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Over current protection of distribution system with impact of solar and wind generation using DIgSIlent power factory

Aashish Kumar Bohre[1]*, Biman Kumar Saha Roy[2]

[1,2]Department of Electrical Engineering, National Institute of Technology Durgapur, INDIA
**Corresponding Author: e-mail: aashishkumar.bohre@ee.nitdgp.ac.in*

Abstract

The utilization of renewable resources has been growing very fast worldwide recently to manage the increasing energy gap, but it also raises some challenges like protection issues, transient stability issues and security issues in the power system operation. Mainly, wind and solar photovoltaic renewable power generation sources are account for bulky renewable energy share. The transients in power systems including renewables are reduced and have recently attracted wide attention. The impact of renewables generation on power system transients should be effectively analyzed and evaluated to improve power system reliability, stability, operation and security. DIgSILENT Power Factory software is more powerful and useful for providing phasor of fundamental power frequency components better than other existing software's; therefore, DIgSILENT Power Factory is proposed for modeling and analysis of the system.

Keywords: Power system protection, Renewable energy sources, Relay coordination, over current protection.

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This paper was earlier presented at the SDCEE-2021: 1st International Online Conference on Sustainable Development in Civil and Electrical Engineering, National Institute of Technology Kurukshetra, Kurukshetra, India, December 17-19, 2021 and substantially improved for this Special Issue. Guest Editors: (i) Dr. Sri Niwas Singh, Professor (HAG), Department of Electrical Engineering, Indian Institute of Technology Kanpur, 208016 (U.P.) India, Director, ABV-Indian Institute of Information Technology & Management Gwalior; (ii) Dr. Ashwani Kumar, SMIEEE, Fellow IE (I), Fellow IETE (I), LMISTE, LMSCIEI, Professor and Head, Department of Electrical Engineering, NIT Kurukshetra Haryana, India. Dr. Kumar has 27 years teaching experience and an industrial experience of 2 years, 8 months.

1. Introduction

The integration of renewable distributed generations (DGs) has impact on the power distribution network loading, fault current and other performance parameters. This optimum allocation of different DG units with aim to limit the fault current in multi-stage using coyote optimization and Electrical Transient Analyzer Program (ETAP) under faulty and normal operating conditions is proposed (El-Ela *et al*, 2021). Simultaneous allocation of tie-lines and DGs during post-outage condition to minimize energy losses using Teaching-learning-based optimization (TLBO) is presented (Shojaei *et al*, 2021). The planning of DSTATCOM (Distribution Static Compensator) with wind generator is have been studied (Mahela *et al*, 2021), which include the analysis of the power quality issues during different disturbances. The study related to design photovoltaic (PV) and wind-based hybrid renewable energy system based on multi-scenario oriented multi-objective function to maintain reliable operation is reported (Wang *et al*, 2016). The placement of DSTATCOM under network reconfiguration to reduce losses, improve voltage profile and increase savings in distribution system is analyzed (Gupta *et al*, 2016). The transient stability and dynamic behavior analysis of distribution systems in presence of distributed generation by considering unbalanced loads is presented (Madruga *et al*, 2018). The renewable based hybrid micro-grid considering the different utility tariffs is analyzed the tecno-economic performance (Bohre *et al*, 2021). The analysis of multiple grid-connected PV with its penetration impacts on the static voltage stability in distribution system is investigated using improved voltage stability index and PV curve (Kamaruzzaman *et al*, 2015). The case study of distribution networks with effect of photovoltaic distributed generation on fault detection and short-circuit currents is proposed (Alcala-Gonzalez *et al*, 2021). The PV based DG with is penetration including different type of time-varying load models is presented using new analytical method by multiobjective index (Hung *et al*, 2014). The analysis of dynamics and enhance stability of distribution systems together with the solid-oxide fuel cell models is reported to control fluctuations of frequency and power supply (Sedghisigarchi *et al*, 2004). The optimal allocation of DGs with practical load models using optimization techniques based on novel multi-objective function is studied to enhance the system performance parameters (Bohre *et al*, 2016). The permissive overreach protection for clearance of fault rapidly in MV distribution including signal comparison schemes by performing short circuit calculations and electromagnetic transient using DIgSILENT PowerFactory is proposed (Borgnino,*et al*, 2018). The PV-Wind based renewable DGs planned in distribution systems using grasshopper optimization with operating time of overcurrent relay (Belbachir *et al*, 2021). The novel method to find the faulty feeder in distribution systems to reduce problem of fault signal and low sensitivity of faulty feeder selection is investigated (Jin, *et al*, 2019). In view of above literature review this work presents the feeder protection of distribution system using relay coordination in presence of Solar PV and Wind based renewable distributed generations.

2. Methodology

Transient analysis of distribution systems has gained more attention because of the ongoing growth of grid-connected distributed generations. Also, the dynamic performance of distribution networks and generation systems with advanced equipment increases the complexity of transient stability's numerical analysis. This work offers new way for transients analysis in distribution system with renewable distributed generation. The presented method can be divided into three steps: first is the network model representation, the second is the choice of buses and disturbances for implementation, and the third is the variation of control systems parameters for stability analysis.

This work proposed a methodology for feeder protection and transient analysis for distribution systems including:

(a) Feeder protection and transient analysis by making a representative network model.
(b) The criteria for relay setting and feeder protection by considering characteristics of protection devices.
(c) Consider dynamic model representation with renewables (Solar & wind) generation.
(d) Assessment of the impact of disturbance and response of protective devices in distribution systems.

The transients issues in the power system can be explained by considering the set of differential equations as given in equations (1) and (2).

$$M_j \times \frac{d^2 \mu_j}{dt^2} + D_j \mu_j = P_{mj} - P_{ej} \tag{1}$$

$$\frac{d\text{¢}_j}{dt} = \mu_j(t) - \mu_s \tag{2}$$

Where, Mj: j[th] machine inertia constant; t: time in seconds; Dj: j[th] machine damping constant; ω_j: j[th] instant angular velocity; Pmj: j[th] machine mechanical input power; Pej: j[th] machine injected active power; δj: j[th] machine angular position; ωs: synchronous speed.

The application and effectiveness of the presented method is demonstrated by considering the IEEE 33-bus distribution network using DIgSILENT Power Factory software. The major types of faults are possible in the system such as three lines to ground, double line to ground, single line to ground, and line to line faults. The three-phase fault and single line to ground fault is considered here to system feeder protection and transient analysis. Initially the hybrid renewable solar PV and Wind distributed generation are off or deactivated mode. Here the inverse definite time relay 751, (1A, phase fault relay 51P1, 50P1 and earth fault relay 51G1, 50G1) is used for phase fault and the earth fault protection. After that the relay operation for system protection under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind for radial 33-bus system. The radial 33-bus distribution system is implemented with 12.66 kV rated voltage and 100 MVA. The generator is considered at substation as external grid for this study, which fulfil the load demand of system. The system 33-bus distribution network is represented in Figure 1 in DIgSilentSilent Powerfactory environment. Here the following cases are presented for the analysis as:

- Base case system without DG (Hybrid solar PV & Wind DG) under normal and faulty condition.
- System with (Hybrid solar PV & Wind DG) under normal and faulty condition.

3. Power Generation of Wind and Solar System

The power generated by solar photovoltaic (PV) and wind turbine (WT) system are depends on the solar irradiance along with ambient temperature and wind speed of the considered location. Therefore, the PV and wind systems output power can be evaluated during time segments using the equations (3) and (4) as given below.

$$P_{WT}^{t} = \begin{cases} 0; & if\ V \le V_{cut-in}\ OR\ V \ge V_{cut-out} \\ P_{WT}^{Rated}\left(\dfrac{V - V_{cut-in}}{V_{Rated} - V_{cut-in}}\right); & if\ V_{cut-in} \le V \le V_{rated} \\ P_{WT}^{Rated}; & else \end{cases} \tag{3}$$

$$P_{PV}^{t} = N \times FF \times V_i \times I_i \tag{4}$$

Where, FF is form factor; I_{SC} is short circuit current; V_{OC} is open circuit voltage.

4. Result and Discussion

This section presents the simulation results and discussion of the planned method for protection and transient analysis with and without hybrid solar and PV distributed generations (DGs) with selected test systems are provided. The simulation diagram of radial IEEE 33-bus system in DIgSilentSilent Powerfactory environment is shown in Figure 1. Initially the hybrid renewable solar PV and Wind distributed generation are off or deactivated mode. Here the inverse definite time relay 751, (1A, phase fault relay 51P1, 50P1 and earth fault relay 51G1, 50G1) is used for phase fault and the earth fault protection. After that the relay operation for system protection under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind for radial 33-bus system are recorded as revealed in Figure 2.

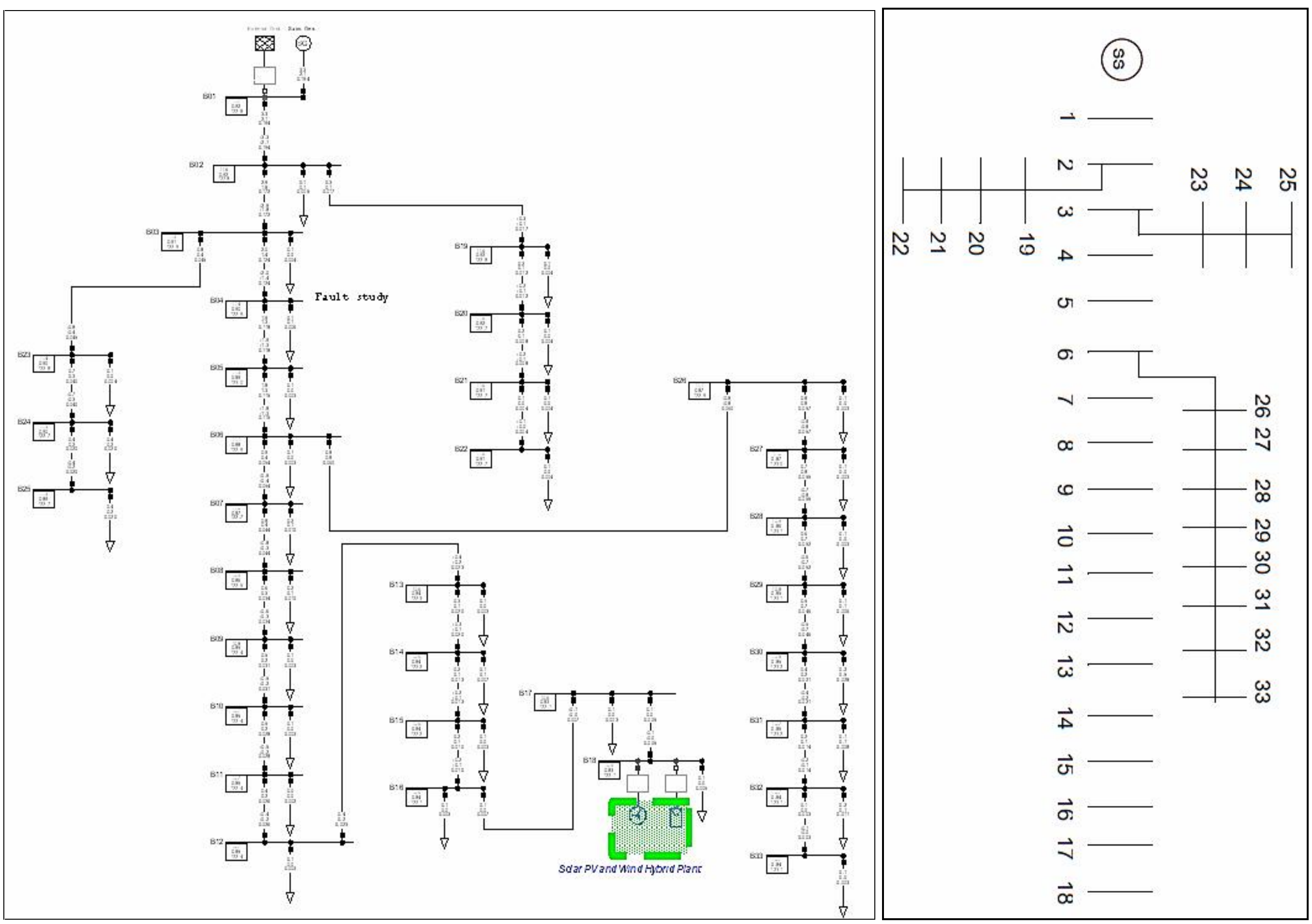
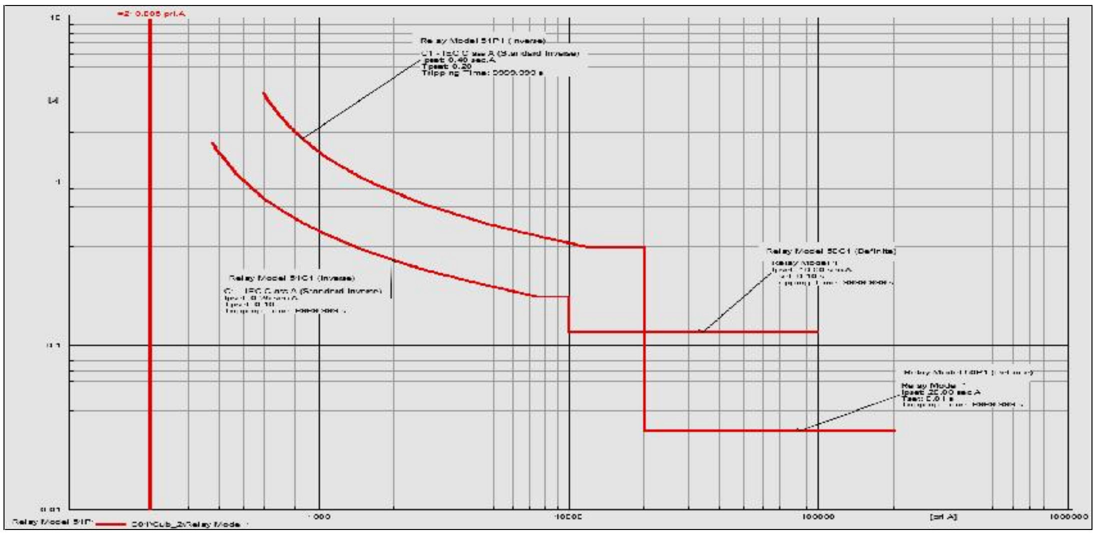
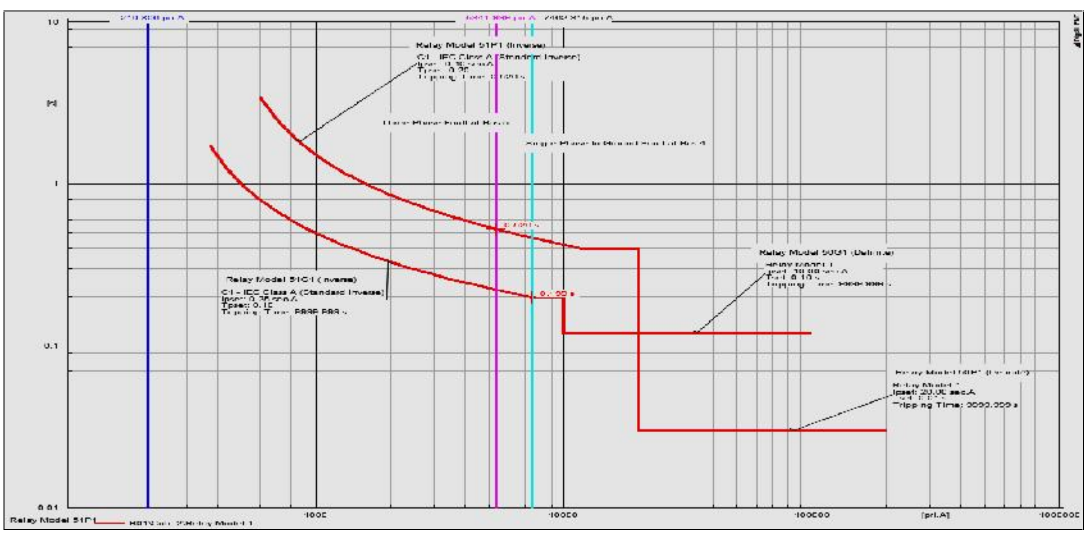


Figure 1. IEEE 33-bus radial system and its simulation diagram in DIgSilentSilent Powerfactory.

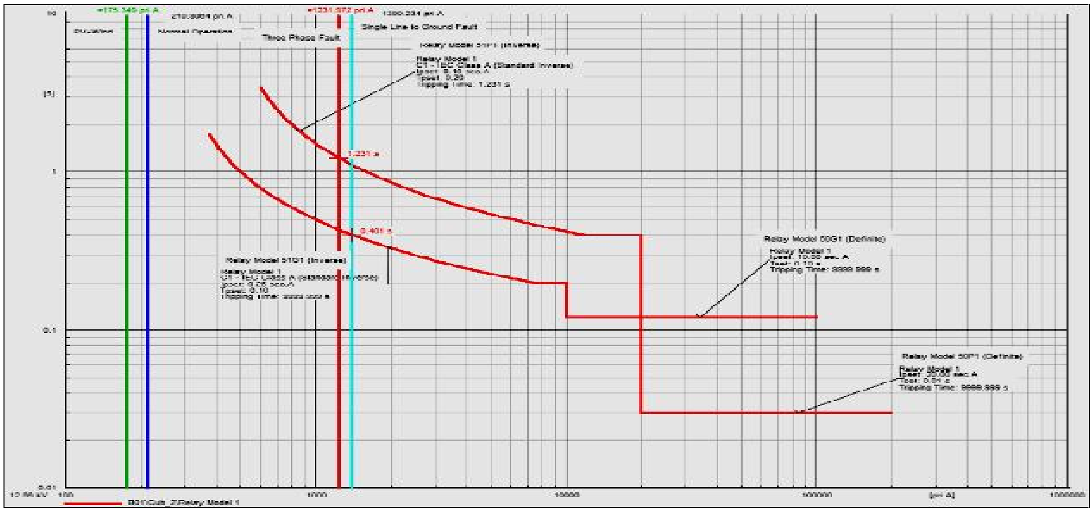
The current for normal operating condition is 210.8 A (represented in red color in Figure 2 (a)) which is reduce to 175.34 A (represented in green color in Fig 2 (c)) with Solar and Wind DG without faulty condition. The fault current value for 3-phase fault and relay operating time are 5341.99A (Primary) (represented in magenta color in Figure 2 (b)) and 0.526 sec for base case system of IEEE 33-bus system; but when we consider solar and wind the 3-phase fault current and relay operating time are 1231.97A (Primary) (represented in red color in Figure 2 (c)) and 1.23 sec. Here, the inverse time characteristic of relay can be verified because the fault current is decreasing the fault clearing time is increasing. Hence, the system feeder is protecting against 3-phase fault by operating phase fault protective relay 51P1 and 50P1. Similarly, the single line to ground faults is protected by ground fault relay 51G1 and 50G1 as shown in Figure 2(b-c). The fault current of single line to ground fault and operating time are 7482.31A and 0.199 sec but with solar PV and wind generation these are 1280.23A and 0.421sec. therefore, inverse time characteristic is verified. The Figure 3 shows the speed, rotor angle and frequency variation under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind system for radial IEEE 33-bus system, which shows the less transient with solar and wind hybrid renewable DG. The volage and current variation under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind system for radial IEEE 33-bus system are demonstrated in Figure 4.



(a)



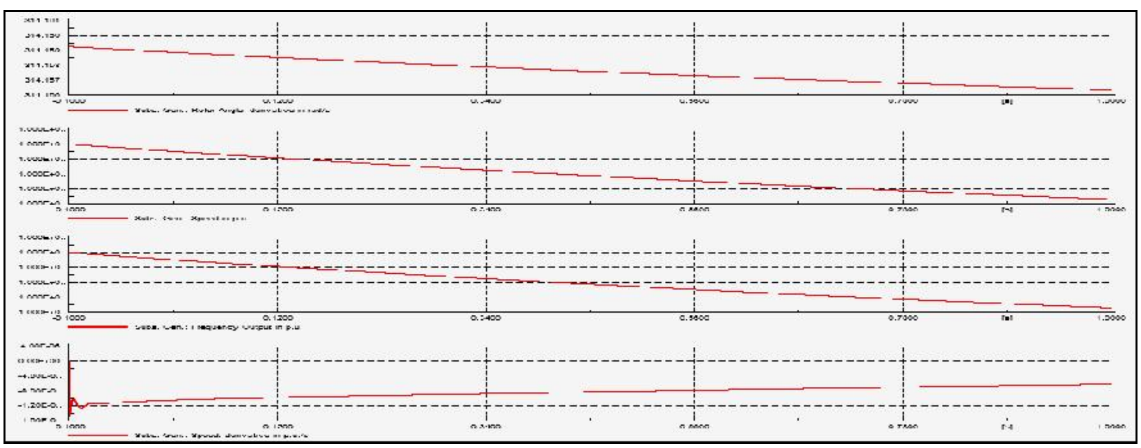
(b)



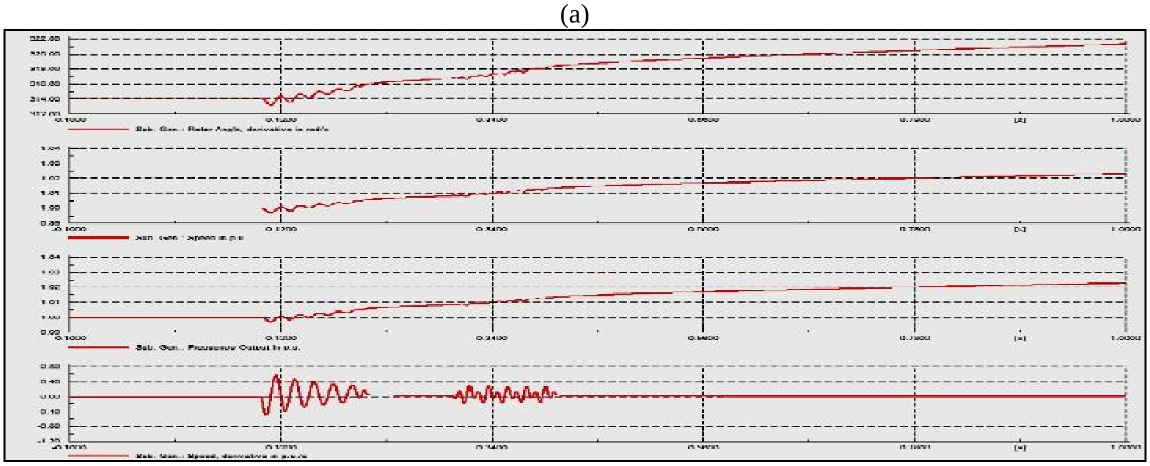
(c)

Figure 2. Relay operation for system protection under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind system for radial IEEE 33-bus system.

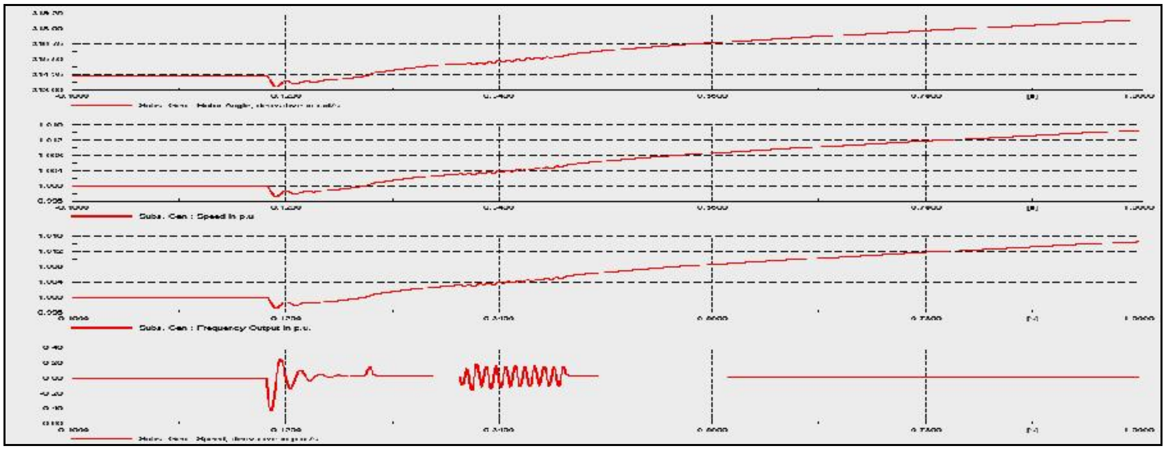
The 3-Phase fault during 0.1sec to 0.2 sec and single line to ground fault during 0.3sec to 0.4sec is considered. The peak value of fault currents is high for base case as compared to system with renewable Solar and Wind DG. The substation load loading for the base case is 84.05%, while considering PV and wind Generation the loading of substation is reduced to 69.9%%. Therefore, the system can operate with improved reliable and efficient manner. Results of radial 33-bus system for base case are tabulated in Table-1, which shows the losses of system are 0.21MW and 0.14MVAr also the highly overloaded bus is 18th bus. Therefore, based on overloading and voltage sensitivity concept 18th bus is the suitable location to install the hybrid solar PV and wind generation.



(a)

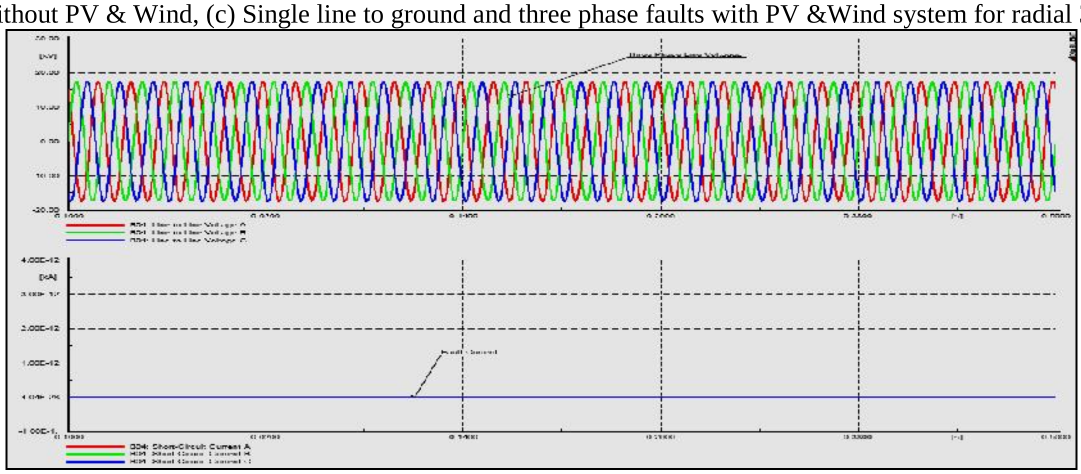


(b)

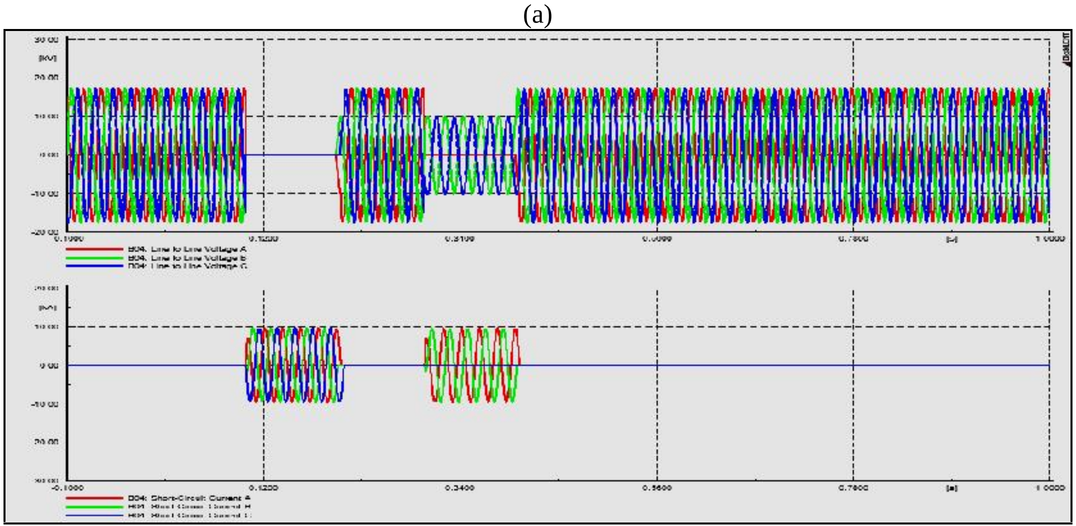


(c)

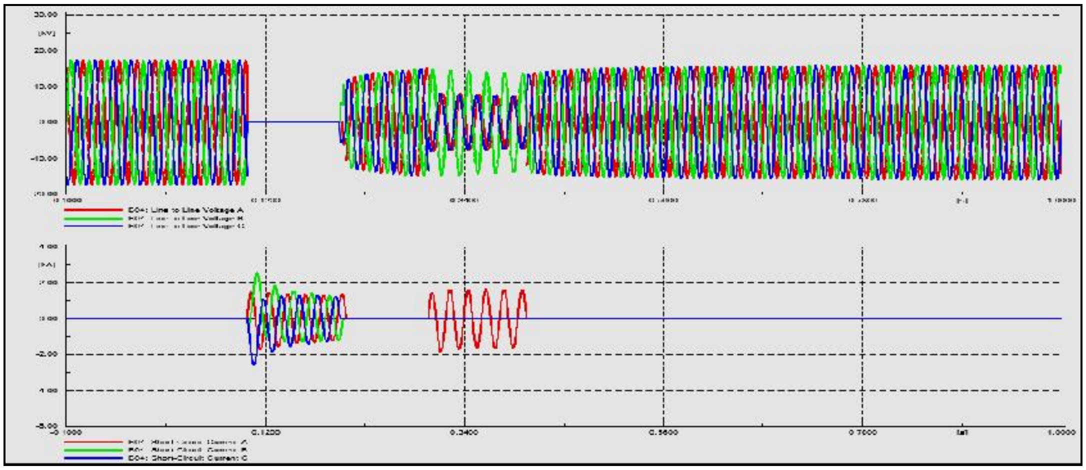
Figure 3. Rotor angle, speed and frequency variation under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind system for radial 33-bus system.



(a)



(b)



(c)

Figure 4. Volage and current variation under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind system for radial IEEE 33-bus system.

Table-2 confirms the results of radial 33-bus system with PV and Wind distributed generation (DG) case, which shows that the losses of system are reduced to 0.14MW and 0.09MVAr as compared to base case system i.e. without DG. It is also clear that the voltage profile at buses is improved and overloading is reduced with hybrid solar PV and wind generation. Finally, it can be summarized that the system feeder is protecting against 3-phase fault by operating phase fault protective relay 51P1 and 50P1. Similarly, the single line to ground fault is protected by ground fault relay 51G1 and 50G1 as shown in Figure 2(b-c). The speed, rotor angle and frequency variation under different condition (a) Normal, (b) Single line to ground and three phase faults without PV & Wind, (c) Single line to ground and three phase faults with PV &Wind system for radial IEEE 33-bus system as illustrated in Figure 3, which shows the less transient with solar and wind hybrid renewable DG.

Table 1. Results of IEEE 33-bus distribution system for base case

Load Flow Calculation

AC Load Flow, balanced, positive sequence			
Automatic tap adjustment of transformers	No		
Consider reactive power limits	No	Max. Loading of Edge Element	80.00 %
Automatic Model Adaptation for Convergence	No	Lower Limit of Allowed Voltage	0.95 p.u.
		Upper Limit of Allowed Voltage	1.05 p.u.

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Study Case: Study Case | Annex: / 1

Name	Type	Loading [%]	Voltage [p.u.]	Voltage [kV]	Station/Branch	Apparent Power [MVA]	Current [kA]	Current [p.u.]
Overloaded Elements								
B06	Term		0.95	12.02	Grid33			
B07	Term		0.95	11.98	Grid33			
B08	Term		0.93	11.80	Grid33			
B09	Term		0.93	11.72	Grid33			
B10	Term		0.92	11.65	Grid33			
B11	Term		0.92	11.64	Grid33			
B12	Term		0.92	11.62	Grid33			
B13	Term		0.91	11.54	Grid33			
B14	Term		0.91	11.51	Grid33			
B15	Term		0.91	11.49	Grid33			
B16	Term		0.91	11.48	Grid33			
B17	Term		0.90	11.45	Grid33			
B18	Term		0.90	11.44	Grid33			
B26	Term		0.95	12.00	Grid33			
B27	Term		0.95	11.96	Grid33			
B28	Term		0.93	11.82	Grid33			
B29	Term		0.93	11.71	Grid33			
B30	Term		0.92	11.67	Grid33			
B31	Term		0.92	11.62	Grid33			
B32	Term		0.92	11.61	Grid33			
B33	Term		0.92	11.60	Grid33			
Subs. Gen.	Sym	84.05			B01	4.62	0.21	0.84

Total System Summary						Study Case: Study Case		Annex:	/ 9
	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	No load Losses [MW]/ [Mvar]
\aashi\RIG33\Network Model\Network Data\Grid33									
	3.92	0.00	3.71	0.00	0.00	0.00	0.21	0.21	0.00
	2.44	0.00	2.30	0.00	0.00	0.00	0.14	0.14	0.00
Total:									
	3.92	0.00	3.71	0.00	0.00		0.21	0.21	0.00
	2.44	0.00	2.30	0.00	0.00		0.14	0.14	0.00

1 Conclusion

The presented study considers the implementation of standard IEEE 33-bus distribution system for protection and relay coordination with and without renewable (Solar PV and Wind) distributed generation. The simulation results of study clearly indicates that the coordination of protective devices is changed under faulty condition in the distribution system while the renewable distributed generations (DGs) solar and wind are considered. Also, the short-circuit analysis confirms that the grid fault current is decreased and different buses fault level changes, because the additional fault current is supplied by DGs. The bi-directional current flows in the distribution network branches are observed because of the renewable DGs penetration. The appropriate protective device coordination is very important in the distribution system while considering renewable DGs to increase reliability and avoid maloperation of tripping circuit in the system. This work has implemented an efficient direct approach to maintain protective devices coordination and also the inverse definite time relay to control the additional fault current provided by DGs. This direct approach can resolve the coordination complexity problem caused with integration of renewable DGs.

Table 2. Results of IEEE 33-bus distribution system with DG (PV and Wind Generation)

Load Flow Calculation			
AC Load Flow, balanced, positive sequence			
Automatic tap adjustment of transformers	No		
Consider reactive power limits	No	Max. Loading of Edge Element	80.00 %
Automatic Model Adaptation for Convergence	No	Lower Limit of Allowed Voltage	0.95 p.u.
		Upper Limit of Allowed Voltage	1.05 p.u.

	DIgSILENT PowerFactory 2019 SP4	Project:
		Date: 04-10-2021

Study Case: Study Case								Annex: / 1
Name	Type	Loading [%]	Voltage [p.u.]	Voltage [kV]	Station/Branch	Apparent Power [MVA]	Current [kA]	Current [p.u.]
Overloaded Elements								
B28	Term		0.95	11.97	Grid33			
B29	Term		0.94	11.87	Grid33			
B30	Term		0.93	11.82	Grid33			
B31	Term		0.93	11.77	Grid33			
B32	Term		0.93	11.76	Grid33			
B33	Term		0.93	11.75	Grid33			
PV System	Pvsys	10000.00			B18	0.10	0.00	103.14

	Generation [MW]/ [Mvar]	Motor Load [MW]/ [Mvar]	Load [MW]/ [Mvar]	Compen-sation [MW]/ [Mvar]	External Infeed [MW]/ [Mvar]	Inter Area Flow [MW]/ [Mvar]	Total Losses [MW]/ [Mvar]	Load Losses [MW]/ [Mvar]	No load Losses [MW]/ [Mvar]
\aashi\RIG33\Network Model\Network Data\Grid33									
	3.85	0.00	3.71	0.00	0.00	0.00	0.14	0.14	0.00
	2.39	0.00	2.30	0.00	0.00	0.00	0.09	0.09	0.00
Total:									
	3.85	0.00	3.71	0.00	0.00		0.14	0.14	0.00
	2.39	0.00	2.30	0.00	0.00		0.09	0.09	0.00

Nomenclature

DG	Distributed generation
PV	Photovoltaic
Mj	j^{th} machine inertia constant
Dj	j^{th} machine damping constant
Pmj	j^{th} machine mechanical input power
Pej	j^{th} machine injected active power
FF	Form factor;
I_{SC}	Short circuit current
V_{OC}	Open circuit voltage

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Biographical notes

Aashish Kumar Bohre received M. Tech. and Ph.D. from Maulana Azad National Institute of Technology Bhopal, India in 2009 and 2016, respectively. Presently he is Assistant Professor in the Department of Electrical Engineering, National Institute of Technology Durgapur, India. His research interests include distribution system planning, distributed generation, power system optimization & control, renewable generation, voltage security and stability analysis, electric vehicle and application of optimization techniques for power system problems.

Biman Kumar Saha Roy received the Ph.D. in Electrical Engineering from Indian Institute of Technology Kharagpur., India, in 2013. He has been with the Department of Electrical Engineering, National Institute of Technology, Durgapur, India, since 2018. Presently, he holds the post of Assistant Professor. His research interest includes application of synchrophasor measurements in power system.