A study on the Normal Steady State Operation Characteristics of PV System Based on the Test Device

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태양광전원용 시험장치를 이용한 정상상태 운용특성에 관한 연구

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Abstract-Recently the Korean government's green energy growth policy has been taken at the national level due to the sufficient supply of renewable energy. Some specific technique should be taken in consideration for the operation of the grid voltage and power quality management .In this case, there may have some chance of operational problems.Typical problems arise when grid-connected solar power produced by Pacific sunshine. The power flow in the reverse direction can create overvoltage on the distribution line and gives value of malfunction on the system. Line voltage and overvoltage adjustment practice can stop these symptoms occurred. Under these circumstances, this paper presents an interconnection test devices for photovoltaic(PV) systems composed of distribution system simulator, PV system simulator and control and monitoring systems using the LabVIEW S/W, and simulates the customer voltage characteristics considering the 3 parameters on the introduction capacity for PV systems, system configuration and Power factor. This paper also proposes a new calculation algorithm for voltage profile to make comparison between calculation values and test device values. The results show that the simulation results for the normal operation characteristics of PV systems which are very practical and effective.

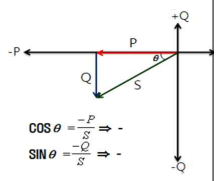
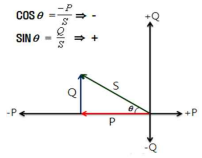
1. Introduction

Recent work in dispersed storage and generation (DSG) systems which would be connected to the distribution system has led to increased interest on the part of consumers and utility personnel in the operation of small generators in the distribution system. A PV system has been installed in a village named Mokcheon nearby Cheonan City in South korea ..In this Photovoltaic power generation system, by rising the flow and considering the reverse direction flow, it causes the overvoltage of 240V .In this paper, solar power distribution system with real time operating system has been discussed. The system operating characteristics has been analyzed and solar power test device has also been constructed. The initial steps has taken by introducing test device simulator and solar power distribution system simulator. Using LabVIEW software, control device can be monitored and configured. Three parameters such as solar power capacity, the simulated line/load,Power factor are needed for system calculation. The random variables can define by the operator to manually operate the device. This method is easy enough, but without a realistic simulation it has some disadvantage and that could not be implemented for distribution system.

2. Concept for voltage drop calculation algorithm using rectangular co-ordinate axes

Solar power drop has an effect on line voltage drop characteristics due to reverse power flow, so, voltage drop algorithm is required. In figure1 a basic

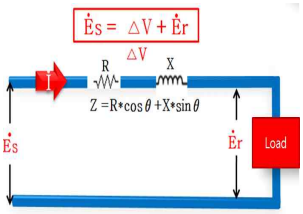
single-phase AC circuit can give the idea. Considering the

comparison condition	Load Capacity < Solar Power		
	Reactive Power factor for Capacitive load(-Q)	Reactive Power factor for Inductive load (+Q)	
Vectors			
Line condition	Rcosθ>0, Xsinθ>0	Rcosθ< Xsinθ	Rcosθ >Xsinθ
The voltage Drop	ΔV=I×(-Rcosθ-Xsinθ)	ΔV=I×(-Rcos+Xsinθ)	
Line Voltage	-ΔV (Voltage rise)	+ΔV (voltage drop)	-ΔV (Voltage rise)

line impedance Z=R+jX an equation can be established for voltage rise or fall .The voltage drop equation can be written as:

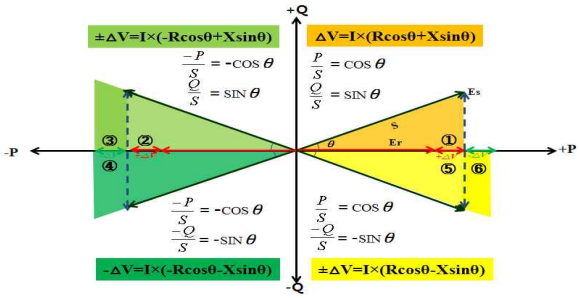
$$\Delta V=|Es|-|Er|=I(R\cos\Theta+X\sin\Theta) \quad (1)$$

Here ,Es and Er are the source and load side voltage respectively.The comparative magnitude of solar power capacity and load determines the positive and negative value of ΔV.



[Figure 1] Conceptual circuit for voltage drop.

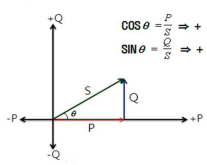
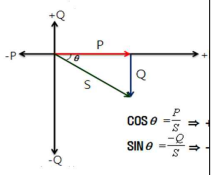
Distributed power flow can generate reverse flow . The current direction of the effective power and the reactive power can cause voltage drop as well as the rise of the voltage on the system. The forward and reverse flow of power depends on a factor called the power Factor (CosΘ). The inductive power (+Q) is positive in an inductive load circuit where the load phase angle is positive and the current is lagging the voltage. The reactive power(-Q) is negative in capacitive load circuit, where the load phase angle is negative and the current is leading the voltage. However, method of calculating the lagging or leading power factor is important . In the position of 1,2, 3, 4, coordinate vector must be in consideration and the need to calculate ±△v. The factor (cosΘ) and sinΘ can also calculate ,where Θ=tan-1(Q/P). Resultant voltage can be found by drawing complex vector diagram as shown in the following figure 2.



[Figure 2] Voltage drop co-ordinate axis

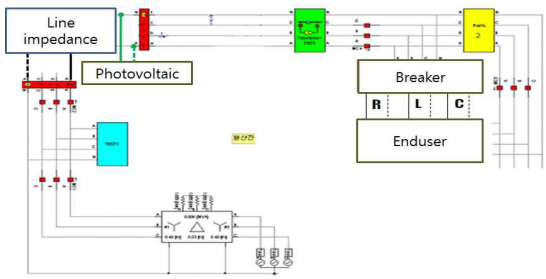
According to axis conditions as six cases, voltage rise (+△V) and voltage drop (-△V) can be easily calculate by the equation △V=I×(RcosΘ+XsinΘ).The mathematical reason for voltage rise or drop can be derived by considering the solar capacity and load capacity magnitudes in following Table 1.

[Table 1] Voltage drop-rise factors condition

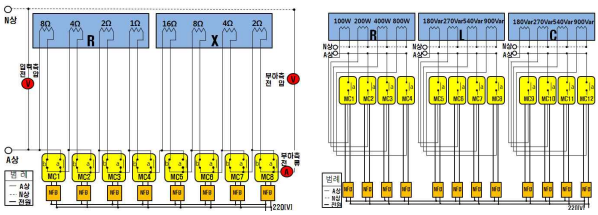
comparison condition	Load Capacity > Solar Power		
	Reactive Power factor for Inductive load (+Q)	Reactive Power factor for Capacitive load(-Q)	
Vectors			
Line condition	Rcosθ>0, Xsinθ>0	Rcosθ> Xsinθ	Rcosθ< Xsinθ
The voltage Drop	ΔV=I×(Rcosθ+Xsinθ)	ΔV=I×(Rcos-Xsinθ)	
Line Voltage	+ΔV (Voltage drop)	+ΔV (voltage drop)	-ΔV (Voltage rise)

3.Simulated distribution system test equipment concepts

A Simulated distribution system test device as shown the figure3 below. An isolated transformer of 380/220V with 3-phase-4 wire configuration system has designed .The each section of the track, the M /C and NFB operated as protective devices and switchgear in case of fault current detection.

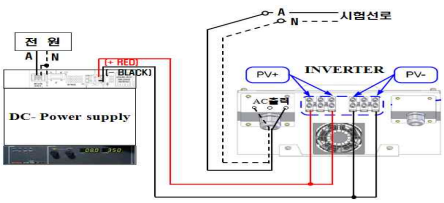


[Figure 3] Grid-Connected Photovoltaic system device



[Figure 4] Line and load control circuit diagram

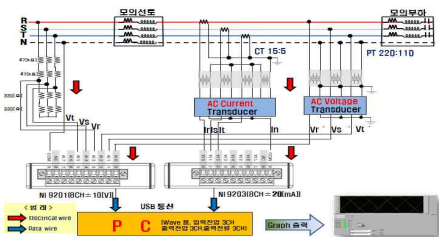
In the line control circuit simulated line impedance (R+jX) can be adjusted by the operations of M/C and NFB combination, R values and the value of X can changes 1~15 [Ω]. In the load control circuit different types of loads (resistors, inductors, capacitors) are adjusted by the combination of MC 100 [W] and NFB of 100 ~ 1500 [W].The inductor ,loads and capacitors are adjusted thus reactive power factor value varies 100 ~ 1,500 [VAR].The system consists Solar power inverter (3KVA) and the DC power supply (1,200 W).DC power supply output current has a variable range and this artificial solar power can be adjustable. DC power supply output voltage range is 400 [V] × current 3 [A] and capacity 300 ~ 1,200 [W]. This output has been fed to inverter as shown in the following figure 5



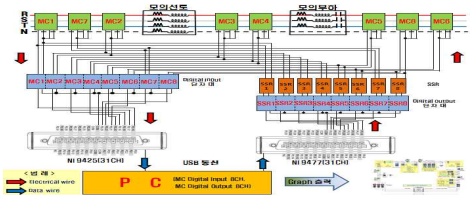
[Figure 5] The DC supply and inverter connection

4. Device Monitoring and control by LabVIEW software

LabVIEW software has intuitive graphical icons and flow charts to analyze a system device. An analog input device using NI9201 and NI9203 has been included on the system. Through LabVIEW a real-time voltage and current waveform can be obtained .The NI9425and NI9477 digital devices are used in this system ,a PC is linked to the solar system test device thus ,M/C control (On/Off) can be performed and monitored.



[Figure 6] Analog input diagram for LabVIEW analysis



[Figure 7] Digital Input and Output view in LabVIEW

4.1.. The Theoretical value compared to LabVIEW test

By collecting the average values, comparative analysis with the theoretical value can be performed by LabVEIW. An analysis of voltage fluctuations for test conditions are also proved by Lab VIEW . In the case of the load = 400 [W], line impedance =1[Ω],Solar Power=0 [W]. The calculation has done by the following Table 2

[Table 2] Load sideVoltage analysis (PV=0)

Theoretical value	comparison between Theoretical value RMS value
V(Main voltage side) : 221.1[V] P = I * V, 400 = I * 221.1, I = 1.81[A] R = 1[Ω], ΔV = I*R = 1.82*1 = 1.81[V] R = 1[Ω], ΔV = I*R = 0.45*1 = 0.45[V] R = 1[Ω], ΔV = I*R = 1.82*1 = 1.81[V]	● RMS value : number / voltage[V] 1 / 219.12 2 / 219 3 / 218.82

5. Comprehensive analysis of voltage fluctuations characteristics

By using the collected data, the comparison between LabVIEW and the theoretical can easily carried out. The lagging and leading power factor also associated with that matter. Numerical results for the voltage fluctuation test and comparison analysis showed the normal charac teristics. Another test conditions for heavy load power=400[W], line impedance=1[Ω], solar Power=1200W. This acceptable analysis of voltage fluctuations can also explain as below. Table 3 shows the results and the theoretical value for the test device. By the comparing result analysis, approximately 1% error rate occurs. So, no major problems have been identified.

[Table 3] Load side Voltage analysis (PV 1200W)

Theoretical value	Comparison between Theoretical and RMS value
V(Main voltage side) : 227.8[V] P = 400(Load) - 1200(PV) = -800[W] Q=0[VAR], S= $\sqrt{P^2+Q^2}$= 800[VA] Cos θ =P/S=800/800=-1 Sin θ =Q/S=0/800=0 Z = R+jX[Ω], = r*(-cos θ)+x*(sin θ) = (5*-1)+(2*0)=-5[Ω] P = I *(-cos θ) V, -800=I (-1)* 227.8 I = 3.51[A] △V=I*Z= 3.51*(-5) =-17.55[V] V(Load side) = 227.8 -△V = 245.35[V]	● RMS value number: 1 244.9[V], 2 244.8[V], 3 245.0[V] voltage[V]: 244.9[V]

In this case a particular overvoltage occurs ,when the solar power capacity increases, the threshold voltage of the inverter exceeds (253 [V]). In this time the inverter OVR action causes separation.In Table 4 it can be shown by introducing reactive load power as 180[VAR]. The inductive reactance power factor will increased. In other words, the power factor is acceptable according to changes in the customer side voltage 245 [V] to 239 [V].

[Table 4] Load side Voltage analysis (PV 1200W, lagging Power factor)

Theoretical Calculation	Comparison of Theoretical and RMS value
V(Main voltage side) : 223[V] P = 400(load) - 1200(PV) = -800[W] Q=180[VAR], S= $\sqrt{P^2+Q^2}$= 820[VA] Cos θ =P/S=-800/820=-0.976 Sin θ =Q/S=180/800=0.22 Z = R+jX[Ω], = r*cos θ +x*sin θ = 5*(-0.976)+2*0.22=-4.44[Ω] P = I * Vcos θ , -800=223*I (-0.976) I = 3.67[A] △V=I*Z= 3.67*(-4.44) =-16.295[V] V(Load side) = 223 -△V = 239.3[V]	● RMS value number: 1 242.0[V], 2 242.3[V], 3 241.7[V] voltage [V]: 242[V]

If the capacitive reactance of the line impedance is taken in consideration for reactive power 180 [VAR] then and the calculation can be represented as follows in Table 5

[Table 5] Load side Voltage analysis(PV 1200W, Leading Power factor)

Theoretical Calculation	comparison for Theoretical value and RMS value
V(Main voltage side) : 224[V] P = 400(load) - 1200(PV) = -800[W] Q=180[VAR], S= $\sqrt{P^2+Q^2}$= 820[VA] Cos θ =P/S=(-800)/820 = -0.976 Sin θ =Q/S=-180/820 = -0.22 Z = R+jX[Ω], = r*cos θ +x*sin θ = 5*(-0.976)+2*(-0.22)=-5.32[Ω] P = I*V*Cos θ , -800=I(-0.976)*224 I = 3.66[A] △V=I*Z= 3.66*(-5.32) = -19.47[V] V(Load side) = 224 -△V = 243.47[V]	● RMS value number: 1 241.7[V], 2 241.9V], 3 241.5V] voltage[V]: 241.7[V]

6. Conclusions

This paper proposed a grid-connected solar power system by constructing a test device .Three parameters such as power factor, simulated line-load and solar power capacity has been taken in consideration for voltage fluctuations .For the normal steady-state properties, the customer side voltage characteristics has analyzed. In addition, for an exact solution of the voltage drop calculations has been compared with test results. Important key findings are summarized as follows

(1) The load-side voltages increase proportionally to the solar power capacity. For increasing the over voltage in extreme cases ,PV power inverter exceeds threshold voltage (253V) and OVR action in the inverter caused the inverter to separate from lines.

(2) The voltage drop due to the inductive reactance, Lagging power factor has contributed for affected customers side voltage . Due to the inductive line impedance the main side-voltage 245V decreases to 239 V , in this time power factor determined the grid voltage quality [under voltage / overvoltage]

(3) The Leading power factor for capacitive reactance load caused voltage rise . In this case for leading power factor has been calculated for raising voltage 239V to 244V.So, power factor confirms that a significant factor.

(4) The length of the line impedance, load size and solar power capacity etc are the main factors to maintain a suitable customer side voltage characteristics .For the limits of solar power capacity special technical aspects should considered .In a real system voltage fluctuation problems can be solved experimentally and theoretically by the proposed method.

(5) In order to compare experimental and mathe matical concept about proposed algorithm, i.e the voltage drop calculation relating to solar power , values within 1% error rate in both case gives the usefulness of the proposed technique which has confirmed.

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