A New Voltage based Relay Scheme to Protect Micro-Grids dominated by Embedded Generation using Solid State Converters.

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ABSTRACT

This paper describes a new relay that uses disturbances in the three phase voltages to provide reliable and fast detection of different types of faults within the micro-grid. The algorithm uses the d-q reference frame to provide a disturbance signal which is used to detect the fault, identify its type and initiate the isolation the faulted section.

The paper presents both analysis of the protection and network to demonstrate the operation of the relay and the associated scheme. Simulation results for a variety of different faults within the micro-grid and the network when operating in parallel are included to demonstrate its operation.

INTRODUCTION

Deregulation of the electric utility industry, environmental concerns associated with central electric power plants, volatility of electric energy costs, and rapid technological developments of embedded generation systems all support the proliferation of embedded generators in electric supply systems. Furthermore, the increase in the penetration of embedded generation and the presence of multiple generators in close proximity to one another have brought about the concept of the micro-grid [1, 2].

Several definitions are available to describe the components and applications of a micro-grid. The definition used in this research is 'a cluster of loads and micro-sources operating as a single power system that provides power to its local area'. The micro-grid can operate in parallel with the bulk utility supply or can operate in isolation from that supply as a self-contained power island [3, 4].

The protection of Micro-Grid systems is a major challenge for power engineers, particularly when it includes embedded generation using solid-state converters used to convert the energy into an ac supply. Such generators are typically concerned with a variety of renewable energy sources including both photovoltaic and fuel-cells.

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Under 'normal' conditions, the micro-grid will operate in parallel with the grid and short circuit faults will result in potentially 'large' currents. However, when it operates as a self contained power island, any fault current will have to be supplied by those generators still connected to it. With solid state converters, these fault currents will be limited to relatively low values to protect the converter's solid state output devices. Typically, this limit is set to about twice the units rated output current. This is insufficient to trip conventional over-current protection and therefore other protection techniques have to be found [5, 6, 7].

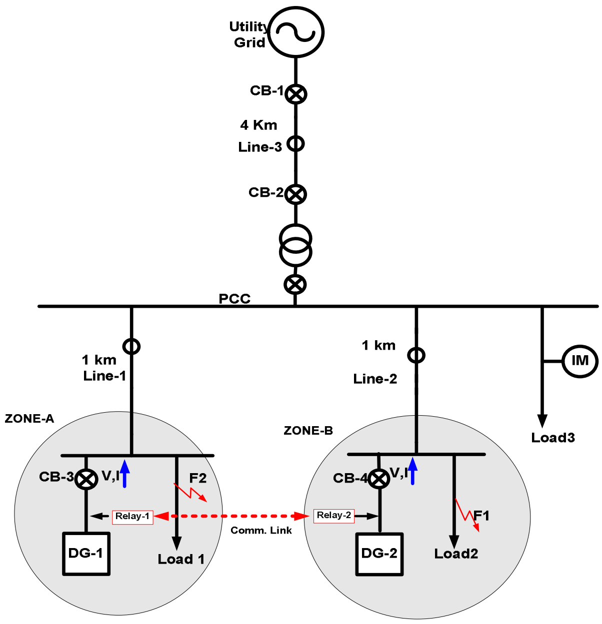

Figure 1. Micro-Grid system.

Several approaches have been reported which use the detection voltage disturbances that are based on the abc-dq transformation. These transform the measured ac quantities to dc ones which reveal voltage disturbances on the utility supply [8,9].

This paper introduces a new voltage based relay which is able to detect faults and discriminate between those that are internal or external to a set zone of protection associated with the micro-grid. This relay will complement traditional types of protection which will respond to the high current faults associated with utility connected operation.

MICRO-GRID SYSTEM CONFIGURATION

An example of a micro-grid system which has been used to demonstrate the operation of the protection scheme under various fault and switching conditions is shown in figure 1. This includes two embedded generators, various loads and the connection to the utility supply system. The system has been divided into sections. Each section should be formed such that it has a reasonable balance of load and embedded generator capacity.

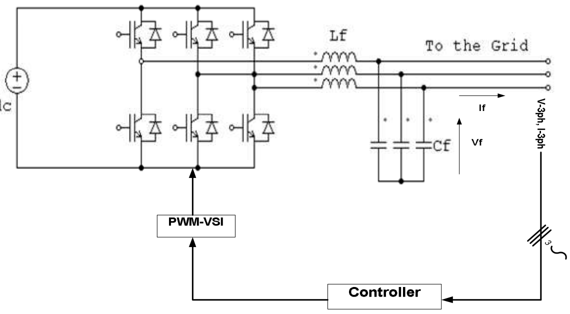

Figure 2. The Solid-State Power Converter

The solid-state converter used in the model uses pulse-width modulation to provide an ac output voltage, as shown in figure 2. Switching transients are filtered by the output filter. The controller for this converter uses two control loops: an outer voltage regulation loop and an inner current regulation loop. This provides for an improved output voltage waveform to reduce harmonic distortion under 'normal' operation [10].

VOLTAGE-BASED RELAY DESIGN

The proposed protection scheme is represented in figure 3. It uses the three phase ac input voltages, measured using standard VTs. The algorithm relies on converting the measured signals first from the abc operating frame to stationary dq frame and then to the dq synchronous rotating frame where all line frequency components are removed yielding only dc values for the dq variables. This double conversion process uses the equations (1) and (2).

$$\begin{bmatrix} Vds \\ Vqs \\ Vo \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} \mathrm{Va} \\ \mathrm{Vb} \\ \mathrm{Vc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Vdr \\ Vqr \end{bmatrix} = \begin{bmatrix} \cos(wt) & -\sin(wt) \\ \sin(wt) & \cos(wt) \end{bmatrix}\begin{bmatrix} Vds \\ Vqs \end{bmatrix} \quad (2)$$

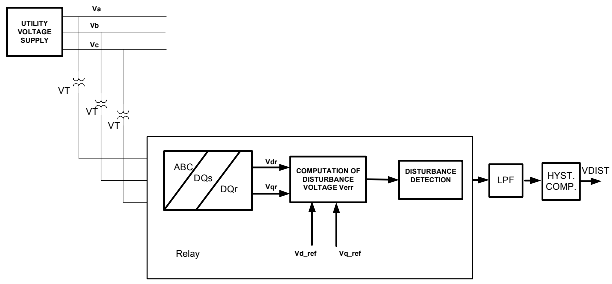

Figure 3. The Proposed Voltage-Based Relay.

The fault detection process uses a set of three-phase balanced voltages as a reference, which represents a constant dc value in d-q synchronous rotating frame. The deviation of the utility input voltages from this given reference, V_{DIST}, is used to detect the disturbance and with further analysis provides details of the type of fault and its location. $V_{\mathrm{error\_q}}$ and V_{DIST} are obtained as shown in equation (3).

$$V_{DIST} = V_{error\_q} = V_{qref} - V_{qr} \quad (3)$$

V_{DIST} is digitally filtered and then processed by a dual hysteresis comparator. The lower and upper limits of this determine the sensitivity of the fault detection. Under normal conditions V_{DIST} is zero, otherwise V_{DIST} is a dc signal varying according the nature of the disturbance.

For a three-phase disturbance, V_{DIST} will be a pure dc voltage. For phase to phase disturbance, it will be a dc voltage with an ac ripple and for a single phase disturbance, it will be an oscillating signal varying between zero and a maximum value. The characteristics of the signals are used to discriminate between the different types of fault.

The fault detection algorithm uses information from both the local relay and other relaying points in the micro-grid to discriminate between in-zone and out of zone faults. As shown in figure 1, this involves a communication link to send the measured values between Relay1 and Relay2. By comparing the mean average values *($V_{ave}1$)* and *($V_{ave}2$)* from the two relays, the location of the fault can be identified and the appropriate zone isolated from the network. A moving averaging filter is used to reject any noise in the measured signal.

V_{ave} is derived from V_{DIST} is calculated as in equation (5):

$$V_{ave.}(n) = \frac{1}{N}\sum_{n=0}^{N-1} V_{DIST}(n) \quad where \quad n = 0,1,2,3,....,N-1 \quad (5)$$

where N is the number of samples in the window.

The flow chart in figure 4 summarise the proposed voltage-based protection scheme.

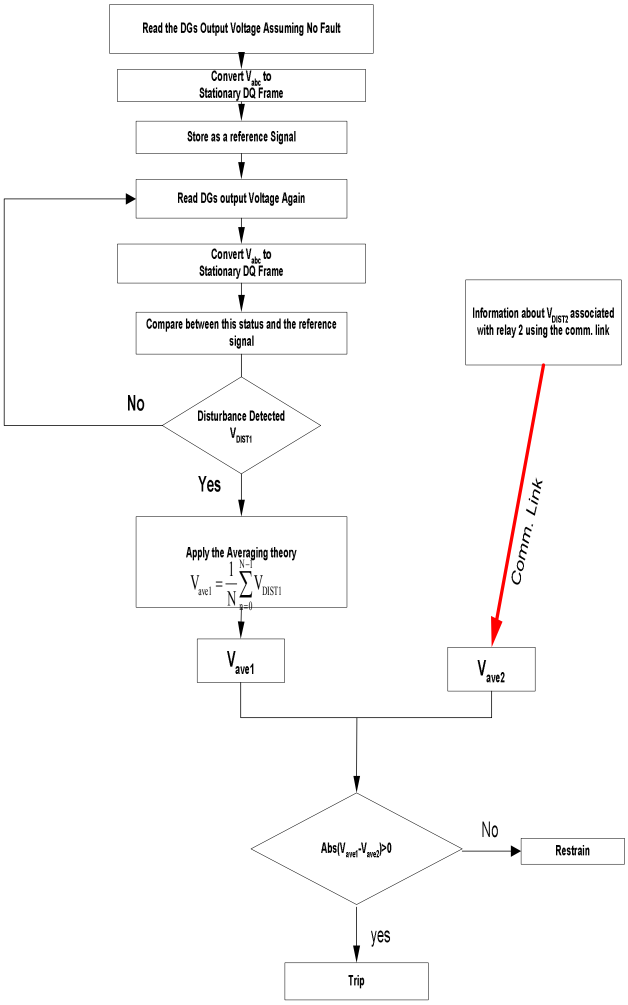

Figure 4. Flow Chart Summarised the Protection Scheme

V_{ave} will be calculated for the full period of disturbance. The protection algorithm is able to decide which relay should trip by calculating the difference between the two average outputs of the two relays using the decision making loop below.

$$\begin{aligned}&If \quad abs \quad (V_{ave}1 - V_{ave}2) > 0\\&Then\\&Trip \ = 1; \ else \ Trip \ = 0\\&end\end{aligned}$$

The scheme will calculate the difference ($V_{ave}1$- $V_{ave}2$). If the absolute value of *abs* ($V_{ave}1$- $V_{ave}2$) is greater than zero the relay1 will trip the associated DG otherwise it will restrain and the same methodology is valid for relay 2.

RESULTS AND ANALYSIS

The response for relay 2 to a three phase fault applied at point "F1" in zone B in figure 1, is shown in figure 5. The fault impedance, R_f, is 0.5Ω

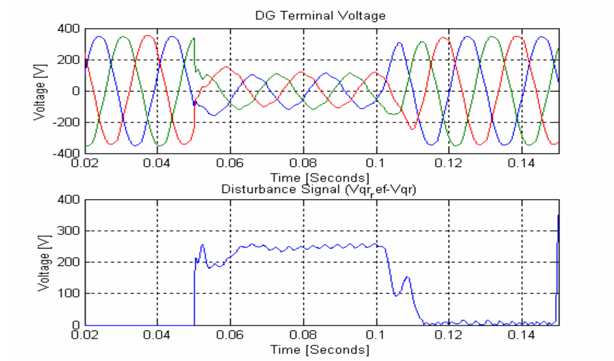

Figure 5. Relay 2's response to a Three-Phase Fault at location F1 in Zone B and Rf=0.5Ω

Relay 1's response to the same fault is shown in figure 6.

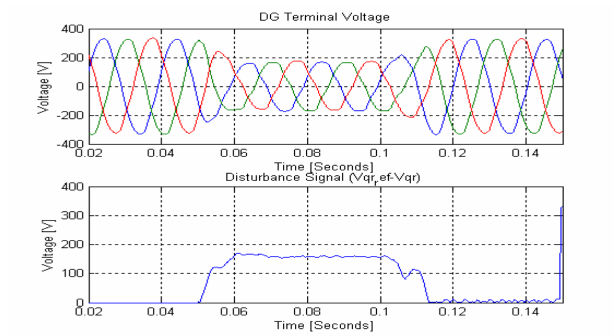

Figure 6. Relay 1's response to a Three-Phase Fault at location F1 in Zone B and with R_f =0.5Ω .

Comparing $V_{ave}1$ *and* $V_{ave}2$, reveals that *relay 2* will trip and isolate *zone B,* as shown in figure 7.

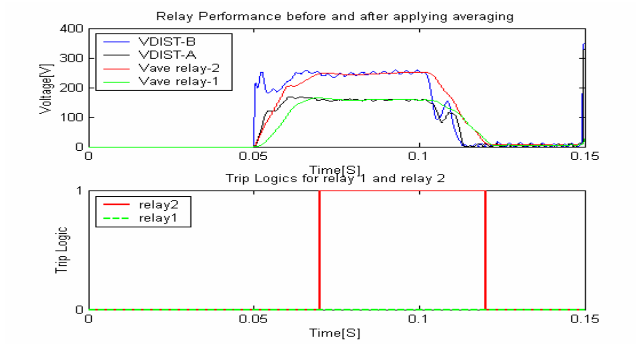

Figure7. Comparisons between V_{ave} for relays 1 & 2 for Three-Phase Fault in zone B and with R_f =0.5Ω

The responses to single phase to ground and to phase to phase faults are complicated by the sinusoidal contents of the output from the harmonic extraction filters.

Figure 8 shows the V_{ave} responses from relays 1 and 2 to a phase to phase to ground fault in zone B. Comparing these reveals the basis for the decision for relay 2 to trip.8 It clearly shows that the relay 2 mean average value is much greater that the mean average value for relay1. As a result, by comparing these values the scheme determines that the fault is zone B, and therefore in this case, relay 2 will trip. It trips at 0.07 seconds and resets at 0.12 seconds, following fault clearance.

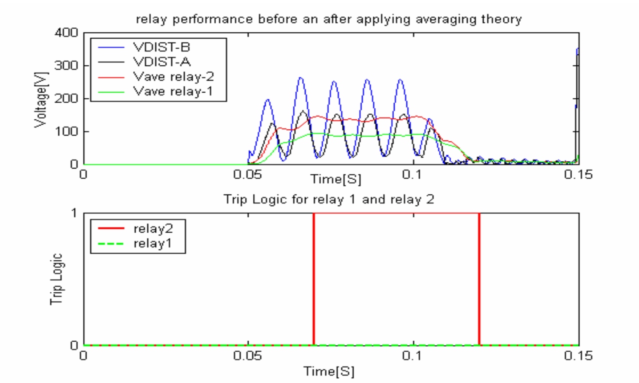

Figure 8. Comparisons between V_{ave} for relays 1 & 2 for a phase to phase to ground Fault in zone B, with R_f=0.1Ω.

The response of the protection scheme to a single phase fault is shown in figure 9. A secure trip command for relay 2 is provided by the protection scheme based on the fact that the relay 2 mean average value is much greater that the mean average value for relay1. As a result by comparing these values it can be concluded that the fault is in zone B, so relay 2 will trip.

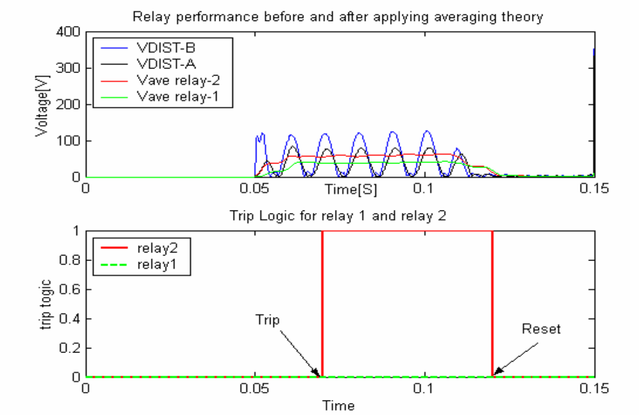

Figure 9. Comparisons between V_{ave} values of relay 1 & 2 for phase to ground (b-g) Fault in zone B, with Rf =0.05Ω.

CONCLUSIONS

The growing interest in micro-grids is providing a challenge for protection engineers. This is particularly so when the micro-sources involve solid-state converters.

A new voltage-based relay has been described which uses the abc-dq transformation of the system voltage to detect the presence of a short circuit fault.

This scheme has many advantages over the conventional superimposed technique such as: improved system responses, increased reliability and ease of implementation. This scheme avoids the complications caused by the variations in potential fault currents associated with the utility connected and islanded operation of the micro-grid. It is envisaged that it will provide a complimentary protection to conventional over-current relaying.

ACKNOWLEDGMENT

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REFERENCES

[1] Hatziargyriou N. D. and Meliopoulos A. P. S., “Distributed energy sources: Technical challenges,” Proc. IEEE PES WM, vol. 2, New York, 2002, pp. 1017–1022.

[2] Smallwood C. L., “Distributed generation in autonomous and nonautonomous micro grids,” Proc. Rural Electric Power Conf., 2002, pp. D1–D1-6.

[3] R. H. Lasseter, “Microgrid,” Proc. IEEE PES WM, vol. 1, New York, 2002, pp. 305–308.

[4] P. Piagi and R. H. Lasseter, “Industrial Application of MiroGrids,” Power System Engineering Research Center, Univ. Wisconsin, Madison, WI, 2001.

[5] Doyle, M.T.; “Reviewing the impacts of distributed generation on distribution system protection” PES SM, 2002 IEEE, Vol: 1, 21-25 July 2002 pp 103 – 105.

[6] R.C. Dugan and T.E. McDermott. “Operating conflicts for distributed generation on distribution systems”. Rural Electric Power Conf, pp A3/1-A3/6, 2001.

[7] R.C. Dugan and T.E. McDermott. “Distributed Generation”. IEEE IA Magazine, 8(2), pp19- 25, 2002.

[8] K. Haddad, G. Joos, S. Chen, “Control algorithms for series static voltage regulators in faulted distribution systems,” Proc Power Electronics Conf, pp. 418-423, 1999.

[9] P.T. Cheng, R. Lasseter, D. Divan, “Dynamic Series Voltage Restoration for Sensitive Loads in Unbalanced Power Systems.” US Patent No. 5,883,796. 1999.

[10] H Al-Nasseri and M A Redfern, “Control and Transient Operation of Grid-Connected Voltage Source Converter under Unbalanced Voltage Conditions”. CIGRE Symposium - Power Systems with Dispersed Generation, Athens 13-16th April 2005.