Surge Current Calculation and Limit Strategy of the IIDG during Loop Closing Operation in Distribution Networks

Meiyi Li, Wentao Huang*, Nengling Tai
School of Electronic Information and Electrical Engineering
Shanghai Jiao Tong University
Key Laboratory of Control of Power Transmission and Conversion
Ministration of Education
Shanghai, China
hwt8989@sjtu.edu.cn limeiyi@sjtu.edu.cn

Zhenyu Chen, Bin Yang, Wenjun Ruan
Marketing Department
State Grid Jiangsu Electric Power Co., Ltd.
Shanghai, China

***Abstract*—The operation of upgrading primary feeders from radial and open loop to a closed-loop arrangement may results in a rather large surge current especially with increasing penetration of distributed generators (DGs). Existing studies focus more on the feasibility of the loop closing operation by analyzing the steady-state output of DGs, whereas the transient progress and the flexibility of the control are ignored. This paper presents a method for calculating the surge current of two types of inverter-interfaced distribution generators (IIDG)-voltage source inverters and current source inverters during the loop closing operation. Further, a limit strategy to restrain the surge current is proposed by adjusting the control parameters. The control parameters are adjusted when the current of the IIDG falls to its lowest point in order to minimize the impact of parameter variations. The limit strategy won't change the steady-state operating condition of the system. The proposed strategy is further verified based on PSCAD/EMTDC. Results confirm that the proposed strategy can effectively inhibit the surge current of the IIDG and improve the reliability of DGs dominated distribution network.**

Keywords—closed loop, open loop, Inverter interfaced distributed generator (IIDG), surge current, control strategy

I. Introduction

The feeders in the distribution network are mostly operated in radial, whereas a closed loop is also designed for the distribution network so that no customers connected to the loop will be out of service when a fault occurs at the feeder main of the loop [1]. The inverter interfaced distributed generator (IIDG) is promising featuring in fast response, flexible control and environmentally friendly electrical power [2]. However, as the penetration of distributed generators increases, there is a need to analyze the system performance of DGs dominated distribution network when upgrading primary feeders from radial and open loop to a closed-loop arrangement.

Current studies on the loop closing operation in DGs dominated distribution network is mainly about the feasibility of the operation. Reference [3] derives the current expression of feeders in DGs dominated distribution network after the loop closing operation. However, the transient process of the control system of the IIDG is ignored and the surge current of IIDG is yet to be studied. Reference [4] establishes the mathematical model of the DG connected as PQ and PV buses to develop a comprehensive distribution system power flow program. Reference [5] uses optimal power flow to assess distribution network capacity for the connection of distributed generation. These studies provide mathematical tools for calculating the surge current of the IIDG after the loop closing operation.

Once the system type is upgraded from open-loop to a closed-loop arrangement, the existing software and hardware of the distribution system should be improved to meet the requirement of the new system with new feeder arrangement [1]. Reference [6] presents a multi-objective evaluation approach for finding the optimal schemes for the closed-loop arrangement. Reference [7] proposes the protection schemes for closed-loop DGs dominated distribution network. However, the influence of the control strategy on the output of the IIDGs is not taken into consideration. The regulator of IIDGs is able to respond to disturbances in the time-scale of a millisecond [8]. The IIDG output is affected by control strategies significantly. Therefore, if the flexibility of the control is fully taken advantage of, the surge current would be restrained without additional devices [9], which will help to build a DG-friendly distribution system.

This paper derives the surge current of voltage-source-inverter IIDG and current-source-inverter IIDG during the loop closing operation. A control strategy is proposed to limit the surge current of the IIDG by adjusting the control parameters. The proposed strategy makes use of the flexibility of the control system and adjusts the control parameters when the current of the IIDG falls to its lowest point to avoid fluctuations caused by parameter variations. Simulation results based on PSCAD/EMTDC show that the proposed strategy can effectively limit the surge current and prevent the output current of the IIDG from exceeding the threshold.

II. Modeling of the DGs Dominated Distribution Network

Most DGs are connected to medium- and low-voltage (MV/LV) network. According to the technical rules made by State Grid Corporation of China, DGs are connected to the network in three typical schemes:

1) The DG is connected to the LV or MV bus of the power grid directly (Fig.1(a)).

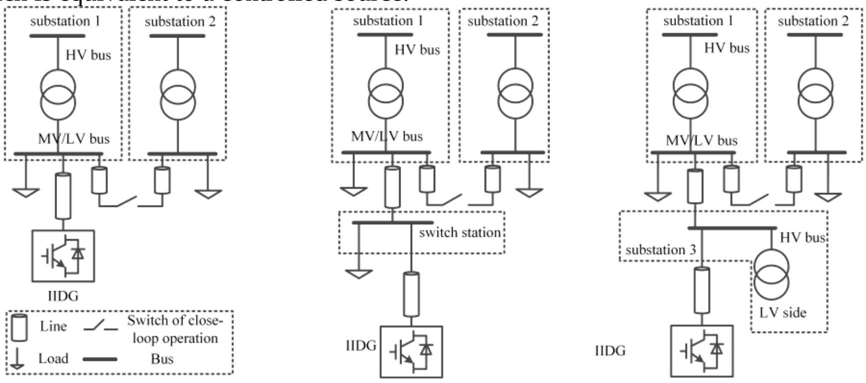
2) The DG is connected to the LV or MV bus of the substation through a switch station (Fig.1(b)).

3) The DG is connected to the LV or MV bus of the substation through being connected to the high-voltage (HV) bus of a substation first (Fig.1(c)).

According to the three typical schemes, the distribution network model is established as Fig.2 to analyze the closed-loop network. Branch 1 and branch 2 are the branches

This work was supported in part by Shanghai Sailing Program [grant number (17YF1410200)], National Natural Science Foundation of China [grant number (51807117)], Major Scientific Research and Innovation Projects of Shanghai Education Commission [grant number (2019- 01- 07- 00- 02- E00044)].

of sources, whose impedance is the summary of the transformer reactance and the line impedance. Branch 3 includes the IIDG, which is equivalent to a controlled source. The switch of loop closing operation is on branch 4. The loads are equivalent to branch 5 and branch 6.



(a) connected to the LV or MV bus (b) through a switch station (c) through the HV bus of the substation

Fig. 1. Typical connecting schemes of DGs.

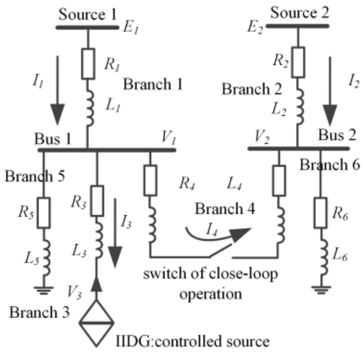


Fig. 2. Distribution network model.

The closed-loop current i_4 of branch 4 is consist of non-periodic current due to the inductance of the network [10]. The expression of i_4 is:

$$i_4 = I_{m,4}\sin(\omega t + \varphi_4) + I_c\sin(\alpha - \beta)e^{-\frac{t-t_c}{T_c}} \tag{1}$$

where I_c is the amplitude of the closed-loop current caused by the voltage difference between the two sides of the loop closing switch. α is the angle difference between both sides of the loop closing switch. β is the impedance angle of branch 4. t_c is the moment of closed-loop operation. T_c is the decay time constant of non-periodic current. $I_{m,4}$ and φ_4 are the amplitude and the angle of steady-state closed-loop current.

As for other branches, the expression of the closed-loop current is as equation (2), where $I_{m,k}$ and φ_k are the amplitude and the angle of the steady-state closed-loop current of branch k, respectively.

$$\begin{cases} i_k = I_{m,k}\sin(\omega t + \varphi_k) + c_k e^{-\frac{t-t_c}{T_k}} \\ c_k = I_{m,k,0}\sin(\omega t_c + \varphi_{k,0}) - I_{m,k}\sin(\omega t_c + \varphi_k) \end{cases} \tag{2}$$

The closed-loop voltage of bus 1 is as equation (3):

$$\begin{aligned} v_1 &= e_1 - L_1\dot{i}_1 - i_1R_1 \\ &= E_1\sin(\omega t + \theta_1) - I_{m,1}Z_1\sin(\omega t + \varphi_z) + (L_1 - R_1c_1)\frac{c_1}{T_1}e^{-\frac{t-t_c}{T_1}} \\ &= V_{m,1}\sin(\omega t + \delta_1) + (L_1 - R_1c_1)\frac{c_1}{T_1}e^{-\frac{t-t_c}{T_1}} \end{aligned} \tag{3}$$

Where E_1 and θ_1 are the amplitude and the angle of the steady-state voltage of source 1. L_1, R_1, Z_1 and φ_z are the inductance, resistance, impedance and its angle of branch 1, respectively. $V_{m,1}$ and δ_1 are the amplitude and the angle of the steady-state closed-loop current of bus 1, respectively.

III. Calculation of the Surge Current of the IIDG due to the Closed-loop Operation

The output of the IIDG is determined by the control strategy. The IIDGs can be divided into voltage source inverters and current source inverters according to different external characteristics. A typical current source inverter is the PQ controlled IIDG (PQ-IIDG) and typical voltage source inverters are the droop controlled IIDG (droop-IIDG) and the virtual synchronous generator (VSG). The A-phase current of the three types of IIDGs is analyzed below. The methods of calculating the B-phase and C-phase current are similar and are not illustrated in detail. Assume the DG is connected to bus 1 with constant impedance Z_3. Besides, the transient progress of the inner loop controller is ignored.

A. PQ-IIDG

The output power of the PQ-IIDG is regulated by the governor as equation (4) and the control scheme of the PQ-IIDG is shown in Fig.3.

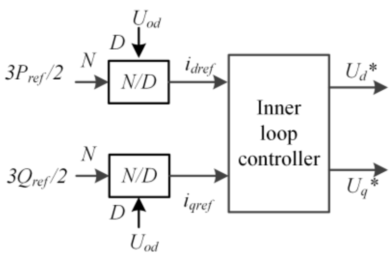


Fig. 3. PQ controller.

$$\begin{cases} P_{ref} = \dfrac{2}{3}u_d i_d \\ Q_{ref} = \dfrac{2}{3}u_d i_q \end{cases} \tag{4}$$

The output current of the PQ-IIDG is adjusted according to the output voltage and the output voltage is determined by the circuit equations of the network. When k=1，the output current of the PQ-IIDG won’t change abruptly since the IIDG is a current source inverter. Then $i_3(t_1)=i_{3,0}(t_1)$. According to circuit theories, the output voltage of the PQ-IIDG is：

$$v_3(t_1)=i_{3,0}(t_1)Z_3+v_1(t_1) \tag{5}$$

The control system measures the voltage and introduces it as feedback to calculate the current reference. It should be mentioned that the non-periodic part will be eliminated because of the coordinate transformation from the ABC coordinate system to the DQ0 coordinate system. Then the voltage introduced to the control system is as:

$$\begin{aligned} u_d(t_k) = \sqrt{\frac{3}{2}}\{ & \cos\theta*[V_{m,1}\sin(\omega t_k+\delta_1)+i_{3a}(t_k)Z_3] \\ & +[-\frac{1}{2}\cos\theta+\sqrt{\frac{3}{2}}\sin\theta]*[V_{m,1}\sin(\omega t_k+\delta_1-120°)+i_{3b}(t_k)Z_3] \\ & +[-\frac{1}{2}\cos\theta-\sqrt{\frac{3}{2}}\sin\theta]*[V_{m,1}\sin(\omega t_k+\delta_1+120°)+i_{3c}(t_k)Z_3]\} \end{aligned} \tag{6}$$

When k>1, the current reference is obtained as (7) according to the voltage measurement.

$$i_3(\mathrm{t}_k)=\sqrt{\frac{3}{2}}[\frac{P_{ref}}{u_d(\mathrm{t}_{k-1})}\cos\theta-\sin\theta\frac{Q_{ref}}{u_d(\mathrm{t}_{k-1})}] \tag{7}$$

B. Droop-IIDG

The governor of the droop control is as equation (8), and the control diagram is in Fig.4 [8].

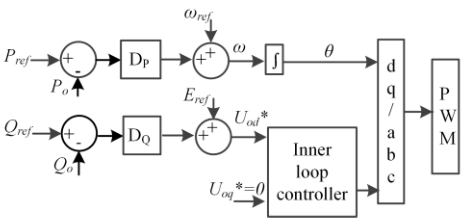


Fig. 4. Droop controller.

$$\begin{cases} \omega-\omega_{ref}=D_P(P_{ref}-P) \\ E-E_{ref}=D_Q(Q_{ref}-Q) \end{cases} \tag{8}$$

Unlike the PQ-IIDG, the droop-IIDG is equivalent to a voltage source inverter. The output voltage is regulated by the controller according to the output power and angular frequency of the IIDG, but the output current is determined by the circuit equations of the network.

When k=1，the output voltage of the droop-IIDG won’t change abruptly. Then $v_3(t_1)=v_{3,0}(t_1)$. According to circuit theories, the output current of the droop-IIDG is：

$$i_3(t_1)=[v_{3,0}(t_1)-v_1(t_1)]/Z_3 \tag{9}$$

The output power of the droop-IIDG is：

$$\begin{cases} P_o(t_k)=V_{m,3,0}^2G-V_{m,3,0}V_{m,1}G\cos(\delta')+V_{m,3,0}V_{m,1}B\sin(\delta') \\ Q_o(t_k)=V_{m,3,0}^2B-V_{m,3,0}V_{m,1}B\cos(\delta')+V_{m,3,0}V_{m,1}G\sin(\delta') \end{cases} \tag{10}$$

where $\delta'=\delta(\mathrm{t}_k)-\delta_1$.

When k>1, the control system will use the power measurement as feedback with the non-periodic part eliminated. The amplitude and angle of the output voltage are obtained according to the governing equation:

$$\begin{cases} V_{m,3}(\mathrm{t}_k)=E_{set}-D_QQ_o(t_{k-1}) \\ \omega(t_k)=\omega(t_{k-1})+\dfrac{[P_{ref}-P_o(t_{k-1})-D(\omega(t_{k-1})-\omega_{ref})]\Delta t}{2H}\Delta t \\ \delta(t_k)=\delta(t_{k-1})+\omega(t_k)\Delta t \end{cases} \tag{11}$$

Then the output power of the droop-IIDG is：

$$i_3(t_k)=[V_{m,3}(t_k)\sin(\delta(t_k))-v_1(t_k)]/\mathrm{Z}_3 \tag{12}$$

C. VSG-IIDG

If DG is equipped with an energy storage device, virtual synchronous motor (VSG) control strategy can be applied to enhance the stability [2]. The governor of the VSG control is as equation (14) and the control diagram in Fig.5.

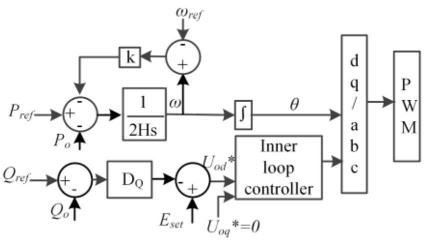


Fig. 5. VSG controller.

$$\begin{cases} 2H\dfrac{d\omega}{dt}=P_{ref}-P-\mathrm{D}(\omega-\omega_{ref}) \\ \dfrac{d\delta}{dt}=\omega \\ E=E_{set}+D_Q(Q_{ref}-Q) \end{cases} \tag{13}$$

Similar to the droop-IIDG, when k=1, the output voltage of the VSG-IIDG won’t change abruptly. The output of the VSG-IIDG is obtained as (10).

When k>1，the amplitude of the output voltage and the angular frequency are calculated based on the previous measurement:

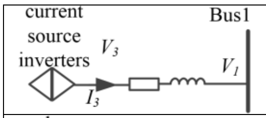
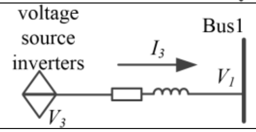
$$\begin{cases} E(\mathrm{t}_k)=D_Q(Q_{ref}-Q(\mathrm{t}_{k-1}))+E_{set} \\ \omega(\mathrm{t}_k)=D_P(P_{ref}-P(\mathrm{t}_{k-1}))+\omega_{ref} \end{cases} \tag{14}$$

Then the output current of the VSG-IIDG is obtained according to (13).

In summary, the methods of calculating the surge current of current source inverters and voltage source inverters are different. As stated in Table I, the output current of current source inverters won’t change abruptly at the moment of the loop closing operation. The output voltage is determined by the circuit equations and the output current is adjusted according to the governing equations. On the other side, the output voltage of voltage source inverters won’t change abruptly at the moment of the loop closing operation. The output voltage is calculated according to the governing equations and the output current is determined by the circuit equations.

TABLE I. THE METHODS OF CALCULATING THE SURGE CURRENT OF CURRENT SOURCE INVERTERS AND VOLTAGE SOURCE INVERTERS

Inverters	**Methods of calculating the surge current**

current source inverters 	V_1 changes(I_3 remains) → V_3 changes(circuit equations) → I_3 changes(governing equations)
voltage source inverters 	V_1 changes(V_3 remains) → I_3 changes(circuit equations) → V_3 changes(governing equations)

IV. LIMIT STRATEGY OF THE SURGE CURRENT

According to section III, there is surge current of the IIDG due to the closed-loop operation. Therefore, a current limit strategy is desirable to ensure the reliable operation and help build a DG-friendly distribution system. This paper proposes a general current limit of the surge current applicable for current source inverters and voltage source inverters. In the current limit, the control parameters P_{ref} and Q_{ref} are adjusted according to the calculation of the surge current. The control scheme offers a significant cushioning and dampening effect for the closed loop operation. The algorism of the limit strategy is shown in Fig.6.

1) Calculation of the output current.

Calculate the output current of the IIDG according to section III. If there is a time when either of the phase current exceeds the threshold current $I_{\max}$, the surge current of the IIDG should be restrained.

2) Restraint of the surge current.

Let t_{k*} be the last time that the output current of the IIDG exceeds the threshold current. Find the first time $t_{k_s,p},(p=a,b,c)$ that the output current of the IIDG reaches its minimum and $t_{k_s,p}>t_{k*}$. Let t_{k_s} be the maximum of $t_{k_s,p},(p=a,b,c)$. Then, all the t_k satisfying $i_{3,p}(t_k)>I_{\max}$, $(p=a,b,c)$ are included in the interval $[t_c,t_{k_s}]$. Decrease $\lambda(t_k)$ by 0.01, where λ is a power coefficient that $P_{ref}(t_k)=\lambda(t_k)P_{ref}$ and $Q_{ref}(t_k)=\lambda(t_k)Q_{ref}$. Then recalculate the output current $i_{3,p}(t_k),(p=a,b,c)$.

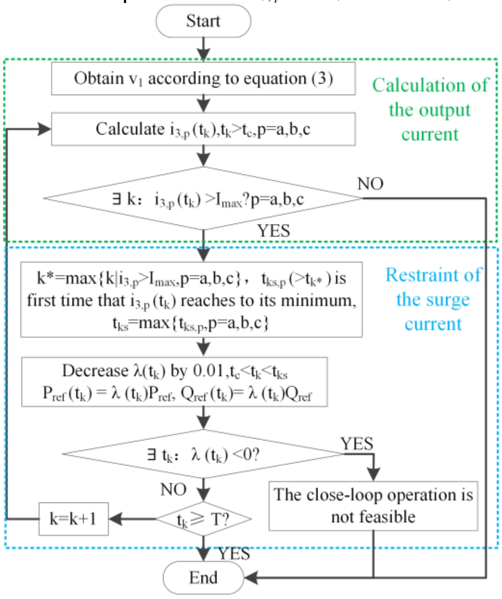


Fig. 6. Algorism diagram of the limit strategy.

After the adjustment of the parameters, if $\lambda(t_k)<0$, it means that the loop closing operation is not feasible. This may be because the steady-state output current exceeds the threshold current $I_{\max}$, or the steady-state output current is so close to the threshold current that the even small disturbances due to changes of parameters may cause the surge current. Therefore, the loop closing operation is not feasible under such circumstances.

In the limit strategy, the parameters are adjusted when the output current reaches its minimum so that the effect of parameter changing can be alleviated. Fig.7 gives an example of the limit strategy.

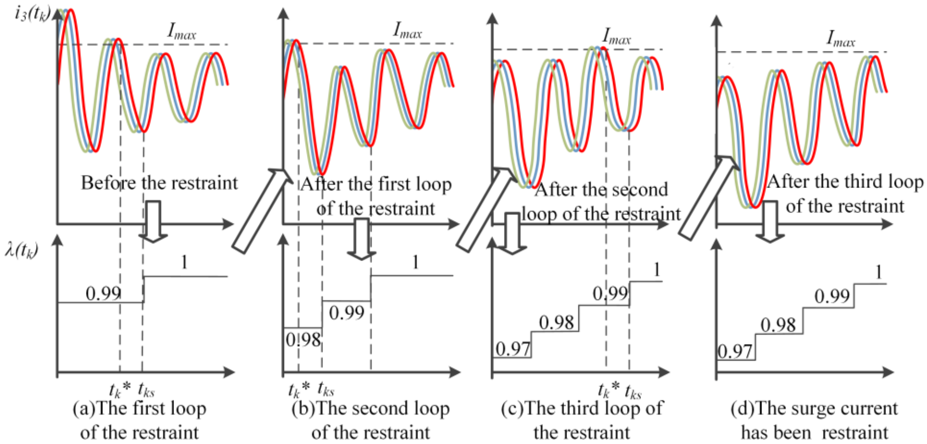


Fig. 7. A simple example of the limit strategy.

Before the limiting, the output current of the IIDG is as Fig.7(a). Since there is some time when the phase current exceeds the threshold current $I_{\max}$, the last time t_{k*} that the output current of the IIDG exceeds the threshold current is found. Then, find the first time $t_{k_s,p},(p=a,b,c)$ that the output current of the IIDG reaches its minimum and $t_{k_s,p}>t_{k*}$. Compare $t_{k_s,p},(p=a,b,c)$ and t_{k_s} is the maximum of them. $P_{ref}(t_k)=\lambda(t_k)P_{ref}$ and $Q_{ref}(t_k)=\lambda(t_k)Q_{ref}$. Decrease $\lambda(t_k)$ ($t_k\in[t_c,t_{ks}]$) to 0.99. Recalculate $i_{3,p}(t_k),(p=a,b,c)$ and Fig.7(b) shows the output current of the IIDG after the first loop of the restraint. The surge current has been alleviated to a certain degree, but there is still some time when the phase current exceeds the threshold current $I_{\max}$. Hence, decrease $\lambda(t_k)$ ($t_k\in[t_c,t_{k_s}]$) to 0.98. Recalculate the output current of the

IIDG after the second loop of the restraint. As shown in Fig.7(c), the increase of control parameters from 98% to 99% leads to new fluctuations though the parameters are adjusted when the output current reaches its minimum. Hence, decrease $\lambda(t_k)$ $(t_k \in [t_c, t_{k_s}])$ to 0.97. The output current of the IIDG after the third loop of the restraint is shown in Fig.7(d). The surge current has been limited and there isn't any time that the phase current extends the threshold current.

It should be mentioned that the threshold current is set based on the max load current and the setting value of the protection. Reference [11] points out that the transient process of loop current of the feeders only affects the instantaneous current protection for the radial distribution network. If the steady-state current after the loop closing operation is smaller than the max current of the feeders, the loop closing operation won't affect the reliability of protection. However, with the increasing penetration of distributed generators, differential protection is provided. Therefore, the effects of the surge current on differential protection should be taken into consideration.

V. Study Cases

The simulation model of power systems of Songjiang District of Shanghai is established to verify the proposed control strategy. The simulation model is shown in Fig.8.

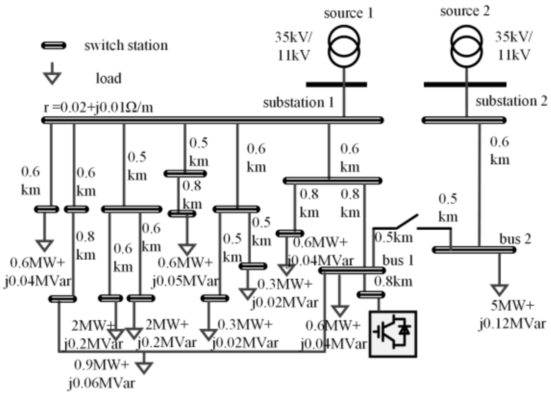


Fig. 8. Systematic single line diagram of the simulation model.

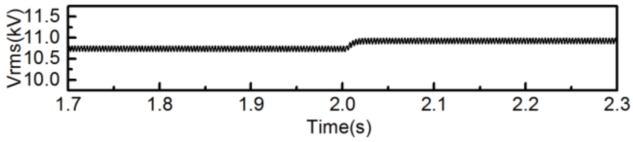
The simulation results of the PQ-IIDG, the droop-IIDG and the VSG-IIDG are shown below and control parameters are in Table II.

TABLE II. CONTROL PARAMETERS

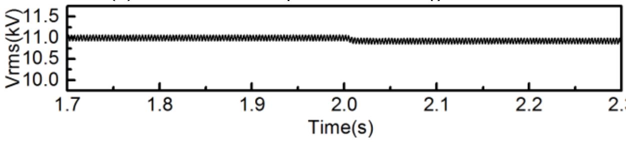
	Parameter	Value	Parameter	Value
PQ control	P_{ref}	0.6MW	Q_{ref}	0.1MW
Droop control	D_P	0.1	D_Q	1
	ω_{ref}	314.15926	E_{ref}	0.32kV
VSG control	H	0.1	D	0.01
	D_Q	0.1	E_{set}	0.32kV

A. VSG-IIDG

The angle difference between source 1 and source 2 is 4°. The switch is closed at 2s and the feeders are updated from radial loop to a closed-loop arrangement. The root-mean-square of the voltage of Bus 1 and Bus 2 is shown in Fig.9. The voltage of Bus 1 increases and the voltage of Bus 2 decreases due to the loop closing operation. The threshold current $I_{max} = 0.4729kA$.



(a) The root-mean-square of the voltage of Bus 1



(b) The root-mean-square of the voltage of Bus 2

Fig. 9. Simulation results of the bus voltage.

When the IIDG is controlled by the VSG controller, the output current before the surge current limit are shown in Fig.10. The steady-state current after the loop closing operation is smaller than that before the operation. However, the output current of the IIDG exceeds I_{max} between 2s and 2.15s. Hence, apply the limit strategy. The control parameter $\lambda(t_k)$ is obtained as in Fig.11, and the output current of the IIDG after the limit is shown in Fig.12. As shown in Fig.12, the surge current between 2s and 2.15s is limited by the control strategy.

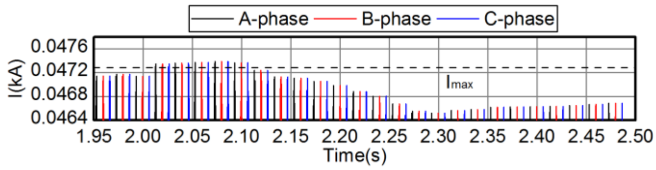


Fig. 10. The output current of the VSG-IIDG before limiting.

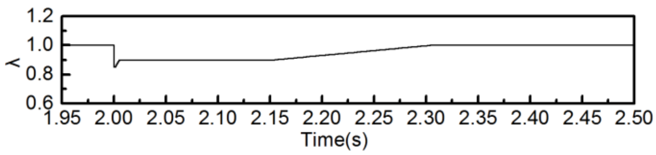


Fig. 11. The control parameter $\lambda(t_k)$.

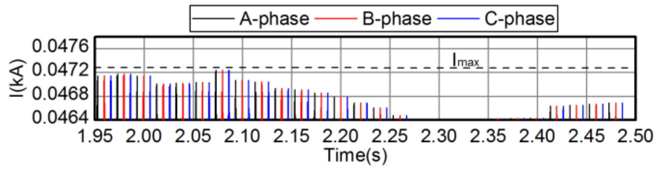
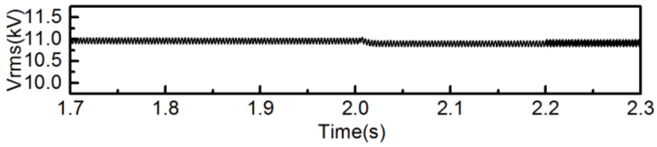


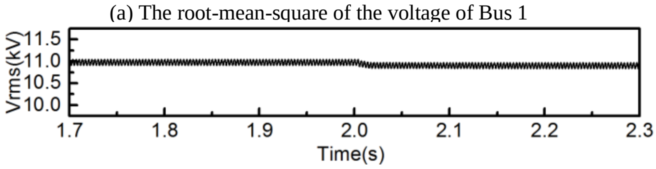
Fig. 12. The output current of the VSG-IIDG after limiting.

B. PQ-IIDG

The angle difference between source 1 and source 2 is -10°. The switch is closed at 2s. The root-mean-square of the voltage of Bus 1 and Bus 2 is shown in Fig.13. The voltage of Bus 1 and Bus 2 decreases due to the loop closing operation. The threshold current $I_{max} = 0.471kA$.



(a) The root-mean-square of the voltage of Bus 1



(b) The root-mean-square of the voltage of Bus 2

Fig. 13. Simulation results of the bus voltage.

When the IIDG is controlled by the PQ controller, the output current before current limit are shown in Fig.14. The steady-state current after the loop closing operation is much larger than that before the operation and is close to the threshold current. The current limit scheme shows there exists a time that the control parameter $\lambda < 0$. The loop closing operation is not feasible under such circumstance.

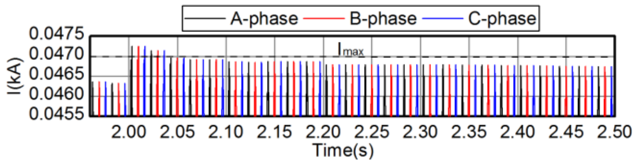
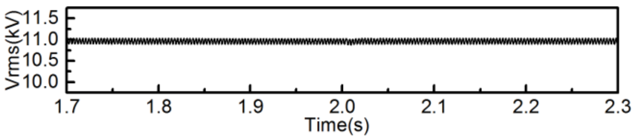


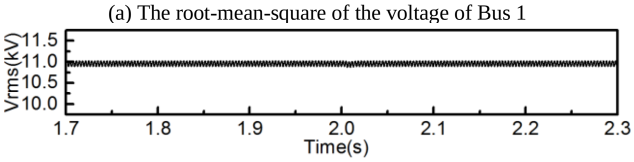
Fig. 14. The output current of the PQ-IIDG before limiting.

C. Droop-IIDG

The angle difference between source 1 and source 2 is -4°. The switch is closed at 2s. The root-mean-square of the voltage of Bus 1 and Bus 2 is shown in Fig.9.



(a) The root-mean-square of the voltage of Bus 1



(b) The root-mean-square of the voltage of Bus 2

Fig. 15. Simulation results of the bus voltage.

The output current of the droop-IIDG before the restraint of the surge current is shown in Fig.16. The threshold current $I_{max} = 0.471kA$, and the control parameter $\lambda(t_k)$ is obtained as in Fig.17. The output current of the IIDG after the restraint is shown in Fig.18. The surge current between 2s and 2.05s is limited by the control strategy.

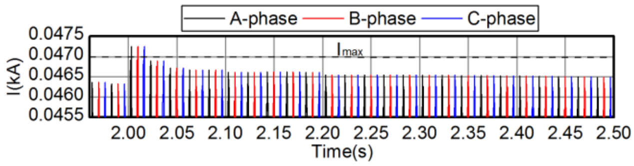


Fig. 16. The output current of the VSG-IIDG before limiting.

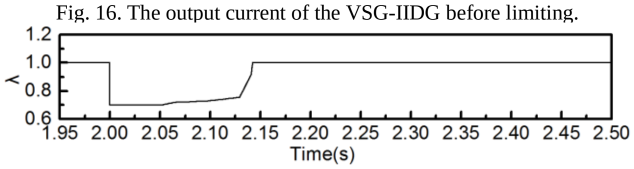


Fig. 17. The control parameter $\lambda(t_k)$.

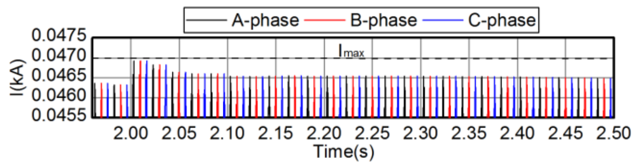


Fig. 18. The output current of the VSG-IIDG after limiting.

VI. CONCLUSIONS

This paper presents a method for calculating the surge current of the IIDG during the loop closing operation. The output voltage of current source inverters is determined by the circuit equations and the output current is adjusted according to the governing equations. Whereas the output voltage of voltage source inverters is calculated according to the governing equations and the output current is determined by the circuit equations.

Further, a surge current limit strategy is proposed by adjusting the control parameters to limit the output current. The control parameters are adjusted when the current of the IIDG falls to its lowest point in order to minimize the impact of parameter variations. The proposed strategy can effectively inhibit the surge current and improve the reliability of DGs dominated distribution network.

REFERENCES

[1] T. Chen, W. Huang, J. Gu. "Feasibility Study of Upgrading Primary Feeders From Radial and Open-Loop to Normally Closed-Loop Arrangement," IEEE Transactions on Power Systems, vol. 19, pp. 1308 - 1316, August 2004.

[2] M. Li, W. Huang, and N. Tai. "Lyapunov-Based Large Signal Stability Assessment for VSG Controlled Inverter-Interfaced Distributed Generators," Energies, vol. 11, pp 1-15, August 2018.

[3] H. Chen, J. Chen, X. Duan. "Study on Power Flow Calculation of Distribution System with DGs," Automation of Electric Power Systems, vol. 30, pp.35-40, January 2006.

[4] H. E. Farag, E.F.El-Saadany, R. E. Shatshat. "A generalized power flow analysis for distribution systems with high penetration of distributed generation," Electric Power Systems Research, vol. 81, pp. 1499-1506, July, 2001.

[5] G. P. Harrison, A. R. Wallace. "Optimal power flow evaluation of distribution network capacity for the connection of distributed generation," IEE Proceedings- Generation, Transmission and Distribution, vol. 152, pp. 115 – 122, Jan. 2005.

[6] T. Chen, E. Lin, N.Yang. "Multi-objective optimization for upgrading primary feeders with distributed generators from normally closed loop to mesh arrangement," International Journal of Electrical Power & Energy, vol. 45, pp.413-419, February 2013.

[7] B. Li, X. Yu, Z, Bo. "Protection schemes for closed loop distribution network with distributed generator," International Conference on Sustainable Power Generation & Supply 2009, April 2009, Nanjing, China.

[8] M. Yu, W. Huang, and N. Tai, "Transient stability mechanism of grid-connected inverter-interfaced distributed generators using droop control strategy," Applied Energy, vol. 2, no. 10, pp. 737-747, Nov.2018.

[9] Viawan, A. Ferry, Karlsson. "Voltage and reactive power control in closed loop feeders with distributed generation," 2007 IEEE Lausanne Power Tech, July 2007, Lausanne, Switzerland.

[10] G. Gan, Z. Wang, R. Li. "Methods and Simplified Formulas for Calculating Surge Currents from Loop Closing in Distribution Networks," Automation of Electric Power Systems, vol. 38, pp.115-120, October 2014.

[11] J. Liu, Q. Sun, X. Zhang. "Analysis on and criteria for loop closing operation for distribution grids," Automation of Electric Power Systems, vol. 38, pp.1-6, June 2014.