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Stability Analysis of AC Microgrid taking into account the Load Dynamics

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Abstract:

In the AC micro-grid the different control strategies are for its faithful control such master-slave, droop control etc. The most commonly used is the droop control one as it converts the control of the micro-grid into wireless one. This paper deals with the stability analysis of the ac micro-grid having droop control scheme.. Since the controller setting commonly used as P or PID controller has significant effect on the stability of the micro-grid and large values of these parameters can lead to instability. At the same time the diversity of the loads is also increasing on the micro-grid which may also lead to the instability of the micro-grid. The major contribution of the paper work is the insertion of the load dynamics on the stability of the micro-grid. The stability analysis of the AC micro-grid has been carried in terms of the eigen values obtained from the linearized equations.

Keywords :- AC micro-grid, eigen values, distributed generators, PID controller.

1. Introduction:

The trustworthiness of power supply can be improved considerably by introducing parallel connection of two or more DG units as can be seen in [1-5]. This idea additional extended to an idea called micro-grid. A micro-grid is a cluster of loads and micro sources operating under a unified controller within a certain local area. The energy sources feeding the inverters have enough capability to supply the loads in micro-grid. A control mechanism is required to administer balance of generation and demand. For this purpose a master slave control strategy may be adopted where the master controller generates the control commands and the slave follows the same. But the reliability depends on the master controller and the failure of it may lead to failure of the entire system. Therefore a need arises for the masterless control of inverters, where every inverter is a grid-forming unit defining the voltage frequency and magnitude of the micro-grid. A very few papers has been published on the stability of AC micro-grid taking into account the effect of dynamics of the load. In this paper the dynamical equations for the loads has been linerarized and their effect on the stability has been carried out. The stability analysis has been carried out in terms of eigen values of the system.

Control Strategy:

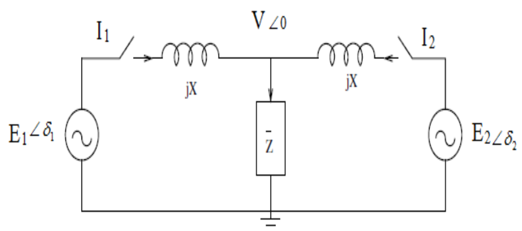

Figure 1. Circuit diagram of the proposed two inverter system under consideration

Fig. **1** demonstrates comparable circuit of two inverters associated to a common load. It is assumed that the line or cable connecting the two inverters is purely inductive and the load voltage is at reference position. If the output impedance of inverters will be inductive, the active and reactive powers becomes

$$P = \frac{EV}{X} Sin\delta \qquad (1)$$

$$Q = \frac{EVCos\delta - V^2}{X} \quad (2)$$

Therefore the corresponding values of the active and the reactive power supplied by the inverter I and inverter 2 are given by

$$P_1 = \frac{E_1 V}{X_1} Sin\delta_1 \quad (3)$$

and $$P_2 = \frac{E_{21} V}{X_2} Sin\delta_2 \quad (4)$$

$$Q_1 = \frac{E_1 VCos\delta_1 - V^2}{X_1} \quad (5)$$

and $$Q_2 = \frac{E_2 VCos\delta_2 - V^2}{X_2} \quad (6)$$

Where

E1 and E2 = voltages of the inverter 1 and inverter 2

δ_1 and δ_2 =load angles of the inverter 1 and inverter 2.

V= terminal voltage of the load

X_1 andX_2 = impedances of the cable of the of inverter 1 and inverter 2

2. Drop Control Scheme:

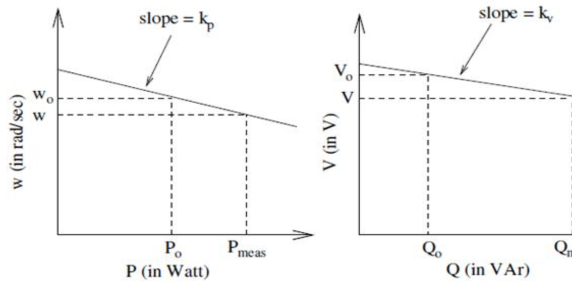

Figure 2. Droop Characteristics of the inverters

From the equations (1) and (2) it can be derived that active power *P* is dominantly dependent on the power angle δ while the reactive power Q mainly depends on the output voltage amplitude E. So, most of wireless-control of paralleled-inverters employs traditional droop method, which explores following droops in amplitude *E* and frequency **ω** of inverter output voltage as shown by

$$\omega = \frac{d\delta}{dt} = \omega^* - K_p(P_{0i} - P_0) = \omega^* - K_p P_i \quad (7)$$

$$E = E^* - K_v(Q_{0i} - Q_0) = E^* - K_v Q_i \quad (8)$$

Where

ω_o = nominal frequency

E_o= nominal voltage amplitude

P_{oi}= nominal real power

Q_{oi} = nominal reactive power

k_p= droop coefficient for frequency

k_v= droop coefficient for voltage magnitude

ω^*= frequency at steady state on-load Z

E= voltage amplitude at steady state on load Z

P_o= Real power output at steady state on-load Z

Q_o= Reactive power output at steady state on-load Z

So, to make sure the control laws defined by (3) and (4), it is essential to compute the output power of each inverter. This computing block employs a low-pass filter. Hence, after passing through the low pass filter the resultant average value of power is given by

$$P = \frac{\omega_f}{(s + \omega_f)} P_i \quad (9)$$

$$Q = \frac{\omega_f}{(s + \omega_f)} Q_i \quad (10)$$

Due to droop characteristics, frequency and voltage of system falls to a value so that all units function at similar frequency and voltage magnitude, therefore reduces the circulating current. Due the droop characteristics the two inverters share the active and reactive power as per their rated capacity without the need of any supervisory control.

3. Inverter Control Scheme:

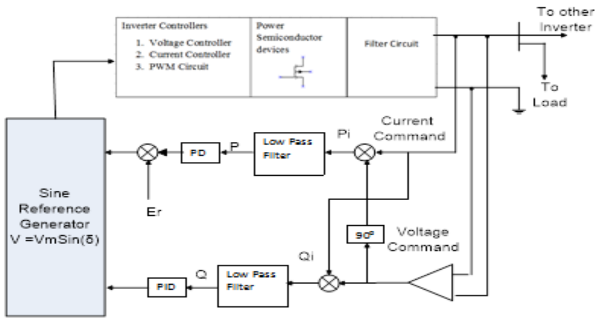

Figure 3. Block Diagram of the inverter control scheme

Fig. 3 demonstrates the control scheme of every inverter connected in a stand-alone system. Every inverter presents a classical pulse width modulation (PWM) controller through an inner current loop and an outer voltage loop, together by proportional plus integral (PI) compensators. The sinusoidal reference for the outer voltage loop of every inverter is obtained in the reference block from the amplitude signal and frequency signal explained by power droop descriptions.

Otherwise, to carry out the droop functions, given by **(7)** and **(8),** it is essential to compute the average value above one line-cycle of the output active and reactive instantaneous power, which will be capable of be implemented by resources of low-pass filters with a smaller bandwidth than closed-loop inverter. So, power calculation filters and droop coefficients decide to a large extent dynamics and the stability of paralleled-inverters. Damping and oscillatory phenomenon of phase shift difference between the modules might root instabilities, and a large transient circulating current that can overload and harm the paralleled inverters.

4. Modified Control Technique:

This proposed work, explores a controller that has been designed, analysed and implemented for voltage output and the phase control of every inverter. The controls of every inverter are autonomous from other. The droop control strategy has been used for autonomous control of inverter. The controller has been designed to advance the transient response of the inverter in case of load change. Simultaneously, the modified controller will also helps in reducing circulating current flowing across two inverter local circuit. This circulating current has unfavourable effects on the performance of the inverters operating in parallel [15].

$$\delta = -M\int Pdt - M_p P - M_d \frac{dP}{dt}$$

(11)

$$E = E^* - NP - N_d \frac{dQ}{dt}$$

(12)

Where

N_d= derivative coefficient the reactive power Q;
M = integral coefficient the reactive power P
M_p = proportional coefficient the reactive power P
M_d= derivative coefficient of the active power P.

Linearization of the System Equations:

Here in the proposed circuit diagram shown in figure 1, two inverter are used. Suffix 1 used is to present the linearised variables of inverter '1' and suffix '2' is used for inverter 2 side variables. Linerized form of equation 9 and 10 are given by

$$\Delta\delta = (-\frac{M}{s} - M_p - sM_d)\Delta P \qquad (13)$$

$$\Delta E = (-N - sN_d)\Delta Q \qquad (14)$$

Now linerizing equation 9 and 10, we get,

$$\Delta P = \frac{\omega_f}{(s+\omega_f)}\Delta P_i \qquad (15)$$

$$\Delta Q = \frac{\omega_f}{(s+\omega_f)}\Delta Q_i \qquad (16)$$

Linearized form of the equation 1 and 2 is given by

$$\Delta P_i = \frac{\Delta EV}{X}Sin\delta + \frac{E\Delta V}{X}Sin\delta + \frac{EV}{X}\cos\delta\Delta\delta \qquad (17)$$

$$\Delta Q_i = \frac{\Delta EVCos\delta}{X} + \frac{E\Delta VCos\delta}{X} - \frac{EV\sin\delta\Delta\delta}{X} - \frac{2V\Delta V}{X} \qquad (18)$$

$$= \frac{E\Delta VCos\delta}{X} - \frac{EV\sin\delta\Delta\delta}{X} + (\frac{ECos\delta}{X} - \frac{2V}{X})\Delta V$$

Putting the values of the $\Delta Pi\ and\ \Delta$Qi in equation 15 and 16 we have

$$\Delta P = \frac{\omega_f}{(s+\omega_f)}(\frac{\Delta EV}{X}Sin\delta + \frac{E\Delta V}{X}Sin\delta + \frac{EV}{X}\cos\delta\Delta\delta) \qquad (19)$$

$$\Delta Q = \frac{\omega_f}{(s+\omega_f)}[\frac{E\Delta VCos\delta}{X} - \frac{EV\sin\delta\Delta\delta}{X} + (\frac{ECos\delta}{X} - \frac{2V}{X})\Delta V] \qquad (20)$$

Putting the values of the $\Delta P\ and\ \Delta$Q in equation 13 and 14 we have

$$\Delta\delta = (-\frac{M}{s} - M_p - sM_d)\frac{\omega_f}{(s+\omega_f)}(\frac{\Delta EV}{X}Sin\delta + \frac{E\Delta V}{X}Sin\delta + \frac{EV}{X}\cos\delta\Delta\delta) \qquad (21)$$

$$\Delta E = (-N - sN_d)\frac{\omega_f}{(s+\omega_f)}[\frac{E\Delta VCos\delta}{X} - \frac{EV\sin\delta\Delta\delta}{X} + (\frac{ECos\delta}{X} - \frac{2V}{X})\Delta V] \qquad (22)$$

Repeat the same sequence of operations for inverter I

$$\Delta\delta_1 = (-\frac{M_1}{s} - M_{p_1} - sM_{d1})\frac{\omega_f}{(s+\omega_f)}(\frac{\Delta E_1 V}{X_1}Sin\delta_1 + \frac{E_1\Delta V}{X_1}Sin\delta_1 + \frac{E_1 V}{X_1}\cos\delta_1\Delta\delta_1) \qquad (23)$$

$$\Delta E_1 = (-N_1 - sN_{d1})\frac{\omega_f}{(s+\omega_f)}[\frac{E_1\Delta VCos\delta_1}{X_1} - \frac{E_1 V\sin\delta_1\Delta\delta_1}{X_1} + (\frac{E_1 Cos\delta_1}{X_1} - \frac{2V_1}{X_1})\Delta V] \qquad (24)$$

The same sequence of operation can also be adopted for the inverter 2. The basic requirement is to obtain the perturbed equation for the phase difference $(\Delta\delta_1 - \Delta\delta_2)$ between the inverter 1 and inverter 2. The phase difference between the inverter1 and inverter 2 lead to the flow of circulating current in local path and may lead to losses in the two inverters. This cause a dip in the power output which is not desirable. On solving the equations 23 and 24 for the invertet 1 and inverter 2 we have,

$$(s^3K_{10}\Delta\delta + s^2K_{11}\Delta\delta + sK_{12}\Delta\delta + K_{13}\Delta\delta)(s^2Y_{16}\Delta\delta + sY_{15}\Delta\delta + Y_{14}\Delta\delta) - \qquad (25)$$
$$(s^3Y_{10}\Delta\delta + s^2Y_{11}\Delta\delta + sY_{12}\Delta\delta + Y_{13}\Delta\delta)(s^2K_{16}\Delta\delta + sK_{15}\Delta\delta + K_{14}\Delta\delta) = 0$$

Where

K1=[VX1cos(δ_1)w];Y1=[VX2cos(δ_2)w];

K2=[E1VX1cos(δ_1)w];Y2=[E2VX2cos(δ_2)w];

K3=[V^2E1w^2]; Y3=[V^2E2w^2];

K4=[wVAsin(δ_1)]; Y4=[wVAsin(δ_2)];

K5=E1sin(δ_1)X; Y5=E2sin(δ_2)X;

K6=[EVwcos(δ_1)sin(δ_1)];Y6=[E2Vwcos(δ_2)sin(δ_2)];

K7=K4+K6; Y7=Y4+Y6;

K8=K7N1+K5w;   Y8=Y7N2+Y5w
K9=Nd1K7+wK5;   Y9=Nd2Y7+wY5;
K10=(1+K1Nd1+K2Md1+NdMd1);
Y10=(1+Y1Nd2+Y2Md2+Nd2Md2);
K11=[2w+K1(N1+Nd1w)+K2(Mp1+wMd)+K3(N1Md1+Mp1Nd1)];
Y11=[2w+Y1(N2+Nd2w)+Y2(Mp2+wMd2)+Y3(N2Md2+Mp2Nd2)]
K12=[w^2+K1Nd1w+K2(M1+wMp1)+K3(NMp1+M1Nd1)];
Y12=[w^2+Y1Nd2w+Y2(M2+wMp2)+Y3(N2Mp2+M2Nd2)];
K13=K2wM1+K3N1M1;
Y13=Y2wM2+Y3N2M2;
K14=-wM1;   Y14=-wM2;
K15=-wMp1;   Y15=-wMp2;
K16=-wMd1;   Y16=-wMd2;

System Parameters [8, 15]:

S. No.	Components	Nominal Values
1.	VirtualInductor1 L1	80 uH
2.	VirtualInductor2 L2	880 uH
3.	Parasitic Resistor 1 R1	0.10 ohm
4.	Parasitic Resistor R2	0.11ohm
5.	Common Load Z	50 Q
6.	Nominal Output Power S	1 KVA
7.	Nominal frequency	50 Hz
8.	Nominal Amplitude E	100 V
9.	Q-V Droop M	0.001V/Var
10.	P-δ Droop N	0.001 rad/Watt
11.	Md	$5*10^{-5}$ rad-sec/W
12.	Mp	$2*10^{-5}$rad-sec/W
13.	Initial Phase Difference δ0	0.02 rad
14.	Filter Order N	1
15.	Filter Cut off Frequency	10 rad

5. Stability Analysis of The two Inverter System:

From the above analysis the eigen values for the two inverter system are found to be

λ_1 = (-3.6211 + 5.5790i)
λ_2=(-3.6211 - 5.5790i)
λ_3=(-3.0492)
λ_4 =(-1.0070 + 1.7500i)
λ_5 =(-1.0070 - 1.7500i)
λ_6 =(-1.0009)

Since all the eigen values lies in the left half of the complex plane, that indicates an stable operation of the inverter.

Step Response for the Phase Difference:

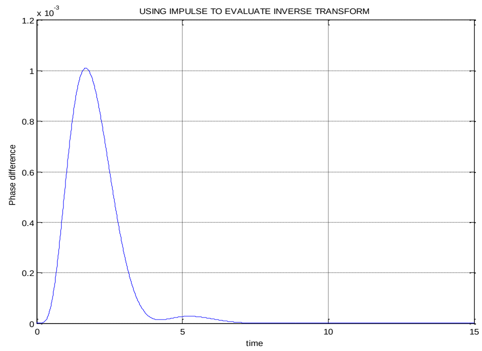

Figure 4. Step response for the phase difference for typical values of the parameters of the controller PID and PD of the inverter 1 and Inverter 2

N1=0.001;
N2=0.001;Nd=0.0001;Nd2=0.0001;M=0.0015;
M2=0.009;
Mp=2*10^(-3);Mp2=2.10^(-4);   Md=5.10^(-4);Md2=5.10^(-4);

From the above figure it is clear that for the setting of the controller parameters the operation of two inverter system is highly stable.

6. Conclusion

The above analysis suggests that if the load is varied over a small range the step response of the inverter system remains more or less same. As the parameters of the controller are to adjusted so as to minimize the circulating current in the local circuit of the inverter. However form the analysis it is clear that the settling timer of the phase difference is more but the steady state error value is very small. This analysis of the system makes the exact analysis**.**

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