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FAULT IDENTIFICATION OF STABILITY IN A WEAK AC MICROGRID WITH RENEWABLE INTERFACE

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ABSTRACT

The increased penetration of renewable energy sources like PV, wind etc. into the electrical grid network has led to an increased demand to address the various issues associated with grid connected system such as bus voltage fluctuation, active power variations and poor system dynamics. This paper emphasizes on the effect of weak grid characterized by high grid impedance on the stability of the power system network by observing the real power oscillations produced when the network is subjected to disturbances. The effect of grid impedance on the stability of current control algorithm, when a 3 phase inverter is integrated to the grid, is also studied here. Experimental demonstration of synchronization of a 3 phase inverter (3.3kVA) with the grid is done here along with testing of the 3 phase inverter hardware developed during the course of the work.

***Keywords:* Inverter, Microgrid, Reactive power, Impedance, Distributor generator.**

I INTRODUCTION

The evolution of renewable energy based sources of generation over the past decade has been on a continuous rise in different parts of the world. This is supplemented by technological advancements and policy research bringing in favorable conditions in order to enhance the renewable energy market. It is the electricity sector that has benefitted the most with increased penetration of solar, wind and other renewable energy based sources into the grid network. Today, with the rising prices of conventional fossil based energy sources and with a sustainable and environment friendly development approach adopted in various parts of the world, the demand for clean and green energy sources have taken a sharp rise and the development of such systems have become the prime area of research. The issues associated with the integration of renewable sources to the grid include bus voltage fluctuation, active power variation and poor system dynamics and these are to be addressed by means of efficient and flexible power conditioning and conversion devices. Therefore, the role of power electronic in designing such circuits has become very significant. This paper essentially emphasizes on the stability issues associated with grid network renewables. This paper also emphasizes on the control techniques used to enhance the stability of the system and therefore examine the multi-functional services provided by the grid connected inverter. The main criteria that defines the weakness in the grid is the Short Circuit Ratio (SCR) which depends on the impedance of the grid network.

$$SCR_{pu} = \frac{1}{Z_{pu}} \tag{1}$$

II STABILITY ASPECTS OF GRID NETWORK

A microgrid is defined as an integrated system of distributed energy sources and multiple loads operating either in islanded mode or in grid connected mode. In literature, microgrid is classified into 3 categories from the stability point of view as

a) Utility microgrid, which is connected to the utility grid at one or more points of common coupling (PCC), spans over a large area and can be operated in both the grid connected and autonomous islanded mode.
b) Remote microgrid, which is not connected to the utility grid and operates with decentralized control methods.
c) Facility microgrid, wherein a single business-entity micro grid typically an industrial microgrid and is also connected to the utility network [1].

Stability of microgrids can be grouped under three categories namely small signal, transient and voltage stability similar to the categorization of the stability aspects of a large power system network and the most common issues pertaining to each of these stability aspects is discussed in literature. Faults with subsequent islanding is contributes to most of the transient stability problems in the microgrid. Similarly, reactive power limits and load dynamics contribute to voltage stability problems and the DG feedback controllers and current limiters poses significant problems to small signal stability of the network.

There are different techniques described in literature that describe about the various methodologies adopted to improve the stability of the microgrid. These approaches depend on the type of microgrid under study and the category of stability to which they belong. Stabilizers and Coordinated control of DG help to improve the small signal stability of the system while control of storage systems and power electronic control can improve the transient stability of the network. Voltage regulation and reactive compensation are the techniques suggested in literature to improve the voltage stability of the network [2].

1.1 STABILITY STUDIES

Stability aspects of a micro grid could be further studied by applying the concepts of power system dynamic and steady state stability concepts. In fact, with increased level of grid integrated systems, the grid network gradually shifts from a multi-machine system to single machine network [3][10]. This results in reduction of inertial elements in the network and the network becomes vulnerable to disturbances [10] [11]. In Fig.1, an alternator and an inverter with a regulated DC supply powered using a renewable energy based source, is synchronized to the grid.

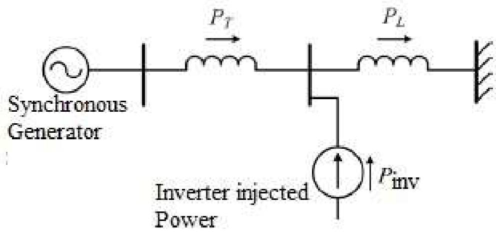

Fig.1: Grid connected inverter injecting power into the single machine network [3]

Power system stability can be categorized as steady state stability and transient stability. This work emphasizes on the dynamics of the network and hence transient stability studies are of main concern. Active and reactive power flow through the line are observed and study of these parameters are important in this study. Apart from this, observations and analysis of the variations in power angle, voltage and current waveform is also significant for the study. Steady state power flow between 2 buses of the power system is represented by the equation. [5]

$$P = \frac{V_1 V_2}{X_1} \sin(\delta_1 - \delta_2) \tag{2}$$

Where V_1 and V_2 are the magnitudes of bus voltage and δ_1 and δ_2 are the respective power angles, X_1 is the line reactance

Here, the assumption considered is that the line is assumed to be lossless and hence the reactive in nature. As a result of this critical angle for stability is 90º [4].

Now, in a single machine network, the effect of the disturbances in the line power flow or the electrical power injected by the machine into the grid is governed by the machine dynamics and is represented by the following equation [3].

$$\frac{2H}{\omega_0}\frac{d^2\delta}{dt^2} = P_m - P_e - K_f \Delta\omega_r \tag{3}$$

where H is the inertia constant of the machine, ω_0 is synchronous speed, P_m is the mechanical power input to the generator, P_e the electrical power output from the generator, K_f stands for the damping constant and $\Delta\omega_r$ for the change in rotor speed. At steady state $P_m = P_e$ and here power flows at a particular value of $\delta = \delta_1 - \delta_2$ this value of power angle plays an important role in determining the stability of the network.

Observations were made after subjecting the network to disturbances in order to validate the dependence of power oscillations on the overall system inertia and is shown in Fig.2

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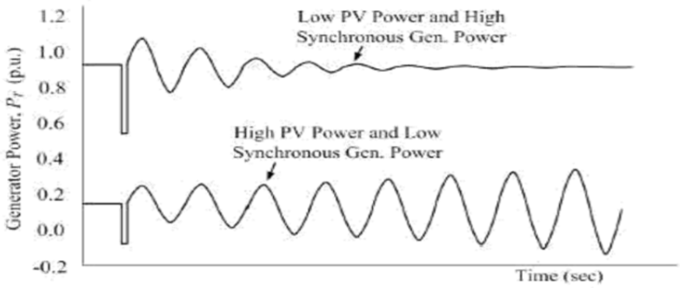

Fig.2: Power oscillations with different combinations of PV and conventional generators [7] [10].

WEAK GRID SCENARIO

In electrical grid network, a weak grid is referred to a grid network having large value of network impedance. Two main characteristics that determine the weakness of the grid are the Short Circuit Ratio (SCR) of the network and the X/R ratio of the grid network. A grid network is weak when it offers a higher impedance at the point of common coupling. Here we analyze both the cases with respect to their contribution to the stability of the network.

CASE 1: HIGHER LINE REACTANCE

In this case, grid is considered to be reactive and offering minimum losses. Fig.3 depicts this effect where a strong grid and a weak grid is compared in terms of their power angle curves.

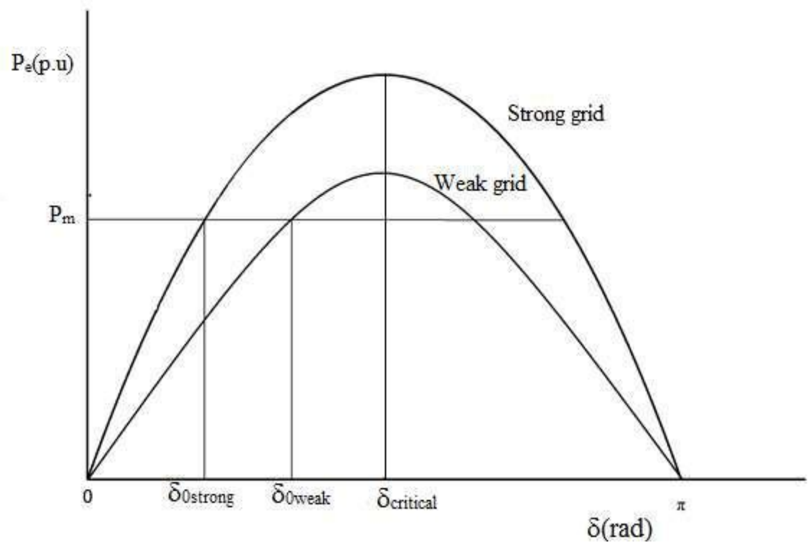

Fig.3: Power angle curves for strong and weak grid scenarios

CASE 2: LOWER X/R RATIO

In this scenario, where line offers significant resistance commonly seen in distribution lines, a similar weak grid conditions are created wherein the critical power angle is less than 90º. In the network shown in Fig.1, the power flow from the point of common coupling to the grid is represented by the following equation.

$$P_g = \frac{V_{PCC}}{Z_g}\left(V_{PCC}\ \cos\beta - V_g\ \cos(\beta+\delta)\right) \tag{4}$$

Where V_{PCC} represents voltage magnitude at the point of common coupling, V_g stands for grid voltage magnitude, Z_g represents the magnitude of grid impedance, β represents impedance angle and δ is the power angle. This relation represents the power transfer between 2 lines considering the line losses. Here, the stability limit in terms of power angle is defined as

$$\delta_{critical} = \beta \tag{5}$$

When the line is assumed to be lossless, β = 90º and hence it follows the case discussed before. Here, therefore the stability limit of the network is reduced making the network vulnerable to disturbances.

2. STABILITY ASPECTS OF GRID INTERFACED CONVERTERS

Inverters or DC/AC converters form a very important segment of this part. Synchronization of their filtered output voltage with the grid voltage, control over output current, maintaining the harmonics in the output voltage and current within standard limits i.e. 5 percent of the fundamental and the control of active and reactive power injected by the converters to the grid are some of the major areas investigated. [6] Effect of higher grid impedance on each of these topics would be discussed here.

2.1 GRID CONNECTED INVERTERS

This section deals with design of grid connected inverters and their control. The schematic of a typical voltage source converter connected to the grid and its current control is shown in Fig.4

The output active power injected by the inverter to the grid could be controlled in 2 ways, output voltage control, and output current control. Here, in a 3 phase network, current control needs to be realized in all three phases. As a result of this, implementation of the above block diagram in all 3 phases would involve the use of 3 compensators and this would affect the robustness and the dynamics of control. In order to optimize this or to make use of the least amount of compensators, transformation techniques are adopted.

Based on the active and reactive power reference inputs to the grid connected VSC, the reference current values are obtained. [8]

$$I_{dref} = \frac{1}{V_d^2 + V_q^2}\,\frac{2}{3}\,(P_{ref}\,V_d + Q_{ref}\,V_q) \qquad (6)$$

$$I_{qref} = \frac{1}{V_d^2 + V_q^2}\,\frac{2}{3}\,(P_{ref}\,V_q - Q_{ref}\,V_d) \qquad (7)$$

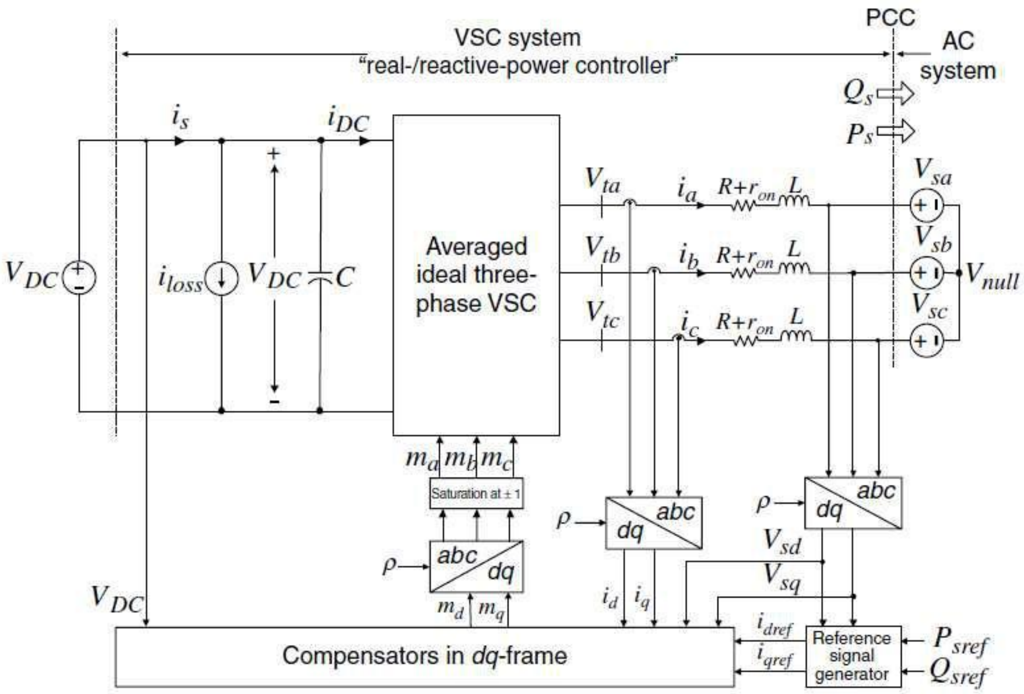

Fig.4: Current control of grid connected inverter [8]

Where P_{ref} and Q_{ref} are the reference real and reactive power, V_d and V_q are the grid voltage magnitude in dq0 domain. The reference currents are then used to generate the error signal which is fed to the compensators for reference tracking.

2.2 STABILITY ANALYSIS OF GRID CONNECTED INVERTERS

This is done by performing a small signal analysis of an inverter which is represented by a current source in parallel to the impedance, which is then connected to a voltage source that represents the grid through a series impedance [9]. The small signal is shown in Fig.5

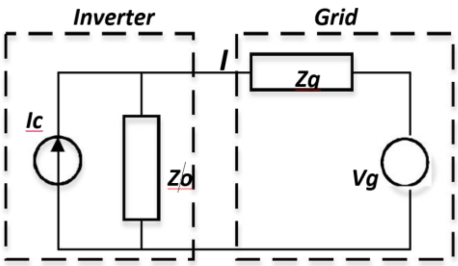

Fig.5: Small signal model of the inverter

Here, to perform the stability analysis of the network, the current injected by the inverter based on the above model was obtained as follows

$$I_s(s) = \left[I_c(s) - \frac{V_g(s)}{Z_0(s)} \right] \frac{1}{1+\frac{Z_g(s)}{Z_0(s)}} \quad (8)$$

With increased impedance of the grid, the current control approaches its stability limit. However, this criterion can be ensured by tuning the current control parameters in order to meet the stability condition.

3. HARDWARE IMPLEMENTATION

This section deals with the experimental analysis of the network studied in this paper. The main components involved in this setup and their ratings is given in table.1.

Table 1: Different components involved in the hardware

Alternator	3 phase, 415 V, 5kVA
Grid	415V, 3 phase 4 wire line
Voltage Source Inverter	3 phase, 3kVA
Filter inductor	5mH
Grid side inductance	14mH
Voltage and Current sensing board	30A current sensor, OPA2277 precision opamp based voltage sensor
DSP control card	TMS320F28335

The hardware connections implemented here is shown using a single line diagram similar to the one given in previous and is depicted in Fig.5

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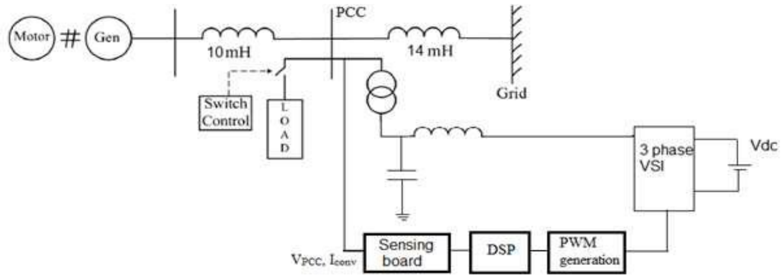

Fig.6: Single line diagram of the hardware test setup

Different sets of experiments were tested beginning from the synchronization of the alternator to the grid to creating disturbances in the system to generate power oscillations.

4.1 SYNCHRONIZATION OF THE ALTERNATOR

The 3 phase synchronous machine driven by a DC motor is synchronized to the grid. Here, synchronization was performed using dark and bright lamp method. Frequency and phase synchronization is ensured using the lamp method. Voltages at both the ends were matched using a control knob that adjusted the field circuit of the machine so as to ensure voltage magnitude synchronization. The alternator is driven by a DC drive of whose speed of rotation can be controlled manually using the DC drive control panel. The machine along with the control panel used for the test is shown in Fig.7.

Fig.7: 3 phase synchronous generator and DC motor controller setup.

The synchronous generator is synchronized to the grid and active power is injected to the grid by increasing the speed of the rotating machine.

4.2 TESTS PERFORMED ON 3 PHASE INVERTER

4.2.1 OPEN LOOP TEST

A 3 phase H-bridge inverter was developed with MOSFETs rating at 600 V, 20A each. All the switches were driven using 6 A3120 driver IC's wherein, 3 gate driver IC's of the top switches of all the three legs were electrically isolated from each other. An auxiliary power supply board with single input and 6 outputs was also developed in order to supply and meet the biasing requirements of the gate driver circuits. Open loop test was conducted on the developed 3 phase inverter. A low DC voltage of 30 V was applied and the sinusoidal PWM pulses were fed as gating signals to the driver IC. Fig.8 shows the experimental setup for this test and the output AC voltage waveform.

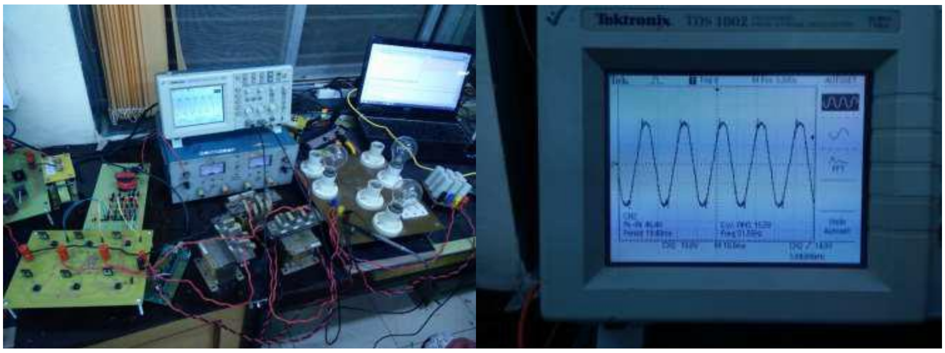

Fig.8: Experimental setup for inverter open loop test and Waveform
Of filtered output voltage of the 3 phase inverter

4.2.2 SYNCHRONIZATION OF THE 3 PHASE INVERTER TO THE GRID

Here, the 3 phase inverter is synchronized to the grid by implementing the PLL logic in the DSP. The control logic is realized in code composer studio (CCS) software. Here, grid side voltage which is stepped down by the autotransformer is sensed and is fed to the ADC pins of the DSP control card. The sampling rate of ADC is at a higher rate than interrupt generation and so signals are sampled effectively. Here, PLL algorithm is implemented based on the design used in simulations and the values of PI controller gains are computed. Finally, ω corresponding to the frequency of the voltage signal is tracked. The phase information obtained is then used in the current control implementation. Once tracking is ensured, PWM signals are generated using both open loop and closed loop current control algorithm. These signals are then fed to the gate drivers of the 3 phase inverter. The inverter is powered by a DC source and at the AC side, an LC filter is connected, designed for a cutoff frequency of 800Hz.

4.2.3 GENERATION OF LOW FREQUENCY POWER SWINGS

In this test, the alternator interfaced to the grid is subjected to disturbance at their point of common coupling. The disturbance is introduced by switching of 3 phase load, in this case being a resistive lamp load. During this test, the alternator is injecting an active power into the grid. The lamp load comprises of series of lamps connected in parallel to each phase. For testing purpose here, manual control of the breaker is employed. A total

IJARSE
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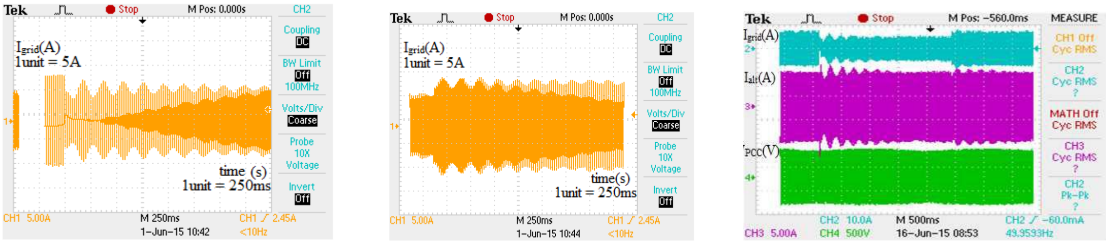
of 2kW load is connected at the point of common coupling. Current injected to the grid is tracked using DSO and here for this purpose, the time scale of the DSO is set at a higher value. The breaker is closed and then opened and a series of such tests were performed in order to observe the oscillations. The current waveforms depicting the oscillations while switching on the breaker is shown in Fig.9.



(a) (b) (c)

Fig.9: (a) Oscillations in the grid current waveform when the load was turned on (b) Current Injected to the grid when the load is switched off (c) Current injected to the grid, current drawn from the generator and the VPCC waveforms respectively from top to bottom.

Here, all the 3 waveforms were taken for a larger time step of 500 ms and voltage waveform is has not undergone any changes when the disturbance was introduced in the network. The disturbance introduced is switching of a lamp load of 1.2kW. Hence, implementation of the control law to enhance the system stability and damp the low frequency power swings could not be validated experimentally.

4. CONCLUSIONS

The integration of DG sources like PV, wind etc. into the existing grid brings about several challenges. These issues are dealt with an efficient power electronic converter governed by a robust control strategy. This report however has emphasized on the stability issues associated with weak grid and how it affects the network stability. Laboratory implementation of this work could not be completely realized. This is due to laboratory constraints of introducing a disturbance that can affect the grid voltage. Introducing a momentary fault at the point of common coupling requires use of breakers that can be controlled automatically. The alternator used in this setup has the capability to withstand a momentary disturbance for 3 seconds, which cannot be realized by manual operation. Apart from this the 3 phase resistive load, though with a low value of resistance (40Ω) per phase, could introduce oscillations in the current waveforms, necessary variations in the grid voltage could not be realized using these.

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