PROTECTION AND POWER QUALITY IN DISTRIBUTED GENERATION INTERFACED DISTRIBUTION SYSTEM

Puladasusudhakar  Dr. Sushama Malaji  Dr. B. Sarvesh
Research Scholar  Professor  Senior Professor
JNTUA CECA  JNTU CEH  JNTU CEK
Mahabubnagar, India  Hyderabad, India  Kakinada, India

Abstract: The prevalence of electrical accidents has constrained of resilient electrical distribution systems (EDS). Electrical accidents, 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 quality and 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.

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 is used to progress voltage profile, voltage stability margin, benefit/cost ratio, voltage limit load ability and reliability, and to curtail the loading effect of transmission line on grid operation, power loss, energy loss, energy cost. Merely it shows issues associated with the grid integration of various distributed generation sources particularly solar photovoltaic, wind energy conversion systems, and solid oxide fuel cell. Furthermore, defies, the problems 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 e.g. electrical accidents 2. DG penetrations. To accomplish primary objective of this paper i.e. protection, the reverse power relay (RPR) is proposed 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, deviations partially during DG insertion and considerably large while faults enters in to the network these deviations are named as power quality issues. 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 is 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 SOFC DG, 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 on how the changes in both objectives are considered, required chemical reactions to produce power from the SOFC are as follows. The SOFC reactions are:

\[ \text{Anode: } H_2 + O^2- \rightarrow H_2O + 2e^- \quad (1) \]
\[ \text{Cathode: } 1/2O_2 + 2e^- \rightarrow O^2- \quad (2) \]
\[ \text{Overall: } H_2 + 1/2O_2 \rightarrow H_2O \quad (3) \]

Cathode: 1/2O_2 + 2e^- \rightarrow O^2- (2)
Overall: H_2 + 1/2O_2 \rightarrow H_2O (3)

Page 112 of 118
Above phase voltages in Equations (2), (3) and (4) can be rewritten as follows

\[ V_{Sa} = i_{Sa} R_{Sa} + L_{Sa} \left( \frac{di_{Sa}}{dt} \right) + V_{ta} \]  

(2)

\[ V_{Sb} = i_{Sb} R_{Sb} + L_{Sb} \left( \frac{di_{Sb}}{dt} \right) + V_{tb} \]  

(3)

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

\[ V_{Sc} = i_{Sc} R_{Sc} + L_{Sc} \left( \frac{di_{Sc}}{dt} \right) + V_{tc} \]  

(4)

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

\[ V_{Sa} = V_{La} + i_{La} R_{sa} + L_{Sa} \left( \frac{di_{La}}{dt} \right) \]  

(8)

\[ V_{Sb} = V_{Lb} + i_{Lb} R_{sb} + L_{Sb} \left( \frac{di_{Lb}}{dt} \right) \]  

(9)

\[ V_{Sc} = V_{Lc} + i_{Lc} R_{sc} + L_{Sc} \left( \frac{di_{Lc}}{dt} \right) \]  

(10)

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

\[ \left( \frac{di_{La}}{dt} \right) = \left( V_{Sa} - V_{La} - i_{La} R_{Sa} \right) / L_{Sa} \]  

(11)

\[ \left( \frac{di_{Lb}}{dt} \right) = \left( V_{Sb} - V_{Lb} - i_{Lb} R_{Sb} \right) / L_{Sb} \]  

(12)

\[ \left( \frac{di_{Lc}}{dt} \right) = \left( V_{Sc} - V_{Lc} - i_{Lc} R_{Sc} \right) / L_{Sc} \]  

(13)

**2.2. ELECTRICAL ACCIDENTS**

Another cause to inculcate protection and power quality issues are inception of losses in to network Protection and power quality is intricate in Distribution system during the faults, presence of DG can cause bidirectional power flow, enrichment of 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 $I_{n}$ 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:

$$I_{n-1} = \frac{V_{n-\text{pre}}}{Z_{nn-1}}; I_{n-0} = I_{n-2} = 0.$$  (1)

**Single line-to-ground fault**

The sequence components of the fault currents at phase a :

$$I_{n-0} = I_{n-2} = I_{n-1} = \frac{V_{n-\text{pre}}}{Z_{nn-0} + Z_{nn-1} + Z_{nn-2} + 3ZF}; I_{n-0} = I_{n-2} = 0$$  (2)

In this $ZF = 0$ is assumed.

**Line-to-line fault**

Fault currents of sequence components at phase b and c:

$$I_{n-1} = \frac{V_{n-\text{pre}}}{Z_{nn-1} + Z_{nn-2} + ZF}; I_{n-0} = 0$$  (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:

$$I_{n-1} = \frac{V_{n-\text{pre}}}{Z_{nn-1} + Z_{nn-2} + 2ZF} \cdot \frac{Z_{nn-0} + 3ZF}{Z_{nn-0} + 3ZF}; I_{n-0} = (-I_{n-1})$$  (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.

**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 ($\phi$): 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:

$$P_{GS} = \frac{S_{G} \cdot \cos(\phi)}{\sqrt{3} \cdot n_{U} \cdot n_{I}}$$  (1)

With the permissible generator reverse power $P_{GS}$, the setting value $PR$ is then calculated as follows:

$$P_{R} > (%) = \frac{\sqrt{3} \cdot n_{U} \cdot n_{I} \cdot P_{MC}}{U_{n} \cdot I_{n}}$$  (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:

$$P_{GS} = \frac{S_{G} \cdot \cos(\phi)}{3 \cdot n_{U} \cdot n_{I}}$$  (3)

With the permissible generator reverse power $P_{GS}$, the setting value $PR$ is then calculated as follows:

$$P_{R} > (%) = \frac{3 \cdot n_{U} \cdot n_{I} \cdot P_{MC}}{U_{n} \cdot I_{n}}$$  (4)

#### 3.2. DESIGN OF COMPENSATORS
a) **DYNAMIC VOLTAGE RESTORER:** DVR is connected in series with source and load; it facilitates 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 compensate the current harmonics and source end harmonics primarily mitigates the line impedance remaining contents can be eliminated by filtering circuit in Figure(2).

![DVR block diagram](image)

Figure: 4. DVR block diagram

Fault level of a load bus is resolved based on impedance system Zs. To maintain load voltage within acceptable limits transformer injects the DVR voltage in the event of disturbances in voltages are evaluated as

\[ V_{dvr} + V_s = V_l + ZsI (1) \]

Where,
- \( V_l \) = desired load voltage magnitude
- \( Zs \) = System impedance
- \( I_l \) = load current
- \( V_s \) = system voltage during fault condition

Load current can be written as

\[ I_1 = \left[ \frac{P_i + jQ_s}{V_s} \right] \]

(2)

\[ V_{dvr} = V_s + ZsI_l(\beta - \theta) - V_s \theta \delta \]

(3)

Where \( \alpha, \beta, \) and \( \delta \) are the angle of \( V_{dvr}, Zs \) and \( V_s \), respectively and \( \theta \) is the load power factor angle with

\[ \theta = \tan^{-1}\left( \frac{Q_i}{P_i} \right) \]

(4)

DVR injected power can be written as

\[ S_{dvr} = V_{dvr}I_1 \]

(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.

\[ V_{ta} = i_{Ca}R_c + L_c\left( \frac{di_{Ca}}{dt} \right) + v_{Ca} \]

(1)

\[ V_{tb} = i_{Cb}R_c + L_c\left( \frac{di_{Cb}}{dt} \right) + v_{Cb} \]

(2)

\[ V_{tc} = i_{Cc}R_c + L_c\left( \frac{di_{Cc}}{dt} \right) + v_{Cc} \]

(3)

\[ V_{Ne} = -i_{Ne}R_c - L_c\left( \frac{di_{Ne}}{dt} \right) \]

(4)

\[ \frac{di_{Ca}}{dt} = \frac{(V_{ta} - v_{Ca} - i_{Ca}R_c)}{L_c} \]

(5)

\[ \frac{di_{Cb}}{dt} = \frac{(V_{tb} - v_{Cb} - i_{Cb}R_c)}{L_c} \]

(6)

\[ \frac{di_{Cc}}{dt} = \frac{(V_{tc} - v_{Cc} - i_{Cc}R_c)}{L_c} \]

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

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.

To mitigate the power quality issues in contemporary days practices Dynamic Voltage Restorer and Distribution Static Compensator are best choices, to interpret voltages 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

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Fault resistance in Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG</td>
<td>0.001</td>
</tr>
<tr>
<td>LLG</td>
<td>0.002</td>
</tr>
<tr>
<td>LLLG</td>
<td>0.003</td>
</tr>
</tbody>
</table>

To mitigate the power quality problems (voltage and current variations) D-STATCOM is employed in Figure [11].

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 voltages 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

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Fault resistance in Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG</td>
<td>0.001</td>
</tr>
<tr>
<td>LLG</td>
<td>0.002</td>
</tr>
<tr>
<td>LLLG</td>
<td>0.003</td>
</tr>
</tbody>
</table>
At phase shift of 180 degrees, a load contributed harmonic component induces. To reimburse current harmonics D-STATCOM in Figure [11] operates in current controlled voltage source mode. And test setup with 3 controllers (PID, FUZZY and MARC) are analyzed both DVR and D-STATCOM compensators in current variations, MRAC controller results are effective in optimizing the current variations is shown in figure [12].

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

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-STATCOM compensators with MARAC controller configuration will posses optimal current variations.

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.

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.

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.

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 recital
improvement of power quality.

References
resources. The CERTS micro grid concept,” in Proc. Consortium
approach for determination of DG parameters to support voltage profiles in
1360,
http://dx.doi.org/10.1109/TSG.2014.2301394.
sizing method to improve the voltage stability margin in a distribution
differential evolution accounting voltage stability consideration, Int. J.
generator placements for service quality improvements, Int. J.
Electra.Power Energy Syst. 29 (3) (2007) 268–274,
http://dx.doi.org/10.1016/j.ijpees.2006.07.008.
for meeting the increased load demand, Int. J. Electra. Power Energy Syst.
renewable resources mix for distribution system energy loss minimization,
http://dx.doi.org/10.1109/TPWRS.2009.2030276.
doing place on reliability and efficiency with time-varying loads,
http://dx.doi.org/10.1109/TPWRS.2005.869043.
sizing of distributed generation via an improved no dominated sorting
http://dx.doi.org/10.1109/TPWRD.2014.2329398.
herd algorithm for multiple DG placement and sizing in a radial distribution
Peres, Optimal allocation of distributed generation with reconfiguration in
183, http://dx.doi.org/10.1016/j.ijepes.2013.05.017.
maximization in distribution networks, IEEE Trans. Power Syst. 28 (2)
[14] Anees, A.S. “Grid integration of renewable energy sources: Challenges,
issues and possible solutions—5th IEEE International Conference on
Power Electronics (ICPE),2012, Page(s):1-6.
[15] Puladasu Sudhakar, Dr. Sushama Malaj, Dr. B.Sarvesh “Reducing the
impact of DG on distribution networks protection with reverse power relay”
[16] C. Gopinath,1 C. Yaashuwanth,2 R. Ramesh,1 J. R. Maglin,1 and T.
AjitBosco Raj1 “Analysis and Mathematical Model for Restitution of
Voltage Using Dynamic Voltage Restorer" Mathematical Problems in
Engineering Volume 2014, Article ID 845873, 18 pages,
http://dx.doi.org/10.1155/2014/845873.
[17] Rajeev Kumar Chauhan1 and J.P. Pandey2 “Mitigation of Power
of Electronic and Electrical Engineering.ISBN 0974-2174, Volume 7,
Number 3 (2014), pp. 255-262

[18]. DeepaPatil, DattaChavan"Modelling of Dynamic Voltage Restorer for
Mitigation of Voltage Sag and Swell Using Phase Locked
Loop",International Journal of Science and Research (IJSR),Volume 3
Issue 6, June 2014.

AUTHORS

Paladasu Sudhakar born on 1st January 1985 in polakal, Kurnool
(District) ,A.P ,India Obtained B.Tech degree in 2006 and M.Tech degree in 2010 from JNTUK, presently he is a
researchscholar at JNTUA, Ananthapuramu, India.he has published
8 international and1 national journals and his areas of research
interests are power quality protection and distributiongenerations.

Author

Dr.M.Sushama, born on 8th Feb 1973, in Nalgonda ,near
NagarjunaSagar, A.P, India . Obtainedher B.Tech degree in 1993
and M.Tech degree in 2003 JNTU,INDIA. She obtained her
Ph.D from JNTU Hyderabad, India in 2009 in the area of “Power
Quality” using WaveletTransforms. she has 15 years of research
experience. She has published 30 international conference papers in
various IEEE sponsored conferences, 25 International journal
papers. Her research interests include Power Quality, Wavelet
Transforms, and Neural & Fuzzy expert Systems.

Author

Dr.B.Sarvesh Professor in Electrical and ElectronicsEngineering at
JNTUK, INDIA. He has 35years of teaching experience .25 years
of research experience he has published 10 national and
15international journals he is also attended the one international
and 10 national conferences heServed as Head of the EEE Dept,
from 2002-2005 at JNTUCE, Kakinada, A.P, India from 2010-
2012 at JNTU CE, Anantapuramu. And he is also served as Vice-
Principal at JNTUA CE,Pulivendula A.P, India from 2007-2010.
His research areas are control systems.

Author