A Novel Method for Connecting the PV unit to Hybrid Microgrid Systems Based on Smart Controlling Structure

Reza Rahmani
Qazvin Science and Research, Islamic Azad University
Qazvin, Iran
Email: r.rahmani1985@gmail.com

Ahmad Fakharian
Faculty of Electrical, Biomedical and Mechatronic Engineering, Qazvin Branch, Islamic Azad University
Qazvin, Iran
Email: ahmad.fakharian@qiau.ac.ir

Abstract—Hybrid microgrid is a practical network structure for new AC, DC or AC/DC power system topologies with various sources and loads. Operating the hybrid microgrid creates the smart controllability of all power sources based on the load demand in island mode especially. This paper proposes a hybrid AC microgrid structure which is designed for automatic interconnection between different sources in island mode. This paper control strategy is planned with considering to the configuration of two implemented power sources. The main DG source supplies the all local load demand with using its droop control characteristic. In critical conditions, a PV (photovoltaic) source with battery energy storage is quickly linked to the DG source to ensure the hybrid microgrid performance. A novel control scheme is introduced to truly damp the system frequency and voltage disturbances and connect mirogrid sources to each other with high reliability and without any network failures in power sharing moments. The truth behavior of proposed control approach is verified throughout the simulation results.

Index Terms— Droop control, hybrid microgrid control system (HMCS), PV unit.

I. INTRODUCTION

Hybrid microgrid is among the most considerable endeavors of modern power networks. The hybrid microgrid concept could be used in passive and active power system in connected and island modes. Presently, hybrid microgrid is utilized in LV (low voltage)/ distribution level and in this way the power generation is supplied by various types of micro-sources and renewable DGs (distributed generations).

In the real power system, all generators are linked together to guaranty the stability and power quality. The most important weakness of such networks is the low reliability in situations that if the network involves the disturbances [9]. Hybrid microgrid provides the acceptable reliability for power network and the required power quality for different loads. But the defect of this kind of network is the complexity of frequency and voltage control because of the absence of main power grid in island mode and different working modes. Therefore, the hybrid microgrid frequency and voltage control almost is the controversial subject in most papers.

These challenges bring about the new researches concentrate on problems that happened in island modes. Hybrid microgrid is introduced to facilitate the connection of AC and DC sources and manage the proper power sharing and operation of hybrid microgrid [1]. The main objective of hybrid microgrid is to ensure uninterrupted and quality power based on the local load demand in island mode [2]. Recently, many schemes are implemented for controllers and power sharing management systems in hybrid networks. A rule-based power management system for an isolated hybrid AC/DC microgrid is developed in [3]. Also, a multi-proportional resonant (multi-PR) controller is used for voltage regulation in the presence of unbalanced and nonlinear loads [4]. In [8], a control scheme is introduced for power sharing management system in a three-port hybrid microgrid to automatically satisfy the load demand in autonomous modes. As the control of DC values is more reliable and comfortable, a DC bus voltage controlling approach with using a nonlinear disturbance observer (NDO) is proposed in [11]. In our previous research [18], two case studies are suggested in the field of micrpark grogrid control system to evaluate such control schemes. Based on the truth behavior of this type of controllers, this paper proposes a new version of frequency and voltage controllers of mentioned methods in hybrid systems.

This paper studies a sample hybrid microgrid system based on the combination of an AC DG and PV sources in island mode. The aim of this research is to provide a practical scheme for hybrid microgrid controller which covers all system operating modes. Two frequency and bus voltage controllers with a main droop controller as a unit control pack could guaranty the secure and qualified power sharing between sources. The transient modes and disturbances are simulated by suddenly exchanging between six fixed loads.

This paper is organized as follows. Section II involves the hybrid microgrid challenges in island mode. The routine power system circuit equations are represented for easier microgrid system analysis. In Section III, the main structure of HGCS is discussed for load requirements in island mode. Section IV introduces a new control method based on a transient mode PI controller. Section V shows the results of implementation of this effective method for system frequency and voltage control in this paper. In Section VI, a synopsis argument is on the HMCS methods and uncertainties because of the various working modes.

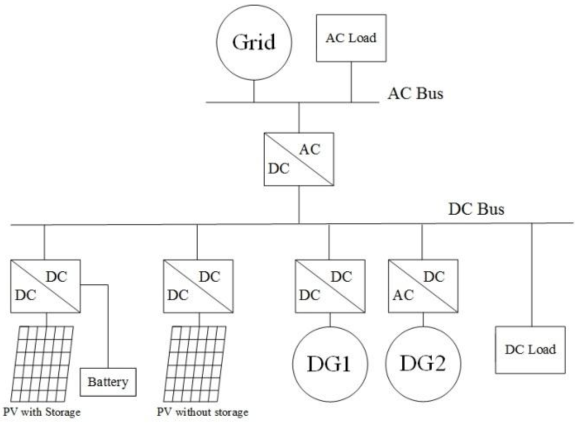

Fig. 1. Typical model of hybrid microgrid network

II. PROBLEM STATEMENT

The purpose of this paper is to model a sample hybrid microgrid network with high reliable operation an all modes. The critical problem is these kind systems is the complex control of system frequency and voltage deviations in island mode. Another difficulty is the hard conflict between different sources which supply the load demand in hybrid systems. Also, the performance of each source does not be separated to close study on the source behavior and as a result for smarter controlling on the power sharing.

The vital issue in microgrid systems is controller and the rate of its safety and security. Some researches like [10] focus on the system frequency and voltage controllers. The control approach is based on the PI controllers but it is not detailed and explained how to operate these parts of control scheme. Also, the main defect of this paper method is that no PI control block diagram is represented to have an imagination of PI controller structures.

Although many theoretical methods are introduced to control the performance of hybrid microgrid systems, which idea is efficient to practically ensure the power system requirements such as reliability and security. For this end, all parts of studied system must be controllable separately and in addition, how they work. In [1] and [10], the task of hybrid system sources is not determined. The efficiency of hybrid microgrid network is a result of an unknown combination of several control parts and sources without specifying the amount of each segment effect on overall operation. This paper accurately analyses the portion of two PV and DG sources for supplying the load demand.

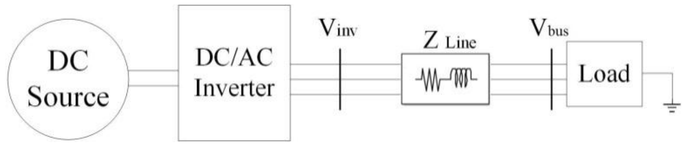

Fig. 2. Schematic diagram of studied hybrid microgrid system

III. MATHEMATICAL FORMULATION

The purpose of this paper is to coordinate the hybrid system sources and damp the deviations in the frequency and voltage from nominal values. Some researches like [17] use the $d-q$ technique that has high capability for controlling the system outputs but on the other hand; this method requires long time stability and the complexity of control. Some new papers apply three phase circuit equations as a simple control technique [10]. This method is confined by a number of constant values and gains and by the way, the flexibility of controller is removed.

Fig. 1 shows a main power grid with the branches of local networks as hybrid microgrids. The detailed structure of sampled hybrid microgrid is given in this figure for precise analysis of inner operation of hybrid system. Here, the total hybrid microgrid is simplified with a DG and PV unit (PV with battery energy storage); Normally, the microgrid is parallel with the main grid and the system frequency and voltages are guaranteed by the main grid. When a fault occurs in the main grid, the microgrid can disconnect in order to locally support it's local loads. In this case, the major control problems are appeared.

Fig. 2 shows a single line diagram of a distributed generator with a PWM inverter source. The power circuit equations of **Error! Reference source not found.** can be described as [1]:

$$P = \sqrt{3} V_{inv} I_{inv} \cos\theta \quad (1)$$

$$Q = \sqrt{3} V_{inv} I_{inv} \sin\theta \quad (2)$$

V_{inv} and I_{inv} are the three-phase sinusoidal waveform. These waves have different harmonics in high frequency that cause the disturbances in produced active and reactive powers of 3-phase power block. For removing these extra fluctuations, two low pass filters are embedded in the entrance of droop controller.

$$P_r = \frac{\omega}{S^2 + \omega} P \quad (3)$$

$$Q_r = \frac{\omega}{S^2 + \omega} Q \quad (4)$$

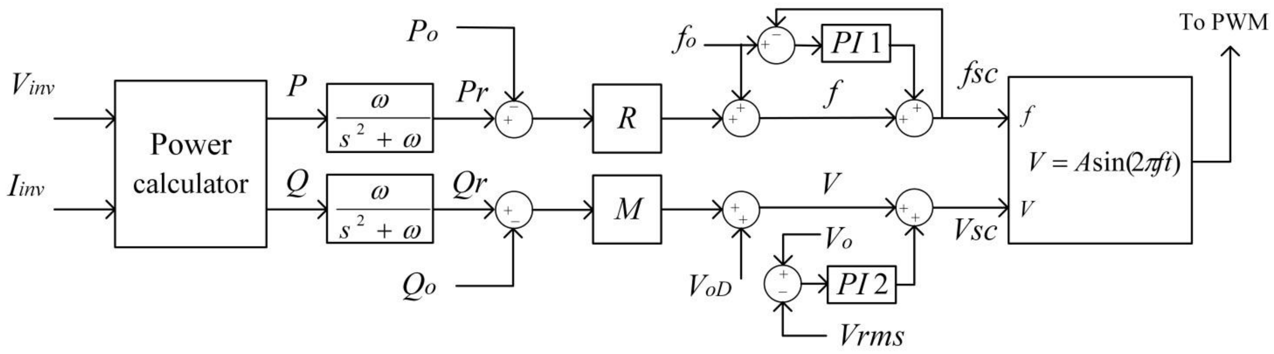

Fig. 3. Control block diagram of new control approach for HMCS

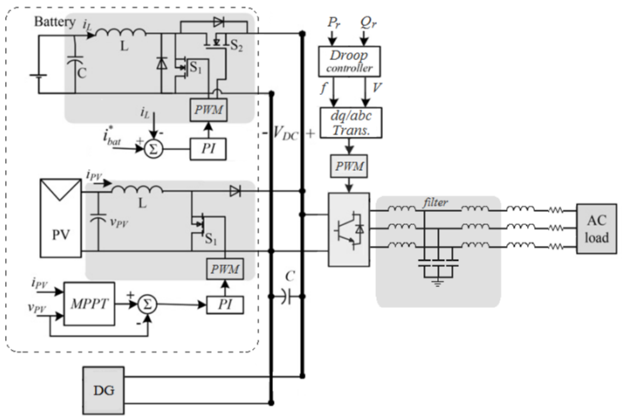

Fig. 4. Interconnection structure of hybrid microgrid system

The droop control method is implemented for generating the demanded active and reactive power by load. Droop control equations provide P/f and Q/V relations as:

$$(P_r - P_O)R + f_O = f \tag{5}$$

$$(Q_r - Q_O)M + V_{OD} = V \tag{6}$$

P_O, Q_O, f_O and V_{OD} are the nominal values of active and reactive powers, system frequency and DC bus voltage respectively. R and M are the slopes of droop characteristics. The reason of usage of V_{OD} is that PWM works with the DC bus (sources bus) scale.

IV. NEW CONTROL METHOD

In the previous studies [10-17], the control system does not make the stable voltage. In fact, the consumer voltage follows all system changes as ramp. However, the power system end-user requires to a fixed profile voltage with high reliability. Therefore for establishing such condition, this paper proposed a novel control scheme includes HMCS with PI controllers.

In Fig. 3 this control scheme is exhibited in a block diagram form. As shown, HMCS has a cascade structure and it is comprise of a droop with two PI controllers. The droop control output frequency and voltage are not desirable triggering signals for supporting all states which occurs in island mode. Therefore, a new control approach with using the PI control methodology is put into the paths of resultant f and V of droop controller. The novelty of suggested PI controllers is the procedure of feedbacks and generation the appropriate signals for PWM. The equations of PI controllers are represented as:

$$f_{SC} = \int (f_O - f_{SC})\, dt + (f_O - f_{SC}) + f \tag{7}$$

$$V_{SC} = \int (V_O - V_{rms})\, dt + (V_O - V_{rms}) + V \tag{8}$$

f_O and V_O are the nominal values $50\, Hz$ and $220\, V$ repectively. Also, f_{SC} and V_{SC} are the needed control signals for making the PWM sin-wave.

Finally, the system frequency and bus voltage are equal nominal values and HMCS satisfies the load requirements by precise sensing the system output parameters.

Fig. 4 shows the interconnections and topology of studied hybrid system. In this diagram, DC bus is considered for hybrid sources and AC bus is for loads. A PV with storage unit and a DG source are connected to the DC bus to provide the entrance power of inverter. The voltage of DC bus is fixed and required load power is supplied by mentioned sources. The DG has the capability to provide the demanded power $30\ kw$ (DG rated power), when the requested power be more than DG nominal power, PV unit quickly injects its maximum power. In this way, battery storages the surplus PV and DC bus extra powers.

PV is a boost converter which is controlled by MPPT algorithm and battery energy storage is charged and discharged by a buck-boost converter in exchange moments.

Table I. Microgrid system parameters

	Mode I	Mode II	Mode III	Mode IV	Mode V	Mode VI
time	0 – 0.2	0.2 – 0.4	0.4 – 0.6	0.6 – 0.8	0.8 – 1	1 – 1.2
R_{line}	0.05	0.05	0.05	0.05	0.05	0.05
L_{line}	0.0016	0.0016	0.0016	0.0016	0.0016	0.0016
k_{p1}, k_{i1}	1.2, 100	1.2, 100	1.2, 100	1.2, 100	1.2, 100	1.2, 100
k_{p2}, k_{i2}	2.5, 15	2.5, 15	2.5, 15	2.5, 15	2.5, 15	2.5, 15
R	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
M	0.004	0.004	0.004	0.004	0.004	0.004
P_{Load}, Q_{Load}	26, 0.5	36 , 1.8	20 , 0	22 , 1	28 , 1.5	25 , 0

$(P_{rated} = 30\ kw, V_{rated} = 380\ V\ and\ f_{rated} = 50\ Hz)$

V. CASE STUDIES

This paper studies a new control approach for an islanded hybrid microgrid system. The HMCS that was used in previous researches is improved in this paper based on the power system indexes and load requirements.

For surveying the performance of this HMCS, the system frequency and bus voltage deviations are represented in the presence of the PV and without it in all probable conditions. Also, the system parameters and nominal values are shown in Table I. Two PI controllers are added in the control paths of frequency and voltage controllers in proposed control scheme. The reason for using the PI controller is that the mathematical equations do not govern on the microgrid system in the transient states. Therefore, the HMCS by power system equations is unable to control the all system modes. The coefficients of PI are set on definite values with considering to the PV operation. These parameters as k_p and k_i are shown in Table I. The overall performance of control system could be optimum by truly coordinating the more PV and DG units.

In this section, the vital outputs are chosen to depict the precise and flexible operation of suggested controller. The results show that the HMCS has efficient performance for this paper sample framework and probably be useful in more complex and expanded hybrid microgrid system.

Error! Reference source not found. shows the active and reactive powers variations with considering the six states. The total simulation time is in 1.2 second period and for each variation, the powers values are strictly fixed on a given measure.

In first variation between $0 - 0.2$, active power is $26\ kw$ and reactive power is set $0.5\ kw$. For the next variation between $0.2 - 0.4$, load has active power about $36\ kw$ with reactive power $1.8\ kw$. In $0.4 - 0.6$, active power suddenly declines to $20\ kw$ without reactive power. In the next part between $0.6 - 0.8$, the load active power is about $22\ kw$ with reactive $1\ kw$. For the last step between $0.8 - 1$, both active

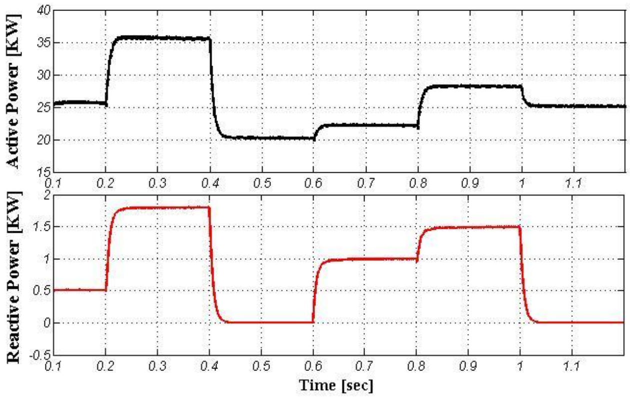

Fig. 5. Inverter output active and reactive powers

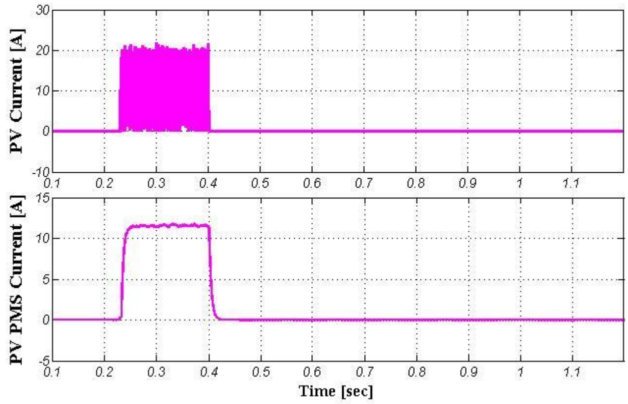

Fig. 6. PV unit operation modes

and reactive powers have a value about $28\ kw$ and $1.5\ kw$ respectively. In final part, load is completely active by $25\ kw$.

With considering to the power changes, the active power is more than rated power $30\ kw$ between $0.2 - 0.4$. Therefore, the PV unit automatically comes into the circuit to compensate the extra demanded active power. Fig. 6 shows the PV circuit curve and the precise performance of controller. As shown, the PV unit just supplies the overloads and other changes which are lower than the DG rated power could be supported by only DG unit.

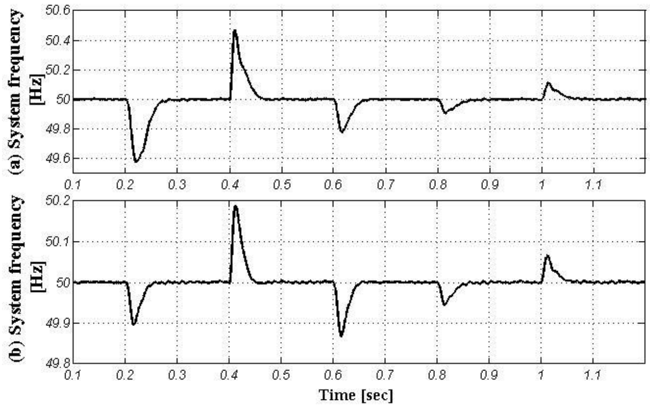

Fig. 7. System frequency fluctuations: (a) in absence and (b) in presence of PV unit

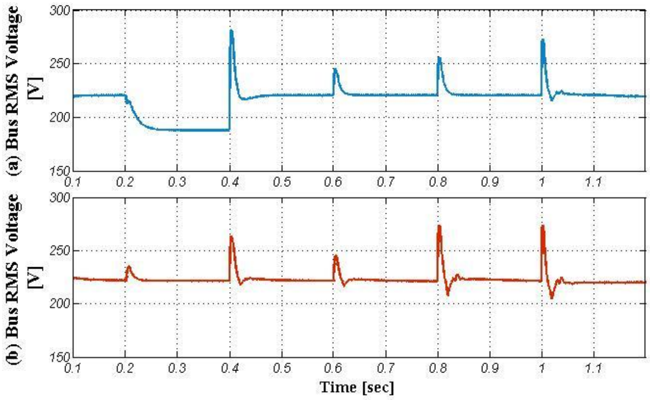

Fig. 8. Bus voltage profile deviations for two case studies

Fig. 7 shows the system frequency deviations without the power grid attendance. After removing transient states in both discussed case studies, the system frequency is strictly preserved within nominal frequency of $50\,Hz$. The fundamental difference is the amount of deviation from nominal value that it is out of power system normal operation range in curve (a).

When starting the simulation, the local load is fixed and control parameters are capable to regulate the system frequency on $50\,Hz$ until 0.2 . Between $0.2-0.4$, the local load suddenly climbs and causes the frequency to fall down. This disturbance is eliminated instantly and the frequency backs to it's nominal value. In $0.4\,s$ and $1\,s$, the load reduces and the frequency again settles to the nominal value.

Fig. 8 shows the bus voltage regulation based on the load changing and sources. This scenario is shown for two hybrid system and proves that the HMCS with PI controllers can be able to firmly stable the hybrid microgrid system in each load variations.

In Fig. 8, the voltage fluctuations truly follow the changes in local load in 0.2 to 0.4 seconds with secondary power of PV and quickly stable on nominal value. However, the critical

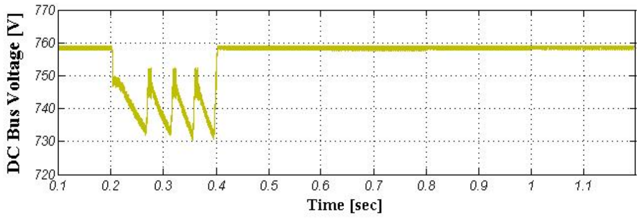

Fig. 9. PV unit performance based on DC bus voltage

overload part could not back to the rated voltage without PV injected power. The over and under shoots in voltage curve can be damped by optimum coefficients for PI controller.

In this study, the PV unit operates with considering to the value of DC bus voltage. Fig. 9 shows the normal voltage of DC bus and also the limitation of voltage drop. When the DC bus voltage declines under reference value $740\,V$, the PV unit controller senses the actual voltage measurement and start to compensate these losses.

In fact, the resultant bus voltage from the proposed HMCS is an indication for hybrid microgrid system stability despite the so many uncertainties in island modes.

VII. CONCLUSION

In this paper, a new control approach is proposed based on the HMCS. The control method is a combination of power system circuit equations with PI controllers. The discussed hybrid system is simulated in island mode in spite of the complexity of control concepts and uncertainties of this mode. In addition, different transient states were considered to verify the security of recommended HMCS. The main DG source could not manage the abnormal conditions which caused by overload. Therefore, a mixture of DG and PV sources can provide the load requirements.

The aim of this paper is the hybrid microgrid system stability in island mode. The results for system frequency and bus voltage confirm the good operation of represented control method in this paper. Moreover, this new control method could be applied in expanded hybrid microgrid systems.

Another important point was the coordination between controllers. The PI control parameters of this paper could stable the system whereas the optimal parameters will absolutely have more accurate response. This point will be one of the future works.

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