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Power Flow Control of Hybrid Micro Grid using 3 Phase Bidirectional Converter: A Review

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ABSTRACT: This paper proposes the use of a three phase power converter setup with suitable controller, for power flow management over a hybrid micro-grid (including AC and DC grids), without need to any permanent storage systems (batteries or fuel cells) on the DC bus to counteract their high cost, complexity of design and integration. Such proposed system is capable of serving low voltage residential and commercial loads, where there would be an availability of renewable energy sources and possible DC loads (heaters, LED lights, electronics, etc ...). Bidirectional power transmission is achieved between AC and DC buses through a three phase bi-directional converter whose primary objective is to maintain a constant DC bus voltage with respect to DC sources or loads change. A proportional integral controller is utilized to stabilize the reference DC bus voltage by varying the reference AC grid side current that is controlled by a hysteresis controller.

KEYWORDS: hybrid, bi-directional, power control, unity power factor, grid connected.

I. INTRODUCTION

Conventional AC power system was one of the few worldwide systems taken for granted during the last century, for its simplicity, high efficiency, simple maintenance and power transmission for long distances on various voltage levels. All the improvements this conventional grid witnessed were exercised on its power quality, improved distribution and more robust protection schemes; however, the concept of the conventional AC grid still intact. Hybrid grid is the new millennium of the conventional grids [1], specially its micro scheme. Such type of hybrid grid emerged due to appearance of new DC power sources, easily integrated on a DC bus such as fuel cells, photo-voltaic (PV) and wind turbines. Fortunately, DC loads are commercially available like light systems (incandescent, LED...), heating and loads with power electronics scheme such as DC/AC converters of wind turbine generators. The appearance of these DC sources and loads urged the presence of a DC grid while AC grid still in service. DC grid is proved to have a high efficiency transmission, no need for reactive power components and increase of overall hybrid system efficiency due to less switching losses since part of loads are fed directly from DC bus [2], so avoiding possible multiple reverse conversions [3]. DC grid voltage would be decreased/increased by buck/boost converter. A proportional integral (PI) controller was utilized in to control the DC bus voltage and grid current. Although such control scheme is basic, it requires tuning of several parameters to ensure an adequate response. In [4], bidirectional power flow was achieved through a pulse width modulated, three-level converter producing a low distortion output current. However, the controller has to deal with balancing neutral point voltage, which increases controller complexity and measurement requirements. Moreover, the used modulation scheme utilized only half the available DC bus voltage, which reduces the output current rating. A modified one-cycle control scheme is proposed in [4] to deal with poor power factor issues in rectifier operation of a bidirectional converter. However, the controller parameter is dependent on circuit parameters and requires measurement of the highly distorted output voltage of the converter. Moreover, such controllers are either complex, require high computational burden and several parameters require tuning. In this paper a single level hysteresis controller [5] is utilized to control the grid side current achieving a simple, robust, low error, extremely good

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dynamics, and unity power factor mode current behavior]. Moreover, a PI controller is in charge of maintaining a constant DC bus voltage which adds to the simplicity of the implemented controller setup and low computational efforts. Operation modes include the cases of the increase/decrease of the PV available power or decrease/increase the DC load demand, while the DC bus voltage is maintained constant by injecting/absorbing active power to and from the AC grid side.

II. CONSTRUCTION AND OPERATING PRINCIPLE

Typical permanent storage elements connected to the DC bus help maintain a constant DC bus voltage during DC power oscillations. However, such elements present a limitation due to their storage capacity and causes additional cost and maintenance. The main objective of the proposal is to eliminate the requirement of any permanent storage elements, allowing future power level increase on DC bus with no storage limitations. This will require continuous monitoring of DC bus voltage, since any fluctuations in the DC bus power will result in direct impact on the DC bus voltage, by utilizing the presence of the AC grid to assist in maintaining a constant DC bus voltage. This result has been achieved through three different modes of operation as seen in fig. 1; mode 1: inverter mode (also known as unity power factor “UPF” mode) or current injection to the AC grid that happens when the PV source would produce DC power (PPV) more than required by DC load. Mode 2: rectifier mode (also known as grid connected “GCM” mode) or current drawn from AC grid that happens when the PV produces PPV less than required by DC load. Finally mode 3: OFF mode, when DC load power is exactly equal to the value of PPV leading to no power exchange between grids. Fig. 2 demonstrates the power diagram of the proposed hybrid grid system where a three-phase bi-directional converter is located between a stiff infinite bus three-phase grid and a DC micro-grid. The proposed control technique uses a PI controller that gets an error signal of the reference DC voltage ($V_{DC Ref.}$) compared to the actual DC bus voltage (V_{DC}). PI works on providing the hysteresis controller a reference current signal to achieve a stable V_{DC} . This three phase current is synchronized with three phase grid voltage V_A , V_B and V_C by getting PI output multiplied with the reference per unit (P.U.) signal of phase "A" ($V_A P.U.$) then compared to actual three phase feedback AC grid current (I_A , I_B , I_C). Hysteresis controller gives the converter the desired gate signals to achieve that current reference to satisfy the required $V_{DC ref.}$ through the PI controller. feedback AC grid current (I_A , I_B , I_C). Hysteresis controller gives the converter the desired gate signals to achieve that current reference to satisfy the required $V_{DC ref.}$ through the PI controller.

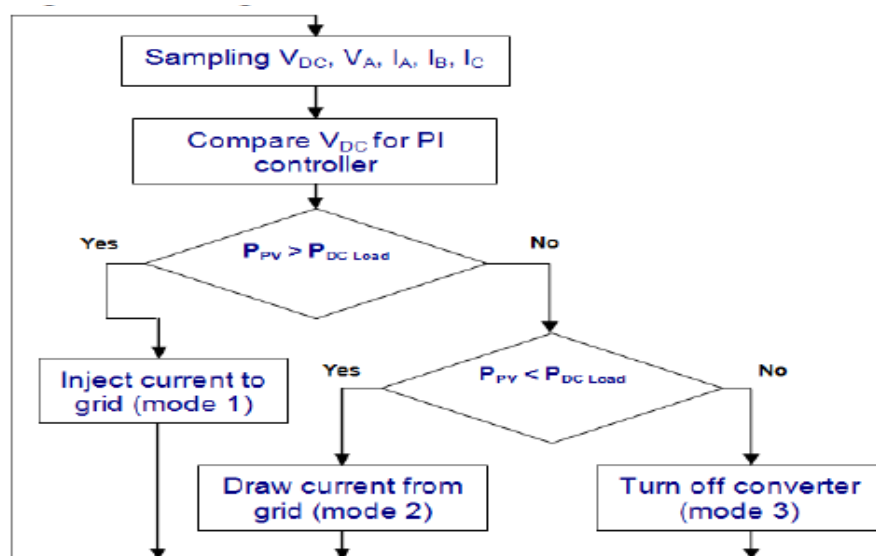


Fig. 1. Flowchart demonstrating modes of operation

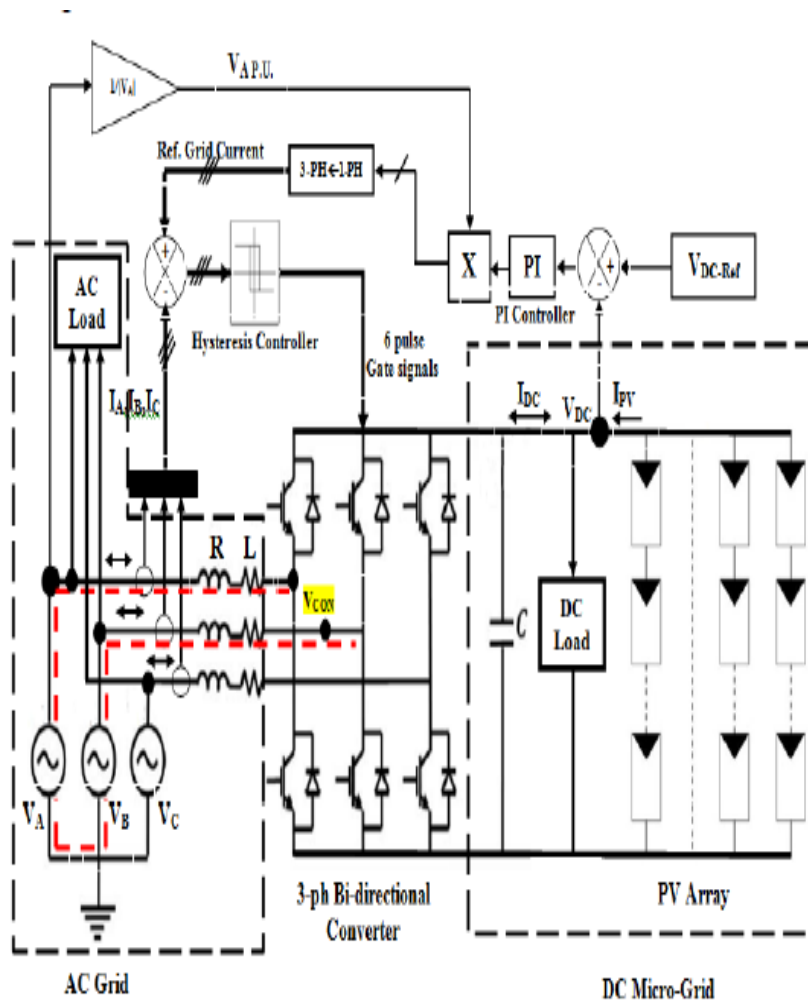


Fig. 2. Proposed setup of hybrid grid with bi-directional power flow

III. SET UP DESIGN AND CALCULATIONS

Previous section is objected to the limitations concerning the proposed system due to absence of permanent storage elements. These limitations dictate the maximum I_A supplied to the grid during mode 1 and the maximum I_A absorbed from the grid during mode 2. To simplify the analysis, the converter losses are neglected and the PV source is represented by a variable dc source V_S connected to a series resistance R_S as proposed in [6] which follows an approximate equivalent linear characteristics of a PV cell.

The bi-directional converter AC side is connected with AC grid through the necessary L filter required for the hysteresis controller operation, while a PV is modeled by V_S and R_S as seen in fig. 3 and fig.4.

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A. Mode 1 (inverter mode)

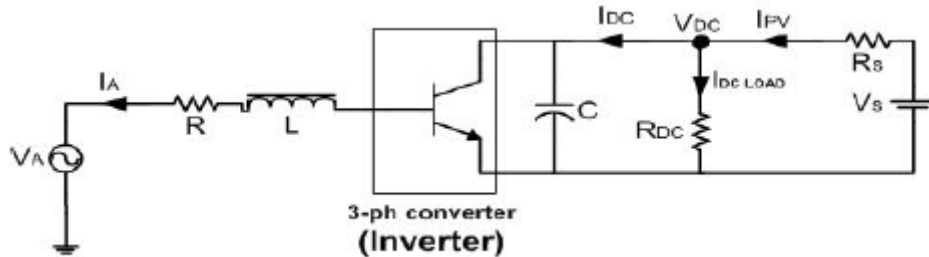


Fig. 3. Per phase power diagram in inverter mode

Equation (1) is inspired from power flow calculations; having power flowing ($P_{inv.}$) from DC to AC grid

$$3V_A I_A \cos\phi = P_{inv.} - 3I_A^2 R \quad (1)$$

$$P_{inv.} = P_{PV} - P_{DC \text{ load}} \quad (2)$$

Mode 1 is operated in UPF, then:

$$\cos\phi = 1$$

Knowing that:

$$P_{PV} = V_s I_{PV} \quad (3)$$

$$P_{inv.} = V_{DC} I_{DC} \quad (4)$$

$$I_{DC} = I_{PV} - I_{DC \text{ load}} \quad (5)$$

By solving 2nd order equation (1), its root would be:

$$I_A = \frac{-V_A + \sqrt{V_A^2 + \left(\frac{4}{3}P_{INV.R}\right)}}{2R} \quad (6)$$

Hysteresis controller has been used due to its ability to let 3-ph converter produce a peak voltage up to V_{DC} which is the highest compared to sinusoidal pulse width modulation (SPWM) where V_{DC} up to $(V_{DC}/2)$ and space vector modulation where V_{DC} up to $(V_{DC}/\sqrt{3})$ [5]. Hysteresis controller can be considered as a current source controller, so that it adapts the value of converter voltage V_{con} according to the available power then the available I_A to be injected. Maximum current to be injected is:

$$I_{A \text{ max}} = \frac{-V_A + \sqrt{V_A^2 + \left(\frac{4}{3}P_{INV.\text{max}}R\right)}}{2R} \quad (7)$$

It occurs when there is no DC load, which means that $P_{inc} I_{DC}$ are maxima:

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$$P_{inv\ max.} = P_{PV} = V_{DC} I_{DC\ MAX} \quad (8)$$

$$I_{DC\ max} = I_{PV} = \frac{V_S - V_{DC}}{R_S} \quad (9)$$

It should be noted that in practical setup, a PV array would be modeled using a variable DC source (V_S) with a series resistance (R_S) assuming the operating points will occur in linear region of the real PV array [6], hence

$$V_{DC} = V_S - (R_S I_{PV}) \quad (10)$$

A. mode 2 (rectifier mode):

The critical DC load resistance ($R_{DC\ crit.}$) of mode 3 at which the converter will tip over from being in inverter mode to be in rectifier mode.

$$R_{DC\ crit.} = \frac{V_{DC}}{I_{PV}} \quad (11)$$

Where:

$$I_{DC} = 0$$

Since there are no used batteries, the system should have an operating range to work within, or else the system will go out of stability and the desired reference voltage will not be achieved anymore. That working range is defined by the following 2nd order equation inspired also by the power flow (P_{RECT}) from AC to DC and assumed 100% efficient converter.

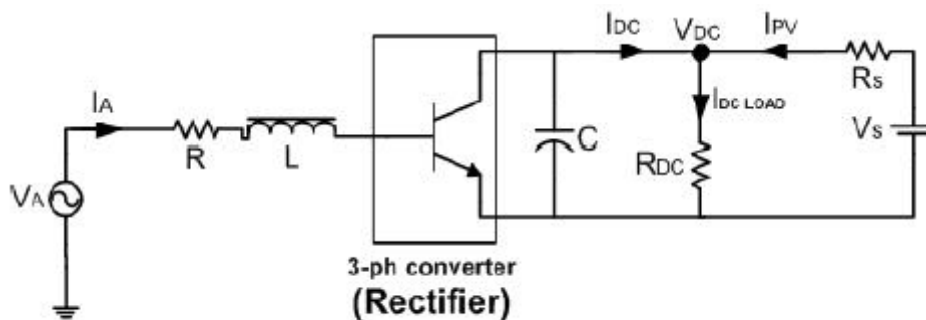


Fig. 4. Per phase power diagram in rectifier mode

$$P_{RECT.} = 3V_A I_A \cos\phi \quad (12)$$

Where:

$$\cos\phi = 1$$

In fig.5, the operating range of I_A is plotted according to equation (12) where $P_{RECT.}$ increases steadily to its maximum value of 211.4 Watts at I_A of 11.4 A. Any required power by the DC grid from the AC side more than 211.4 W will cause the controller to withdraw by default more current " I_A " from the AC grid hoping for more power; but once I_A is more than 11.4 A, filter copper losses ($3I_A^2R$) increases dramatically causing power transfer from AC to DC side diminishing less than 211.4 Watts.

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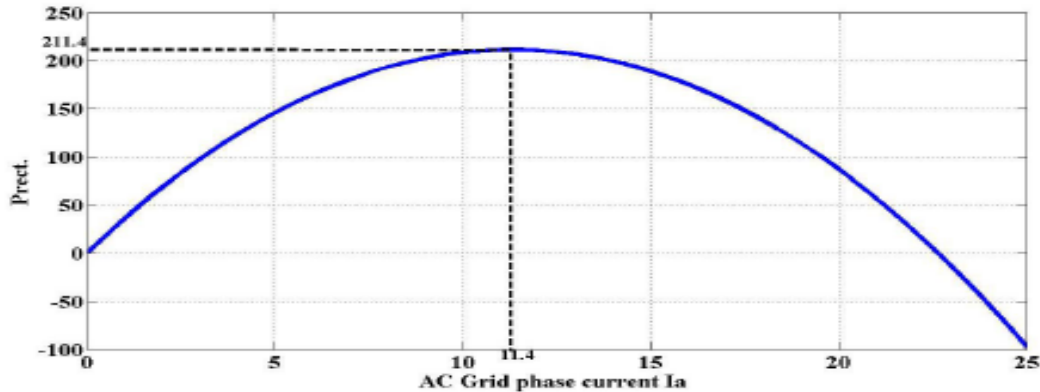


Fig. 5. Operating range in rectifier mode

To prove it analytically;

$$\frac{dP_{RECT}}{dI_A} = 0 \quad (13)$$

$$3V_A - 6I_{A \max} R = 0 \quad (14)$$

$$I_{A \max} = V_A / 2R \quad (15)$$

$$I_{DC \max} = P_{RECT \max} / R \quad (16)$$

$$\begin{aligned} P_{RECT \max} &= 3V_A I_{A \max} - 3I_{A \max}^2 R = 3V_A^2 / 2R - 3V_A^2 / 4R \\ &= 3V_A^2 / 4R \end{aligned} \quad (17)$$

There is a minimum resistance ($R_{DC \min}$) or maximum DC load power where system will be critically stable. Less resistance will drive system to instability and immediate decay of V_{DC} can be given by:

$$R_{DC \min} = V_{DC} / (I_{PV} + I_{DC \max}) \quad (18)$$

IV. CONCLUSION

This paper studied a hybrid grid using computer simulation and practical implementation. It aimed to prove no need for any permanent storage elements whatsoever using simple and dynamic controllers in the proposed setup. Exclusion of any batteries or fuel cells could allow the system to be upgraded to several KWs with no storage limitations but with the suitable size of bi-directional converter and filter. Such hybrid grid power system cannot be islanded, due to its full dependency on a stiff infinite bus AC grid and absence of storage element. Hysteresis controller has been utilized to manage AC grid current value, side by side with a PI controller monitoring and controlling the DC bus voltage. Such system is simple, dynamic and viable providing direct "plug and play" simple installation for renewable energy source, such as PV. Maximum power tracking could be available if a buck/boost converter is installed with the array.

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