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Theoretical Analysis of Islanding Phenomenon in Distributed Generation

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Distributed generation faces several issues when integrated to power grid in large scale. Unintentional islanding is one such issue which needs to be addressed. Several methods already exist in literature to detect islanding instant like positive feedback method, passive method and communication based methods. This paper provides an overview of islanding phenomenon, theoretical explanation on islanding and the dynamics of the typical distributed generation system in islanded mode.

Keywords: *Distributed Generation, Modeling, Simulation, Islanded Operation,*

1.0 INTRODUCTION

The need for renewable energy is significant today than ever before. Most cases the renewable energy that we can harvest is distributed in large area. This makes the concentrated renewable power plant less attractive. Thus the most effective way to integrate renewable energy to grid is through distributed generation. Apart from facilitating effective renewable integration, distributed generation system has benefits like reduced transmission loss, usage of waste heat etc. Distributed generation faces several challenges like voltage fluctuations, islanding protection etc [1]. Islanding is the phenomenon in which a small portion of the grid with both generation and load is disconnected from main grid and operates independently. In this paper theory behind the islanding phenomenon, how islanding can be a threat to large scale distributed generation integration, the probability of such occurrence is discussed. The relationship between islanded system's frequency and reactive power mismatch voltageand real power mismatch is derived. Finally mathematical model of how an islanded system is presented for a generic case

2.0 ISLANDING PHENOMENON

Intelligent systems like microgrid can operate in islanded mode as it is designed to handle comparatively better load change [2]. On the other hand island formation is largely undesirable for distributed generation system because it is hard to maintain voltage, frequency of a small islanded system. Some of the other reasons to avoid islanding are [3],

1. A distributed generator's behavior may be unpredictable if loads are mismatched to thesupply characteristics.
2. If Circuit breaker (CB) is equipped with auto-reclosure then when the CB recloses after fault the distributed generator may not be synchronized with grid.
3. Islanded system may pose a threat to utility workers who might be unaware that the line is energized.
4. The power provided to the load in islanded system is not free from power quality problems.

2.1 Formation of an Island

Island can be formed only when the local load and local generation closely matches before the system is islanded. Consider the system in Figure 1. A DG is connected to a grid which is modeled as a thevenin voltage source with thevenin impedance in series. The local load is modeled as a constant

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impedance load. In case if the DG power flow P_{dg} and Q_{dg} is equal to P_L and Q_L then P_g and Q_g will be zero. The grid is just floating with the DG system with no power flow from grid to load. In this case when the circuit breaker CB is opened there won't be any significant change in voltage or frequency atthe point of common of coupling (PCC). The relays such as over frequency and under frequency relay or the over voltage and under voltage relay will fail to operate because of no significant change in voltage or frequency.

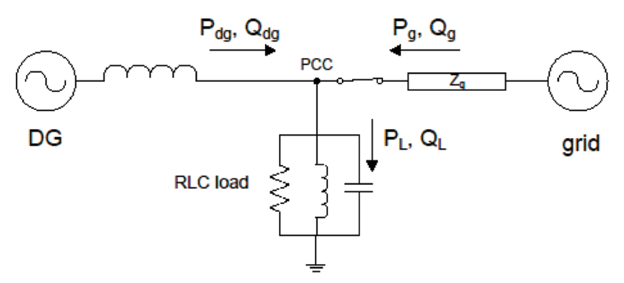

FIG. 1 DG CONNECTED TO GRID WITH LOCAL LOAD

2.2 Theory behind islanding

Consider the case when the P_{dg} and Q_{dg} not equal to P_l and Q_l. The power flow to the load changes to P_{dg} and Q_{dg} when the CB is opened. This sudden change in power flow will result in change in frequency and voltage at the point of common coupling. The relationship between change in frequency and voltage with respect to the reactive and real power mismatch can be derived as follows,

$$\Delta P = P_{load} - P_{DG}$$

$$\Delta Q = Q_{load} - Q_{DG}$$

$$P_{load} = \frac{V_g^2}{R}$$

$$Q_{load} = V_g^2 \left(\frac{1}{\omega_g L} - \omega_g C\right)$$

$$= P_{load} R \left(\frac{1}{\omega_g L} - \omega_g C\right)$$

$$= P_{load} \frac{Q_f}{\omega_0 C} \left(\frac{1}{\omega_g L} - \omega_g C\right)$$

$$= P_{load} Q_f \left(\frac{\omega_0 L}{\omega_g L} - \frac{\omega_g C}{\omega_0 C}\right)$$

$$= P_{load} Q_f \left(\frac{f_0}{f_g} - \frac{f_g}{f_0}\right)$$

considering unity power factor setting in inverter control, the DG power equation becomes

$$P_{DG} = P_{load} + \Delta P = V_g I_g$$

$$Q_{DG} = Q_{load} + \Delta Q = 0$$

$$Q_f \left(\frac{f_{min}}{f_g} - \frac{f_g}{f_{min}}\right) \leq \frac{\Delta Q}{P_{load}} \leq Q_f \left(\frac{f_{max}}{f_g} - \frac{f_g}{f_{max}}\right) \quad ....(1)$$

The equation (1) provides the required minimum reactive power mismatch to detect islanding for the given relay pick up limit.

$$\frac{(V+\Delta V)^2}{R+\Delta R} = \frac{V^2}{R}$$

$$\frac{V^2+\Delta V^2+2\Delta V V}{V^2} = 1 + \frac{\Delta R}{R}$$

$$\frac{\Delta V^2}{V^2} + \frac{2\Delta V}{V} = \frac{\Delta R}{R}$$

$$\frac{\Delta R}{R} = \frac{\Delta V}{V} + \left(\frac{\Delta V}{V}\right)^2$$

The power that flows to the grid when the DG is not islanded is,

$$\Delta P = \frac{V^2}{R+\Delta R} - \frac{V^2}{R}$$

$$\frac{\Delta P}{P} = \frac{\frac{1}{R+\Delta R} - \frac{1}{R}}{\frac{1}{R}}$$

$$= -\frac{\Delta R}{R} \left(\frac{1}{\frac{\Delta R}{R}+1}\right)$$

$$= -\left(\frac{\Delta V^2}{V^2} + \frac{2\Delta V}{V}\right) \left(\frac{1}{\frac{\Delta V^2}{V^2}+\frac{2\Delta V}{V}+1}\right)$$

$$= -\frac{\left(\frac{\Delta V}{V}+1\right)^2 - 1}{\left(\frac{\Delta V}{V}+1\right)^2}$$

$$= \left(\frac{V}{\Delta V + V}\right)^2 - 1$$

$$\left(\frac{V}{Vmax}\right)^2 - 1 \le \frac{\Delta P}{P_{load}} \le \left(\frac{V}{Vmin}\right)^2 - 1 \quad ....(2)$$

The equation (2) provides the required real power mismatch to detect islanding for the given relay pick up limits. Thus if the load mismach is such a way that the islanded system frequency and voltage falls within the relay setting then the island will not be detected and the system will continue to operate as long as the load and generation doesn't change.

2.3 Probability of islanding

Most of the DG sources are intermittent like solar or wind. In such cases DG power production continuously varies for every second. The fact that the load can also be continuously varying really makes the chance of exact power match between DG and load, very less. The probability of exact power match between DG and local load is very remote but the fact that the island can still be formed if the mismatch in power is within certain limit increases the chance of islanding. The report [4] claims that the power mismatch of upto 30% can result in failure to detect islanding if conventional relays are used. Thus islanding protection is required for all grid connected distribution system. IEEE 1547 standard requires that the islanding protection is mandatory for all grid connected DGs and the protection system should be able to detect islanding instant within 0.2 sec.

3.0 TEST SYSTEM FOR ISLANDING

The standard test system for islanding detection includes a three phase constant impedance parallel RLC load connected at PCC [5]. The quality factor (QF) for the load with resonance frequency at 50 Hz is chosen as 2.5. This QF represents worst case possible value [6].

3.1 Sample system for analysis

The system chosen for analysis is shown in Figure 2. An inverter based distributed generation

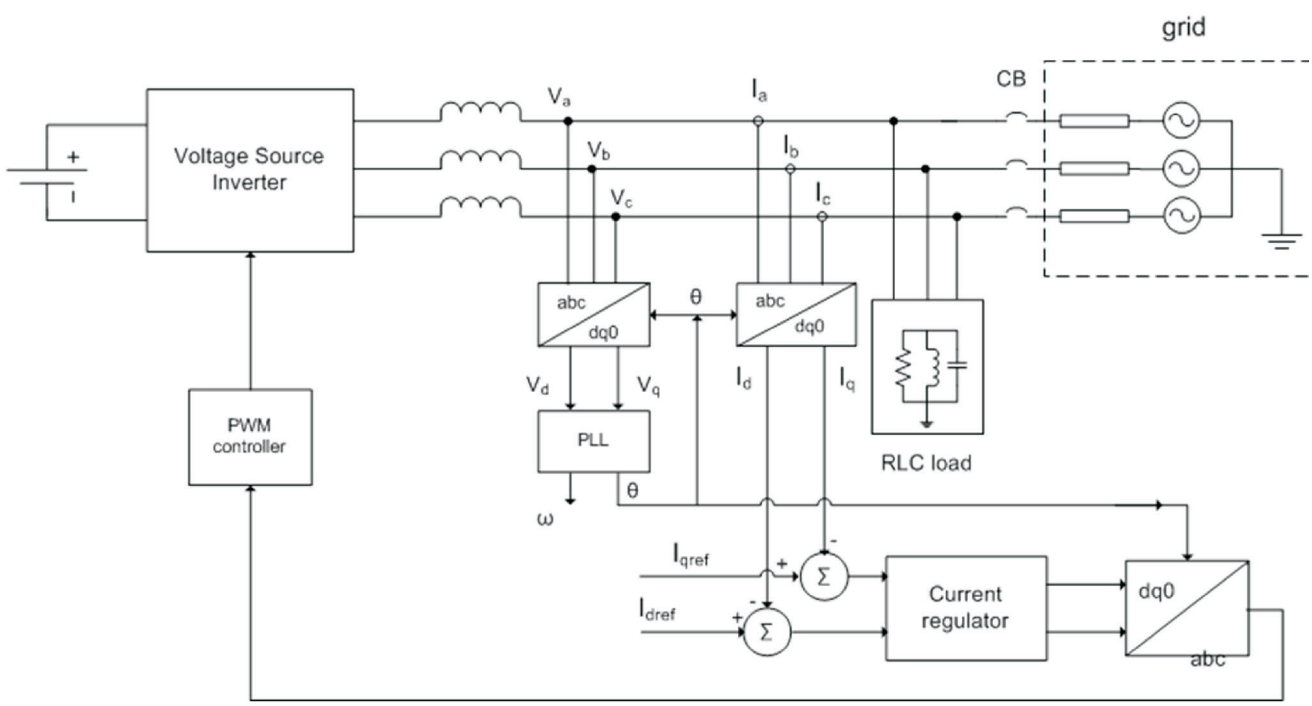

FIG. 2 BLOCK DIAGRAM OF SAMPLE SYSTEM

is chosen for analysis as most of the grid connected DGs in current and future scenario will be from renewable resources like solar. A voltage source current controlled inverter based on pulse width modulation is chosen as the DG interface. A constant DC voltage battery source is chosen as the generating source. CB is the circuit breaker that disconnects the load and DG from the grid and allowing them to form an island when CB is opened. PI current control technique is deployed to control the output current of inverter. The current controller works in dq0 domain. Hence forward and reverse dq0 transformations are deployed to transform back and forth from dq0 and abc domain.

4.0 MATHEMATICAL ANALYSIS

Inorder to analyze an islanding detection method based on any passive schemes, we require to have a mathematical formulation. Passive islanding detection schemes work by monitoring the change in voltage and frequency at PCC [7]. In this section a generic mathematical analysis is provided for analyzing the system in islanded mode with passive islanding detection techniques.

Since the inverter control works in dq0 domain it is easier to look into the system in the same domain. So the differential equations are transformed to dq0 domain. The parallel RLC load can be mathematically represented by a second order system, i.e. by two first order differential equations. The two states V, the voltage at PCC and IL, the current through the inductor can be written as shown in equations (3) to (6).

$$\frac{dV_d}{dt} = \frac{I_d}{C} + \omega V_q - \frac{V_d}{RC} - \frac{I_{ld}}{C} + \frac{I_{gd}}{C} \quad \text{....(3)}$$

$$\frac{dV_q}{dt} = \frac{I_q}{C} - \omega V_d - \frac{V_q}{RC} - \frac{I_{Lq}}{C} + \frac{I_{gq}}{C} \quad \text{....(4)}$$

$$\frac{dI_{Ld}}{dt} = \frac{V_d}{L} + \omega I_{Lq} \quad \text{....(5)}$$

$$\frac{dI_{Lq}}{dt} = \frac{V_q}{L} - \omega I_{Ld} \quad \text{....(6)}$$

The supply voltage is assumed to be balanced and hence there won't be any zero sequence components. Thus three phase transformation from dq0 domain results in only two components viz. direct (d) and quadrature (q) axis components.

x_1 and x_2 are the outputs from PI current controller block and its state space equation is,

$$\frac{dx_1}{dt} = k_2(I_{dref} - I_d) + k_1 \frac{d(I_{dref} - I_d)}{dt}$$

$$\frac{dx_2}{dt} = k_4(I_{qref} - I_q) + k_3 \frac{d(I_{qref} - I_q)}{dt}$$

TABLE 1

PARAMETERS OF TEST SYSTEM

Pameter	Values
k_2	0.3
k_2	20
k_3	0.3
k_4	20
k_{p1}	60
k_{p2}	1400
R	0.8 pu
L	0.0106 pu
C	1.326×10^{-4}pu
I_{dref}	1
I_{qref}	0
l	1.591×10^{-4}
r	0.002

The control of I_d and I_q is completely decoupled and hence the dynamics of inverter current becomes,

$$\frac{dI_d}{dt} = \frac{x_1}{l}$$

$$\frac{dI_q}{dt} = \frac{x_2}{l}$$

The phase lock loop [8] that is used to synchronize with the grid can be simplified as a combination of loop filter and integrator. The output from loop filter is the sensed angular frequency and output from integrator is θ.

$$\frac{d\omega}{dt} = k_{p2}V_q + k_{p1}\frac{dV_d}{dt}$$

$$\frac{d\theta}{dt} = \omega$$

This set of differential equations are non linear. To analyse the small signal stability of the islanded system the equations can be linearised to obtain the state space matrix A

5.0 VALIDATION

To validate the obtained model, solution of the differential equations and output of Simulink simulation for the modeled system is compared. Let us consider a scenario in which the real load is 0.8 pu and the reactive power generated is 0.05pu (leading VAR)and reactive power consumed is 0.2 pu (lagging VAR). The parameter values are chosen as shown in Table 1.The steady state system is islanded at 5s. Shown in Figure 3 is the plot of frequency and voltage obtained by solving the differential equations of the islanded system and the simulation through Simulink. The Simulink simulation is similar to that of the solution to the differential equations.

6.0 RESULTS AND DISCUSSION

The solution to the differential equations matches with the Simulink simulation. The absence of ripple in Vd, Vq and frequency plot obtained through solving the differential equations can be explained by the fact that the considered mathematical model assumes the source and inverter to act as a an ideal controlled voltage source. To obtain a perfect model that reflects actual operation the mathematical equations should include the source and inverter dynamics which will complicate the analysis further.

7.0 CONCLUSION

In this paper a theoretical explanation to the islanding phenomenon, the probability of occurrence of islanding are discussed. The relationship between voltage, frequency of DG output and the local load is derived. Finally mathematical approach to analyze the islanded system is provided and its limitation is provided.

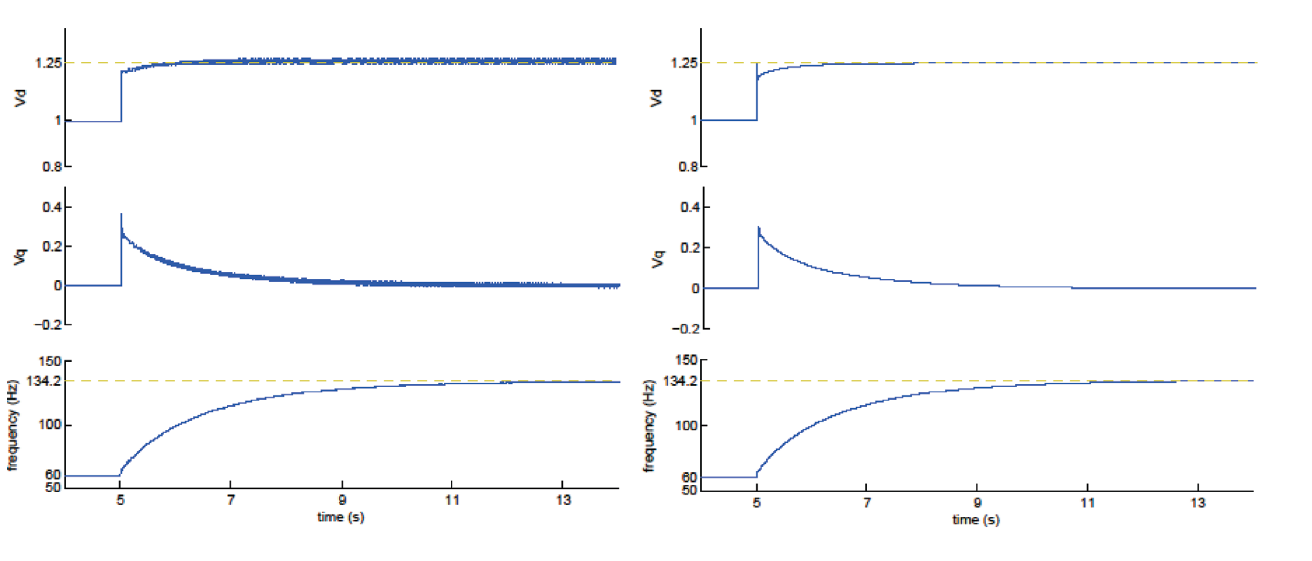

FIG. 3 A) SIMULINK SIMULATION B) SOLUTION TO DIFFERENTIAL EQUATION

REFERENCE

[1] Driesen, Johan and Belmans, Ronnie. 2006.Distributed generation: challenges and possible solutions. Power Engineering Society General Meeting, 2006. IEEE. pp. 8-pp.

[2] Katiraei, F, Iravani, MR and Lehn, PW.Micro-grid autonomous operation during and subsequent to islanding process. IEEE, 2005, Power Delivery, IEEE Transactions on, Vol. 20, pp. 248-257.

[3] Evaluation of islanding detection methods for photovoltaic utility-interactive power systems. PVPS, IEA. 2002, Report IEA PVPS T5-09.

[4] Ye, Zhihong, et al., et al.Study and development of anti-islanding control for grid-connected inverters. National Renewable Energy Laboratory, 2004.

[5] Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources With Electric Power Systems, IEEE Std. 1547.1, 2005.

[6] Gonzalez, Sigifredo, Bonn, Russell and Ginn, Jerry.Removing barriers to utility interconnected photovoltaic inverters. Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE. pp. 1691-1694.

[7] De Mango, Francesco, et al., Overview of anti-islanding algorithms for PV systems. Part I: Passive methods. et al. 2006. Power Electronics and Motion Control Conference, 2006. EPE-PEMC 2006. 12th International. pp. 1878-1883.

[8] Freijedo, Francisco D, et al., et al.Grid-synchronization methods for power converters. Industrial Electronics, 2009. IECON'09. 35th Annual Conference of IEEE. pp. 522-529.