Study of Fault Currents and Relay Coordination of a Chemical Industry After Integrating with PV Generation and Simulation with a Software.

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Abstract — *In the present de-regulation and distributed generation era, most of the large industries are adopting various distribution generators with the use of Renewable energy resources like solar, wind etc. The main purpose of this paper is to discuss the basic principle of solar photo-voltaic system, its integration with the existing utility grid and protection issues. As all are aware, solar power generation is being encouraged globally with the tag of "Green Power", but there are certain issues like synchronisation, power- flows, harmonics and especially protective relay coordination. Later has been discussed thoroughly in this paper. A continuous chemical Industry, whose incoming grid power is integrated with solar PV power, has been selected for the case study. In the selected industry, a part of electrical net-work, which covers with point of coupling (POC) and detailed fault calculations are done as per the available literature for both the scenarios of pre-PV integration and post-PV integration. Also similar fault calculations are done with e-tap software and compared both the results. Then the relay coordination or Time Current Characteristics (TCC) of both pre and post PV integration scenarios are simulated with the software and the both results are compared to arrive a final conclusion of Relay coordination.*

Key words: *Solar Photo Voltaic, Relay co-ordination, PV integration, Fault currents, Point of coupling*.

I. INTRODUCTION

The power industry across the globe is experiencing a radical change in business as well as in operational model when the vertically integrated utilities are being un-bundled [1] and opened up for competition in power generation area which ends up the monopoly era of power system generation, with the advancement in Power Electronic Devices (PED), the integration of distributed generation in to the existing power network has increased rapidly. Business community, both state and private, are adopting renewable energy generations [2] either to meet the regulatory norms like respective geo-graphical Electricity Regulation Commissions in the form of Renewable Power Purchase Obligation (RPPO) or to reduce power bills. One of the major distributed integration facilities [3] is solar power, with the help of solar photo-voltaic (SPV) cells. The basic schematic diagram of a solar power plant is shown in Fig. 1. and described briefly as follows:

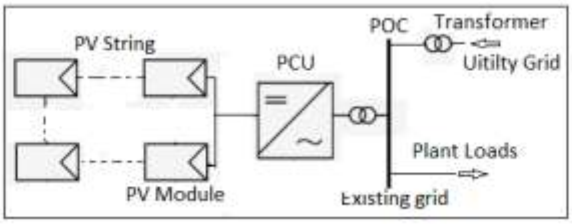

Fig 1: Schematic diagram of a solar power plant

The PV module, consisting of PV cells, converts the solar radiation in to DC electricity which again will be converted in to AC by inverters. The PV modules are first formed into strings by connecting in series to get the required voltage and then strings are connected is parallel to get the required power capacity. Then the output is fed to a Power Conditioning Unit (PCU) where it is converted in to AC. The PCU is not only acting as an inverter but also doing the functions of voltage regulation, maximum power point tracking (MPPT), synchronisation with grid, auto sleep and wake up functions and as a protective device. Also it monitors the power-flow at the Point Of Coupling and faults occurring in system.

II. DESCRIPTION

Keb Chemicals, The industry under study, is a chemical industry whose power schematic diagram is diagram is shown in Fig. 2.

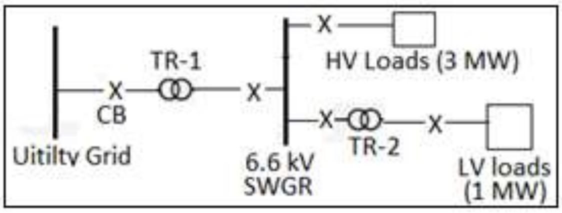

Fig 2: Power Schematic diagram of industry

The brief technical particulars of the Transformers are given in Table-I

TABLE I
TRANSFORMERS DATA

Parameters	TR-1	TR-2
MVA Rating	10	1.6
Primary voltage - KV	33	6.6
Sec. voltage- KV	6.6	0.415
% Z	8.75	6
Amps-primary	175	140
Amps-secondary	875	2130
Vector group	Dyn 11	Dyn 11
Grounding	Through a 3.8ohms resistor	Solid

Even though the total electrical network is large in size, the present study is restricted to 6.6 kV SWGR i.e., POC and its power 'in' and 'out' connections for fault currents calculations and simulations. The total load of the industries was 4 MW which was totally met from the utility grid. In the recent past, the unit was decided to go for a 1 MWp solar power plant and installed the same to meet the legal requirements. The power schematic diagram of main electrical power net work after PV integration is shown in Fig. 3. and the details of PV equipment given below.

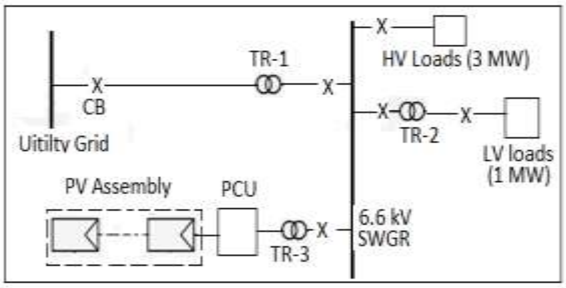

Fig 3: Power Schematic diagram post-PV integration

Each PV module: 255W, 30 V (Vmp), 37 V (Voc), 8.5A (Imp), 8.9A (Isc)
Each String: 21 nos of modules in series to give 340 V, 5.355 kW, 8.5 A
Total Strings in parallel: 2 arrays X 94 nos to give 630 V,
2 x 0.5 MWp, 790 A

All the circuit Breakers (CB) are of Vacuum circuit breakers.
The HT switchgear is standard indoor type with all interlocks. Transformer, TR-3 : 3 winding, 340 V/340 V/6.6 kV, 50Hz, Dy5y5, 6 %, 1.25MVA, 1061A/ 1061A/ 109A. The detailed schematic diagram of PV assembly is shown in Fig. 4.

Inverter (in PCU): 630 V DC/ 630 V AC, 50Hz, 3ph.
Loads are mostly induction motors.

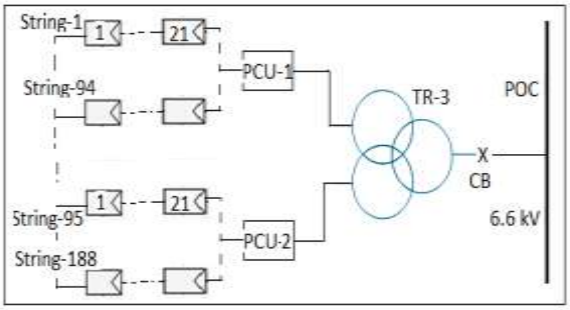

Fig 4: Schematic diagram of PV Assembly

III. PV System Integration Issues

These are certain issues encountered by the industry due to SPV integration [4] like over voltages, Bi-directional power flow, power quality, harmonics, power fluctuations, protections, synchronisation etc.. However the scope of this paper is restricted to protection issues. Power system analysis reviews [5] the study of the various faults currents, rating of equipment [6] to with stand these faults [7] and protective relay settings accordingly. Since the protective device provides a form of insurance [8] for vital electrical equipment which reduces the equipment damage and en danger to human in the vicinity. Whenever an equipment or distributed generation is added, proper relay coordination [9] to be ensured so as to protect the entire network as intended and to meet the overall objective of coordination of protection and switching devices. Fault current for various faults, play a significant role in electrical protection system. Their magnitude varies from grid to grid. The integration may cause of loss of sensitivity of over current and earth fault relays [10]. Hence a detailed analysis is required to avoid mal operation and unwanted trips. When a fault occurs in grid, the fault is additionally supplied by distributed generators and may change operating sequence of circuit breakers [11]. Hence it is to be ensured that during any fault in system, the distributed generators like PV generation should be isolated as quickly as possible so that conventional protection system will isolate the faults as intended.

IV. Calculation of Fault Currents and Methodology

Fault currents of a utility grid are very high in magnitude and all the electrical equipment is suitably designed to with stand these fault currents. In this paper following methodology is followed by restricting to these major faults viz L-L-L (Symmetrical) and L-G (Un symmetrical) faults:

1. Calculation of L-L-L fault current at POC by power MVA method for pre-PV integrated system.
2. Calculation of L-G fault current at POC by power MVA method for pre-PV integrated system.
3. Repeating the steps (1) to (2) for post- PV integrated system to arrive a conclusion of variations in fault currents of pre and post integration scenario.
4. Simulation of L-L-L fault with e-tap software to know the fault currents for comparison purpose.
5. Estimation of fault clearing times (i.e. Trip time) for L-L-L and L-G faults, at POC of both pre and post PV integration scenario with TCC Curves of Relay.
6. Analysis and conclusions of calculations and review study done for final recommendations if any for post-PV integration scenario.

A. Pre-PV Integration Scenario

1) ***L-L-L fault***: Fault MVA diagram with simplified calculations [12] is shown in Fig. 5. with further simplification in the same figure itself.

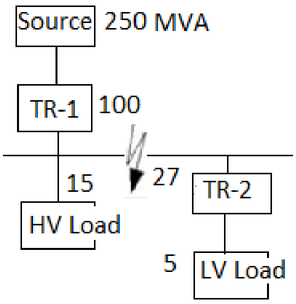

Fig. 5.1

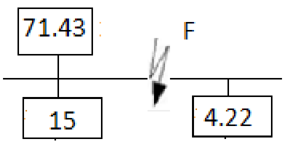

Fig. 5.2

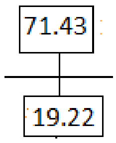

Fig. 5.3

SC MVA = = 71.43 + 19.22 = 90.65 or
Short Circuit Current, If = 7.9 kA which is termed as Over Current.

2) ***L-G Fault:***

Fault diagram is shown in Fig. 6.

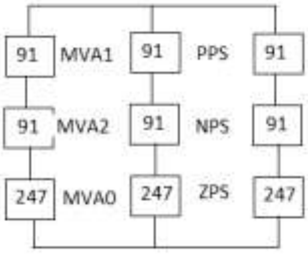

Fig. 6

Here the Delta connected winding of TR-1 blocks the flow of zero sequence current from source.
Also in motors, X0=50% of X1= 12.5%.
MVA_{ZPS} of HV motor= 15/0.125=120 and
MVA_{ZPS} of LV motor= 1.25/0.125=10 (But blocked by Delta connected winding of TR-2)
MVA_{ZPS} = 100 +27+120 = 247

Total fault MVA=38.4 X 3 = 115.27 or If=10.1 kA

B. Post-PV integration scenario

1) ***L-L-L fault***: Fault MVA diagram is shown in Fig. 7.

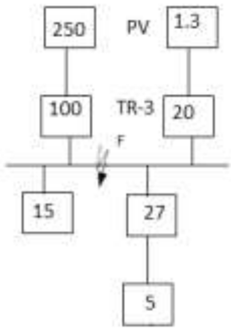

Fig. 7.1

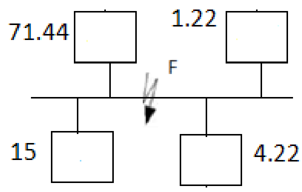

Fig. 7.2

Total fault MVA=91.84 or If=8.03 kA

2) ***L-G fault:*** Zero phase current flows from PV system is blocked by delta winding of transformer. Now the fault MVA diagram shown in Fig. 8.

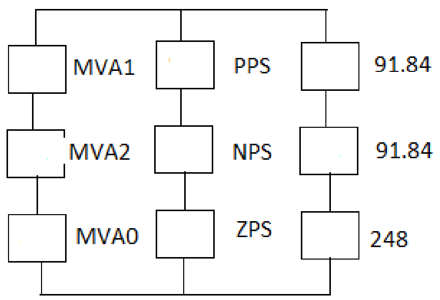

Fig. 8

Total fault MVA= 3 X 38=114 or If=10.17 kA

All the above calculated results are tabulated in Table-II.

TABLE-II

CALCULATION RESULTS

Fault Current in kA	L-L-L	L-G
Pre-PV integration	7.9	10.10
Post-PV integration	8.03	10.17

3) ***Inference:*** It is confirmed that there is not mush variation in fault currents post PV integration since their contribution to fault is an insignificant value of around 125% of their normal rating dislike 1000% to 2500% of conventional system's fault current.

4) ***Simulation***: The L-L-L fault scenario is simulated in e-tap software and result of screen shot shown in Fig. 9 which indicates both the calculated and simulated values are almost same.

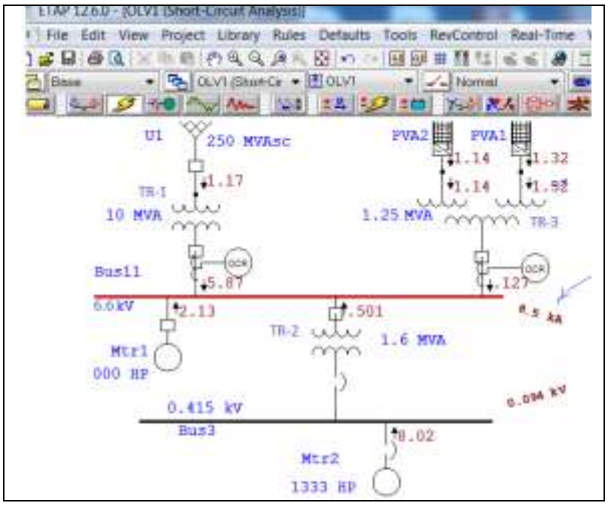

Fig 9 : e-tap simulation screen shot

V. ESTIMATION OF FAULT CLEARING TIME

A. Pre-PV integration:

The protective schematic diagram is shown in Fig. 10.

1) Details of R1: Over current and earth fault relay,

SPAJ-140C of ABB make (fast acting Numerical Relay)

2) Settings made:

Over current: IEC Curve of Very Inverse (VI) with 500% current setting and TMS (Time multiple settings) of 0.3

Earth fault: IEC Curve VI with 20% current and TMS of 0.1.

For faults at F, the relay R1 will operate and isolates the faulty area from system by opening CB-2.

Time of operation:

For L-L-L fault of 7.9KA = 0.6 Sec.

For L-G fault of 10.1KA = 0.18 Sec.

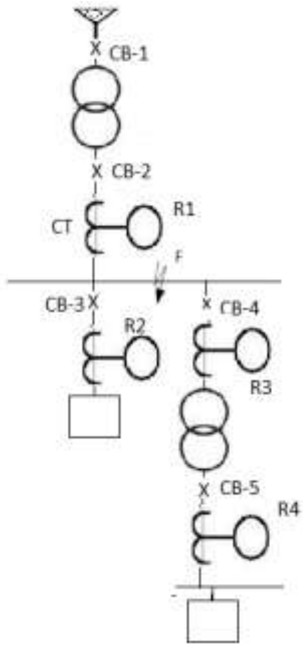

Fig 10 : Protective schematic diagram: Pre-PV

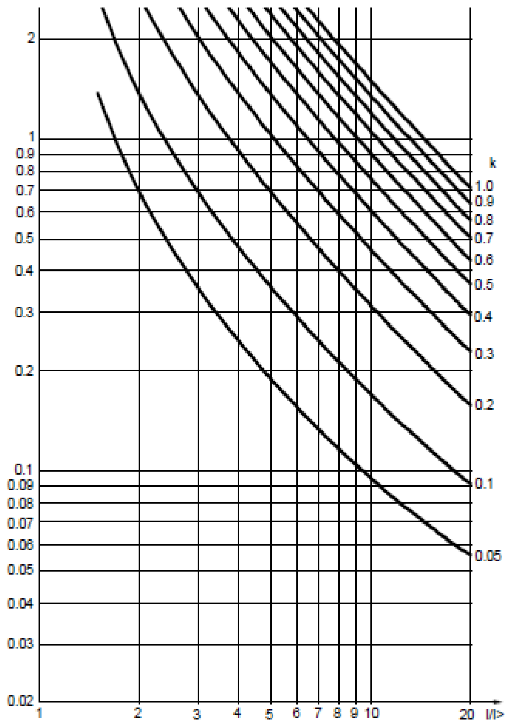

Fig 11: TCC OF SPAJ-140 C RELAY (VI)

B. Post PV integration:

The schematic diagram of protective system is shown in Fig. 12.

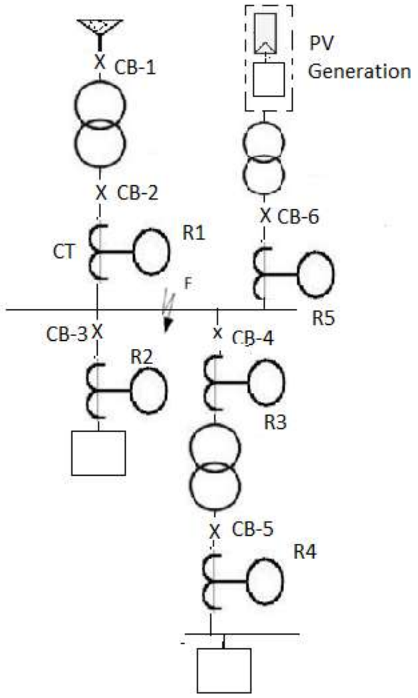

Fig 12 : Protective schematic diagram: Post-PV

For fault at F, the relay R5 shall operate to open CB-6 before R1 opening CB2 so that the PV system's contribution to fault is less and also PV system will not suffer from transients of grid under faults.

Details of R5: Relay SPAJ-140C of ABB make.

1) ***Relay coordination condition**:* For fault at F, the operating time of R5 shall be less than that of R1 i.e. less than 0.6 Sec for over current and less than 0.18 Sec for earth fault.

2) ***Settings made***: Over current: R1=No change from pre-PV integration, R5 = 500% current with TMS of 0.1.

Earth fault current: R1=No change, R5 = 20% current with TMS of 0.05.

3) ***Relay operation*** [13]**:**

For L-L-L fault of 8.03 KA= R5 operates is 0.2 Sec; R1 operates in 0.58 Sec.

For L-G_fault of 10.17 KA = R5 operates in 0.095 Sec, R1 operates in0.17 Sec.

4) ***Inference:*** The above calculated results confirm that there is no much difference in fault clearing time for the pre and post PV integration scenario.

5) ***Final summary**:* It is confirmed that the relay coordination is not violated with PV integration and no significant changes are required as the equipment rating and relay settings post PV integration.

VI. CONCLUSIONS

For the industry selected as a sample, various protection issues that arise due to integrating of PV system in to the existing grid are discussed in detail. Equipment rating for fault currents post PV integrating is also checked and simulated for their adequacy and all the results are tabulated. From the results, it is concluded that there are no significant changes in the equipment rating and Time-current characteristics (TCC) of protection systems. This study implies that the electrical utilities, industries or consumers need not put much attention on their electrical systems adequacy post distributed generators integration especially PV generators in to their grid since their contribution during faults have a marginal impact.

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