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Droop Control Forhybrid Micro grids With Wind Energy Source

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Abstract: **Microgrids are raising to be reliable source of power generation to integrate with the utility grid. Individual AC microgrids or DC microgrids require many conversions of power at the consumer end for DC loads and AC loads respectively, giving a less efficient system.In this paper, a droop control strategy is proposed for management of powerin islanding mode; which is the most challenging operating mode in a Hybrid micro grid. This paper uses a droop method which has been modifies to work efficiently for a Hybrid Micro grids which requires a bi-directional flow of power through it. Control of Power is handled by the main converter during different operating modes of the hybrid micro grid.**

***Keywords*—hybrid microgrid, control strategies, ac/dc converter.**

I. INTRODUCTION

Wind energy is one of the most reliable renewable energy source. It is clean yet the problem with wind power is that it is intermittent. Wind power is intermittent because winds are uncontrollable and unpredictable. Wind energy is expensive to produce. Producing electricity using a wind source is costlier in relation to the conventional sources such as thermal energy. Harnessing the wind is one of the most sustainable ways to generate electricity. Wind power does not generate any toxic emissions and it does not generate any of the green house gases that are responsible for global warming. Large wind turbines, most often used by utilities to provide power to a grid, range from 250 kilowatts up to the enormous 3.5 to 5 MW machines that are being used offshore.

To take advantage of spots where wind flows the strongest, wind turbines are placed in rows. Turbines ranging from a few to a few hundreds together form, wind farms. These wind farms provide enough power for tens of thousands of homes. Power generated by wind sources needs to be increased, as they contribute to a more reliable energy system. With continual adjustment of output power provided by the modern day wind turbines, grid operates can now stabilize the grid more effectively in the face of unexpected operating conditions like a natural calamity etc.

The biggest challenge is to integrate wind energy into the electrical grid. Although, that is an uphill task, it is easier to integrate wind energy in micro grids. Wind energy sources can be a great addition to micro grids network and hence the technology used alongside the micro grids such as control strategies etc need to be designed to be efficient.

Seeing how wind resources are so invaluable a Hybrid micro grids with wind energy source has been designed in this paper. Wind energy resources are used in conjunction with a hybrid ac/dc micro grids which works with the help of multiple distributed energy resources(DERs). Micro grids are slowly leading the charge in the conversion to a better network of electrical connectivity and are a part of the more efficient future of the world. Micro grids can supply a power of anywhere between 100kW and a small fraction of a Megawatt. This calls for a small network of grid connections which are sometimes required to be independent of the main supply. With the control schemes that are already present we can affectively control a standalone micro grids but we need a different strategy of control scheme for the Hybrid Micro grid.

The main converter is controlled using a droop control method which is modified to fit the functioning of a hybrid micro grid, which requires a bidirectional flow of power. To demonstrate power sharing technique, the droop characteristics of individual ac micro grids and dc micro grids are marked to common axes. The per unit values on both sides, i.e. , the ac and dc sides are to be maintained the same. This way the load demand can be shared amongst the two micro grids, but we have to note that, continuous operation of the main converter is important for such operation. This results in power loss in the main converter. With so many distributed generators working in the hybrid micro grid, it is inherent that the conversions from ac to dc and dc to ac are reduced considerably, thus enhancing the efficiency of the power system. With the efficiency taken care of, it is only a matter of maintaining the grid frequency and voltage in the case of ac micro grids and maintaining the grid voltage in the case of the dc micro grid. Both types of distributed generations make the proposed micro grid, a compelling force in the domain of renewable energy.

II. SYSTEM MODES AND POWER FLOW

System operations and controls are simulated in a simple hybrid micro grid. To simulate the dc sources, boost converters used. The hybrid micro grids system consists of ac micro grids which has ac sources, ac storage devices, ac load and similarly on the dc side. The ac and dc side are connected to each other through the main converter which is the universal bridge. which can work in both directions. Dc bus and ac bus are used in which, the dc loads are connected to dc bus and ac loads are connected to ac bus respectively. The ac network of hybrid micro grids system is connected to the main utility grid. The hybrid micro grids can function in two different modes islanded mode and grid connected mode.

A.Grid Connected Mode

In the grid connected mode, the converter in between the ac and dc micro grids, also known as the interlinking converter, is able to take care of less tasks. Of the functions that are most important for a converter, it is to maintain stable bus voltage and frequency of the ac micro grids and stable voltage of the dc micro grid, other than enabling the flow of power in either directions inside the micro grid. The converter does not have to enable the power sharing between the two micro grids as the main grid or the utility grid acts as slack bus and enables the stable maintenance of the bus voltage and frequency in the ac micro grid. It can take care of the load power demands of the ac and dc micro grids as well. This is because the main grid is connected to the ac micro grids and also compensates for the lack of power capacity in the dc micro grid. The converter's only work is to make sure the dc bus voltage is maintained stable and that the dc load demand is met according to the changing demand in load

$$\text{dc microgrid}: P_{IC}^{*} = \sum_i P_{dc,i}^{load} + P_{dc}^{loss} - \sum_i P_{dc,i} \quad (1)$$

However when the power demand of dc loads is less than the dc power output, the main converter is required to send the excess power to the main grid, where the power can be effectively utilized. Stability during grid connected mode, affects the quality of power supplied by the micro grid. If the bus voltages on either side and frequency are not stable, quality power may not be up to the mark.

$$\text{ac microgrid}: P_{grid}^{*} = \sum_i P_{ac,i}^{load} + P_{ac}^{loss} + P_{IC}^{*} \quad (2)$$

Maximum Power point mode can be used by the renewable energy sources in this mode. Non-renewable sources can be managed and energy storages can charge, DGs can generate a specified reactive power in the ac micro grid for peak shaving purposes or loss reduction..

B.Islanded Mode

In the standalone mode, the main grid is cut off from the micro grid. This inherently implies that the micro grids needs to sustain itself by maintaining smooth sharing of power and maintaining stable bus voltages on either side and maintaining stable frequency of the ac bus. The control strategy that we employ here have to be swift and fluid, switching back and forth from the role of supplier at one moment to the state of load at another moment. In case, the load demand is more than the total generating capacity of the micro grid, the converter should be able to quickly deploy a load shedding strategy which can stabilize the micro grids and avoid it from disintegrating. In this paper, a regionalized control is employed as opposed to a centralized control strategy to avoid high cost of setting up the hybrid micro grid. In designing a control strategy it is paramount to define a few keystone operating states which can enable efficient functioning of the control strategy, in addition it also makes the converter an intelligent system which can act swiftly in the face of changing load conditions in the standalone state :

Islanding state I: In this state, the total load demand in the ac micro grids and dc micro grids is less than the total generating capability of the micro grid. The main converter does not transfer any active power during this state. This is referred to as the light load condition. The power equations in this case, can be summarized as given below :

$$P_{IC}^{*} = P_{grid}^{*} = 0$$
$$\text{dc microgrid}: \sum_i P_{dc,i}^{load} \le \sum_i P_{dc,i} \quad (3)$$

Islanding state II: In this state, there is a deficiency of power in one micro grids while there is an excess of power in the other. For this case, the load on the ac micro grids is a lot higher than its generating capacity. On the other hand dc micro grids has excess power because of light load, so the main converter transfers this excess power to the ac side. So, to summarize :

$$\text{dc microgrid}: \sum_i P_{dc,i}^{load} < \sum_i P_{dc,i} \quad (4)$$

$$\text{ac microgrid}: \sum_i P^{load}_{ac,i} > \sum_i P_{ac,i}$$
$$P^*_{grid} = 0, P^*_{IC} = \sum_i P_{ac,i} - \sum_i P^{load}_{ac,i} - P^{loss}_{ac}. \quad (5)$$

Islanding state III: In this state, the vice versa of state II happens, i.e. the ac micro grids which was overloaded is now lightly loaded and the dc micro grids is not in overload condition. So, the excess power in ac micro grids is transferred to the dc micro grids by the main converter. The main converter helps realize the most important abilities of the hybrid micro grids through its actions in states II and III. The equations in this state are :

$$\text{dc microgrid}: \sum_i P^{load}_{dc,i} > \sum_i P_{dc,i}$$
$$\text{ac microgrid}: \sum_i P^{load}_{ac,i} < \sum_i P_{ac,i}$$
$$P^*_{grid} = 0, P^*_{IC} = \sum_i P_{dc,i} - \sum_i P^{load}_{dc,i} - P^{loss}_{dc}. \quad (6)$$

Islanding state IV: In this state, both the ac micro grids and the dc micro grids are overloaded and hence, the load demand in both is greater than the total generating capability of the hybrid micro grid. The IC promptly stops the transfer of power between either sides, a load shedding strategy is quickly put in place. This state can be summarized as:

$$P^*_{IC} = P^*_{grid} = 0$$
$$\text{dc microgrid}: \sum_i P^{load}_{dc,i} \geq \sum_i P_{dc,i}$$
$$\text{ac microgrid}: \sum_i P^{load}_{ac,i} \geq \sum_i P_{ac,i}. \quad (7)$$

III. CONTROL STRATEGY

A. *Control of DGs in AC operation*

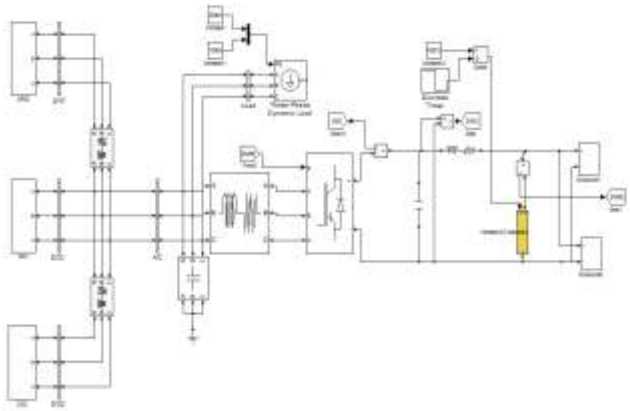


Fig.1: Simulink model of Hybrid Microgrid

Frequency-droop ω-P characteristic has a huge say in real power generation of a DG. The frequency of the micro-grid changes by means of demanded power variations since there is no dominant source to impose the base frequency in the islanded micro grid. Increasing the active power generation of DGs when the system frequency decreases is the primary idea of this control. The reactive power demand can be managed by the voltage droop. Fluctuations in bus voltage and power generation can be monitored and corresponding values of frequency and voltage can be calculated from the droop characteristics. The frequency and voltage can affect the real power generation in the generating stations in this way. This can be mathematically represented as:

$$P^{ref} = -\frac{1}{k_{ac}}(\omega^0 - \omega) + P^0$$
$$Q^{ref} = -\frac{1}{k_q}(V^0 - V) + Q^0$$
$$k_{p,ac} = -\frac{\omega^{max} - \omega^{min}}{P^{max}}$$
$$k_{q,ac} = -\frac{V^{max} - V^{min}}{Q^{max}}. \quad (8)$$

B. *Control of DGs in DC operation*

The droop control method used for real power sharing for a dc micro grids need not be too different from that of an ac micro grid, the droop characteristics of a dc micro grids can be stated as :

$$P^{ref}_{dc} = -\frac{1}{k_{dc}}(V^0_{dc} - V_{dc}) + P^0_{dc}$$
$$k_{p,dc} = -\frac{V^{max}_{dc} - V^{min}_{dc}}{P^{max}_{dc}}. \quad (9)$$

IV. IC CONTROL PROPOSED FOR ISLANDING OPERATION

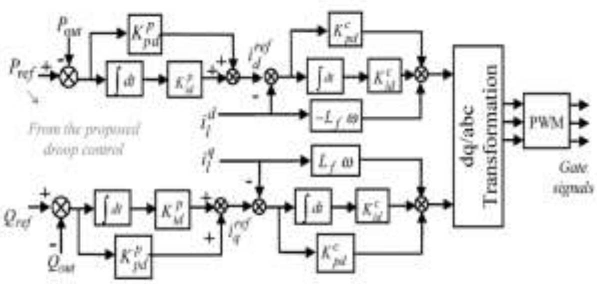


Fig.3: Control block of IC

The power control strategies defined for standalone dc and ac micro grids are of use when the main grid is connected to the hybrid micro grid, when the main grid is disconnected and these control strategies are of no use. A new control strategy needs to be designed for the operation during the islanded mode of operation as the controller needs to enable the working in such a way that, the main converter acts a supplier to one micro grids while simultaneously acting as the load to another. This implies the need for a bidirectional power flow inside the hybrid micro grids which is the most important feature of a hybrid micro grid. The IC is expected to manage a flow of power in two directions between the ac and dc micro grids, n contrast to the standalone ac or dc micro grids. To quash fast communication link, and since we are using droop control method for power transfer for standalone micro grids, which work efficiently. It makes sense, to propose a droop control strategy which is modified and specialized for use in the Hybrid micro grids.

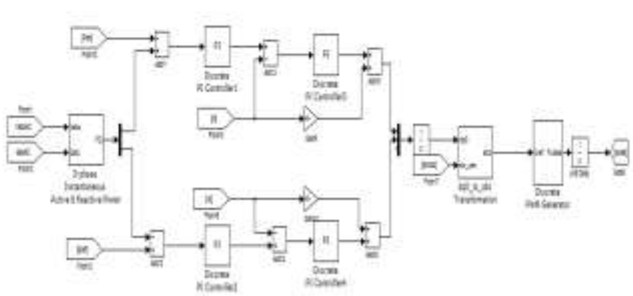


Fig.4 Simulink model of Interlinking Converter

The operating states which might occur during the island state of the hybrid micro grid, are an anchor to design the new control strategy for a hybrid micro grid. The regionalized control strategy is used for this control strategy which is the most efficient strategy in every way. The converter transfers the required power from one micro grids to another while, the power control strategy decides the amount of power it needs to transfer from one micro grids to another. The power reference, which is the command for the amount of power to be transferred is determined by taking two parameters as input, those are, the dc bus voltage and the frequency of the ac micro grid. For these calculations can be carried out as,

$$W_{dc} = \frac{1}{2} C_{dc} V_{dc}^2. \quad (10)$$

The switching losses , can be neglected, in the converter and also, the difference in active power transfer between ac and dc micro grids is equivalent to the dynamics in the dc capacitor energy. Therefore

$$\frac{d}{dt} W_{dc} = \frac{1}{2} C_{dc} \frac{d}{dt}(V_{dc}^2) = P_{dc} - P_{ac} = \Delta P. \quad (11)$$

As discussed earlier, the operating state wherein the dc and ac micro grids both are light loaded, in that case, the main converter needs to shut off and not transfer any power between the micro grids. The distributed generations in each of the ac and dc micro grids can suffice the load demand and hence can regulate the demanded power effectively. This can be done using the droop characteristics that can be applied for standalone dc and ac micro grid. This state and the overloaded state in which both the micro grids are overloaded, are the shut off zone in the new ac dc droop wherein the converter is shut off. The main converter is used not just for the control of ac side frequency or the dc voltage control, it is also important for the converter to enable power sharing between the two micro grids. The output of the modified droop is fed to the droop of the individual micro grids. The sign convention used here is, positive sign for power flow from dc to ac and negative sign for vice-versa. The reference voltage and the real power to be transferred is to be determined by the droops mentioned above.. The impact of the proposed droop control for the IC on the power sharing of sources in each micro grids is illustrated within two load increase scenarios in each micro grid,

An overloaded dc micro grids is assumed in the first case, wherein , the due to the increase of load in the dc microgrid, the dc bus voltage drops or decreases correspondingly. The main converter comes into the picture once the drop in voltage is beyond the shut off region in the ac dc droop characteristics. This voltage drop is inserted in the ac dc droop equation, which gives us the new reference frequency using which we can find the required power that needs to be transferred from the ac side to the dc side. That is, the main converter acts as a source for the dc micro grids while at the same time acting as a load for the ac microgrid. Thus the power generation of the ac micro grids is compensated for, by the proposed control strategy.

$$\Delta P = k_\omega \Delta\omega, k_\omega = \left(\frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}\right) + D \quad (12)$$

V. CASE STUDIES AND RESULTS

The performance of the new droop control for a hybrid micro grids needs to verified. This can be done by designing a stimulant model and simulating the conditions of the power control. For this paper, we considered one renewable source and one non renewable source in the ac micro grids and two dc sources which can be dispatched at any time. For the proposed operating states, the model is tested and the graphs and results are noted which reinforce the efficiency of the proposed method and efficacy with which the main converter transfers power between the ac and dc micro grids.

This droop control scheme is developed for controlling the main converter using a modified droop which encompasses elements of both the micro grids. A defined per-unit range is chosen as the common standard and the droop characteristics of ac and dc micro grids are marked to common axes to enable the bidirectional power flow.

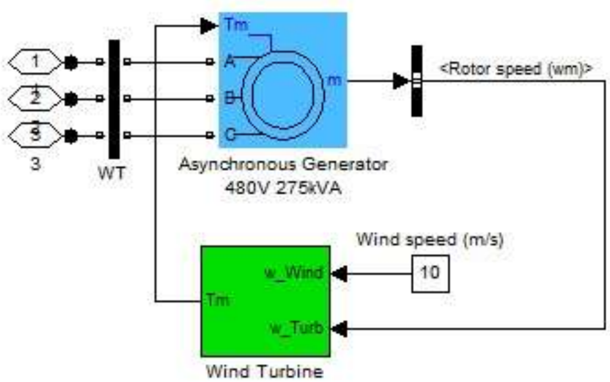
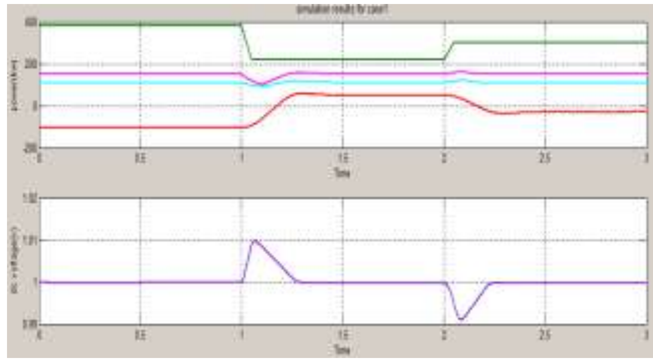


Fig. 5: Wind source with asynchronous generator

By this control, the load demand can be shared amongst the two types of micro grids.

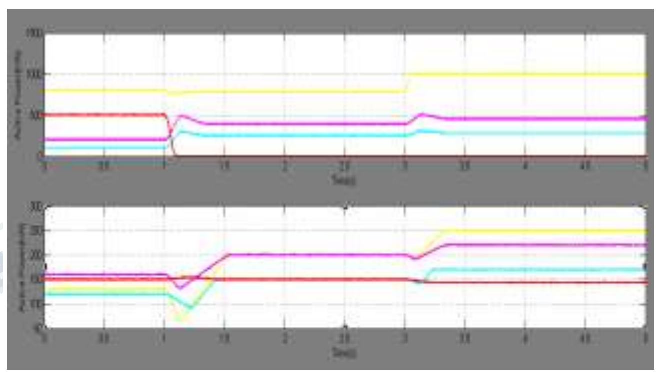
CASE 1: AC light load condition

In this case, the dc micro grid's voltage needs to be maintained and any deficiency in power in the dc micro grids needs to be met for by the main converter. The power transfers from the main grid to the dc micro grids incase the dc micro grids is short of power due to excess load demand. The power transfer through the main converter is positive. This is the summary of the first case of the power control inside a hybrid micro grid.



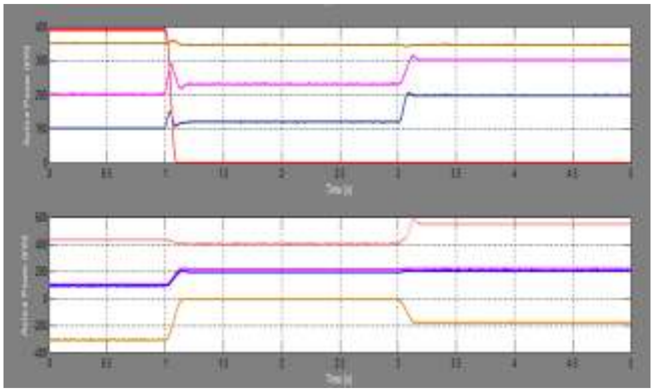
CASE 2: DC light load condition

In this case, the ac sources are generating their maximum capacity and yet the load demand is higher than their maximum rated capacity. So, the main converter is required to transfer the excess power from the dc micro grids to the ac micro grid. It can be seen from the graphs that the control strategy proposed, handles this state efficiently. There is a smooth sharing of power between the two micro grids. This show the efficiency of the proposed grid governing strategy. It can also be seen that the loads are compensated for effectively from the graphs of the state. Hence this is reliable.



CASE 3: Transition mode

In this case, the ac sources are generating their maximum capacity and yet the load demand is higher than their maximum rated capacity. So, the main converter is required to transfer the excess power from the dc micro grids to the ac micro grid. It can be seen from the graphs that the control strategy proposed, handles this state efficiently. This case reinforces the fact that this strategy is a reliable strategy which can be put to good use. There is a smooth sharing of power.



VI. CONCLUSION

This paper can summarised as a control strategy that is proposed for a hybrid micro grids which uses a wind energy source, this paper verifies its theory with a simulink model that is tested for various loads. This in itself is an architecture for fluid power flow between the ac and dc micro grids in a hybrid micro grid. The islanded operation is the most problematic operating state in the ac dc hybrid micro grids and hence it is important to design a control strategy that can deal with the various stability and efficiency issues during this state. By perfecting this system, the conversion stages in a normal power grid network can be drastically decreased to retain costs of electrical infrastructure. Hence, all the operating states are simulated using simulink and different operating states are shown.

VII. APPENDIX

DC SOURCES PARAMETERS.

	dc source 1	dc source 2
Rating (nominal)	300 (kW)	250 (kW)
R_{dc}	0.0013 (A/V)	0.0011 (A/V)

IC PARAMETERS.

	dc source 1
Rating (nominal)	300 (kVA)
DC voltage	1500 (V)
DC capacitance	5000 (μF)
Filter capacitance	2500 (μF)
Filter inductance	100 (μH)
K_{dc}	2 (kW/V)
K_{ac}	11.9 (kW/(rad/s))
K_{ω}	11.45 (kW/(rad/s))

AC SOURCES PARAMETERS.

	ac source 1	ac source 2
Rating (nominal)	300 (kVA)	500 (kVA)
R_{droop}	0.05 ((rad/s)/kW)	0.083 ((rad/s)/kW)
T_G	0.02 s	0.02 s
T_{trb}	0.01 s	0.007 s
k_{fd}	0.07	0.07
T_{fd}	0.08 s	0.08 s
H (generator and turbine)	0.7 s	0.6 s
r_s	0.007 (pu)	0.008 (pu)
x_{ls}	0.19 (pu)	0.18 (pu)
X_d	1.7 (pu)	1.7 (pu)
X_q	1.65 (pu)	1.65 (pu)
r'_{lkq1}	0.001 (pu)	0.001 (pu)
r'_{fd}	0.0011 (pu)	0.0011 (pu)
X'_{lkq1}	0.81 (pu)	0.81 (pu)
X'_{lfd}	0.12 (pu)	0.12 (pu)
r'_{lkq2}	0.009 (pu)	0.009 (pu)
r'_{lkd}	0.014 (pu)	0.014 (pu)
X'_{lkq2}	0.089 (pu)	0.089 (pu)
X'_{lkd}	0.081 (pu)	0.081 (pu)

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