SMALL SIGNAL STABILITY ANALYSIS OF STAND ALONE POWER SYSTEM WITH DISTRIBUTED GENERATION

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ABSTRACT

Stand alone power system with distributed generation is a useful and reliable way to supply energy in critical and rural district with less cost and pollution, better power quality than conventional power station. Transmission and distribution rating voltage of stand alone system is 10kV and 380V. The ratio of Resistance to reactance in LV&MV line is larger than that of HV line, which is $R/X \gg 1$. *In this paper, the power – voltage formula is re-deduced and amended based on it. Some of them are based on solar panel. Generation mode is one of key factors, which have impacts on stability of stand by system. With distributed generators connected with inverter, stand alone system small signal stability problem is different from that with synchronous generators. Characteristic of load is another key factor. Considering characteristics of load and operation condition of system a typical stand alone system is modeled and analyzed, which has a PV station and a SG. Then impact of ratio of load on stability is presented also. According to the characters and the problem of this system, a simulation case based in DigSilent is built. The result of simulation shows that choosing adequate distributed generation control strategy and optimizing load ratio can improve small signal stability of stand alone power system effectively.*

I 。INTRODUCTION

Islanded photovoltaic power system is a useful mode of supplying power for backcountry district, which has been applied several times in China Tibet [1]. During design and construction of the islanded PV power systems, active power capacity of load and PV cell considered and researched usually while voltage stability isn't investigated thoroughly. However this type of system becoming more complicated and extended, which is including transformers and transmission & distribution systems shown in Fig.1. Therefore considering voltage rate of stand alone system is 10kV and 380V. And the parameters of LV&MV are different from that of HV transmission line. The ratio of Resistance to reactance in LV&MV line is larger than that of HV, which have impact on active and reactive power flow, then on voltage deviation from rating. Run with uncertainty of load and operation of load , serious voltage instability appeared. In an extremely serious situation it would lead to operations failure [2]. The situation arising has a negative affects on stand-alone systems regular service severely and restricts it to be applied further.

Voltage deviation in stand alone hasn't been researched thoroughly [3] [4]. Traditionally voltage has intimate relationship with reactive power. However it's not true in stand alone. An approach $\left|\Delta \dot{U}\right| = \left|\dot{U} - \dot{E}\right|$ is adopted to investigate the reason that makes voltage fluctuate from rating. But this formula has limitation that it can't be used to reflected voltage deviation value but phase-angle difference.

Small signal stability analysis is useful tool referring to the system's ability to maintain steady voltage when subjected to small perturbations such as incremental changes in system load [5-8]. This form of stability is influenced by the characteristics of loads, continuous controls, and discrete controls at a given instant of time. This concept is useful in determining, at any instant, how the system voltages will respond to small system changes. In this paper, the power – voltage deviation formula is deduced and amended based on it. Then considering characteristics of load and operation condition of system a typical stand alone system is modeled and analyzed, which has a PV station and a SG. Two kinds of load are laid in system, which are constant impedance and constant power individually. Then impact of ratio of load on stability is presented also. Based on results of analysis and simulation, reactive-load and distribution of load properly and setting adding -load compensation equipments is essential to improve performance of PV stations islanding. The result of simulation shows that choosing adequate distributed generation control strategy and optimizing load ratio can improve small signal stability of stand alone power system effective.

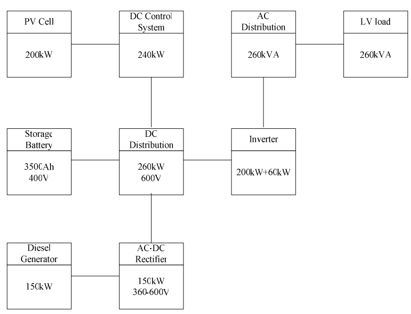


Fig.1 Sketch map of a stand-alone PV system

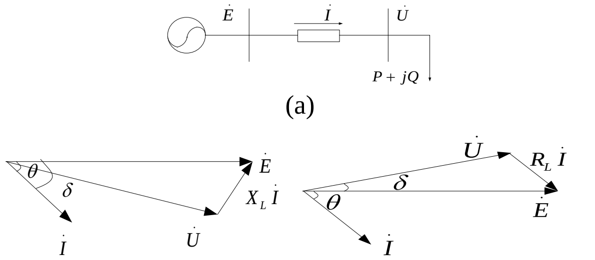
II.VOLTAGE STABILITY OF PV STATIONS STAND-ALONE

2.1 The parameters of LV&MV Transmission line

Voltage rate of Stand alone system is 10kV and 380V. And the parameters of LV&MV are different from that of HV transmission line. The ratio of Resistance to reactance in LV&MV line is larger than that of HV line, which is $R/X \gg 1$ and shown in Table.1. And the phase map of HV and LV is shown in Fig.2. This difference has significant effect to stability of PV stations stand alone based in 10kV and 380V.

Table1 Parameters of transmission line

Parameter	380V	6kV	10.5kV
R (Ω/km)	9.69	3.225	1.28
X (Ω/km)	0.115	0.214	0.094
R/X	84.26	15.07	13.62



(a)

(b)vector of HV (c)vector of LV

Fig.2 Equivalent circuit of power system with load and vector map

Flow of active and reactive-power has impact on voltage stability of system, which voltage rate is 10kV and 380V shown in Table.2.

Table.2 Voltage deviation

Voltage(kV)	Voltage deviation(%/km) with power factor of load			
Power factor	0.2	0.7	0.8	0.9
0.38	1.71	1.55	1.685	1.62
6	——	6.25	6.20	6.14
10	——	2.25	2.23	2.21

2.2 Analysis of power characteristics

In stand alone system, the inverter control strategy is that make voltage of inverter constant. Therefore, from 1.1 analysis, ignoring line reactance, seen from Fig.2 (a),

$$\dot{E} = \dot{U} + R_L \dot{I}$$

From Fig.2(c), then

$$\begin{cases} E\sin\delta = R_L I \sin(\theta+\delta) \\ E\cos\delta = U + R_L I\cos(\theta+\delta) \end{cases}$$

$$\Rightarrow \begin{cases} \sin(\theta+\delta) = \dfrac{E\sin\delta}{R_L I} \\ \cos(\theta+\delta) = \dfrac{U - E\cos\delta}{R_L I} \end{cases} \quad (1)$$

Active and reactive power of load can be expressed as follows:

$$\begin{cases} P = \mathrm{Re}[\dot{U}(\dot{I})^*] = UI\cos(\theta+\delta) \\ Q = \mathrm{Im}[\dot{U}(\dot{I})^*] = UI\sin(\theta+\delta) \end{cases} \quad (2)$$

(1) is substituted to (2), then:

$$\begin{cases} P = \dfrac{UE\cos\delta - U^2}{R_L} \\ Q = \dfrac{UE\sin\delta}{R_L} \end{cases} \quad (3)$$

Make $u = \dfrac{u}{E}$, $p = \dfrac{PR_L}{E^2}$, $q = \dfrac{QR_L}{E^2}$, then (3) can be written as follows

$$\begin{cases} p = u\cos\delta - u^2 \\ q = u\sin\delta \end{cases} \quad (4)$$

(4) is the amended formula of power characteristic in stand alone. Fig.3 shows that family of power curves according to voltage of load.

Seen from Fig.3, an important conclusion can be got that with the voltage of load increasing, power boundary increasing. The relationship between power and voltage of load can be analyzed quantitatively. δ is remove in (3), then

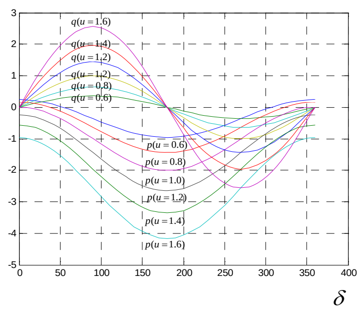


Fig.3 family of power characteristic curves

$$u^4 + u^2(2p-1) + (p^2+q^2) = 0$$

$$u_{1,2} = \left(\frac{1-2p \pm \sqrt{1-4p-4q^2}}{2}\right)^{\frac{1}{2}} \quad (5)$$

Where:

$$\begin{cases} -\dfrac{1}{2} \le q \le \dfrac{1}{2} \\ 0 \le p \le \dfrac{1}{4} - q^2 \end{cases} \quad (6)$$

Or

$$\begin{cases} 0 \le p \le \dfrac{1}{4} \\ -\sqrt{\dfrac{1}{4} - p} \le q \le \sqrt{\dfrac{1}{4} - p} \end{cases} \quad (7)$$

Where (6) is equivalent to (7).

2.3 Analysis of power – voltage formula

It can be certificated that if condition meets the demands of (6) or (7), $u_{1,2}$ have a solution. (5) is significantly essential to small signal voltage analysis of load terminal. p and q represent the static characteristics of load. Assuming system frequency is invariable, then

$$\begin{cases} p = p_0[\dfrac{u}{u_0}]^{p_u} \\ q = q_0[\dfrac{u}{u_0}]^{q_u} \end{cases} \quad (8)$$

In (8), when p_u =0 or q_u =0 时， it shows that load has constant power. When $p_u = q_u$ =2, it shows that load has constant impedance. When $p_u = q_u$ =1, it shows that load has constant current. Fig.4 shows that the relation of p and u with constant reactive.

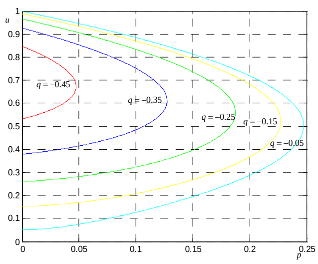


Fig.4 $p-u$ curve

III. STAND-ALONE SYSTEM SIMULATION

3.1 Model of stand alone

From analysis in 1, voltage stability is provoked from active and reactive-power flowing. A simulation model based in DigSilent is built for an actual PV islanded station in Bange Tibet. Bange station has been built in 2001 with 200kW PV cell, where most of loads are lighting equipments. Because transmission line is so long that a scheme with 10kV transmission and 380V distribution is adopted. Mode is shown in Fig.5.

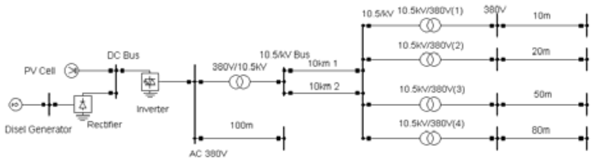
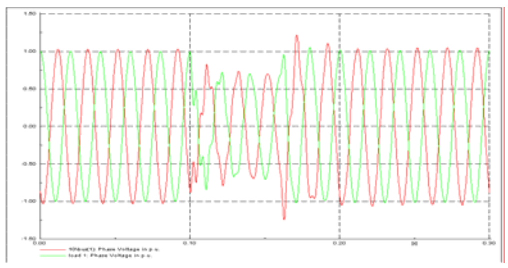


Fig.5 Simulation model of stand-alone system

3.2 Simulation results

3.2.1 Switch off fault line impact on voltage stability

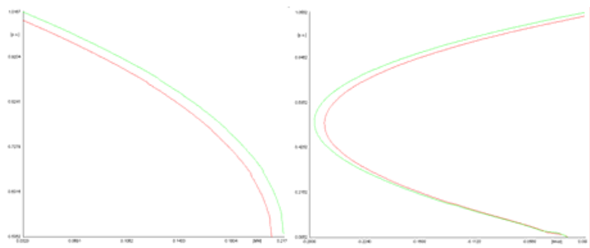
Simulation duration time is 1.5s. Earth fault happens in LV line 4, and time is 0.1s, switch off fault line4 time is 0.16s, and Output voltage of inverter is rated. So voltage of load 1 and 10kV bus is shown in Fig.5, where all loads have constant power, and power factor is 0.8.



(a) EMT voltage of Load bus 1 (p.u.)

Voltage of 10kV line

Voltage of line 1



(b) U-P curve (p.u.) (c) U-Q curve (p.u.)

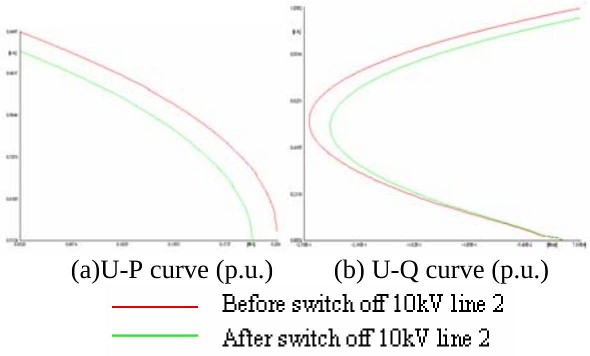
Before switch off line 4

After switch off line 4

Fig.6. Simulation Result1

Seen from Fig.6, after switch fault line4, boundary of voltage in load bus is creased, and system will keep stable. Earth fault happens in 10kV line 2, and time is 0.1s, switch off fault10kV line2 time is 0.16s, and Output voltage of inverter is rated. So voltage of load 1 and 10kV bus is shown in Fig.6, where all loads have constant power, and power factor is 0.8.

Seen from Fig.7, after switch fault 10kV line2, boundary of voltage in load bus is decreased.



(a)U-P curve (p.u.) (b) U-Q curve (p.u.)

Fig.7. Simulation Result2

3.2.2 load characters impact on voltage stability

With load ratio and power factor diversity, Fig.8 shows max voltage fall of load. Seen from it, larger load ratio results in more serious fall of voltage. At the same time, smaller power factor results in more serious fall of voltage. So when load throw-in, control load ratio and power factor can improve performance of system, keep protection un-action, and increase transient voltage stability.

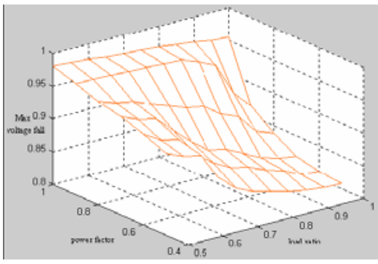


Fig.7 Relation between voltage deviation and PF of load

IV. CONCLUSION

Stand alone system small signal stability problem is different from that with synchronous generators, and it must be is investigated. The ratio of Resistance to reactance in LV&MV line is larger than that of HV line, which is $R/X \gg 1$. In this paper, the power – voltage formula is deduced and amended based on it. Then considering characteristics of load and operation condition of system a typical stand alone system is modeled and analyzed, which has a PV station and a SG. Then impact of ratio of load on stability is presented also. According to the characters and the problem of this system, a simulation case based in DigSilent is built. Conclusion is shown as follows:

1） The parameters of LV&MV are different from that of HV transmission line. It affects the power boundary. With the voltage of load increasing, power boundary increasing.

2） After switch off fault line of load, boundary of voltage in load bus is creased, and system will keep stable. After switch off fault 10kV line, boundary of voltage in load bus is decreased.

3） Capacity and power factor of load meets condition, voltage sag will be within permission. Regards to Bange system with 80% load ratio, load power factor has to be higher than 0.8.

REFERENCES

[1] Wu Ming, 2004, " Solar energy of China equal to ten thousands of Sanxia Project's electrical power ", *Population, Resource & Enviroment of China.* vol. 16, 65-65.

[2] Institute of Electrical Engineering, Chinese Academy of Science, 2001, *Acceptance Report of Bange PV station*, Beijing, P .R . China.

[3] Yang Xiuxia, Zhang Xiaofeng, 2004, "Present situation and developing trend of isolated power system restoration", *Realy*, vol. 19, 74-79.

[4] Liu Shu, Zhao Zhengming, 2005, "One-level photovoltaic grid-connected system based on an improved MPPT algorithm", *JOURNAL OF TSINGHUA UNIVERSITY(SCIENCE AND TECHNOLOGY*, vol. 45, 873-876.

[5] Vachtsevanos, G.J. Kang, H, 1989, 1989, "Simulation studies of islanded behavior of grid-connected photovoltaic systems", *IEEE Transactions on Energy Conversion*, Vol2, 177-183.

[6] Asiminoaei. L, Teodorescu. R, Blaabjerg. F, 2005, "A digital controlled PV-inverter with grid impedance estimation for ENS detection", *IEEE Transactions on Power Electronics*, Vol.20, 1480 -1490.

[7] Yu yixin, Wang Chengshan, 2001, *Power system stability theory and method*. Science Press, Beijing, P. R. China.

[8] P.P Varaiya, F.F.Wu, R.L.Chen, 1985, "Direct Methods for Transient Stability Analysis of Power Systerm Recent Results", *Proceeding of IEEE*, vol.73, 1120-1125.