DESIGN AND ANALYSIS OF MW SCALE SUB-STATION FED BY WINDFARM WITH SUPERCONDUCTING FAULT CURRENT LIMITER

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Abstract: This paper describes the Short circuit analysis for the proposed 220/33kV substation for finding the Maximum & minimum fault level at substation & fault level feeding from the grid network in E Tap. For this a grid network was assumed. With the Maximum & Minimum fault levels arrived from analysis protective relay coordination carried out for the entire proposed 220/33kV substation in E tap. Here the substation is fed with Renewable source, Wind farm. With assumption of growth in IPPs (Independent power purchasers), the fault level feeding to our substation from grid will be increased. So, to mitigate the fault level at our proposed 220/33kV substation, super conducting fault current limiter (SFCL) is implemented. The results & comparisons of fault levels are carried out in MATLAB Simulink with & without SFCL device. It confirms that the presence of SFCL worked out outstandingly in the fault current reduction.

Index Terms- Wind resource assessment, Load Flow, Short circuit, protection coordination, TCC curves, ETAP, SFCL,

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I. INTRODUCTION

In recent years, wind energy has become an important part of electrical generation in many countries and its importance is continuing to increase. The amount if wind generation is growing rapidly and wind farms are growing. Wind as a resource, is characterized by both variability and unpredictability. The approach to conduct wind integration studies depends to some extent on the penetration level to be accommodated in the grid.

Super conducting fault current limiter (SFCL) is a device which has ability to overcome and suppression of SC fault current problems with many significant advantages. Basically, a fault current limiter can be used only for medium & high voltage systems (> 1kA). For low voltage applications it is worthless. Here super conducting fault current limiter device consists of superconductor named Yttrium Barium Copper Oxide (YBCO) as super conducting material, famous for displaying High temperature super conductivity. These compounds have the general formula YBa2Cu3O7-x. Super conductors shows the complete disappearance of electric resistance in materials when cooled to extremely low temperatures. The temperature at which resistance ceases is referred to as the transition temperature or critical temperature (Tc). The critical temperature for YBCO is 93K or -1830C. In this project we adopted resistive type SFCL for mitigation of fault current.

Ramazan bayindir et al. studied the different case studies of Load flow and short circuit analysis of electrical transmission system in Ankara region and evaluated the grid reactions for present and future demands [1]. Dalijeet Kaur et al. carried out the short circuit analysis for 11 bus system by newton Raphson method and found the ratings of the circuit breaker to be adopted [2]. Debniloy di et al. carried out the SC analysis for 72 bus system at 220kv level using Mi power software [3]. Yogesh Patel et al. simulated the power flow and short circuit analysis of 220kV substation and evaluated the fault current which is useful to select the switchgear [4]. Thanigaivel M et al. evaluated the protective device coordination of the system by Etap software to minimize the unnecessary outages [5]. Nur Hazwani Hussin et al modelled and simulated the inverse time over current relay in MATLAB/Simulink [6]. Vipul Rajput et al. explained the different techniques for relay coordination using software techniques [7]. Sehila Mahapatra et al. implemented the over current relay coordination on 72 bus system of 220kv level using Mi software and solved in two methods one is linear programming to optimize the TMS of the relays and to minimize the operating time [8]. Shilpi Yadav et al, Priyanka Mahajan et.al, Sneha rai et al. and Lin ye et al. proposed the mathematical modelling of Resistive type SFCL in Matlab/Simulink and investigated that the fault level and power system transient stability and reliability of system with presence of SFCL. [9-12]. A. Ramadevi et al. proposed the performance analysis of SFCL in three phase systems [13]. M. Nishanthi et al. and K hongesombut et al. investigated the strategic location of SFCL in a smart grid by which fault current can be minimized at high rate [14-15].

The organization of this paper is as follows: Section II describes the Methodology. Section III analyzes the simulation results. Section IV provides conclusions regarding this paper.

II. METHODOLOGY

The Design analysis of proposed 220/33kV substation is carried out in 4 steps: 1. Wind Resource assessment, 2. Short circuit Analysis, 3. Protection coordination, 4. SFCL device Implementation.

2.1 Wind resource Assessment

To determine the adequacy of wind resource, the magnitude and Characteristics of the wind at a selected site, as well as the economic Constraints specific to the site must be assessed. Hereby describing few basic steps involved in identifying and characterize the wind resource. WRA starts with a preliminary assessment and micro siting. In this step, alternate sites are evaluated for adequate wind speed based on publicly available wind resource maps and wind data. If the site is acceptable, then an onsite wind measurement campaign will be conducted. After wind data has been collected for sufficient period, typically one or more year, then a process of detailed WRA begins. It begins wind spatial extrapolation, in which measured data within the project area are used to estimate wind speeds over the project area. Then, a process called measure-correlate-predict is used with reference data. Reference data sets are long term wind data from a variety of sources like national institute of wind energy (NIWE), airports and others. Finally, the output of the WRA is to financial analysis step and to go for power system studies with grid integration for power evacuation

2.2 Short circuit analysis

Fault level or short circuit level is a measure of the current that will flow in case of fault, or short circuit, at a given point in the power system. Fault level is measured directly in amperes or as the product of fault current and the pre-fault voltage, to give a figure in megavolt amperes (MVA). Fault analysis should be carried out to calculate the fault current at various locations in the vicinity of the proposed wind farm which is needed for selection of circuit breakers, Earth mat designing and for protective device coordination which improves the reliability of system. In this work we carried out SC analysis for grid network in E tap and found the fault levels at our 220/33kV Substation. The fault levels on various buses in Grid network shown in the Fig.1.1. By this the fault level at our 220/33kV substation is 1.124kA which is 428 MVA sc.

2.3 Design of 220/33kV Substation

The Single line diagram given below shows the evacuation scheme up to 220kV Grid Sub Station.This section briefs about the modelling of the proposed 220/33kV SS in ETAP software. The Wind turbine generates the Power of 2MW in 33kV level. After checking the grid feasibility here, the proposed plant connected to 220kV Grid substations. So, the Power should be stepped up to 220kV level. Where the power getting pooled from the wind turbines and stepping up to High voltage level is named as pooling substation.By considering the Voltage transformation, protection system adoption & ease Maintenance, one-line diagram modelling has done in ETAP which is shown in Fig.1.2 220/33kV sub-station one-line diagram.Here in this work we assumed total 15 no. of WTGs and considered 3 no. of 33kV feeders where each feeder loaded with 5 no. of WTGs. 50MVA power transformer feeder is to step up the voltage from 33kV to 220kV and power pooled to the network grid through 2 no. of line feeders. Here for this substation we adopted Double main bus bar arrangement with bus coupler at 220kV side. The switchgear ratings adopted in this system is shown in Table1.1.

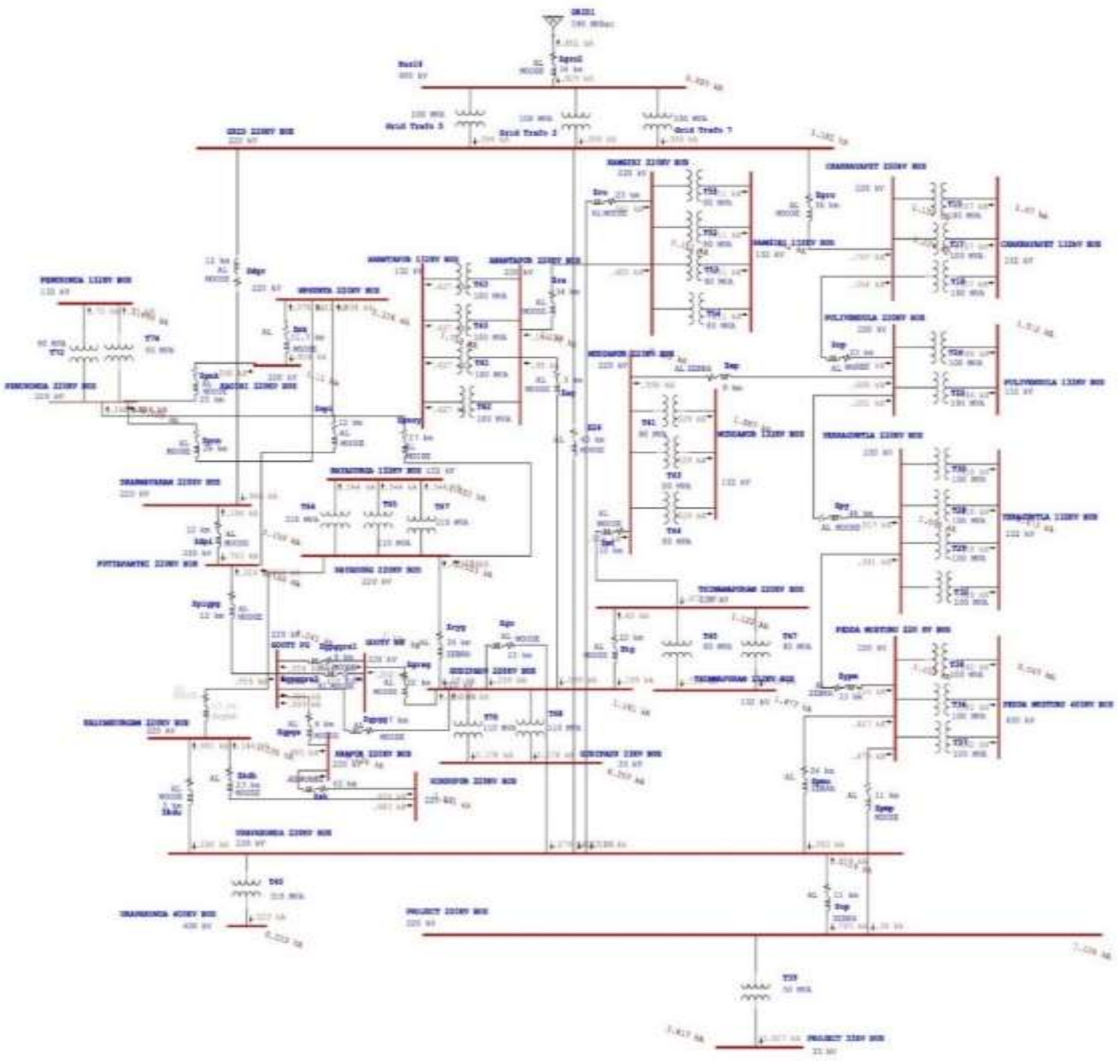

Fig.1.1 Fault levels on various buses on grid network

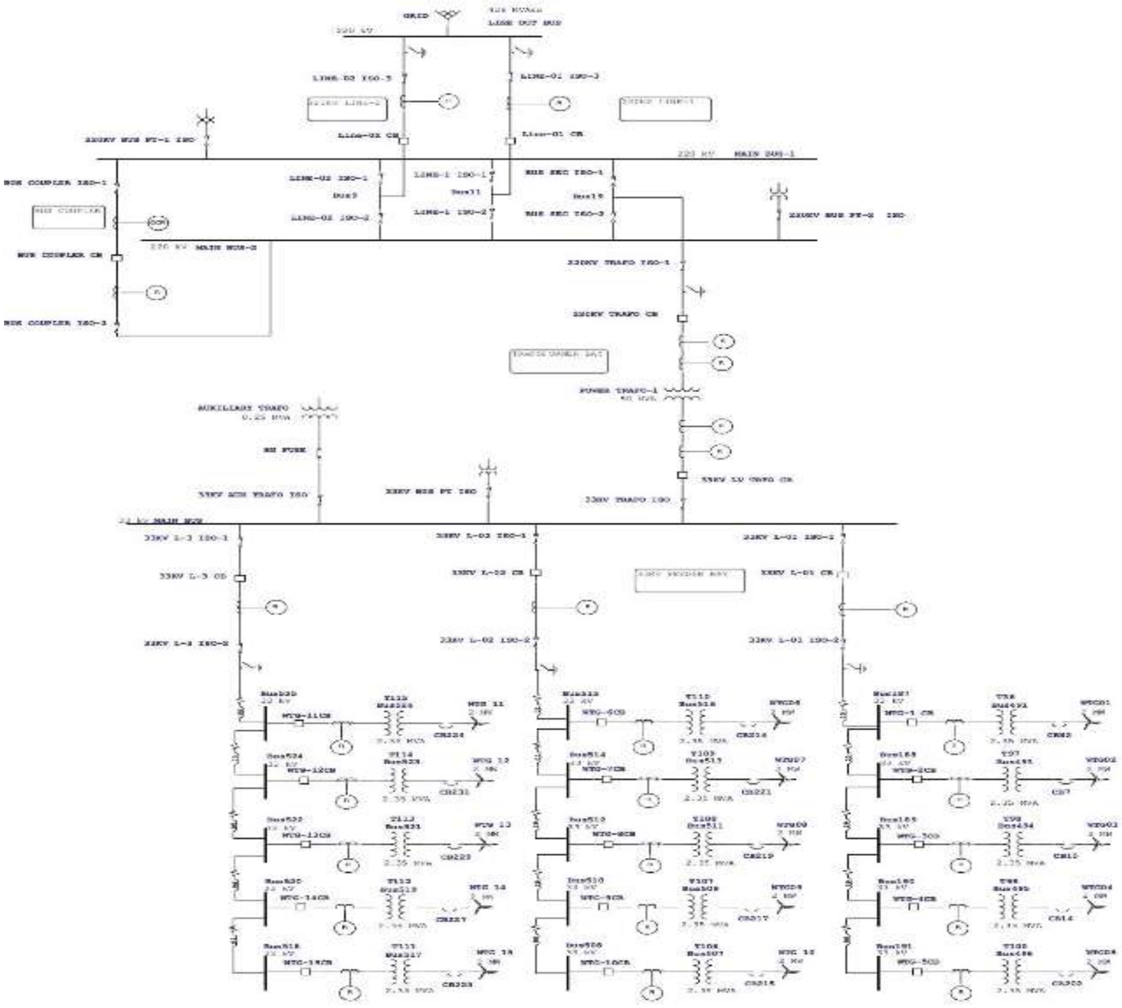

Fig.1.2 220/33kV sub-station one-line diagram.

Table 1.1Switch gear ratings of 220/33kV substation.

S.no	Equipment Description	Location	Rating
1.	Current transformer	WTG feeder	50/1 A
2.	Transformer	WTG feeder	2350 KVA 690V / 33kV
3.	Circuit Breaker HV side	WTG feeder	630 A, 33kV
4.	Circuit Breaker LV side	WTG feeder	2500A, 690V
5.	Current transformer	33kV feeder	300/1 A
6.	Circuit Breaker	33kV feeder	2000 A, 33kV
7.	Current transformer	LV side of Power T/f	1500/1 A
8.	Circuit Breaker	LV side of Power T/f	2000A, 33kV
9.	Power transformer	Transformer feeder	50MVA, 10% Z
10.	Current transformer	HV side of Power T/f	250/1 A
11.	Circuit Breaker	HV side of Power T/f	2000 A, 220kV
12.	Current transformer	Outgoing feeder & Bus coupler	200/1 A
13.	Circuit Breaker	Outgoing feeder & Bus coupler	2000 A, 220kV

Fault analysis carried out for 220/33kV substation in E tap software and found the fault levels on 33kV and 220kV substation as shown in the Fig.1.3

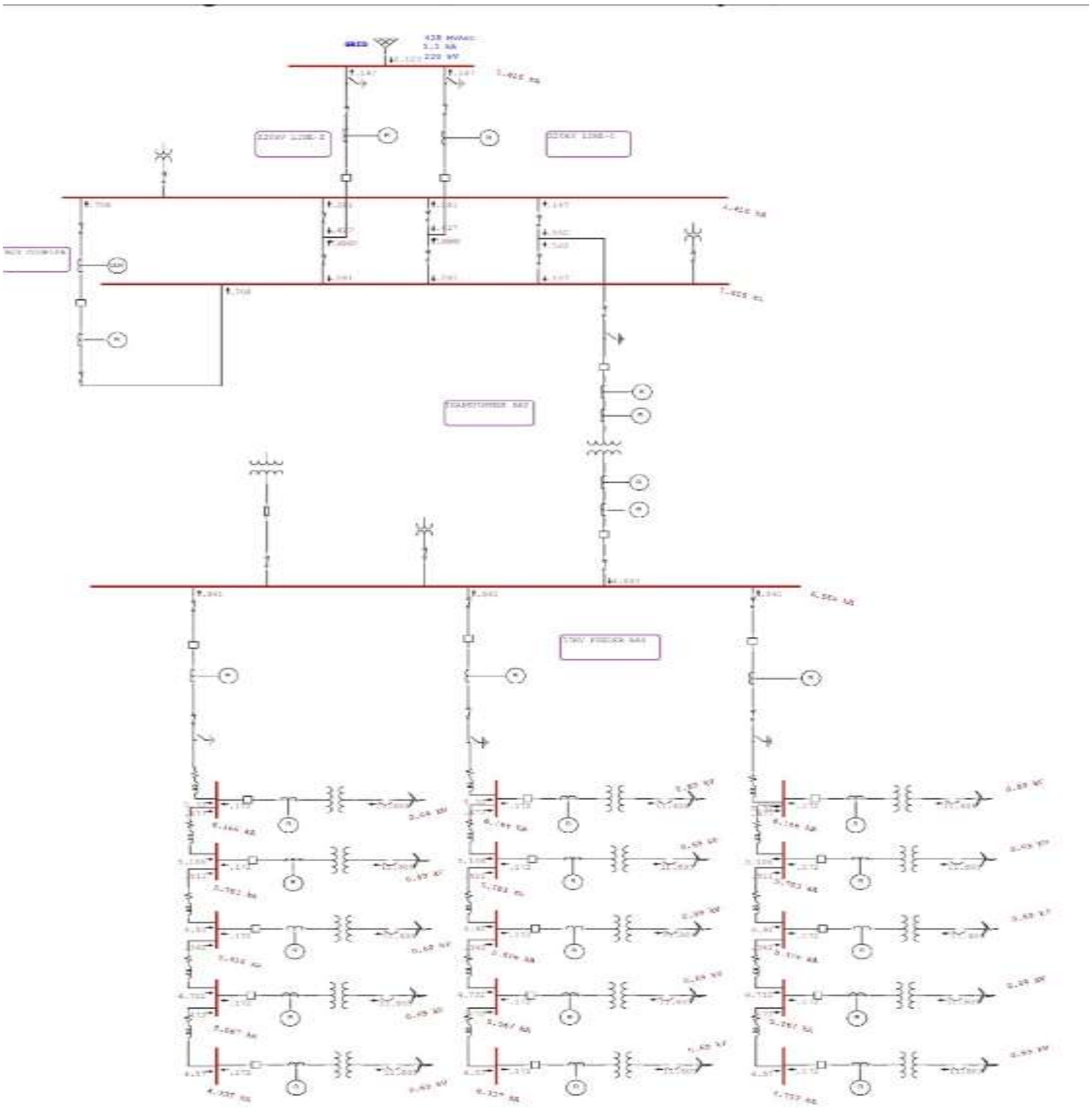

Fig.1.3 Fault levels on 220/33kV Substation.

2.4 Protection coordination

Protection schemes are generally designed with a primary means of clearing a fault, basically in two ways, either on current base which will be instantaneous (primary) or on time base which will be time delay (back up). Where possible, it is preferred that instantaneous methods of detecting over current are used as the primary protection method on all the major equipment associated with the power system. Instantaneous clearing of a fault is desirable to:

- ➢ Minimize the damage due to the fault
- ➢ Minimize the potential exposure of personnel to the hazards of an arc flash and
- ➢ Avoid long clearing times that could result in the entire system becoming unstable, resulting in a complete loss of power to the system.

Relay settings are prepared considering the most possible and severe fault i.e., 3 phase faults. Considering this fault magnitude and grid feeding, settings are made for over current. Based on the operating characteristics, settings deployed are of

- ➢ Inverse time phase over current characteristics (51)
- ➢ Definite time phase over current characteristics (50)

50 and 51 are the ANSI device codes for protections.

2.5 SFCL Integration

The fault in the system cannot be avoided. Apart from the damages in the vicinity of the fault - e.g. due to the effects of an electric arc - the fault currents flowing from the sources to the location of the fault lead to high dynamical and thermal stresses being imposed on equipment like overhead lines, cables, transformer and switchgear. The fault current limiters allow the equipment to remain in service even if the prospective fault current exceeds its rated withstand capacity. Replacement of equipment can be avoided. In case of upcoming plants fault current limiters allows the use of equipment with lower ratings renders possible considerable cost savings. In our work we adopted super conducting fault current limiter (SFCL).

III. MATHEMATICAL MODELLING OF SFCL

Here we adopted resistive type super conducting fault current limiter. The resistance of the superconducting element is essentially zero, thus during normal operating conditions, it operates without any delay limitations and it is possible to minimize the inductive impedance. Suppose any fault occur in system, fault current reaches many times the rated value, but due to the superconducting element it reverts rapidly to its normal state.

This is because the increased in resistance/impedance which limits the fault current to the desired level. During normal operation the current flowing through the superconducting element dissipates low energy. If the current rise above the critical current value, the resistance increases rapidly. The dissipated losses due to the rapid raise in resistance heats the superconductor above the critical temperature and the superconductor resistance changes its state from superconducting to Normal state and fault current is reduced instantaneously.

This phenomenon is called quench of superconductors. When the fault current has been reduced, the resistance element recovers its superconducting state. The resistive type SFCL model developed in the MATLAB Simulink using SimPowerSystem block set. The parameters used to design such model are as: Transition or response time = 2ms,Maximum impedance = 20Ω,Minimum impedance = 0.01Ω,Recovery time =10ms and Triggering current = 550 Amp. Mathematical modelling represents the characteristic behavior of SFCL, which is used to decide the whether the impedance level goes maximum or minimum. The comparison concludes the value of resistance of SFCL as:

1. If the incoming current is below the triggering current level, then the SFCL resistance is minimum.
2. If the incoming current is exceeding above the triggering value, then its resistance is maximum close to the impedance level.

Figure 1.4 shows the Mathematical modelling of SFCL. In which step input and transport delay are used to set the transition, response and recovery time of SFCL. The switch block is used to set the value of impedance to minimum or maximum. After SFCL characteristic subsystem there is a filter block and controlled voltage source block. These are usedto reduce the harmonics and to compensation of voltage sag respectively.

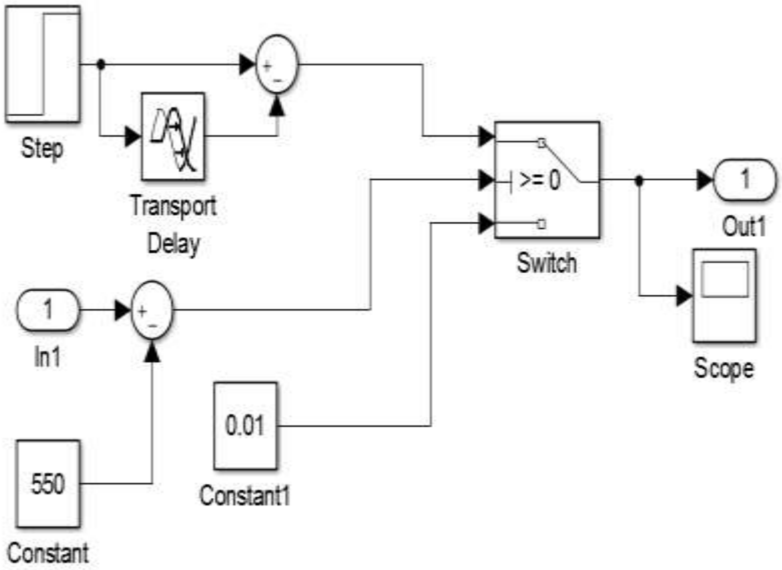

Fig.1.4 Mathematical modelling of SFCL.

By taking the parameters into account SFCL module is developed in Matlab Simulink which is shown in the below Fig.1.5

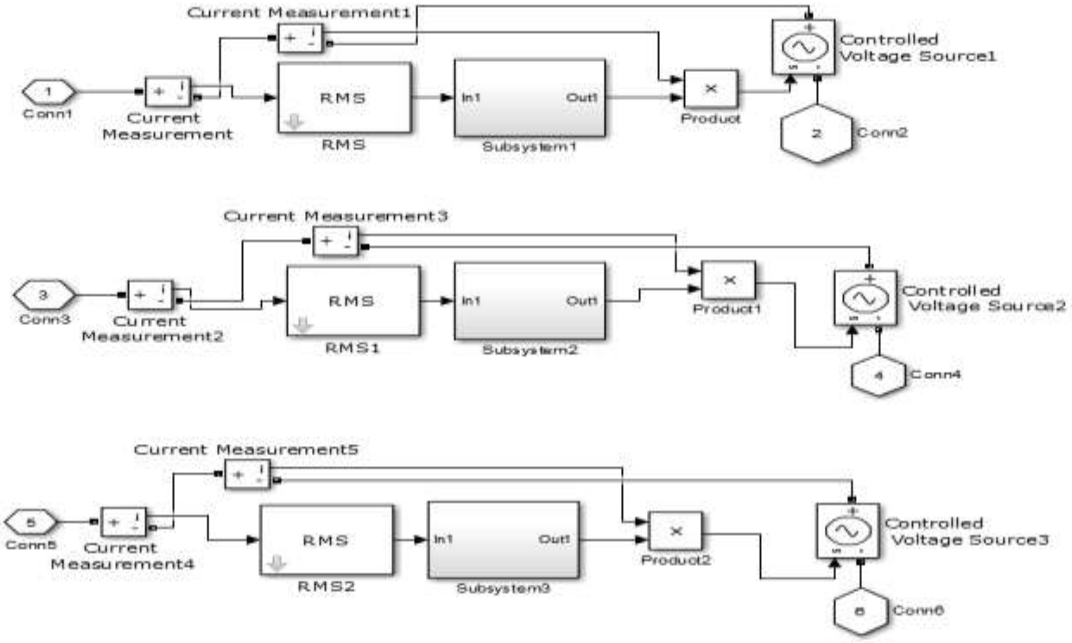

Fig.1.5 SFCL Module for Three-phase system.

IV. RESULTS AND DISCUSSION

4.1. Inference from Short Circuit Analysis at 220/33kV substation:

From three phase fault analysis carried out, it is inferred that fault currents within the wind farm pooling substation & grid substation in the region under study are within the generally adopted breaker ratings i.e. 25 kA at 33 kV level and 40 kA at 220 kV level. But the results which are very crucial for system sizing and protection coordination are tabulated as follows. The different over current magnitudes at different fault locations within the wind farm pooling station when faults occurred are as shown in Table 1.2.

It is important to know that the results are the maximum fault current magnitudes at those points when fault occurs. But the maximum fault current that the CT (current transformer) can see during that fault is to be considered for protection coordination

Table 1.2 Short Circuit Results for wind farm PSS

Short circuit analysis Case description	**3-Phase fault**	**Line- Ground fault**	**Line-Line-Ground fault**
At 33kV feeder within pooling station	6.166	3.423	3.911
At 33kV Bus within the farm pooling station	6.564	7.051	8.885
At 33kV transformer side within the farm pooling station	4.043	5.137	6.474
At 220kV transformer side within the farm pooling station	1.416	0.562	0.357
At 220kV Bus within the farm station	1.416	0.562	0.357
At 220kV Line within the farm station	1.416	0.562	0.357
At 220kV coupler within the farm station	1.416	0.562	0.357

4.2 Inference from Protection Relay Settings & TC Curves

Hence three phase faults are severe compared to other faults from the above tabulated results, three phase fault results are carried out and with three phase values the settings are usually adopted in practice. Based on this, it is inferred that the settings adopted for the protective relays within the wind farm pooling substation are not effected based on the curves attained. The reliable power flow without generation down time are achieved along with safe system. The tabulated time dial settings for the relays used within the wind farm pooling station are the heart of relays actual time of operation. When there exists internal fault or through fault at power transformer, both the circuit breakers at LV and HV side of power transformers shall inter trip with no delay. Thus, how the protection coordination is achieved for the system reliable operation and the results obtained are in safe limits and in line with generally adopted equipment ratings for system design. This can be achieved by proper grading. CB operating time, relay operating time, overshoot time & safety margin should be considered for relay grading. The results of protective device coordination are tabulated as shown in Table 1.3 and the TCC curve characteristics are plotted as shown in Fig.1.6.

Table 1.3 Protection coordination results

Case description when fault occurs	Relay time dial setting		Tripping Characteristic Curves Plot
	Inverse time over current operation in seconds	Definite time over current operation in seconds	
33kV incomer feeder relay	0.1	0.05	Not effected
33kV Bus Feeder relay	0.15	0.25	Not effected
33kV power transformer relay	0.05	0.4	Not effected
220kV power transformer relay	0.05	0.4	Not effected
220kV outgoing line relay	0.101	0.55	Not effected
220kV bus coupler relay	0.153	0.7	Not effected

4.3. Inference from SFCL system Implementation:

Here the Mathematical modelling of SFCL done in MATLAB/Simulink. So, in this work we gone with assumption that, location of SFCL at 33kV transformer side of 220/33kV substation. At 33kV transformer side the three-phase fault level is 4 kA which is tabulated in Table 1.2. SFCL integration carried out in three cases.

4.3.1. Case I: Fault Condition without SFCL device

Below Fig.1.7 shows the block diagram of power system under faulty condition without having SFCL system. The fault current is 4 kA, which is found at 33kV transformer feeder of 220/33kV substation and simulated the results.

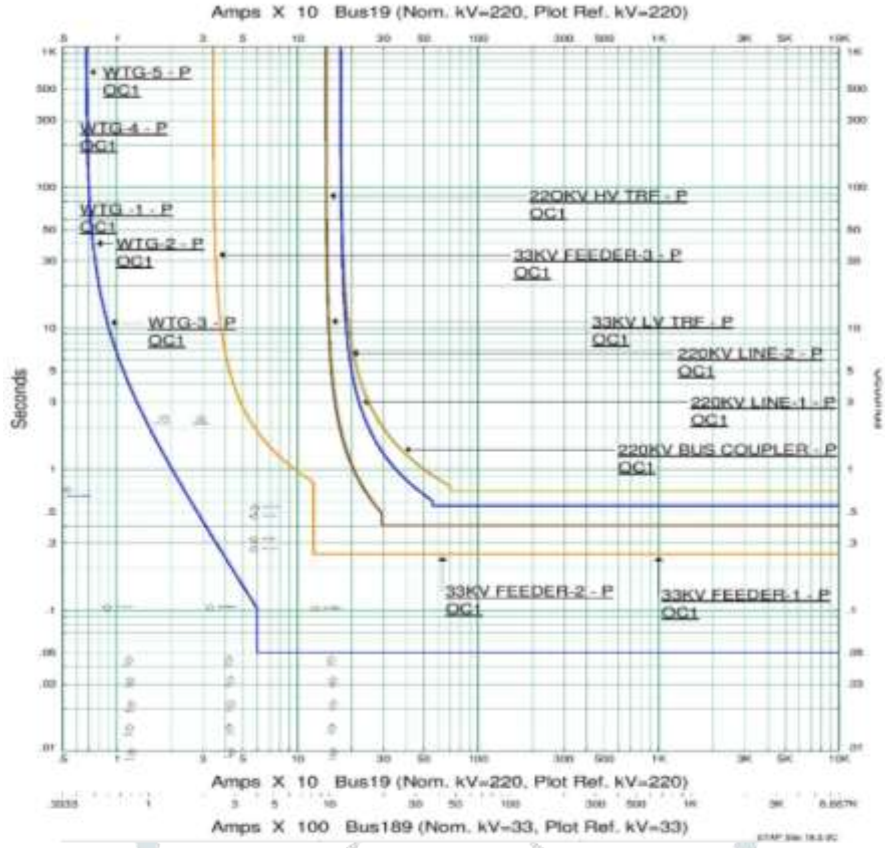

Fig.1.6 TCC Curves

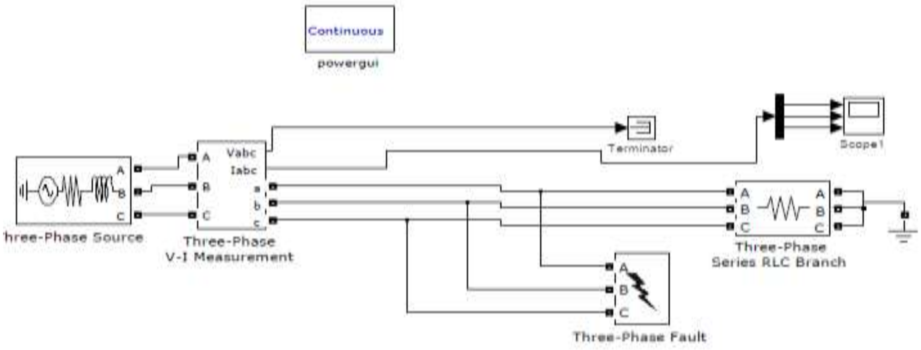

Fig.1.7 Power system under Faulty condition

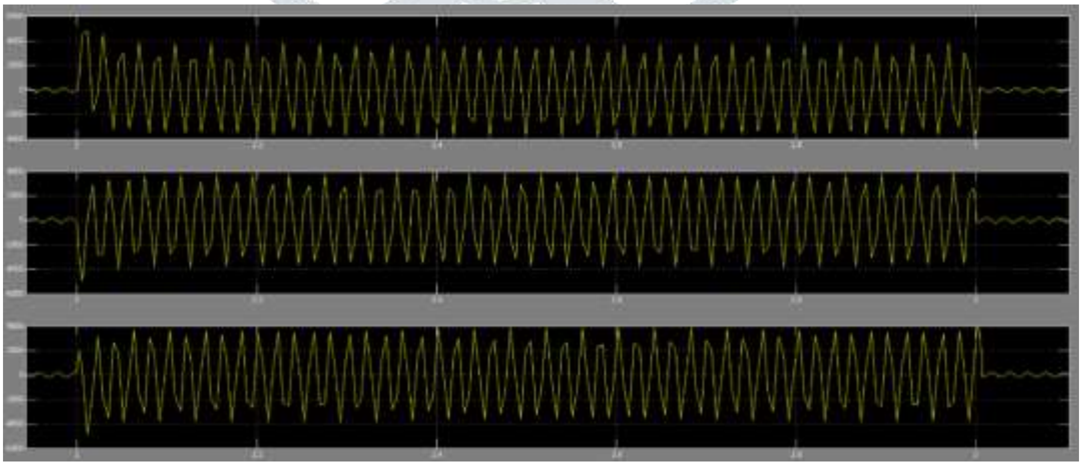

Fig.1.8 Fault condition without SFCL system.

4.3.2Case II: Faulty Condition with SFCL device

The Block diagram of power system under fault condition with SFCL is shown in the Fig.1.9. The results are as shown in the graphFig.1.10.

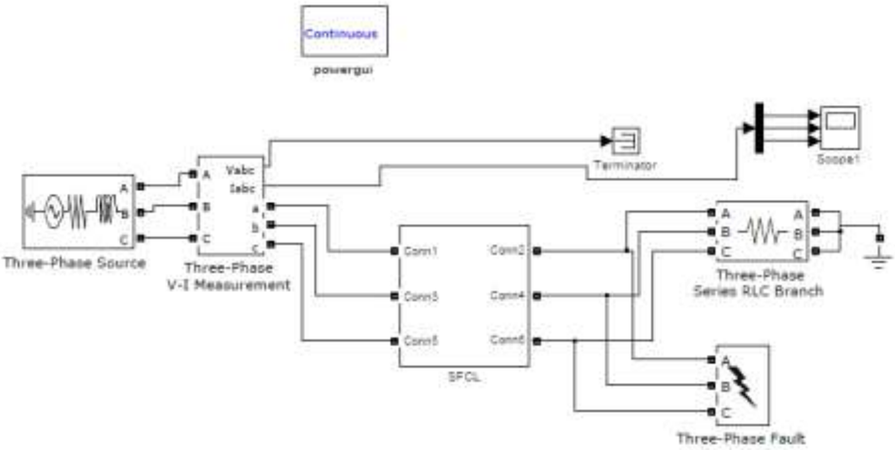

Fig.1.9 Block diagram of Power system under Faulty condition with SFCL system

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Table 1.4 Fault current with and Without SFCL

Case	Condition	Magnitude of fault current
1.	Fault condition without SFCL system.	4000 Amps
2.	Fault condition with SFCL system.	1000 Amps

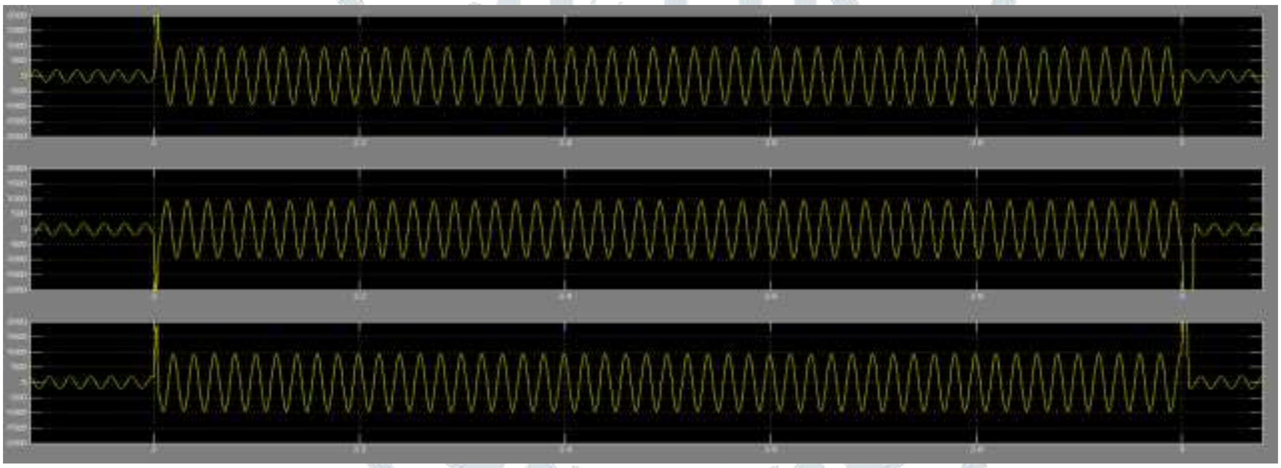

Fig.1.10 Fault condition with SFCL system.

From the above cases the results are tabulated as follows:

It clearly shows that the fault level got minimized to 1000 Amps from 4000 Amps with SFCL device. Hence, similarly if we adopt the SFCL at outgoing lines of our proposed Substation the fault levels entering from the grid can be mitigated.

V. CONCLUSION

Inference from SC analysis, the three-phase fault analysis carried out, it is inferred that fault currents within the wind farm pooling substation & grid substation in the region under study are within the generally adopted breaker ratings. Inference from Protection coordination, the settings adopted for the protective relays within the wind farm pooling substation are not affected based on the curves attained. The reliable power flow without generation down time are achieved along with safe system. Inference from SFCL device Implementation, Fault level got minimized to 1kA from 4 kA which is shown in the above section. By this the fault level at proposed substation can be controlled. Replacement of switchgear can be avoided. Apart from this, the coordination of SFCL with the protective device will be the future scope of work.

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