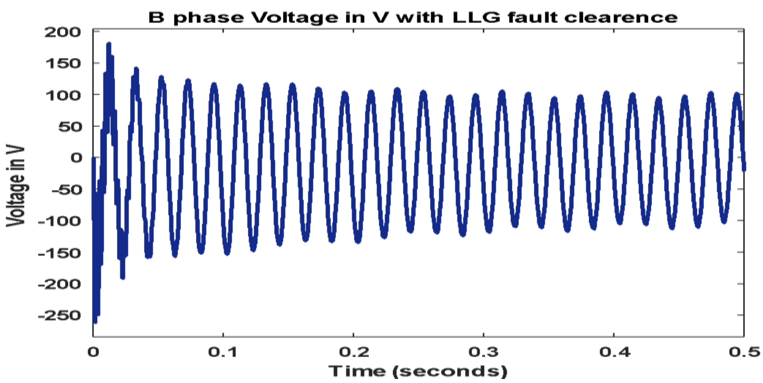

Fig.44 Phase B Voltage with clearance of LLG fault with digital protection

4. Conclusions

Wind plant was designed and with Asynchronous Generator with self excitation equipped with a STATCOM. Fault analysis have been performed in this plant with all kinds of faults such as three phase fault, LG fault, LL fault and LLG faults. Type and location of faults have been detected with the help of identification of low voltages and huge currents in appropriate bus and phase of the system. The wind system is simulated with two cases, case1 with detection of fault and without protection and case2 is with detection and digital protection with isolation of fault. Case 1 signifies the identification of both symmetrical and unsymmetrical faults based on under voltage and over current relays in all three phases. It also detects the type of fault based on over currents in each of the phases and under voltage in all three phases. Case2 encapsulates the results with fault isolation based on digital based protection scheme with digital relays and circuit breakers in appropriate locations. The simulation results have been proven that the digital protection scheme is most powerful in restoring the system with immediate isolation of fault from the rest of the wind energy system.

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