Modelling of Standalone DC Nanogrid system with Line to Ground Fault in Small Scale Industry

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***Abstract*—Now a day world is moving towards renewable energy sources with smart grid. As today's power system is more flexible and complicated than the previous one. To obtain the reliability, it is very much important to obtain a fast fault detection process and isolation of the fault from the healthy section. Standalone photovoltaic (PV) system is the mostly used renewable sources in the generation of electrical energy. This paper shows the detection, localization and protection of L-G fault with standalone PV system with different load conditions.**

Keywords—Standalone PV system, Protection issues, Protection schemes, Nanogrid

I. Introduction

As the demand of electrical energy is increasing rapidly and due to the environment concern, whole world is going to adopt Renewable Energy Sources (RESs) as the source of power. This energy generation in future will be based on the renewable sources such as photovoltaic (PV) array and wind turbines among other forming micro and nano grids [1- 3]. The best way to reduce the impact of fossil energy resources is by producing energy with clean energy near to the consumer's place [4- 6]. This renewable energy sources can be integrate with power grid or can be use this sources as standalone mode also [2]. But when these sources are integrated with power grid then it will changes the system configuration. Similarly conventional protection system is not feasible with this integration [7-8]. In standalone mode the system is formed with renewable energy source, load and storage unit like battery.

An isolated power system can be formed with power sources and loads or combined with other local generators as a microgrid or nanogrid [2-3]. A Nanogrid is a power distribution for a single house/small building, with ability to connect or disconnect from other power entities via a gateway [3, 9-10]. It consists of local power production powering local loads, with the option of utilising energy storage and/or a control system. Typically, the load range of the nanogrid is in between 1kW – 20kW [2], and the loads are located within 5km of the sources. There are basically two types of fault occur in the DC network, i.e. Line to Line fault (LL) and Line to Ground fault (LG). The LG fault is very common type of fault in the DC network [11]. The reason behind this fault may be physical problem due to environmental stresses, electrical problems, and ageing of cable [12]. The differential current protection scheme was proposed in [13-14] to find out the fault in cable of the network [15]. For the data transmission between protected elements terminals, an authentic communication unit is requires. There may be chances of communication failure or data loss, so the differential protection needs an additional protection i.e. back up protection. This leads to increase in cost and size of the protection system and limits its application [16].

II. Standalone PV System

A stand-alone PV system is a solar system which generates electricity with help of solar radiation to fulfil the demand of consumers. This system consists of solar PV array and for storage purpose battery with its control unit.

This system is used in the areas where the electricity is not easily accessible through transmission and distribution network. A stand-alone system is independent of the electricity grid, with the energy produced normally being stored in batteries.

These systems are developed to work individually without other utility grid. Generally these are designed to operate with DC and/or AC loads. Basic simple kind of standalone PV system is directly coupled in which the output of solar PV array is connected to DC load as shown in figure 1.

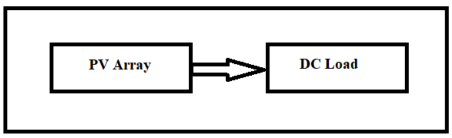

Fig. 1. Simplest type of stand-alone PV system

As in this system, no arrangement of energy storage/ battery, so it is operated only day time. So it's common application is ventilation fans, water pumps etc. In most of the stand alone PV systems, energy storage arrangement is provided. As shown in figure 2 a Standalone PV system supplying the DC as well as AC loads.

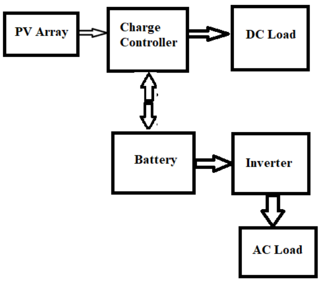

Fig. 2. Schematic diagram of a stand-alone PV application

The application of Standalone PV system is in the areas that are not easily connected to electric grid. Usually standalone PV systems consist of PV array, battery with charge controller. Sometimes inverter is also included in the structure for converting DC output of PV module in to AC as per the requirement of load. A diagram of a stand-alone system is shown in figure 2. The system can satisfy both DC and AC loads simultaneously [17-19].

A. Design of Solar PV system

Considering STC (Standard Test Condition)

The characteristics of one solar cell are as follows:

Open circuit voltage V_{OC} = 0.6 V

Short circuit current I_{SC} = 7.34A

Here 10 solar cells are connected in series to form one solar module.

So the rating of one solar module is as follows:

Open circuit voltage $Voc = 0.6 \times 10 = 6\,V$

Short circuit current I_{SC} = 7.34A

Such five solar modules are connected in series to form the one solar panel, so the rating of solar panel is as follows:

Open circuit voltage $Voc = 6 \times 5 = 30\,V$

Short circuit current I_{SC} = 7.34A

This solar panel may be roof mounted or ground mounted.

B. Standalone PV system with DC load

The MATLAB simulation model of Standalone PV system for DC load only without battery arrangement is shown in figure 3. This model consists of solar panel as source and resistive loads only.

TABLE I. DIFFERENT PARAMETERS OF PV MODULE

Sr. No	Parameter	Value
1	PV module one solar cell a) Open circuit voltage V_{oc} b) Short circuit current I_{sc} c) Temperature	 0.6 V 7.3 A 25^0C

TABLE II. DETAILS OF THE LOADS OF STANDALONE PV SYSTEM WITH DC ONLY

Sr. No	Resistive Load (Ohm)	Switch on time (Sec)
1	R_1 = 20	Continuously on
2	R_2 = 20	2
3	R_3 = 10	3

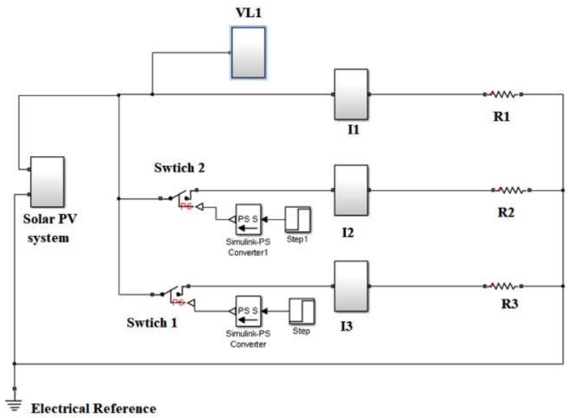

Fig. 3. Model of a Stand-alone PV with DC load only without battery storage

TABLE III. OPERATION OF THE CIRCUIT IS AS FOLLOW

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	0-2	1.48	0.0	0.0	29.5
2	2-3	1.45	1.45	0.0	29.0
3	After 3	1.37	1.36	2.73	27.3

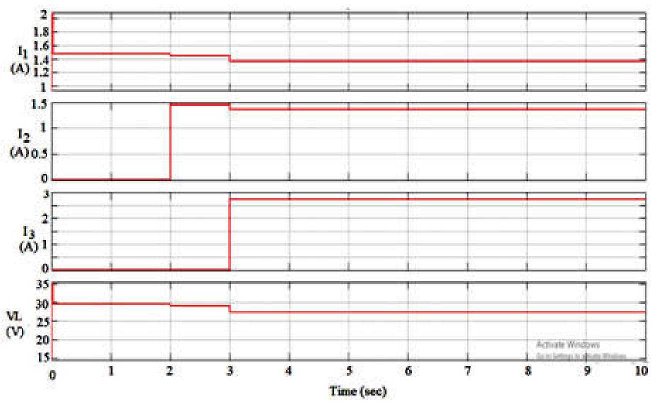

Fig. 4. Current flowing through different loads values

From the above result it is observed that during different time interval how the load will be switched on and according to that how the individual load currents will be flows.

C. *Solar PV system without battery with Line to Ground fault (without auto reclosure)*

As in the DC circuit L-G fault is very common type of fault, so here L-G fault is inserted in the one of the load R_1, to identify the changes in the current. Here only the fault location is detected and after finding the fault location that particular load is disconnected from the healthy system.

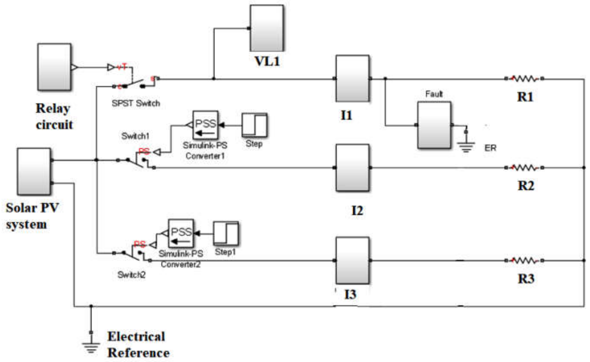

Fig. 5. Model of Solar PV systems without battery with Line to Ground fault (Without auto reclosure)

TABLE IV. SWITCHING ON INSTANCES OF LOADS

Sr. No	Resistive Load [Ohm]	Switch on time [s]
1	$R_1 = 10$	Continuously on
2	$R_2 = 10$	2
3	$R_3 = 10$	3

TABLE V. OBSERVATIONS (BEFORE FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	0-2	2.9	0	0	29
2	2-3	2.7	2.7	0	27.3
3	3-5	2.36	2.36	2.36	23.5

TABLE VI. OBSERVATIONS (AFTER FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	At 5 sec Fault occurred	7.32	0	0	0
2	5 – 7 sec	7.32	0	0	0
3	After 7 sec Relay operates	0	2.73	2.73	0

So from the observation it is observed that the current through load R_1 goes high i.e. short circuit current after L-G fault at a time of 5 second. This fault persists for some time, after that the relay will operate and the load R_1 is disconnected from the other system, though the current through load R_1 goes to zero. As the fault clearing and auto reclosing of the load is not done, so that load R_1 remains disconnected from the system.

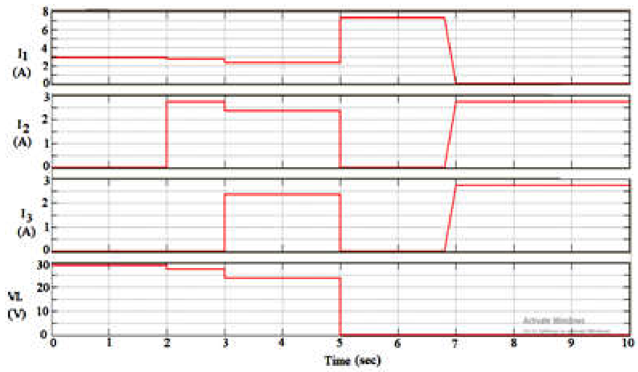

Fig. 6. Current flowing through loads at different time interval

D. *Solar PV system with battery and Line to Ground fault without reclosure*

In the previous model storage system i.e. battery is not included. As solar PV output is stochastic nature, here in this model battery is used for storing the power, which can be used when there is no solar available.

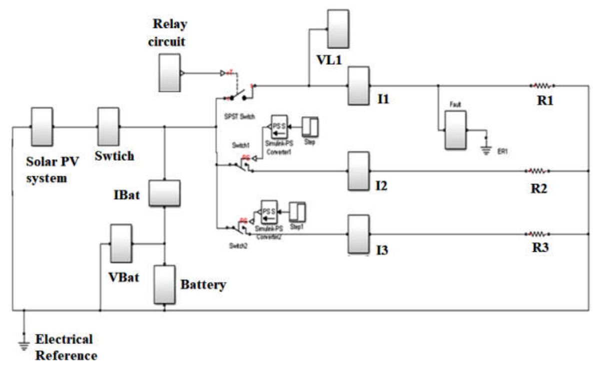

Fig. 7. Model of Solar PV system with battery and Line to Ground fault without reclosure

TABLE VII. OBSERVATIONS (BEFORE FAULT INCEPTION)

Sr. No	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	0-2	2.45	0.0	0.0	24.4
2	2-3	2.45	2.45	0.0	24.2
3	3-5	2.45	2.36	2.4	24.0

Load R_1 is continuously on in the circuit. Load R_2 is switch on at time of 2 second. Whereas Load R_3 is comes into the circuit at the time of 3 second. But when

L-G ground occurs on the load R_1, the current flowing through the R_1 is enormously increases i.e. 205A. This hike in the current is due to battery connection in the circuit. As fault clearing and auto closing is not included so the faulty section is disconnected from the healthy system throughout the operation after the fault inception.

TABLE VIII. OBSERVATIONS (AFTER FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	At 5 sec Fault is occurred	205	0.4	0.4	2.0
2	5 – 5.5 sec	205	0.4	0.4	2.0
3	After 5.5 sec relay operates	0.0	2.42	2.42	0.0
4	After 7 sec solar system is disconnected	0.0	2.35	2.35	0.0

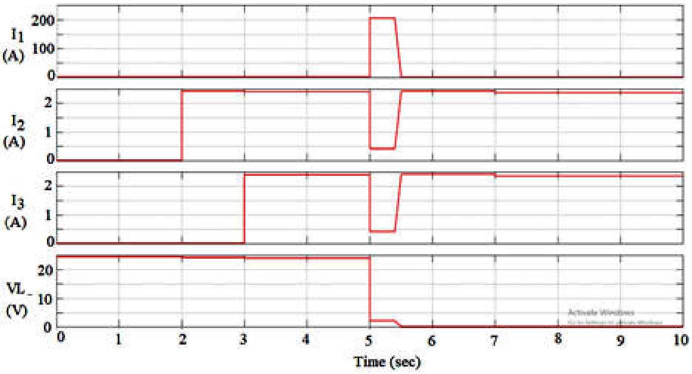

Fig. 8. Current flowing through different loads values

E. *Solar PV system with battery and Line to Ground fault with reclosing circuit*

In this model, provision of fault clearing and auto reclosing of the load in the healthy system is carried out.

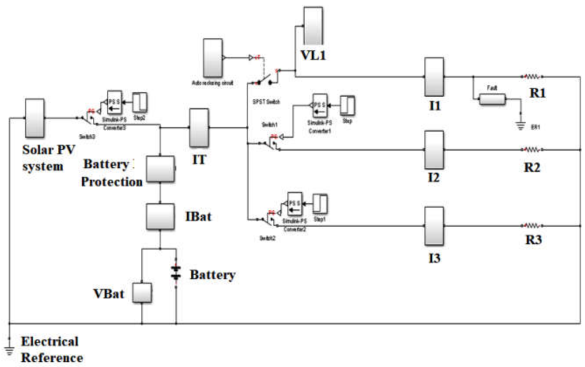

Fig. 9. Model of Solar PV system with battery and Line to Ground fault with reclosing circuit

Load R_1 is continuously on in the circuit. Whereas load R_2 is switched on at the time interval of 2 second, and load R_3 is on at the time of 3 second. At the time interval of 5 second L-G fault is inserted in the load R_1, so here the fault is very high i.e. 190A. As due to the presence of battery the fault current is very high so first battery is disconnected from the circuit. Now the fault current is short circuit current Isc = 7.4A. Now the faulty part is disconnected from the circuit. After clearing the fault the load R_1 is again reconnected to the circuit.

TABLE IX. OBSERVATIONS (BEFORE FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	0-2	2.45	0.0	0.0	24.4
2	2-3	2.42	2.42	0.0	24.2
3	3-5	2.40	2.40	2.40	23.9

TABLE X. OBSERVATIONS (AFTER FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	At 5 sec Fault is occurred	190	0.38	0.38	1.9
2	5 – 5.05	190	0.38	0.38	1.9
3	After 5.05 sec battery disconnect	7.4	0.02	0.02	0.09
4	At 5.1 sec relay operates	0.0	2.42	2.72	0.0
5	At 6 sec recloses circuit	2.4	2.35	2.35	23.5
6	After 9 sec solar disconnects	0.0	0.0	0.0	0.0

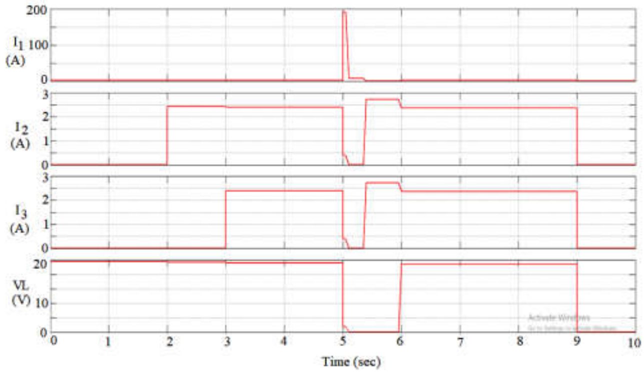

Fig. 10. Current flowing through different loads values

F. *Solar PV system with battery and Line to Ground fault with reclosing circuit*

As in previous model after fault insertion battery is disconnected from the circuit and it not reconnected again in the circuit. So after the solar disconnection all the loads show zero current as it is observed in observation table. But here when fault occurs, the battery is immediately disconnected from the circuit. Then fault current value is reduced to short circuit current value.

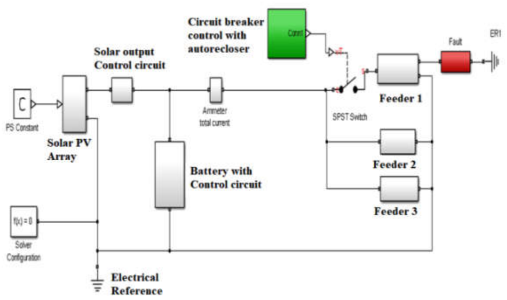

Fig. 11. Model of Solar PV circuit with auto reclosure with battery reconnection

TABLE XI. OBSERVATIONS (BEFORE FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	0-2	2.44	0.0	0.0	24.4
2	2-3	2.42	2.42	0.0	24.2
3	3-5	2.40	2.39	2.39	23.9

TABLE XII. OBSERVATIONS AFTER FAULT INCEPTION)

Sr. No.	Time [s]	I_1 [A]	I_2 [A]	I_3 [A]	V_{L1} [V]
1	At 5 sec Fault is occurred	190	0.38	0.38	1.9
2	5 – 5.05	190	0.38	0.38	1.9
3	After 5.05 sec battery disconnect	7.4	0.02	0.02	0.09
4	At 5.4 sec relay operates	0.0	2.42	2.42	0.0
5	At 6 sec recloses circuit	2.4	2.4	2.4	24
6	After 9 sec solar disconnect but battery reconnects in circuit	2.32	2.32	2.32	2.32

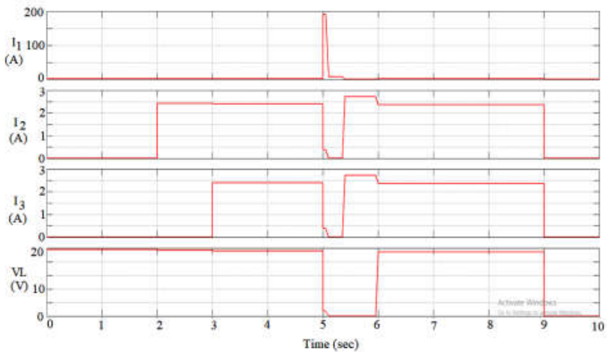

Fig. 12. Current flowing through different loads values

CONCLUSION

In the future the power generation is no longer done by coal burning. It can be done by the renewable energy sources such as solar photovoltaic, wind turbine with energy storage units developing the micro grid and nanogrid. In all this solar PV power generation is one of the best options as it generates electrical energy without carbon emission and with low maintenance.

As due to different rewards of nanogrid over the conventional grid, in this paper standalone PV system is designed, modelled and simulated in the MATLAB software. Here standalone PV system has been taken with DC load only without energy storage unit (battery) similarly standalone PV system with energy storage unit *i.e.* battery. Considering both the conditions, L-G fault is created and their results without auto-reclosing condition and with auto-reclosing condition after fault inception are observed.

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