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Fault Current Characterization using Regression for Solar PV based DC Microgrid

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Abstract:
Many challenges are related with the DC microgrid protection due to lack of well-defined protection standards. DC breakers are studied less as compared to AC breakers for distribution level applications. Fast detection of occurrence of fault and disconnection of healthy section of the line from the faulty section to protect from high fault current surges has become a vital area of research in DC distribution system. However, fault detection and corresponding relay operation and fault location estimation are two separate issues which require separate solutions. In this study, a methodology will be proposed to detect the fault and its location. The implementation of this methodology starts with modeling a low voltage DC microgrid and introducing different faults for analysis. An efficient method will be used to carry out the above said analysis. Using this methodology a fast, effective fault detection as well as accurate fault location calculation can be performed which is used for protecting the microgrid. Also, the behavior of the fault with respect to parameters affecting it is characterized using regreesion analysis.
***Keywords**: Microgrid, Fault location, Fault analysis, Regression*

I. INTRODUCTION

Microgrids are necessary to diminish the electricity costs, replace aged infrastructure, improve flexibility and reliability, reduce CO_2 emissions to mitigate climate change, and provide reliable electricity to areas lacking electrical infrastructure. Microgrids have emerged as a flexible architecture for deploying Distributed Energy Resources (DERs) that can meet the wide ranging needs of different communities from metropolitan cities to rural areas. During normal operating conditions, the microgrid is linked to the ac grid at the point of common coupling (PCC), and the loads are supplied from the local sources and, if necessary, also from the ac grid. If the load power is less than the power produced by the local sources, the excess power can be exported to the ac grid. The sources used in a microgrid are often small (500 kW) and are based on renewable energy, for example, PV arrays, fuel cells, and microturbines. These sources produce power with different voltage amplitude and frequency than those used in the microgrid and, therefore, need to be interfaced through power electronic converters [1]. According to the power properties, microgrids can be divided into AC and DC microgrids. AC microgrids have been extensively researched because of the similarities to the traditional AC

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power system. Nowadays, the advantages shown within DC microgrids arouse increasing interests of scholars around the world. Compared to AC microgrids, DC microgrids require less conversion stages and transmit more DC power through a given cable. Moreover, DC systems are inherently efficient without any skin effect and can decrease line losses. The LVDC microgrid is used to interconnect distributed resources and sensitive electronic loads. In most cases, these systems use grid-connected rectifiers with current-limiting capability during DC faults. A LVDC microgrid must be connected to an AC grid through converters with bidirectional power flow and, therefore, a different protection-system design is needed [2]. Unlike traditional ac systems, dc bus systems cannot survive or sustain high-magnitude fault currents. And if a fault causes the dc bus to de-energize completely, it makes locating faults very difficult. The DC microgrids are able to allow √2 times more power flow than that of an AC system. This is because the usable power is based on the RMS values in an AC system, while the dc power depends on constant current and voltage [3]. One of the main challenges in adopting the DC distribution system is the lack of effective solution for the fault protection. In this paper, a microgrid model will be developed and simulated for different fault conditions. The behavior of the system will then be analyzed and the characterization of the behavior of the system will be done using regression analysis.

II. PROPOSED PV BASED MICROGRID

For the purpose of analyzing the faults stated in section ii and to carry out the simulation, the model shown in fig.4 is considered. It consists of four solar PV arrays (two diode model) PV1, PV2, PV3 and PV4 as shown in the figure each of 100kW respectively. Each PV array consists of 64 parallel strings in which each string comprises of 5 series connected modules. Each of the PV array is connected to a DC/DC boost converter (average model), the outputs of which are connected to a common DC bus of 500V. The boost converter is controlled by MPPT which uses Perturb and Observe technique to vary the voltage across the terminals to obtain the maximum possible power. A three phase Voltage Source Converter (VSC) converts the 500V DC to 260V AC and maintains unity power factor. A 400-kVA 260V/25kV three-phase coupling transformer is used to connect the converter to the grid. The grid model comprises of 25-kV distribution feeders and 120-kV equivalent transmission system.

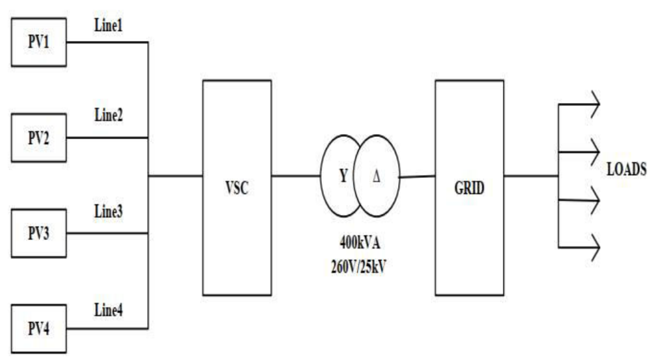

Fig.4. Proposed DC microgrid model

The above system is tested for different cases and the values solar irradiance, Fault distance ratio, fault resistance considered for simulation are as follows:

Solar irradiance – 1000 W/m2, 500 W/m2, 100 W/m2

Fault Distance ratio – 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9

Fault resistance of the line – 10Ω, 1Ω, 0.1Ω, 0.01Ω

Type of fault – Pole to pole fault, Pole to ground fault

Total number of events - 864

Since the solar irradiance is not constant throughout the day, the solar irradiance of each PV array is changed in terms of 1000W/m2, 500W/m2 and100W/m2. Each irradiance value is given to four different lines by changing the fault distance ratio (FDR) from 0.1 to 0.9 along with change in fault resistance of the line in terms of 10Ω, 1Ω, 0.1Ω and 0.01Ω respectively. Line to line and Line to ground faults are subjected to the DC line in each of the case and a total of 864 cases are simulated. The differential currents in all the four lines are extracted and stored in different mat files.

III. SIMULATION AND RESULTS

During fault condition the cable voltage and current change significantly. For an effective fault detection scheme these changes should get identified with minimum detection samples/ time. Regression analysis based average calculation can be achieved through sample by sample approach in which the differential current samples are compared with previous sample value to throw a higher index during sudden changes [6]. Line to Line fault and Line to Ground fault is given on each Line and by changing the fault resistance, 864 cases were performed and the energy values and elevated energy values of all the lines are calculated using cumulative summation algorithm. The differential currents and average values of all the four sections are stored in mat files. These mat files are executed with the help of code written Simulink to extract the energy values in each line. For illustration purpose, the differential currents obtained for six different cases with variation in parameters are depicted in figures 5, 6, 7, 8, 9 and 10 respectively.

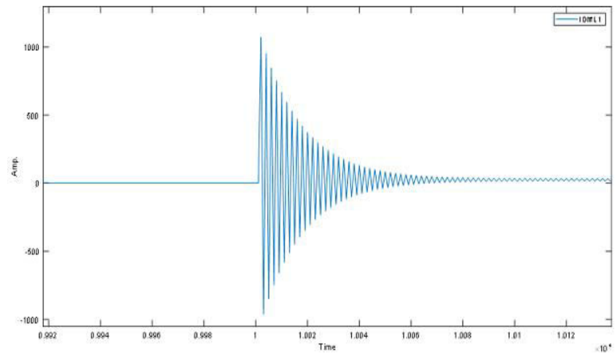

Fig.5 Differential current in line 1 of HVDC line subjected to a pole to pole fault at a solar irradiance of 1000W/m^2 and the line fault resistance of 10 Ω and at a fault distance ratio of 0.1

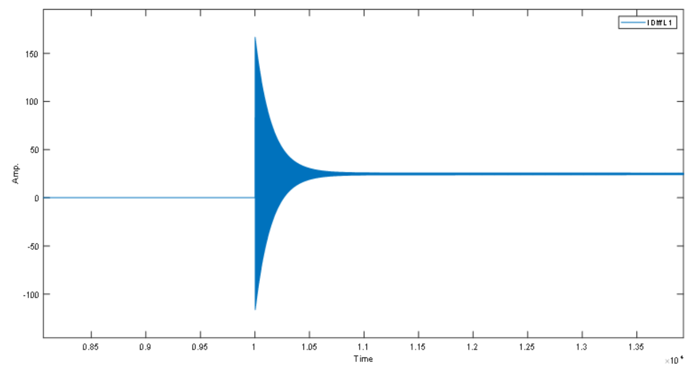

Fig.6 Differential current in line 1 subjected to a pole to pole fault at a solar irradiance of 1000W/m^2 and the line fault resistance of 10 Ω and at a fault distance ratio of 0.9

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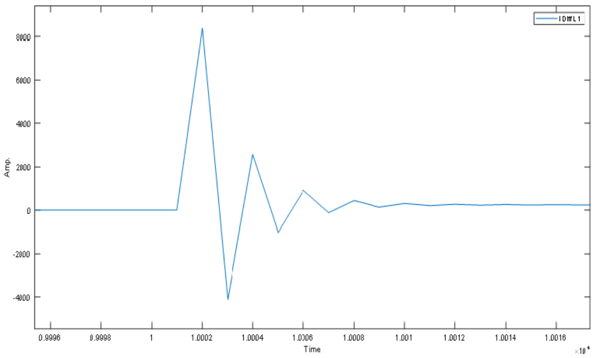

Fig.7 Differential current in section 3 of HVDC line subjected to a pole to pole fault at a solar irradiance of 1000W/m^2 and the line fault resistance of 1 Ω and at a fault distance ratio of 0.1

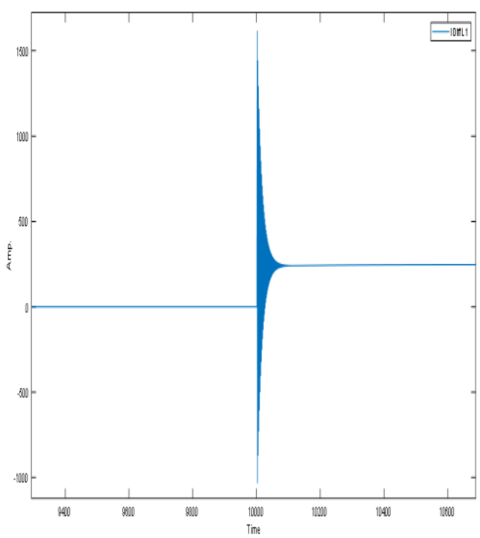

Fig.8 Differential current in section 4 of HVDC line subjected to a pole to pole fault at a solar irradiance of 1000W/m^2 and the line fault resistance of 1 Ω and at a fault distance ratio of 0.9.

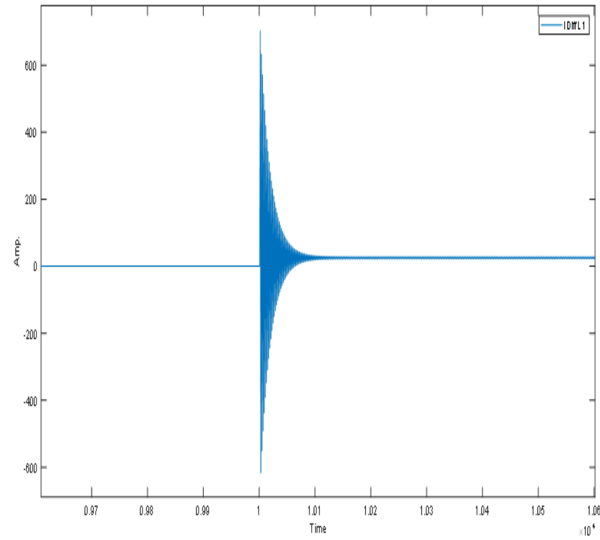

Fig.9 Differential current in section 4 of HVDC line subjected to a pole to pole fault at a solar irradiance of 500W/m^2 and the line fault resistance of 10 Ω and at a fault distance ratio of 0.2.

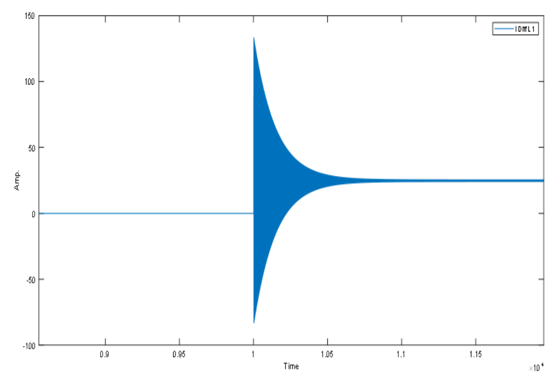

Fig.10 Differential current in section 4 of HVDC line subjected to a pole to pole fault at a solar irradiance of 500W/m^2 and the line fault resistance of 10 Ω and at a fault distance ratio of 0.9.

From the figures 5, 6, 7, 8, 9 and 10, the effect of various parameters on the proposed system can be concluded as shown in the Table 1.

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TABLE - I Effect of various parameters on the system

Parameter	Range	Effect
	0.1 - 0.9	Fault current magnitude decreases
Fault resistance(Ω)	0.1 - 10	Fault current magnitude decreases
Solar irradiance (W/m^2)	100 - 1000	Fault current increases
Fault type	Pole to Pole	Fault current magnitude will be more
	Pole to Ground	Fault current magnitude will be less

IV. FAULT CURRENT CHARACTERIZATION

Correlation is a statistical technique that can show whether and how strongly pairs of variables are related. For example, height and weight are related; taller people tend to be heavier than shorter people. n statistics, correlation or dependence is any statistical relationship, whether causal or not, between two random variables or bivariate data. Although in the broadest sense, "correlation" may indicate any type of association, in statistics it normally refers to the degree to which a pair of variables are linearly related. Familiar examples of dependent phenomena include the correlation between the height of parents and their offspring, and the correlation between the price of a good and the quantity the consumers are willing to purchase, as it is depicted in the so-called demand curve.

Formally, random variables are dependent if they do not satisfy a mathematical property of probabilistic independence. In informal parlance, correlation is synonymous with dependence. However, when used in a technical sense, correlation refers to any of several specific types of mathematical operations between the tested variables and their respective expected values. Essentially, correlation is the measure of how two or more variables are related to one another. The following graphs obtained as result for the following tables mentioned in above chapter with different cases:

Table below gives the correlation between the systems connected under different capacities for Irradiance Vs Fault resistance:

Table 2: Correlation of irradiance

S.No	System Connected	R	Rsqr	Adj Rsqr	Coefficients	Equation
1	100kw off grid	0.9989	0.9977	0.9975	$y_0 = 1.0222$,a=0.0038 b=-3.1427e-6, c=1.612e-9	$I_f = 1.0222 + 0.0038 * I_r - 3.1427e^{-6} * I_r^2 + 1.612e^{-9} * I_r^3$ Where I_f is fault current and I_r is irradiance.
2	100kw grid connected	0.9892	0.9784	0.9777	a=2.9632, b=0.0005	$I_f = 2.9632 * e^{(-0.0005 * I_r)}$ Where I_f is fault current and I_r is irradiance.
3	500kw off grid	0.9996	0.9992	0.9991	$y_0 =$ 1.1017,a=0.0031 b=-5.7216e-7, c=6.1271e-10	$I_f = 1.1017 + 0.0031 * I_r - 5.7216e^{-7} * I_r^2 + 6.1271e^{-10} * I_r^3$ Where I_f is fault current and I_r is irradiance.
4	500kw grid connected	0.9905	0.9810	0.9804	a=2.9443, b=0.0005	$I_f = 2.9443 * e^{(-0.0005 * I_r)}$ Where I_f is fault current and I_r is irradiance.
5	1000kw off grid	0.9996	0.9992	0.9991	$y_0 =$ 1.1012,a=0.0031 b=-6.34e-7, c=6.615e-10	$I_f = 1.1012 + 0.0031 * I_r - 6.34e^{-7} * I_r^2 + 6.615e^{-10} * I_r^3$ Where I_f is fault current and I_r is irradiance.
6	1000kw grid connected	0.9899	0.9798	0.9791	a=2.9432, b=0.0005	$I_f = 2.9432 * e^{(-0.0005 * I_r)}$ Where I_f is fault current and I_r is irradiance.

Table below gives the correlation between the systems connected under different capacities for Fault current Vs Fault resistance:

Table 3: Correlation of fault resistance

S.No	System Connected	R	R Sqr	Adj Rsqr	Coefficients	Equation
1	100kw off grid	0.9799	0.9603	0.9588	$y_0 = 0.5841$, a=149.9547	$I_f = 0.5841 + (\frac{149.9547}{I_{fr}})$ Where I_f is fault current and I_{fr} is fault resistance.
2	100kw grid connected	1	1	1	$y_0 = -0.8904$, a=249.9547	$I_f = -0.8904 + (\frac{249.9547}{I_{fr}})$ Where I_f is fault current and I_{fr} is fault resistance.
3	500kw off grid	0.9768	0.9542	0.9525	$y_0 = 0.7512$, a=153.6114	$I_f = 0.7512 + (\frac{153.6114}{I_{fr}})$ Where I_f is fault current and I_{fr} is fault resistance.
4	500kw grid connected	1	1	1	$y_0 = -0.9531$, a=249.9753	$I_f = -0.9531 + (\frac{249.9753}{I_{fr}})$ Where I_f is fault current and I_{fr} is fault resistance.
5	1000kw off grid	0.9767	0.9540	0.9523	$y_0 = 0.7547$, a=153.9623	$I_f = 0.7547 + (\frac{153.9623}{I_{fr}})$ Where I_f is fault current and I_{fr} is fault resistance.
6	1000kw grid connected	1	1	1	$y_0 = -0.9539$, a=249.9820	$I_f = -0.9539 + (\frac{249.9820}{I_{fr}}))$ Where I_f is fault current and I_{fr} is fault resistance.

Table below gives the correlation between the systems connected under different capacities for Fault current Vs Fault Distance Ratio:

Table 4: Correlation of fault distance ratio

S.No	System Connected	R	R Sqr	Adj Rsqr	Coefficients	Equation
1	100kw off grid	0.9951	0.9902	0.9895	$y_0 = -0.4641$, a=3.0024 b=7.3570	$I_f = -0.4641 + 3.0024 \times \left(1 - e^{(-7.3570 * I_{fdr})}\right)$ Where I_f is fault current and I_{fdr} is fault distance ratio.
2	100kw grid connected	0.9951	0.9903	0.9895	$y_0 = -0.3575$, a=2.9913 b=7.3496	$I_f = -0.3575 + 2.9913 \times \left(1 - e^{(-7.3496 * I_{fdr})}\right)$ Where I_f is fault current and I_{fdr} is fault distance ratio.
3	500kw off grid	0.9952	0.9905	0.9898	$y_0 = -0.4808$, a=3.2609 b=7.2395	$I_f = -0.4808 + 3.2609 \times \left(1 - e^{(-7.23905 * I_{fdr})}\right)$ Where I_f is fault current and I_{fdr} is fault distance ratio.
4	500kw grid connected	0.9938	0.9876	0.9867	$y_0 = -0.5621$, a=3.1771 b=7.0860	$I_f = -0.5621 + 3.1771 \times \left(1 - e^{(-7.0860 * I_{fdr})}\right)$ Where I_f is fault current and I_{fdr} is fault distance ratio.
5	1000kw off grid	0.9951	0.9902	0.9895	$y_0 = -0.5188$, a=3.304 b=7.3546	$I_f = -0.5188 + 3.304 \times \left(1 - e^{(-7.3546 * I_{fdr})}\right)$ Where I_f is fault current and I_{fdr} is fault distance ratio.
6	1000kw grid connected	0.9951	0.9902	0.9895	$y_0 = -0.6081$, a=3.2007 b=7.3386	$I_f = -0.6081 + 3.2007 \times \left(1 - e^{(-7.3386 * I_{fdr})}\right)$ Where I_f is fault current and I_{fdr} is fault distance ratio.

V. CONCLUSION

Fault analysis of the SPV based DC Microgrid for various fault conditions has been presented in this paper. Whenever a fault occurs in a line, the voltage drops whereas the currents in the line increase to a very large value during the fault condition. We can predict a fault by observing the waveforms of ac or dc side voltages or currents which is not sufficient when we are concerned with the protection of the system. In the protection systems, fast and accurate detection of faults is of utmost importance. Therefore a methodology for characterization of the fault and system behavior during fault has been presented using regression analysis. This is useful for understanding the behavior of the system when subjected to faults without in detail modeling and simulations and can be extended to larger systems also.

REFERENCES

[1] Salomonsson D, Soder L, and Sannino A (2009) Protection of low-voltage dc microgrids, IEEE Trans. Power Del.,24:3, 1045–1053.

[2] Dhar S, Patnaik RK and Dash PK (2018) Fault Detection and Location of Photovoltaic Based DC Microgrid Using Differential Protection Strategy, IEEE Transactions on Smart Grid, 9:5, 4303-4312, doi: 10.1109/TSG.2017.2654267.

[3] Park JD, Candelaria J, Ma L, and Dunn K (2013) DC ring-bus microgrid fault protection and identification of fault location, IEEE Trans. Power Del.,28:4, 2574–2584.

[4] Ramakrishna Nuvvula, Elangovan Devaraj & Kishore Teegala Srinivasa (2021) A Comprehensive Assessment of Large-scale Battery Integrated Hybrid Renewable Energy System to Improve Sustainability of a Smart City, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, DOI: 10.1080/15567036.2021.1905109.

[5] Mallick RK and Patnaik RK (2011) Fault analysis of voltage-source converter based multi-terminal HVDC transmission links, International Conference on Energy, Automation and Signal,1-7, doi: 10.1109/ICEAS.2011.6147204.

[6] Kishore T S, Koushik S D, Venu Madhavi Y, "Modelling, Simulation and Analysis of PI and FL Controlled Microgrid System", 3rd IEEE International Conference on Electrical, Computer and Communications Technologies (ICECCT 2019), 20-22 Feb, 2019, SVS College of Engineering, Coimbatore, India.

[7] Tang L and Ooi BT (2007) Locating and isolating DC faults in multi-terminal DC systems, IEEE Trans. Power Del., 22:3, 1877–1884.

[8] Meghwani A, Srivastava SC, and Chakrabarti S (2015) A new protection scheme for DC microgrid using line current derivative, Proc. IEEE Power Energy Soc. Gen. Meeting, 1–5.

[9] Mohanty SR, Pradhan AK, and Routray A (2008) A cumulative sum-based fault detector for power system relaying application, IEEE Trans. Power Del., 23:1, 79–86.

[10] Azizi S, Afsharnia S, and Pasand MS (2014) Fault location on multi-terminal DC systems using synchronized current measurements, Int. J. Elect. Power Energy Syst., 63: 779–786.

[11] Chakravorti T, Patnaik RK, Dash PK (2017) Advanced signal processing techniques for multiclass disturbance detection and classification in microgrids, IEEE transactions on Measurement & Technology, 11:4, 504-515.

[12] Liu D, Wei T, Huo Q and Wu L (2015) DC Side Line to- line Fault Analysis of VSC- HVDC and DC- fault-clearing Methods, IEEE 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, 2395- 2399.

[13] Patnaik RK & Vara P and Rakesh PK (2019) An advanced signal processing based anfis classifier for fault analysis of dfig based hvdc transmission links, Journal of Advance Research in Dynamical & Control Systems, 11:2, 1154-1167.

[14] Muniappan M (2021) A comprehensive review of DC fault protection methods in HVDC transmission systems, IEEE transactions on Protection and Control of Modern Power Systems, doi: 10.1186/s41601-020-00173-9.

[15] Raza A, Akhtar A, Jamil M, Abbass G, Gillani SO, Yuchao L, Khan MN, Izhar T, Dianguo X, Williams BW (2017) A Protection Scheme for Multi-terminal VSC-HVDC Transmission Systems, IEEE transactions of Power Electronics, doi: 10.1109/ACCESS.2017.2787485.