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Microgrid Control Strategy

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Abstract: *The energy sector is moving into the era of distributed generation (DG) and microgrids (MGs). The stability and operation aspects of converter-dominated DG MGs, however, are faced by many challenges. To overcome these difficulties, this paper presents a new large-signal-based control topology for DG power converters that is suitable for both grid connected and islanding modes of operation without any need to reconfigure the control system and without islanding detection. To improve MG stability and to guarantee stability and high performance of the MG system during sudden harsh transients such as islanding, grid reconnection, and large load power changes, a nonlinear MG stabilizer is proposed. We propose a novel control topology for microgrids which can work in both grid connected and islanding modes without reconfiguration so it does not require islanding detection technique, the controller is based on the concept of synchronverter In this paper, a radical step is taken to improve the synchronverter as a self-synchronized synchronverter by removing the dedicated synchronization unit.*

Keywords: *Distributed generation(DG),Grid-connected, Microgrid (MG), Point of Common Coupling (PCC), Synchronverter.*

I. INTRODUCTION

The need of reducing CO2 emissions in the electricity generation, electricity markets restructuring and technological development in the micro generation lead to the growing interest in the use of micro generation. Microgrid is a new type of power systems consisting of generation sources, loads and energy storages. In another words, it is an association of a small modular generation system, a low voltage distribution network and load units inter-faced by means of fast acting power electronics. Microgrids are determined usually in accordance with a few definitive functions. They are usually used in small urban areas or in small industry. The most common power range for microgrids is from 25 to 100 kW. But the systems with lower and upper power levels are also widely used. As micro energy sources in microgrids, usually, diesel or gas motor driven gen sets, fuel cells or renewable genera-tion such as wind parks, photovoltaic systems and gas or biofuel driven micro turbines are used.

The generating technologies which are used in microgrids have potentially lower cost and lower emissions in comparison with traditional power sources. This assumption is based on the idea of generating heat and electrical power simultaneously in the units. The smaller size of these generating units allows them to be placed in the best position for cooling, energy distribution and maintaining of the installation. The most appropriate way to realize the rising potential of small scale generation is to tie loads and generating units together. This is accomplished in microgrids by using inverters to interface generating units with the distribution system. Such applications can increase the efficiency of the system remarkably, especially if the thermal power of the system may be utilized for heating buildings.

Microgrids operate in two basic modes. They can operate in off-grid mode. In that case the power is generated and stored without assistance from the main low voltage grid. These microgrids comprise one or more energy sources, batteries and local loads which are fed by these sources. In other case a microgrid is connected to the main grid in normal interconnected mode. This operating manner, usually called grid-connected mode, is the main operation mode. In this mode microgrid operate as a back-up system or as a part of the utility system. The purpose of the back-up microgrid system is to feed local loads when the main grid fails for any reason. This mode is also called the emergency mode. The configuration of a microgrid in the grid-connected mode also requires a power source and a large battery bank. Batteries or super capacitors are used in microgrids for storage the excess of the generated energy and support energy sources when the loads increase. The size and type of the batteries are determined by systems requirements. During the normal operation of the main grid, the purpose of the microgrid is to maintain the battery bank in full charged condition so that it should be always ready for emergency operating. When microgrid operates like a part of the utility system, the microsources of the microgrid feed local loads. If the generated power exceeds the demanded power level inside the microgrid, excess of the energy is supplied to the main grid. In the other way, if microgrid cannot provide full supplying of its local loads the required energy flows from the main grid. Due to the fact that most of the loads require AC power which is opposed to the DC power generated by the sources, the battery inverters intended to invert and control electrical energy flows are required in both operation modes.

The conventional linear controllers and small-signal analysis reported previously only deal with small variations around the operating point or base load; this refers to small-signal stability because it just deals with stability at one specific operating point when small perturbations appear in the system. However, in a MG system with comparable sizes of DG units and due to the absence of physical inertia and due to high penetration level of converter-based DG units, a MG system will be subjected to large transients and power angle swings. Typical large-signal disturbances in a MG system include transition between grid connected and islanding modes, and sudden large load demands. In these situations, linear controllers are not sufficient to guarantee MG stability at different operating conditions; and accordingly, instabilities due to severe transients are expected. On the other hand, non-linear controller with global stability can be designed to guarantee stable and robust operation at different operating conditions. Motivated by the afore-mentioned issues, we propose a novel control topology for microgrids which can work in both grid connected and islanding modes without reconfiguration so it does not require islanding detection technique. The controller involves angle, frequency, and power loops instead of conventional current and voltage loops. The controller is based on the concept of synchronverter which has been recently proposed to emulate the behavior of a synchronous generator (SG) by a virtual rotor.

The synchronverter concept offers some advantages over the conventional converter control strategy as it introduces emulated inertia and controlled frequency dynamics, whereas in the conventional VSC, frequency dynamics is unknown and cannot be controlled directly. Moreover, synchronverters can be easily embedded in a power system or MGs with many conventional SGs since their dynamic performance is similar to SGs. It is evident that synchronverters are one of the most interesting choices for future power systems.

II. SYSTEM OVERVIEW

Due to fast development of renewable energy resources, the concept of distributed generation (DG) is gaining an important role in future smart power grids [1][3]. DG has many advantages such as closeness to customers, increased efficiency and reduced transmission loss, better reliability, and improved energy management [4]. The majority of DG resources are interfaced to grid/loads via power electronic converters. A cluster of DG units connected to the grid via power electronic interfaces form a microgrid (MG). Fig.1 shows a typical MG. MGs form an important portion of future smart grids and therefore, their roles are vital in power system operation. A microgrid system has two states of operation; namely, they are grid-connected and islanding modes. The islanding is a situation in which the MG is dis-connected from the main grid when a fault is occurred in the grid. Because of power reliability and power quality issues, it is necessary that microgrids continue their operation in autonomous mode when grid is not available.

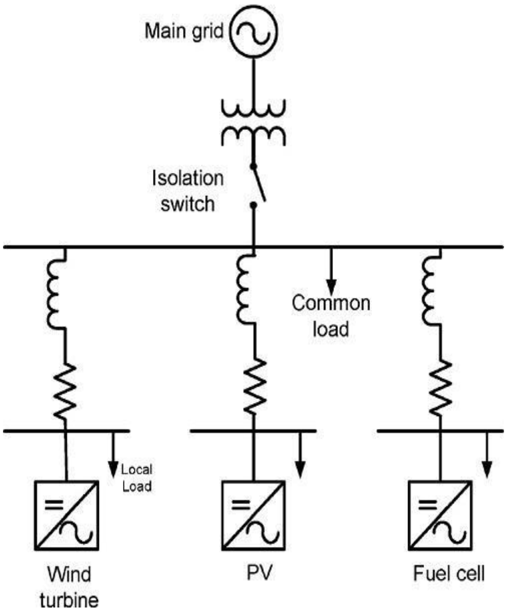

Fig 1: Microgrid Scheme

The existing microgrid control schemes can be divided into droop-based and non-droop based approaches. Controlling DER units based on droop characteristics is the ubiquitous method in the literature. The droop-based approach originates from the principle of power balance of synchronous generators in large interconnected power systems. That is, an imbalance between the input mechanical power of the generator and its output electric real power causes a change in the rotor speed which is translated to a deviation of the frequency. Likewise, output reactive power variation results in deviation of voltage magnitude. The same principle is artificially employed for electronically-interfaced DER units of a microgrid as well. Opposite droop control, i.e., using real power/voltage and reactive power/frequency droop characteristics, has also been applied for low voltage microgrids in view of their low X/R ratios. The main advantage of a droop-based approach is that it obviates the need for communication since the control action is performed merely based on local measurements. This feature gives droop control a significant flexibility in that as long as a balance between generation and demand can be maintained, there is no interdependency between the DER unit local controllers.

2.1 Synchronverter

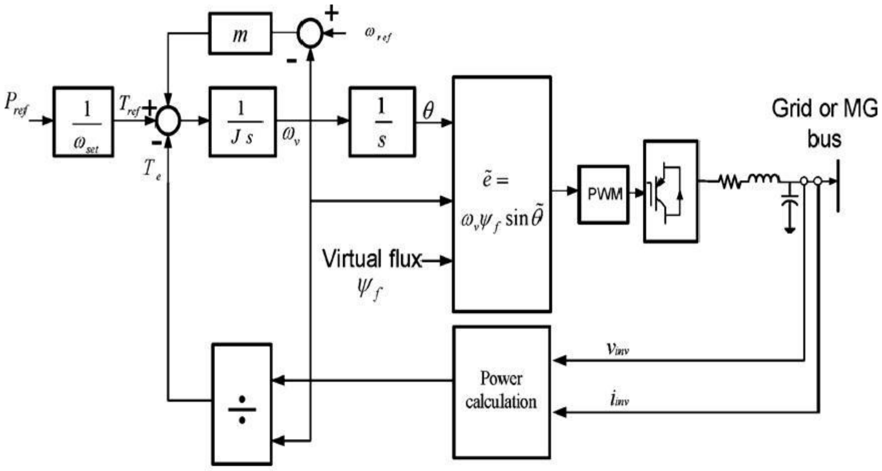

Fig 2: Synchronverter model

Fig. 2 depicts the basic concept of the converter control topology. The basic idea is to mimic back-EMF generation principle and rotor dynamic of a synchronous generator, including its rotor momentum of inertia and friction . The utilization of emulated rotor dynamics improves the converter dynamics and it yields a control structure that is more suitable for MG operation. In this VSC model, the virtual rotor plays the role of controlling the frequency dynamics, which is not accessible in the conventional current/voltage control topology of VSC. The virtual friction is responsible to damp VSC frequency oscillations in grid-connected mode. However, it is proposed to use it as a droop control for power sharing in islanded mode. The voltage generation principle is like back-EMF generation in a typical SG given by,

$$e = \omega_v \varphi_f \sin\theta \qquad (1)$$

where e stands for a balanced three-phase voltage. This equation emulates rotational back-EMF generation in an SG. The frequency dynamics of the VSC is given by,

$$J\frac{d\omega_v}{dt} = T_e - T_{ref} - m\left(\omega_v - \omega_{ref}\right) \qquad (2)$$

which is directly obtained from Fig.2. Similar to every multiphase electrical system, output power is calculated by inner product of three-phase voltages and currents,

$$P_e = \varphi_f \omega_v < i, \sin\theta > \qquad (3)$$

Thus, (3) is simplified to,

$$P_e = \frac{3}{2}\varphi_f \omega_v i \cos(\theta - \varphi) = \frac{3}{2}\varphi_f \omega_v i \cos\delta \qquad (4)$$

The virtual electrical torque is given by,

$$T_e = \frac{P_e}{\omega_v} = \frac{3}{2}\varphi_f \cos\delta\, i \qquad (5)$$

It is worth noticing that unlike electrical machines, there is no real electrical torque and it is just defined for the sake of the control design of a VSC-based DG unit. Similarly, the reactive power equation is obtained as

$$Q_e = \frac{3}{2}\varphi_f \omega_v i \sin\delta \qquad (6)$$

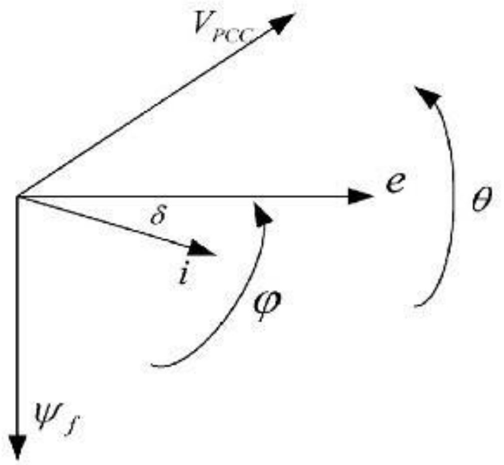

Fig 3:Phasor diagram of system

Fig. 3 exhibits the phasor diagram of a VSC connected to the grid. One of the most attractive features of this VSC topology is the existence of friction coefficient of(m) , which acts like a damper in grid connected mode and is used as a frequency power droop control for power sharing among DG units in islanding. In other words, the term$m(\omega_v - \omega_{ref})$ provides a power sharing tool for DG units. Moreover, the values of and can be selected arbitrarily as a function of design requirements and they can have values which are not feasible in a real SG.The virtual rotor momentum of inertia is obtained by:

$$J = m\tau_f \qquad (7)$$

where $\tau_f$is the time constant of power-frequency droop loop determined by designer according to acceptable frequency dynamics

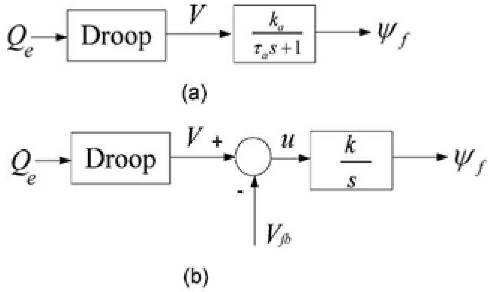

Fig 4 Block diagram of flux control loop

Two different topologies for virtual rotor flux control are proposed as shown in Fig.4, namely they are Model1, which adopts a low-pass filter to generate the virtual rotor flux; and Model2, which adopts a pure integrator. In the first topology, the reference voltage is again generated by a voltage droop function. Processed by the low-pass filter emulating rotor flux decay dynamics of an SG, the rotor ux is obtained. In the latter, the voltage command, which is generated by a reactive power-voltage droop, is compared to the actual voltage and the error is fed into the integrator resulting in the reference rotor ux. It can be noted that in Model2, the low-pass filter behaves like the flux decay equation of a real SG; therefore, in Model 2, the VSC acts as an SG. This helps embedding numerous DG units in a large power system where VSCs and the conventional power plants are seen the same by the power system. The flux decay equation of synchronous generators is due to the fact that applied dc voltage to the rotor excitation appears with a delay in the stator side as a result of rotor winding inductance.T he voltage droop function is as follows:

$$V = V^* - nQ_e \qquad (8)$$

where $V^*$is the no-load voltage and Q_e is DG reactive power. This droop control is used in both modes of operation to share reactive power among DG units. In fact, in ideal case, total reactive power demand is distributed according to static droops constants n .

2.2 Controller

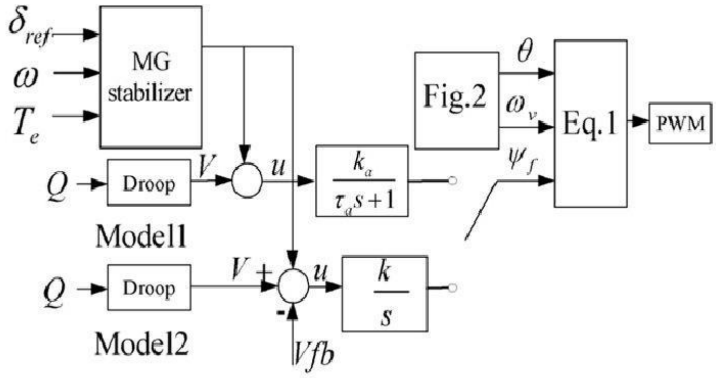

Fig 5 Block diagram of control loop

Fig5 shows the proposed control topology. The controller uses power angle, frequency, and power as control variables instead of conventional cur-rent and voltage control loops. As it is seen, the controller has three control loops, namely angle loop, frequency loop, and torque loop which is afterward called microgrid stabilizer.The first is a power angle tracker in which the controller aims at tracking the desirable power angle by proper frequency and power setting, whereas the latter just tries to damp angle oscillations while there is no defined angle reference.The nonlinear microgrid stabilizer, which can be considered as torque controller, attempts to set torque error equal to zero using a supplementary voltage control. Simply speaking, in contrast to the conventional current-voltage control, the power is directly controlled by varying power angle and voltage amplitude. That is to say that amplitude of current can be controlled by adjusting power angle δ and frequency ω_v via a direct power control strategy.

III. PROPOSED PLAN

3.1 Problem idenfication

The synchronization unit often needs to provide the frequency and the amplitude, in addition to the phase, of the fundamental component of the grid voltage as the references for the power controller. The negative impact of a synchronization unit on control performance is well known. Moreover, because PLLs are inherently nonlinear and so are the inverter controller and the power system, it is extremely difficult and time-consuming to tune the PLL parameters to achieve satisfactory performance. A slow synchronization unit could directly affect control performance and degrade system stability but a complex synchronization unit, on the other hand, is often computationally intensive, which adds significant burden to the controller. Hence, the synchronization needs to be done quickly and accurately in order to maintain synchronism, which makes the design of the controller and the synchronization unit very challenging because the synchronization unit is often not fast enough with acceptable accuracy and it also takes time for the power and voltage controllers to track the references provided by the synchronization unit as well.

3.2 Problem solution

A radical step is taken to improve the synchronverter as a self-synchronized synchronverter by removing the dedicated synchronization unit. It can automatically synchronize itself with the grid before connection and track the grid frequency after connection This leads to much improved performance, simplifed controller, reduced demand for computational power, reduced development cost and effort, and improved software reliability. Moreover, it is able to operate in different modes as the original synchronverter but without the need of a dedicated synchronization unit to provide the grid frequency as the reference frequency.

3.3 Proposed controller

The proposed controller for a self-synchronized synchronverter is shown in Fig.6, after making some necessary changes to the core of the synchronverter controller shown . It is able to be connected to the grid safely and to operate without the need of a dedicated synchronization unit.

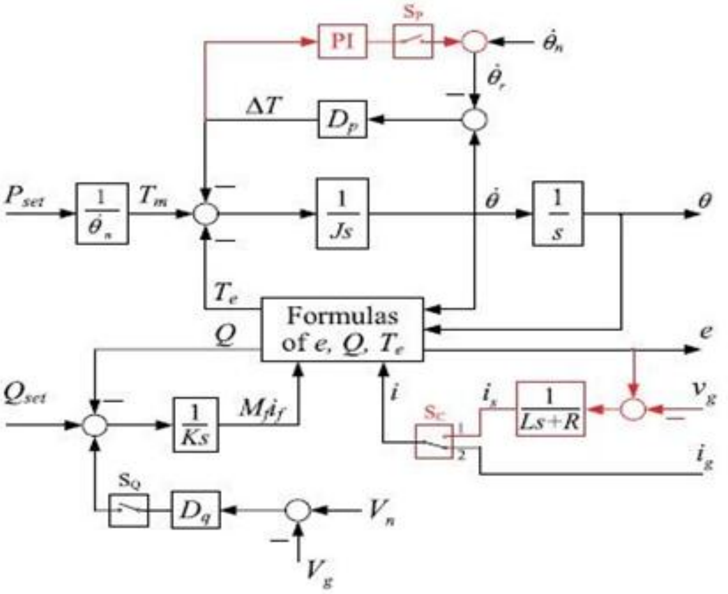

Fig 6 Block diagram of proposed controller of a self- synchronized synchronverter

There are two major changes made: 1) a virtual current is generated from the voltage error between e and V_g is added and the current fed into the controller can be either i_s or the grid current i_g ; 2) a PI controller is added to regulate the output T of the frequency droop block D_p to be zero and to generate the reference frequency θ_r for the original synchronverter. In order to facilitate the operation of the self-synchronized synchronverter, three switches S_C ,S_P ,S_Q and are added to change the operation mode.

3.4 Operation After Being Connected to the Grid

As mentioned before, the power angle delta of a synchronverter can be controlled by the virtual mechanical torque T_m calculated from the power command P_{set} as,

$$T_m = \frac{P_{set}}{\Delta\dot{\theta}} = \frac{P_{set}}{\dot{\theta}_n} \qquad (9)$$

where $\dot{\theta}_n$ is the nominal grid frequency. When S_P is turned ON, ΔT is controlled to be 0 in the steady state via the PI controller. Hence, T_e is the same as T_m and $\dot{\theta}$ is controlled as

$$\dot{\theta} = \dot{\theta}_r = \dot{\theta}_r + \Delta\dot{\theta} \qquad (10)$$

where $\Delta\dot{\theta}$ is the output of the PI controller. The power angle settles down at a constant value that results in P = P_{set} . This operation mode is called the set mode in [8]. In order to differentiate the set mode for real power and reactive power, the set mode for the real power is called the P-mode and the set mode for the reactive power is called the Qmode. If P_{set} = 0, then $\theta = \theta_g$, in addition to $\dot{\theta} = \theta_r$ .When the switch S_p is turned OFF, the PI controller is taken out of the loop and the synchronverter is operated in the frequency droop mode (called the PD -mode , meaning that the real power P is not the same as P_{set} but deviated from P_{set}) with the frequency droop coefficient defined as

$$D_p = \frac{\Delta T}{\Delta\dot{\theta}} \qquad (11)$$

Where

$$\Delta\dot{\theta} = \dot{\theta} - \dot{\theta}_n \qquad (12)$$

is the frequency deviation of the synchronverter from the nominal frequency. It is also the input to the frequency droop block D_p (because S_p is OFF). This recovers the synchronverter frequency as

$$\dot{\theta} = \dot{\theta}_n + \Delta\dot{\theta} \qquad (13)$$

which is the same as (10) but with a different $\Delta\dot{\theta}$. Actually, in both cases, θ converges to the grid frequency θ_g when the power angle δ is less than $\frac{\pi}{2}$ rad, as will be shown below. According to [28], the time constant $\tau_F = \frac{J}{D_p}$ of the frequency loop is much smaller than the time constant $\tau_V = \frac{K}{\theta_n D_q}$ of the voltage loop. Therefore, M_f i_f can be assumed constant when considering the dynamics of the frequency loop. Moreover, according to (5), the real power delivered by the synchronverter (or an SG) is proportional to $\sin\delta$. As a result, the electromagnetic torque T_e is proportional to $\sin\delta$. For $\delta \in \left(-\frac{\pi}{2}, \frac{\pi}{2}\right)$, T_e increases when the power angle increases and T_e decreases when the power angle decreases. If the grid frequency $\dot{\theta_g}$decreases, then the power angle δ and the electromagnetic torque T_e increase. As a result, the input to the and the set mode (P -mode) but not in the droop mode (PD -mode) integrator block $\frac{1}{Js}$ in Fig. 6 decreases and the synchronverter frequency $\dot{\theta}$decreases. The process continues until $\dot{\theta} = \theta_g$. If the grid frequency increases, then a similar process happens until $\dot{\theta} = \theta_g$. Hence, the synchronverter frequency $\dot{\theta}$automatically converges to the grid frequency $\dot{\theta_g}$ (when $\delta \in \left(-\frac{\pi}{2}, \frac{\pi}{2}\right)$and there is no need to have a synchronization unit to provide $\dot{\theta_g}$ for the synchronverter as the reference frequency. The proposed controller preserves the reactive power control channel of the original synchronverter, with the added Switch S_Q to turn ON/OFF the voltage droop function. When S_Q is OFF, $M_f\, i_f$ is generated from the tracking error between Q_{set} and Q by the integrator with the gain $\frac{1}{K}$. Therefore, the generated reactive power Q tracks the set-point Q_{set} without any error in the steady state regardless of the voltage difference between V_n and V_g . This operation mode is the set mode for the reactive power, called the Q-mode .When the Switch S_Q is ON, the voltage droop function is enabled and the voltage error $\Delta V = V_n - V_g$ is taken into account while generating $M_f\, i_f$. Hence, the reactive power Q does not track Q_{set} exactly but with a steady-state error $\Delta Q = Q_{set} - Q$ that is determined by the voltage error ΔV governed by the voltage droop coefficient

$$D_q = -\frac{\Delta Q}{\Delta V} \qquad (14)$$

This operation mode is the voltage droop mode and is called the Q_D - mode, meaning that the reactive power is not the same as Q_{set} but deviated from Q_{set} .

3.4 Synchronization before Connecting to the Grid

Before the synchronverter is connected to the grid, its generated voltage e(strictly speaking, v) must be synchronized with the grid voltage V_g. More-over, the amplitude E is also required to be equal to the amplitude V_g and the phase sequence of e and V_g must be the same as well. For a conventional SG, a synchroscope is often used to measure the phase difference between e and V_g so that the mechanical torque is adjusted accordingly to synchronize the SG with the grid. For grid-connected inverters, PLLs are often adopted to measure the phase of the grid voltage so that the generated voltage is locked with the grid voltage. As mentioned before, the proposed controller shown in Fig. 6 is able to operate the synchronverter under the set mode with Pset = 0 and $Q_{set} = 0$. As a result, the condition (7) can be satisfied when it is connected to the grid. However, the current i_g owing through the grid inductor is 0 until the circuit breaker is turned on, and hence, no regulation process could happen. In order to mimic the process of connecting a physical machine to the grid, a virtual per-phase inductor $L_s + R$ is introduced to connect the synchronverter with the grid and the resulting current,

$$i_s = \frac{1}{L_s + R}\left(e - V_g\right) \qquad (15)$$

can be used to replace i_g for feedback so that T_e and Q can be calculated according to (2) and (4). This allows the synchronverter to operate in the P-mode for the real power with $P_{set} = 0$ and in the Q-mode for the reactive power with $Q_{set} = 0$ so that the generated voltage e is synchronized with the grid voltage V_g . The only difference is that the (virtual) current i_s , instead of the grid current i_g , is routed into the controller via the switch S_C thrown at Position 1. Since the current is is not physical, the inductance L and resistance R of the virtual synchronous reactance X_S can be chosen within a wide range. Small values lead to a large transient current is to speed up the synchronization process before connection. However, too small L and R may cause oscillations in the frequency estimated. Normally, the L and R can be chosen slightly smaller than the corresponding values of Ls and Rs . Moreover, the ratio R L defines the cut-of frequency of the filter $\frac{1}{sL+R}$, which determines the capability of filtering out the harmonics in the voltage V_g . When the virtual current is driven to zero, the synchronverter is synchronized with the grid. Then, the circuit breaker can be turned on at any time to connect the synchronverter to the grid. When the circuit breaker is turned on, the Switch S_C should be turned to Position 2 so that the real current i_g is routed into the controller for normal operation. After the synchronverter is connected to the grid, the switches S_P and S_Q can be turned ON/OFF to achieve any operation mode

IV. SIMULATIONS AND RESULTS

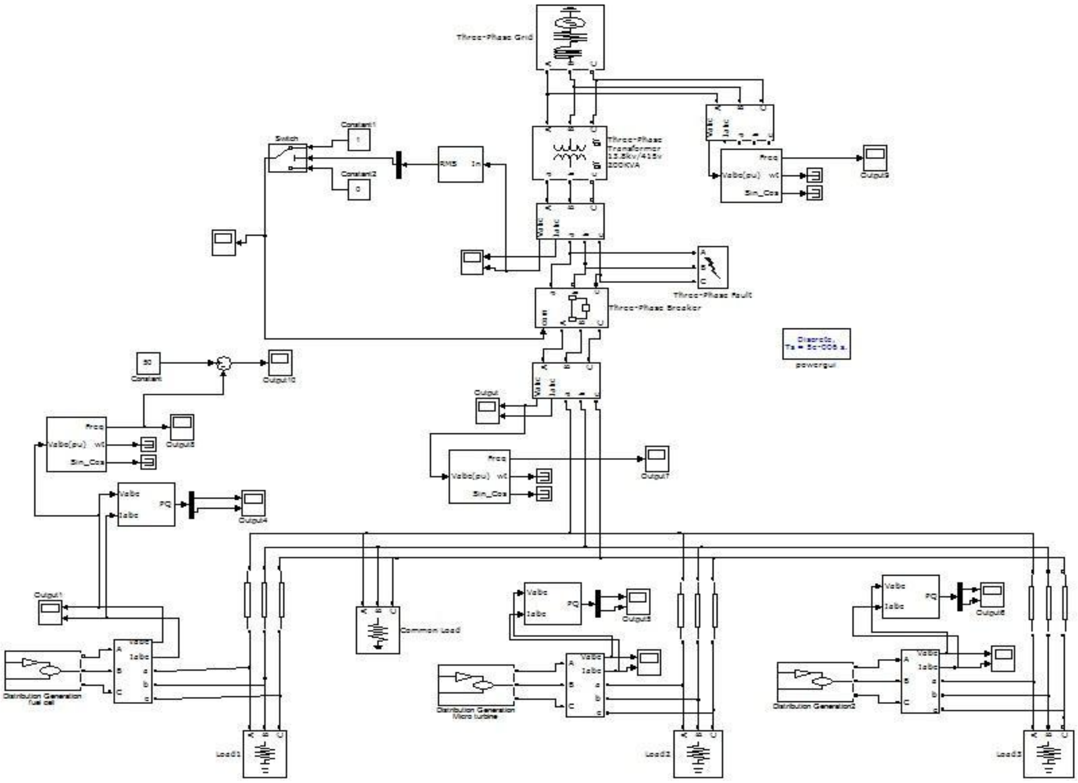

Fig 7 Simulink model of microgrid with 3DGs

The above figure represents the Simulink model of a microgrid consisting of three DGs. Simulations are carried out in MATLAB/SIMULINK environment to study the effectiveness of the proposed control topology. The scenarios involve DG startup and grid synchronization, transition to islanding mode and grid reconnection. Without loss of generality, DG units are considered as dispatchable ones with enough power and inertia-less dc link. The simulated system, depicted in Fig, has three DG units connected in parallel to the main grid through connecting cables and static switch. Each DG unit has a local load and the microgrid supplies one common load connected at PCC.

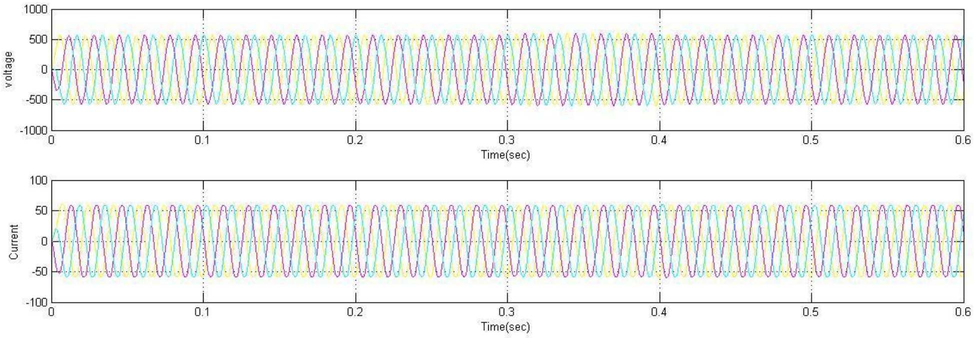

Fig 8 Voltage and current profile

The above figure shows the voltage and current profile of the microgrid system. The grid connected mode will be during the starting of simulation at time 0.3sec the system experiences a voltage sag and the islanding operation will be performed during simulation between 0.3 to 0.4 sec.In the islanding mode the load will be suddenly diconnected in 0.3 to 0.4 sec simulation time

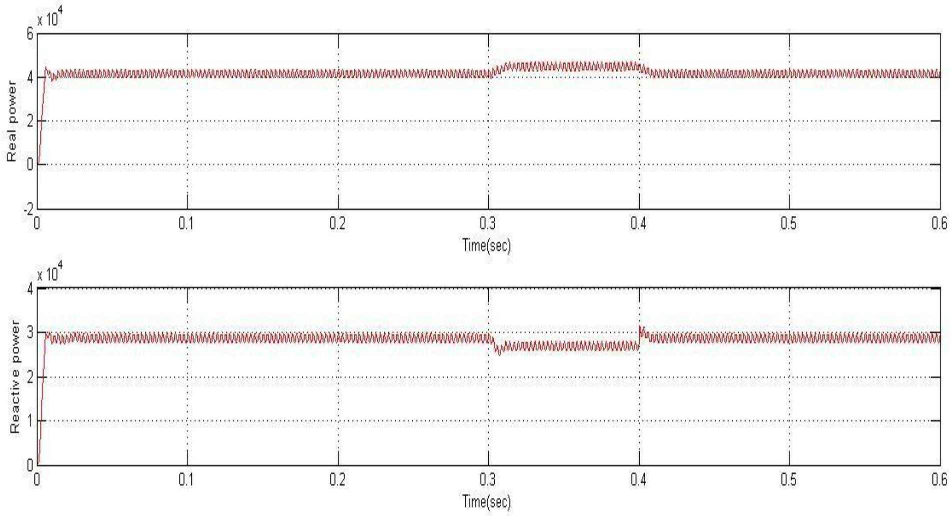

Fig 9 Real and reactive power of DG

The above figure shows the real and reactive power, the real power increases slightly during islanding and after restoration of the grid the power flow is normal . The reactive power decreases during islanding mode.

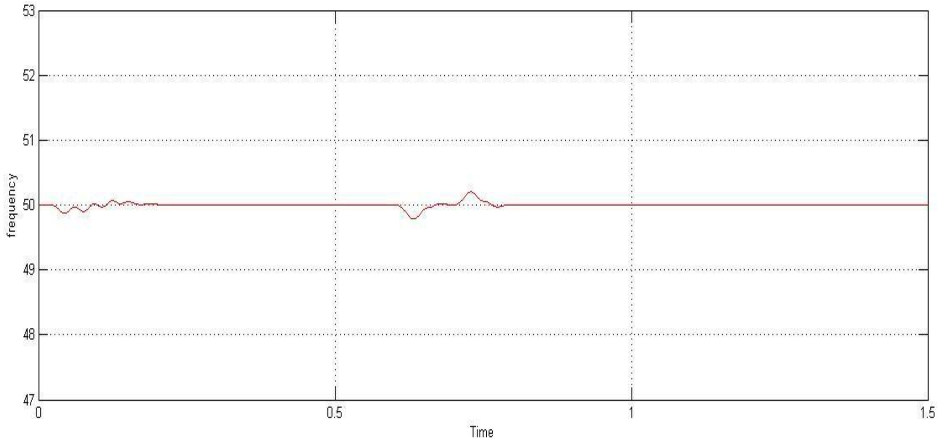

Fig 10 Frequency profile

The frequency response is shown above. The figure shows that even during grid disturbance the frequency profile is maintained and an error difference of 0.25Hz is observed.

V. CONCLUSION

A flexible control method for islanded and grid connected MGs with enhanced stability has been presented in this paper. The control structure does not require reconfiguration upon islanding detection. Further, it involves a nonlinear MG stabilizer that guarantees large-signal stability of the MG system. The nonlinear MG stabilizer adds a supplementary signal to the voltage loop of the VSC so that the augmented system stability is guaranteed. The controller uses only local information where the need for communication is eliminated, and better reliability is yielded. The controller works in the angle, frequency, and power domain instead of the conventional current-voltage controllers. It has been shown that using the proposed control scheme, the system is stable over a wide range of operation with minimum transients. A self-synchronized synchronverter has been implemented, so that there is no need to incorporate a dedicated synchronization unit for synchronization purposes. This leads to much improved performance, simplified controller, reduced demand for computational power, reduced development cost and effort, and improved software reliability. It is able to synchronize itself with the grid before connection and to track the grid frequency automatically after connection. Moreover, it is able to operate in different modes as the original synchronverter but without the need of a dedicated synchronization unit to provide the grid frequency as the reference frequency.

REFERENCES

[1] A. Molderink,"Management and control of domestic smart grid technol-ogy,"IEEE Trans. Smart Grid,vol. 1, no. 2, pp. 109118, Sep.2010.

[2] Seyed Mahdi Ashabani and Yasser Abdel-Rady I. Mohamed, A Flexi-ble Control Strategy for Grid-Connected and Islanded Microgrids With Enhanced Stability Using Nonlinear Microgrid Stabilizer, IEEE TRANS-ACTIONS ON SMART GRID, VOL. 3, NO. 3, SEPTEMBER 2012.

[3] E. Santacana, G. Rackli e, L. Tang, and X. Feng,"Getting smart,IEEE Power Energy Mag., vol. 8, no. 2, pp. 4148, Mar./Apr. 2010.

[4] J. Guerrero et al., Distributed generation,IEEE Ind. Electron. Mag., pp. 5264, Mar. 2010

[5] J. A. P. Lopez, C. L. Moreira, andC.Marnay, De ning control strategies for microgrids islanded operation, IEEE Trans. Power Syst,vol.21, no. 2, pp. 916924, May 2006.

[6] A. A. Salam, A. Mohamed and M. A. Hannan. "TECHNICAL CHAL-LENGES ON MICROGRIDS" ,IEEE Trans. Power syst., December 2008.

[7] Nikkhajoei, H.; Lasseter, R.H.; , "Distributed Generation Interface to the CERTS Microgrid," IEEE Trans. Power Delivery., vol.24, no.3, pp.1598 1608, July 2009 . P. Tenti, H. K. M. Paredes, and P. Matavvelli, Conservative power the-ory, a framework to approach control and accountability issues in smart microgrids,IEEE Trans. Power Electron., vol. 26, no. 3, pp. 664673, Mar. 2011