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Half Cycle Discrete Transformation for Voltage Sag Improvement in an Islanded Microgrid Using Dynamic Voltage Restorer

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ABSTRACT

Growing demand for clean and green power has increased penetration of renewable energy sources into microgrid. Based on the demand supply, microgrid can be operated in grid connected mode and islanded mode. Intermittent nature of renewable energy sources such as solar and wind has lead to number of control challenges in both modes of operation. Especially islanded microgrid throws power quality issues such as sag, swell, harmonics and flicker. Since medical equipments, semiconductor factory automations are very sensitive to voltage variations and therefore voltage sag in an islanded microgrid is of key significance. This paper proposes a half cycle discrete transformation (HCDT) technique for fast detection of voltage sag in an islanded microgrid and thereby provides fast control action using dynamic voltage restorer (DVR) to safe guard the voltage sensitive equipments in an islanded microgrid. The detailed analysis of simulation results has clearly demonstrated the effectiveness of proposed method detects the voltage sag in 0.04 sec and there by improves the voltage profile of islanded microgrid.

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1. INTRODUCTION

Economic activity around the world has lead to growing demand for power and it has put tremendous stress on the existing old electric network which could not meet the exponential demand for power. The concern of climate change and environment has created the need for developing new technologies that will push the use of renewable energy sources to reduce carbon footprint. More over Rural and remote electrification in developing countries cannot be achieved through the traditional grid network due to high cost of installation and other socioeconomic barriers. One of the promising technologies for the above mentioned issue is to incorporate the concept of microgrid [1]-[2].

Microgrid is an integrated singular energy system consisting of Distributed Energy Sources predominately renewable energy sources, Battery Energy Storage Systems (BESS) and distributed loads. The presence of large number of renewable energy sources in microgrid pose number of control challenges such as synchronization, voltage and frequency stability and power quality [3]-[4].

Microgrids can be connected or disconnected to the main grid through Bidirectional Static Transfer Switch (BSTS) either due to fault or deliberately. When the microgrid is disconnected from the main grid it said to be operating in islanded mode [5]. In an Islanded microgrid, most of the distributed energy sources are renewable sources and they have very less inertia. Due to low inertia of these distributed renewable energy sources (DRES) they are unable to meet the sudden loss of generation or disturbances and thus leads to severe voltage sag. Therefore during Islanding, voltage limits are violated and it leads to collapse of the grid, unless proper control action is initiated. As per IEEE STD 1159-2009 voltage sag is defined as decrease of 0.1 – 0.9 p.u in the voltage at system frequency with the duration of half cycle to 1min [6] – [9]. Voltage improvement by DVR depends on the detection time, the time interval at which voltage sag occurs and time when voltage sag is compensated.

Various methods reported in literatures are peak value monitoring, RMS calculation, d-q transformation, wavelet transform, Kalman filtering and other hybrid methods. In Peak value transformation is simple and it calculates the peak voltage based on the voltage gradient [10]. The drawback of this method is it is very slow and not suited for harmonically disturbed islanded microgrid. Second method, Root Mean Square method RMS value is calculated with number of samples [11]. This method is slow as well as voltage sag is considered up to 0.5 p.u instead of 0.8p.u.

Voltage sag d-q transformation technique provides excellent performance with detection time of 1 ms with pure sinusoidal voltage, may not provide the required performance in an islanded microgrid which has lot of harmonics/ distortion [12]. The drawback is overcome using low pass filter implemented with d-q transformation, yet it may not detect the single phase voltage sag of 0.3p.u. Wavelet transform performs multi resolution analysis and provides decomposes the signal in time domain [13]. The main drawback of this method is use of excessive look up table and accurate Phase Locked Loop (PLL) for effective implementation.

Kalman filtering is used for signal disturbance detection in power system studies in state variable form [14]. This method provides best estimation of state variable with minimum number of samples but the drawback is it has slower dynamic response. Several combination methods have been reported in literature [15]-[20]. WT with KF provides faster detection time, LES with KF lowers level of disturbances and refines input signal. The important parameter for performance evaluation of voltage sag compensation is detection time. Hence for proper voltage sag compensation by DVR, detection time plays pivotal role.

This paper proposes implementation of half cycle discrete transformation for accurate sag detection and compensation for islanded microgrid using DVR [21]. This method is applicable for both single phase and three phase systems.

2. HALF CYCLE DISCRETE TRANSFORM FOR VOLTAGE SAG DETECTION

Voltage sag detection time can be estimated by expressing the grid voltage as basic fundamental and harmonic component in Fourier series as follows

Islanded microgrid voltage,

$$Vgis(t) = Vgf \cdot Sin(\omega t+\theta) + \Sigma\ Vgk\ Sin(k.\omega t+\theta k) \quad (1)$$

Where Vgf(t) – Islanded micro grid fundamental voltage
Vgk(t) – Islanded micro grid kth harmonic voltage
ω – Angular frequency - 2πf;
f – Grid frequency – 50 Hz

The direct (d) and quadrature (q) axis components of voltage in single phase rotating frame is defined as follows

$$Vgis.d(t) = Vgis(t).\ Sin(\omega t) \quad (2)$$

$$Vgis.q(t) = Vgis(t).\ Cos(\omega t) \quad (3)$$

Substituting the values of Vgis(t) in equation (2) and (3) separately in equation (1)

$$Vgis.d(t) = [Vgf \cdot Sin(\omega t+\theta) + \Sigma\ Vgk\ Sin(k.\omega t+\theta k)]\ Sin(\omega t) \quad (4)$$

$$Vgis.q(t) = [Vgf \cdot Sin(\omega t+\theta) + \Sigma\ Vgk\ Sin(k.\omega t+\theta k)]\ Cos(\omega t) \quad (5)$$

We know that,

$$Sin(\alpha)\ Sin(\beta) = \tfrac{1}{2}\ [\ Cos(\alpha-\beta) - Cos(\alpha+\beta)] \quad (6)$$

$$\mathrm{Sin}(\alpha)\,\mathrm{Cos}(\beta) = \tfrac{1}{2}\,[\,\mathrm{Sin}(\alpha+\beta) + \mathrm{Sin}(\alpha-\beta)] \tag{7}$$

Substituting Equation (6) and (7) in Equation (4) and (5) we get

$$V_{gis.d}(t) = V_{gf}/2\,[\,\mathrm{Cos}(\theta_f) - \mathrm{Cos}(2\omega t+\theta_f)] + \sum_{k=3,5..} V_{gk}/2\,[\,\mathrm{Cos}((k-1)\,\omega t+\theta_k) - \mathrm{Cos}((k+1)\,\omega t+\theta_k))] \tag{8}$$

Similarly,

$$V_{gis.q}(t) = V_{gf}/2\,[\,\mathrm{Sin}(\theta_f) + \mathrm{Sin}(2\omega t+\theta_f)] + \sum_{k=3,5..} V_{gk}/2\,[\,\mathrm{Sin}((k-1)\,\omega t+\theta_k) + \mathrm{Sin}((k+1)\,\omega t+\theta_k))] \tag{9}$$

From the above equations it is clear that both d and q components contains a dc value and a sinusoidal components at 2,4,6..times the fundamental frequency (50Hz). Fundamental voltage amplitude (Vgf) for voltage sag detection is obtained by calculating an average of d-q components, which takes half cycle of fundamental frequency.

Equation (8) can be written as

$$V_{gis.d}(t)\big|_{dc} = \frac{2}{T}\int_{t-T/2}^{t} V_{gis.d}(t)\,.\,dt = (V_{gf}/2.)\,\mathrm{Cos}(\theta_f) \tag{10}$$

$$V_{gis.q}(t)\big|_{dc} = \frac{2}{T}\int_{t-T/2}^{t} V_{gis.q}(t)\,.\,dt = (V_{gf}/2.)\,\mathrm{Sin}(\theta_f) \tag{11}$$

Where T = 1/f , Fundamental voltage amplitude of islanded microgrid is,

$$[(V_{gis.d}(t)\big|_{dc})^2 + (V_{gis.q}(t)\big|_{dc})^2] = \left(\frac{V_{gf}}{2}\right)^2.\left[\left(\mathrm{Cos}(\theta_f)^2 + Sin(\theta_f)^2\right)\right] = \left(\frac{V_{gf}}{2}\right)^2.\,1 \tag{12}$$

$$\therefore\ V_{gf} = 2.\sqrt{\left(\left(\mathbf{V}_{gis.d}(t)\big|_{dc}\right)^2 + \left(\mathbf{V}_{gis.q}(t)\big|_{dc}\right)^2\right)} \tag{13}$$

Any variation in fundamental change in grid voltage can be calculated by the above half cycle discrete transform method. Same technique can be applied to calculate the voltage swell, because it can follow any change in fundamental voltage amplitude. Thus the proposed method eliminates the use of PLL and excessive use of look up table, which can take considerable amount memory, as well as create delay in detecting the voltage sag.

3. DYNAMIC VOLTAGE RESTORER FOR ISLANDED MICROGRID

Dynamic Voltage Restorer (DVR) is used to improve voltage disturbances in a microgrid, as well as to improve the quality and quantity of power being delivered. The proposed DVR Controller is shown in Figure 1 DVR is used to inject three phase voltage in series and n synchronism with the grid voltages in order to compensate voltage disturbances in an islanded microgrid.

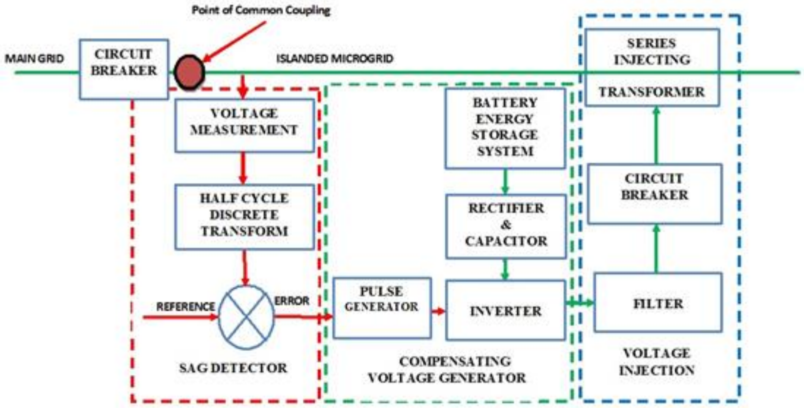

Figure 1. Block diagram of the proposed DVR Controller

VSI converts fixed supply voltage stored in the Battery Energy Storage system into variable supply voltage. The AC voltage supplied by VSI is boosted by injection transformer to the desired voltage level. The winding connection of the injection transformer depends on the distribution transformer. It is either connected in star/open star winding or delta/open star winding.

The star/open star connection injects zero sequence components whereas delta/open star winding does not allow the zero sequence components into the islanded microgrid. The amount of voltage sag/swell compensated by DVR depends upon the rating of injection transformer, inverter and capacity of the Battery Energy storage system.

Filters are used filter the harmonics present in the output of the VSI. The same can be connected at the inverter side or at the HV side of the transformer. If the filter is placed at the inverter side, switching harmonics are prohibited from entering into the injection transformer thereby reduces rating and voltage stress on it. If the filter is placed at HV side of injection transformer, harmonics may enter into HV side hence rating of transformer increases. During compensation, DVR provides the required real power to generate compensating voltage.

Battery Energy Storage System can be created by lead acid batteries, flywheels, dc capacitors and super capacitors. The capacity of Battery Energy Storage System has a greater impact on the compensation capability of DVR. The system with large disturbance requires real power compensation. DC to AC conversion required for batteries whereas AC to AC conversion required for flywheels. Control circuit steadily observe the system. Its function is to detect any disturbance in the system done by comparing the supply voltage with reference voltage and generate the switching command signals for VSI in order to generate the compensating voltage by DVR.

4. SIMULATION MODEL

The system parameters used while simulating DVR for compensating voltage disturbances is shown in Table 1.

Table 1. DVR Simulation Parameters

S.No	Parameter description	Parameter
1	Grid Voltage (Vg)	11 kV
2	Line Resistance	0.1 Ω
3	Line Inductance	0.5 mH
4	DC supply	200 Volts
5	Filter	L_F =7 mH & C_F = 100 µF
6	Grid Frequency	$f_g = 50Hz$
	Switching Frequency	$f_{mod} = 10$ KHz.

Voltage dip occurs due to sudden disconnection of load or faults in the system whereas voltage swell occurs due to connection of capacitive load. Voltage unbalance occurs for certain duration in the system due to faults in the network. During this period voltage disturbance occurs at

PCC (Point Of Coupling) and DVR operates to restore/maintain the voltage profile. Here all voltages are taken in per unit values, whenever disturbance occurs it can be observed that the magnitude voltage profile increases/decreases from its rated value. DVR operates and inject the desired voltage to compensate this voltage rise/dip. After compensation, there is slight disturbance at the start and end point of sag/swell occurs due to addition of compensating voltage during this period.

5. SIMULATION RESULTS

5.1 Compensation of Balanced Voltage Sag:

A three phase fault is generated in the system to create balanced voltage sag for time duration of 0.04s to 0.1s. The PCC voltage after the sag occurs for the duration of 0.06s is shown in Figure 2. The DVR respond to this disturbance and inject the compensating voltage. The compensated voltage is shown in Figure 3. After the sag compensation, the load voltage regains its previous profile. The load voltage after compensation is shown in Figure 4.

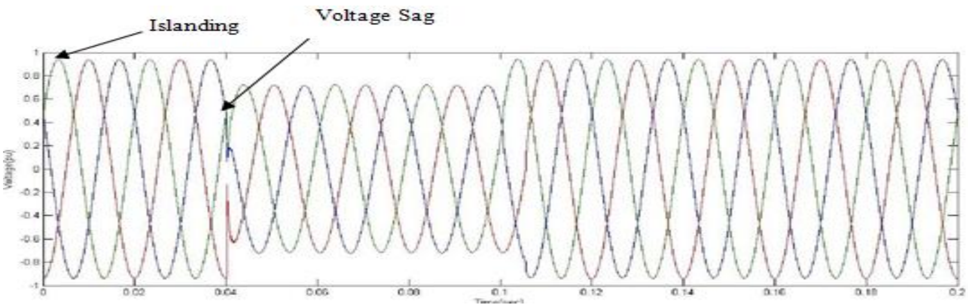

Figure 2.Point of Common Coupling voltage (Vpcc)

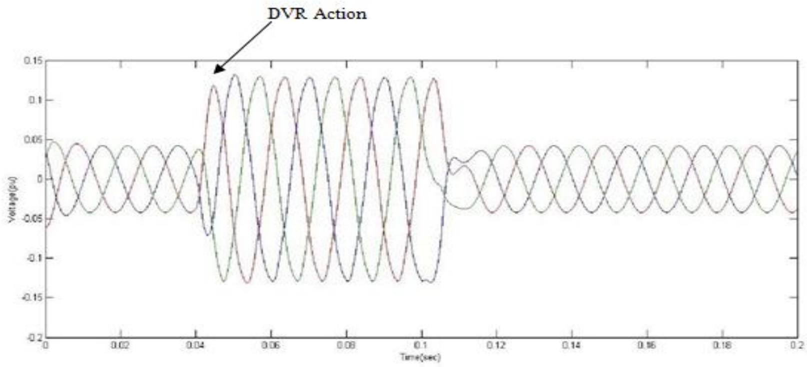

Figure 3. Compensating voltage (VC)

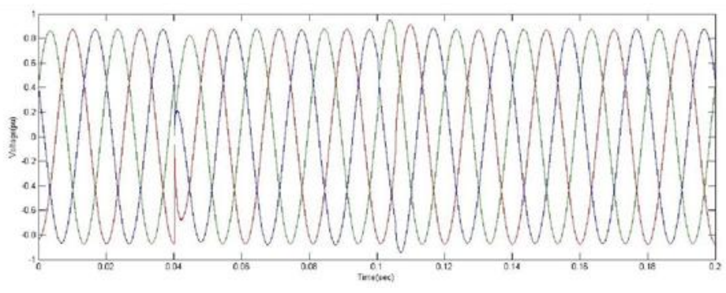

Figure 4. Load voltage after compensation (VL)

5.2 Compensation of Unbalanced Voltage Sag

Unbalanced voltage sag occurs due to SLG fault in the network for time duration of 0.04s to 0.1s. The PCC voltage after the sag occurs for duration of 0.06s is shown in Figure 5. DVR injects the desired voltage for this duration. The compensating voltage injected by DVR is shown in Figure 6. After the successful operation of DVR and sag compensation, the compensated load voltage is shown in Figure 7.

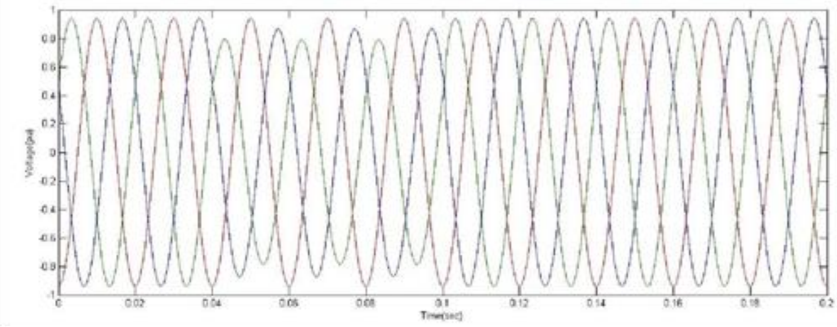

Figure 5. Point of Common Coupling voltage (Vpcc)

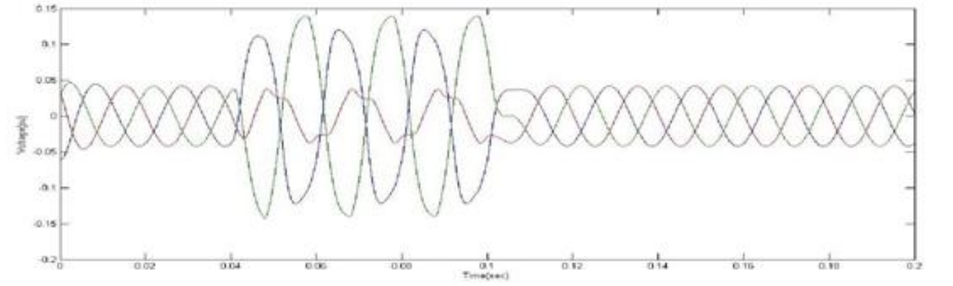

Figure 6. Compensating voltage (VC)

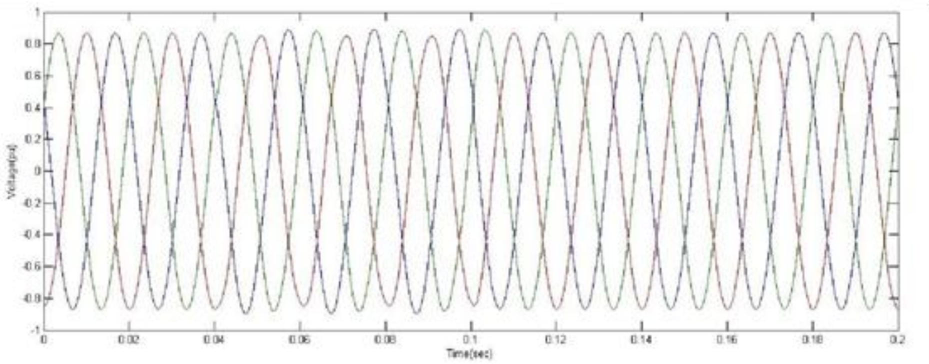

Figure 7. Load voltage after compensation (VL)

6. CONCLUSION

This paper proposes a novel method to accelerate the sag deduction time using half cycle discrete transformation to improve voltage sag in an islanded microgrid. From the analysis of simulation results it is evident that proposed methodology is effective in detecting voltage sag with in 0.04s and initiates necessary control signal to DVR to provide necessary voltage compensation to the islanded microgrid. The test results were analysed and it was concluded that proposed technique improves voltage sag in an islanded microgrid.

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