PROTECTION AND POWER QUALITY IN DISTRIBUTED GENERATION INTERFACED DISTRIBUTION SYSTEM

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Abstract: The prevalence of electricalaccidents has constrained of resilient electrical distribution systems (EDS). Electricalaccidents,non-linear loads and integration of distributed generation units (DGU) into EDS are causes protection and power quality issues. Due to considerable overlap between two technologies, failure of protection can also influence the power qualityand vice versa,the objectives of this paper is to describes protection and power quality issues, suitable schemes implementation to mitigate and restoration of service rapidly. To accomplish objectives of papersolid oxide fuel cell (SOFC) is modelled, opted as distributed generation source,symmetrical and unsymmetrical faults are considered as electrical accidents. D-STATCOM and DVR compensators with PID, FUZZY and MRAC controllers are employed and proposed to examine the power quality issues,Reverse power relay is designed to inspect the protection issues caused by the bidirectional power flow with nonlinear loads, electrical accidents and simulations are carried out in MATLAB SIMULINK platform.

Index Terms—Faults,Distributed generation, protection, Power quality, controllers,(D-STATCOM), DVR,reverse power relay.

I.INTRODUCTION

The Proliferating attributes of present days electrical load scenario constrain distributed generations in refection of EDS to expediting surplus power to adequately meet the demand. Distributed Generation (DG) integration [1] is used to progressvoltage profile [2], voltage stability margin [3,4], benefit/cost ratio [5], voltage limit load ability [6] and reliability [7–9] and tocurtail the loading effect of transmission line on grid operation, power loss [10,11], energy loss [12] energy cost [13]. Merely it shows issues associated with the grid integration of various distributed generation sources particularly solar photovoltaic, wind energy conversion systems [14], and solid oxide fuel cell. **F**urtherthese defiescaused primarily DGS embedded to grid and secondarily faults inception in to the network. The protection and power quality complications are summarized as follows.

A. power quality issues

Harmonics
Over voltage
Under voltage
Power fluctuations

B. protection issues

Unintentional Islanding cases
There might be a resonance case that will cause over
Voltages
Sympathetic tripping of protective devices
Failure of fuse protection technique
Miss-protection as a result of the network's
Reconfiguration
Reduced reach of protective device
Loss of coordination between protective devices.
Loosing sensitivity to faults and not tripping in fault conditions due to inability to detect faults currents.

The literature illustrates that researchers are concentrated only on the distribution system performance considering normal operating conditions. A clear research gap is identified to solve the protection, mitigation and restoration of service considering electrical disasters. A electrical disaster causes multiple damages in the distribution system which may lead to the unavailability of main grid supply and can be continued for several days. After electrical disaster, the aim of the distribution system operators is to supply power to the important loads and initiate mitigation and restoration activities by isolation and clearing of electrical faults. To solve the protection problem considering electrical disaster scenario, the problems mentioned in the existing literature have not considered the provision of protection during electrical disaster scenarios. This paper describes two objectives protection and power quality in distribution system in two incidents 1.electrical accidents 2. DG penetrations, To accomplish primary objective of this paper i.e. protection,the reverse power relay (RPR) is proposed [15] to protect the EDS, if injected DG capacity is cause the situation that load voltage is exceeds the generation voltage, powers are reversed their existing direction which cause reduced reach of protective device employed to give protection. Due to directional capability of RPR it sense the direction and compares the existing direction immediately convey the same to circuit breaker to isolate and protect the EDS in both DG integration and fault occurs in distribution network.To achieve secondary objective i.e. power quality, two compensators have been designed (DVR, D-STATCOM). The instance the EDS is balanced and poses ideal magnitude and Phase angles of parameters like powers ,voltage , currents and impedance under ideal condition, deviates partially during DG insertion and considerably large while faults enters in to the network these deviations are named as power quality issues [16, 17]. DVR is used to mitigate the voltage harmonics and D-STATCOM is interpreted to reduce the current harmonics.

2. PROBLEM FORMULATION

The incorporation of DG into EDS partially restores the continuity of service after electrical accidents during these faults, nonlinear loads connection and DG integration power quality and protection issues are occurs. After electrical accidents, objective of the EDS engineers are to restore power quality (PQ) and protection as a priority. This enables to consider the need of power quality with relation to the protection, in this paper this relation is discussed comprehensively, for this solid oxide fuel cell (SOFC) is opted as distributed generation source and its modelling presented as follows.

2.1. MODELLING OF SOFCDG, SUPPLY SYSTEM AND NON-LINEAR LOADS

The electro-chemical energy conversion principle based operated Solid Oxide Fuel Cell is model to assimilate with grid,to focus onhow the changes in both objectives are considered, required chemical reactions to produce power from the SOFC are as follows.The SOFC reactions are:

Anode: $H_2 + O^{-2} \rightarrow H_2O + 2e^-$ (1)

Cathode: $1/2O_2 + 2e^- \rightarrow O^{-2}$ (2)

Overall: $H_2 + 1/2O_2 \rightarrow H_2O$ (3)

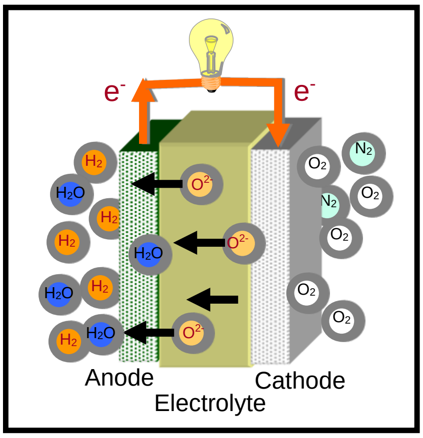

Figure 1: Reactions within SOFC

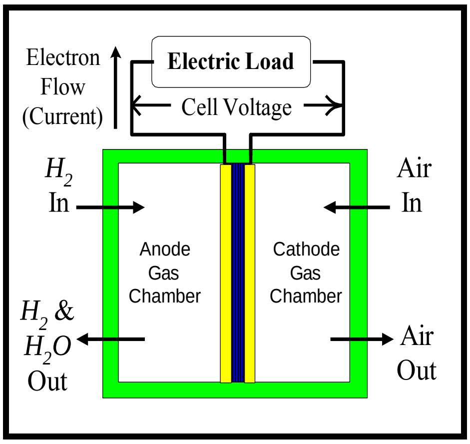

Figure 2: Flow Diagram for SOFC

At anode hydrogen and at cathode oxygen is given as inputs and for required amount of power production is merely rely on the SOFC geometry.Therating of the SOFC is computed based on the evaluation of current from the series connected cells and voltage is computed from the parallel aligned cells produced current from the cells basically in DC which used to convert in to AC by means of inverters with required rating. To scrutinize the both objectives centralized power supply is modeled and presented as follows.The modelingof supply system used primarily for load serving is represented in currents and voltages.

$$V_{Sa} = i_{Sa}R_{Sa} + V_{La} + V_{ta} \quad (1)$$

Where $v_{La} = L_{Sa}\left(\frac{di_{Sa}}{dt}\right)$ then the equation (1) can be written as

$$V_{Sa} = i_{Sa}R_{Sa} + L_{Sa}\left(\frac{di_{Sa}}{dt}\right) + V_{ta} \quad (2)$$

$$V_{Sb} = i_{Sb}R_{Sb} + L_{Sb}\left(\frac{di_{Sb}}{dt}\right) + V_{tb} \quad (3)$$

Above phase voltages in Equations (2) (3) and (4) can be rewritten as follows

$$V_{Sc} = i_{Sc}R_{Sc} + L_{Sc}\left(\frac{di_{Sc}}{dt}\right) + V_{tc} \quad (4)$$

$$\frac{di_{Sa}}{dt} = (V_{Sa} - V_{ta} - i_{Sa}R_{Sa}) \Big/ L_{Sa} \quad (5)$$

$$\frac{di_{Sb}}{dt} = (V_{Sb} - V_{tb} - i_{Sb}R_{Sb}) \Big/ L_{Sb} \quad (6)$$

$$\frac{di_{Sc}}{dt} = (V_{Sc} - V_{tc} - i_{Sc}R_{Sc}) \Big/ L_{Sc} \quad (7)$$

Further to perceive objectives Nonlinear Load is considered and its modelling as follows. The basic equations for the three-phase non-linear loads are represented as

$$V_{Sa} = V_{La} + i_{La}R_{sa} + L_{Sa}\left(\frac{di_{La}}{dt}\right) \quad (8)$$

$$V_{Sb} = V_{Lb} + i_{Lb}R_{sb} + L_{Sb}\left(\frac{di_{Lb}}{dt}\right) \quad (9)$$

$$V_{Sc} = V_{Lc} + i_{Lc}R_{sc} + L_{Sc}\left(\frac{di_{Lc}}{dt}\right) \quad (10)$$

Where above voltagesare load voltages across load capacitors. The state space equations for three phase nonlinear load can be written as:

$$\left(\frac{di_{La}}{dt}\right) = (V_{Sa} - V_{La} - i_{La}R_{Sa}) \Big/ L_{Sa} \quad (11)$$

$$\left(\frac{di_{Lb}}{dt}\right) = (V_{Sb} - V_{Lb} - i_{Lb}R_{Sb}) \Big/ L_{Sb} \quad (12)$$

$$\left(\frac{di_{Lc}}{dt}\right) = (V_{Sc} - V_{Lc} - i_{Lc}R_{Sc}) \Big/ L_{Sc} \quad (13)$$

2.2. ELECTRICAL ACCIDENTS

Another cause to inculcate protection and power quality issues are inception of loses in to network Protection and power quality is intricate in Distribution system during the faults, presence of DG can cause bidirectional power flow, enrichmentof fault current, existing protection strategies has to alter, protection under reach is takes place, symmetrical and unsymmetrical faults are modeled and presented in following sections. Positive, negative and zero sequence components of impedance matrices are consider in finding severity of various faults in DS.

Three-phase fault calculation

The I_{3Ph} at bus n depends on diagonal impedance element Z_{nn} of the impedance matrix which could be though as the impedance computed from network at bus n point of view with all buses expect the n-th bus open. Three-phase fault sequence current at short circuit location bus-n is calculated as:

$$\text{In-1} = \frac{\text{Vn-pre}}{\text{Znn-1}};\ \text{In-0} = \text{In-2} = 0. \qquad (1)$$

Single line-to-ground fault

The sequence components of the fault currents at phase a :

$$\text{In-0} = \text{In-2} = \text{In-1} = \frac{\text{Vn-pre}}{\text{Znn-0} + \text{Znn-1} + \text{Znn-2} + 3\text{ZF}};\ \text{In-0} = \text{In-2} = 0 \qquad (2)$$

In this ZF = 0 is assumed.

Line-to-line fault

Fault currents of sequence components at phase b and c:

$$\text{In-1} = -\text{In-2} = \frac{\text{Vn-pre}}{\text{Znn-1} + \text{Znn-2} + \text{ZF}};\ \text{In-0} = 0 \qquad (3)$$

In this ZF = 0 is assumed.

Double line-to-ground fault

The fault currents of sequence components at phase b to c to ground:

$$\text{In-1} = \frac{\text{Vn-pre}}{\text{Znn-1} + \frac{\text{Znn-2(Znn-0+3ZF)}}{\text{Znn-2+Znn-0+3ZF}}}$$

$$\text{In-2} = (-\text{In-1})\ \frac{\text{Znn-0} + 3\text{ZF}}{\text{Znn-2} + \text{Znn-0} + 3\text{ZF}}$$

$$\text{In-0} = (-\text{In-1})\ \frac{\text{Znn-2}}{\text{Znn-2} + \text{Znn-0} + 3\text{ZF}} \qquad (4)$$

In this ZF = 0 is assumed.

Further symmetrical and unsymmetrical faults inception in to the distribution system, how currents and voltages are deviated, are consider to propose compensators and reverse power relays to facilitate protection and maintain quality of voltages and currents.

3. PROPOSED SOLUTIONS

To conquer objectives of paper i.e. both protection and power quality in this paper reverse power relay for protection and D-STATCOM and DVR compensators for power quality are proposed.And perceive the overlap between two technologies with several illustrations.

3.1. REVERSE POWER RELAY

Radial distribution network transit in to network type due to DG's integration, if local generation is greater than the load, power gets reversed this leads to various protection problems and power quality issues, in the event of faults, if DG is disconnected and islanding operation is initiated power gets bidirectional in this context proposed reverse power relay will play vital role in safe operation and protection of distribution system.

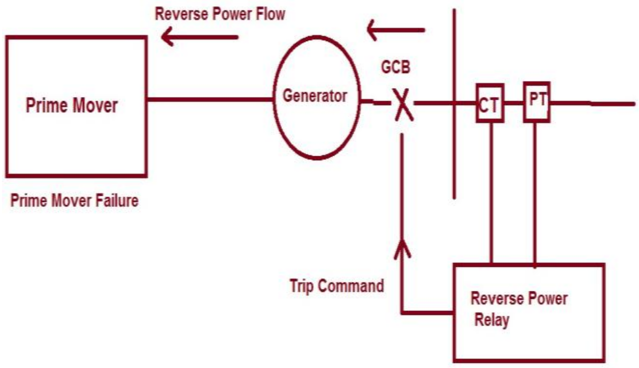

Figure:-3.Bloack diagram of reverse power relay

Reverse power evaluation:-

To design reverse power relay settings for protection against the bidirectional power flows during the faults, when local voltage is exceeds the local demand. From the test system Essential data for computation is as follows

SG [kVA] rated generator apparent power
Cos (φ): rated generator power factor
In: rated current of XP2-R
Un: rated voltage of XP2-R
nI: transformation ratio of the CT
nU: transformation ratio of the VT

Connection of the reverse power relay to phase-to-phase voltage:
Conversion of the generator phase power PGS based on the CT secondary side:

$$P_{GS} = \frac{S_G \cdot \cos(\varphi)}{\sqrt{3} \cdot n_U \cdot n_I} \qquad (1)$$

With the permissible generator reverse power PGS, the setting value PR is then calculated as follows:

$$P_R > (\%) = \frac{\frac{S_G \cdot \cos(\varphi)}{\sqrt{3} \cdot n_U \cdot n_I}}{Un \cdot In} \cdot P_{RG}(\%) \qquad (2)$$

Connection of the Reverse power relay to phase-to-neutral voltage, Conversion of the generator phase power PGS based on the transformer secondary side:

$$P_{GS} = \frac{S_G \cdot \cos(\varphi)}{3 \cdot n_U \cdot n_I} \qquad (3)$$

With the permissible generator reverse power PGS, the setting value PR is then calculated as follows:

$$P_R > (\%) = \frac{\frac{S_G \cdot \cos(\varphi)}{3 \cdot n_U \cdot n_I}}{Un \cdot In} \cdot P_{RG}(\%) \qquad (4)$$

3.2. DESIGN OF COMPENSATORS

a) DYNAMIC VOLTAGE RESTORER: DVR isconnected in series with source and load;itfacilitates filtering property in sensitive loads protection. Harmonics caused by the switching operations from the load end through series transformer, filtering inherent capability of DVR can compensates the current harmonics and source end harmonics primarily mitigates the line impedance remaining contents can be eliminated by filtering circuit in Figure(2).

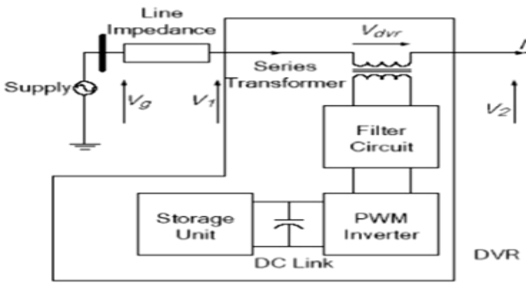

Figure:- 4.DVR block diagram

Fault level of a load bus is resolvesbased on impedance systemZs. To maintain load voltage within acceptable limits transformer injects the DVR voltage in the event of disturbances in voltages are evaluated [18] as

$$Vdvr + Vs = Vl + ZsIl$$

$$Vdvr = Vl + ZsIl - Vs \quad (1)$$

Where,
Vl = desired load voltage magnitude
Zs = System impedance
Il = load current
Vs = system voltage during fault condition

Load current can be written as - $I_1 = \left[\frac{P_i + jQ_i}{V_i} \right]$ (2)

$$V_{dvr}\angle\alpha = V_1\angle 0 + Z_s I_1 \angle(\beta - \theta) - V_s \angle\delta \quad (3)$$

Where α, β and δ are the angle of Vdvr, Zs and Vs, respectively and θ is the load power factor angle with

$$\theta = \tan^{-1}\left(\frac{Q_i}{P_i}\right) \quad (4)$$

DVR injected power can be written as

$$S_{dvr} = V_{dvr} I_1 \quad (5)$$

b) DISTRIBUTION STATIC COMPENSATOR: DSTATCOM is connected in parallel to the source and load; it improves the power factor and enhancing the voltage regulation along with load balancing and also operated as a shunt or parallel active power filter. In this paper it is adopting for compensating the voltage harmonics.

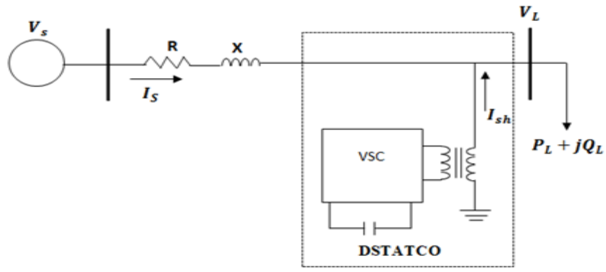

Figure:-5. DSTATCOM block diagram

Modelling of Voltage Source Inverter-Based DSTATCOM

$$V_{ta} = i_{Ca} R_c + L_c \left(\frac{di_{Ca}}{dt} \right) + v_{Ca} \quad (1)$$

$$V_{tb} = i_{Cb} R_c + L_c \left(\frac{di_{Cb}}{dt} \right) + v_{Cb} \quad (2)$$

$$V_{tc} = i_{Cc} R_c + L_c \left(\frac{di_{Cc}}{dt} \right) + v_{Cc} \quad (3)$$

$$V_{Nc} = -i_{Nc} R_C - L_C \left(\frac{di_{Nc}}{dt} \right) \quad (4)$$

$$\frac{di_{Ca}}{dt} = (V_{ta} - v_{Ca} - i_{Ca} R_c) / L_c \quad (5)$$

$$\frac{di_{Cb}}{dt} = (V_{tb} - v_{Cb} - i_{Cb} R_c) / L_c \quad (6)$$

$$\frac{di_{Cc}}{dt} = (V_{tc} - v_{Cc} - i_{Cc} R_c) / L_c \quad (7)$$

4. RESULTS AND DISCUSSIONS

A.PROTECTION

To facilitate the protection to the distribution network during the electrical accidents reverse power relay is used to identify the over voltages in loads and power reversal in figure (6) due to DG integration. Presence of DG's and during fault times in the DS the reversed power can be estimated with equation (4) in section 3.1, to detect the above ailment in DS, relay settings are redesigned in Equations (1,2,3) in section 3.1.

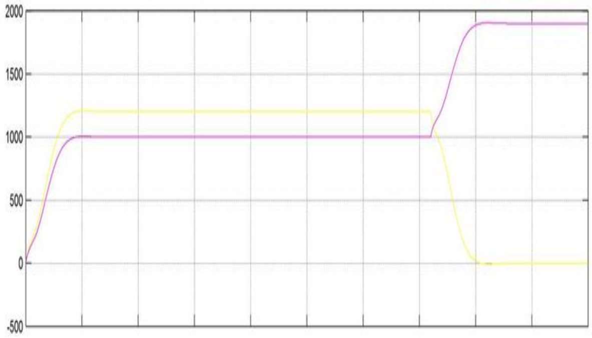

Figure:-6.Active power (P) and Reactive Powers (Q) at Grid with DG

By the integration of SOFC based distributed generation to grid, the existing active and reactive power directionsare gets reversed Figure (6) and imposed under reach of protective devices.

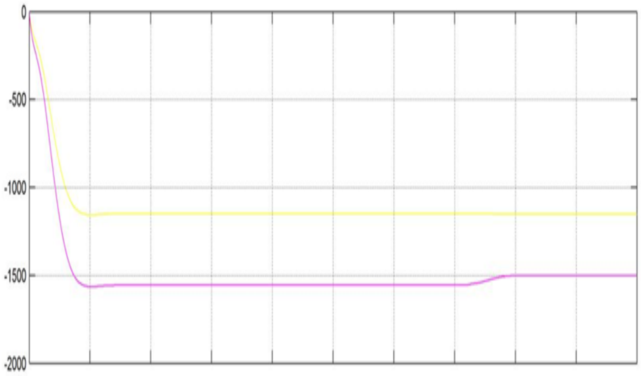

Figure:-7.Inversed Active power (P) and Reactive Powers (Q) at Grid due to power reversals caused by the fault.

The impact of reverse power flow on the performance of protection devices in distribution system is considerably high it will forces to redesigning of protective devices ratings to impart protection during invert direction of existing powers (7)directions.

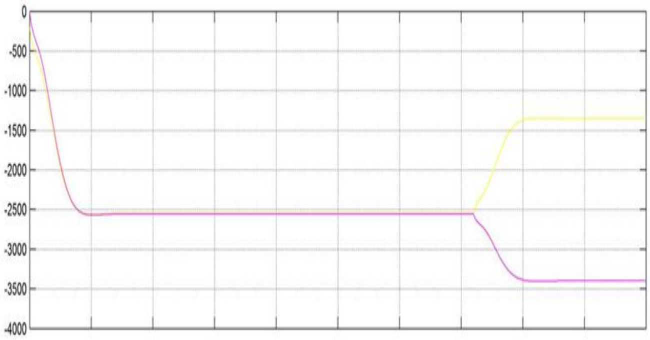

Figure:-8.RemuneratedActive power (P) and Reactive Powers (Q) with reverse power relay at Grid.

And RPR detected and compensated powers are in Figure (8).

B.POWER QUALITY

To mitigate the power quality issues in contemporary days practices Dynamic Voltage Restorer and Distribution Static Compensator are best choices, to interpret voltges in series with the system voltages DVR is opted and to correct the power factor by injecting voltage in series with system voltage D-STATCOM is selected among the custom power devices.From the simulation setup among the considered faults LG,LLG and LLLG the most severe fault is selected based on the fault resistance comparison in table[1].from table [1] LLLG fault is severe and it is used to investigate the distribution network by measuring the voltages in Figure [9] and currents in Figure [10].

Table:-1.fault resistance

Fault type	Fault resistance in Ω
LG	0.001
LLG	0.002
LLLG	0.003

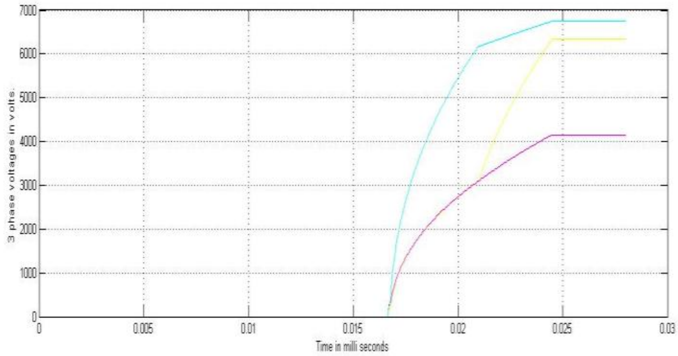

Figure:-9. Voltage fluctuations at PCC during LLLG fault.

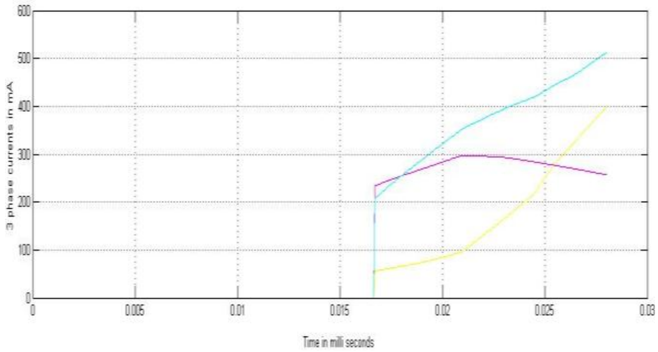

Figure:-10. Current fluctuations at PCC during LLLG fault.

to mitigate the power quality problems (voltage and current variations) D-STATCOM is c[illegible]d in Figure [11].

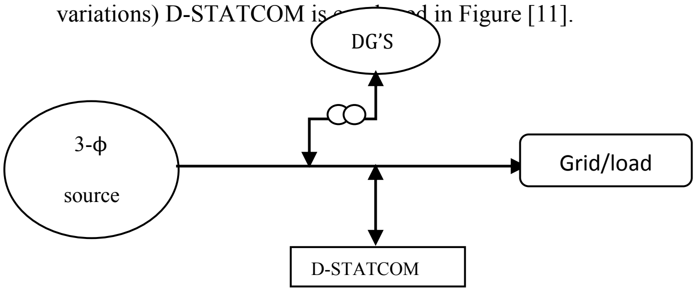

Figure:-11.connection of D-STATCOM in Distribution network.

At phase shift of 180 degrees, a loads contributed harmonic component induces. To reimburse current harmonicsD-STATCOMin Figure [11] operates in current controlled voltage source mode. And test setup with 3 controllers(PID, FUZZY and MARC) are analysed both DVR and D-STATCOM compensators in current variations,MRAC controller results are effective in optimizing the current variations is shown in figure [12].

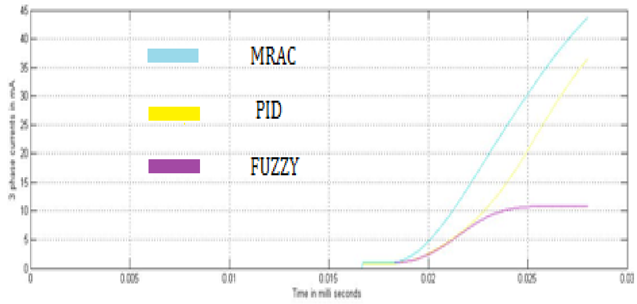

Figure:12. D-STATCOM Compensated 3 Phase currents at load.

Voltages are evaluated by using equations [1] to [7] in section 3.2.b. based on this magnitude D-STATCOM will compensate the current harmonics in the network.

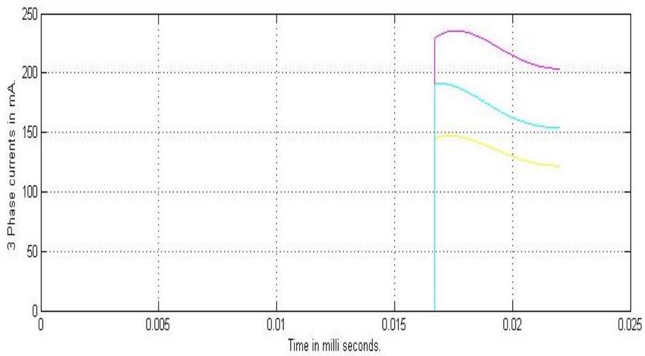

Figure:-13.$\mathbf{I}_{\mathbf{rmsl}}$ compensated currents with DVR at load.

The simulated results of current variations during LLLG faults are compensated by using both compensators D-STATCOM in Figure [11] and DVR in Figure [14] are compared. D-STATCOMcompensators with MARAC controller configuration willposses optimal current variations.

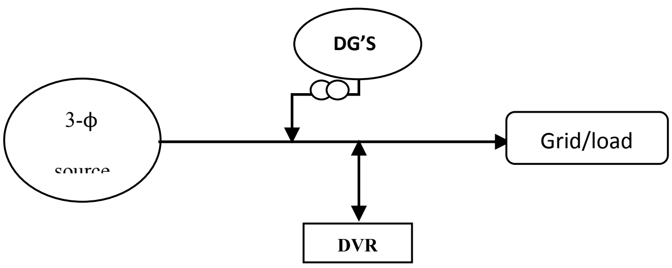

Figure:-14.Schematic diagram of DVR.

Further to compensate voltage fluctuations caused by LLLG fault, same test setup is used with 3 controllers(PID, FUZZY and MARC) with both compensators (D_STATCOM & DVR). The simulation test results are shown in Figure [15] &Figure [16] respectively.Ac voltages with controllable synchronised and inserts in series to the voltages of distribution feeder by DVR, it will renovates the anticipated waveforms with during unbalanced condition of source voltages.

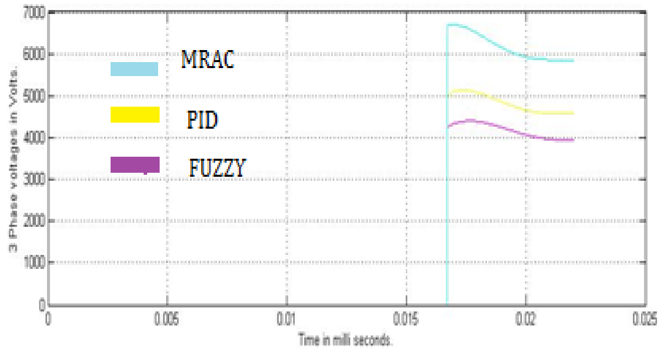

Figure:-15. $\mathbf{v}_{\mathbf{rmsl}}$ compensated voltages with DVR at load.

The voltages, load current, phase angle and apparent powers are computed from equations [1] to [4] in section 3.2.a. based this evaluation DVR will compensate voltage waveforms.

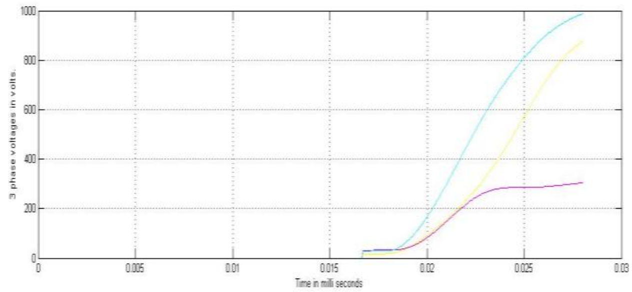

Figure:-16. D-STATCOM Compensated 3 Phase voltages at load.

The simulated results of voltage variations during LLLG faults are compensated by using both compensators D-STATCOM in Figure [16] and DVR in Figure [15] are compared. DVR compensators with MRAC controller configuration willpose optimal current variations.From the power quality issues DVR with MRAC controller and D-STATCOM with MRAC controllers configurations are proposed to mitigate the blinking's in both voltages and currents to restore the power quality.

5. CONCLUSIONS

In this paper substantial overlap between two technologies i.e. protection and power quality in Distributed generation (DG) injected Distribution system is illustrated noticeably. The objectives of this paper is to describes causes for Protection and power quality issues in DG integrated distribution system is examined and proposed solutions to mitigate, restoration of service rapidly, reverse power relay is designed, incorporated during power reversals due to electrical accidents, DG integration and nonlinear loads.Simulation results clearly showed that the effectiveness of proposed relay in the event power gets bidirectional. Further to progress the power quality after electrical disasters in this paper PID, FUZZY and MRAC controllers are used in D-STATCOM and DVR compensators in different cases for both symmetrical and unsymmetrical faults and simulation results showed good recitalin improvement of power quality.

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