

Implementation Of Grid Connected Large Solar Farm

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Abstract

In modern era of time, the large solar farm are facing various problems in process of synchronization with the grid. This paper describes comparative study of synchronization process of large Solar Photovoltaic System (SPV) with the grid system. The grid and SPV system are coupled with the voltage source converter (VSC) followed by filter devices. To get maximum power from Solar Farm, Maximum Power Point Tracking Control (MPPT) is used. To synchronize the PV Farm (SPV) with the transmission system, a new control strategy is proposed in this paper. The proposed control scheme is performed with the test system in the MATLAB / SIMULINK environment.

Keywords

Solar Farm, MPPT, VSC, Active Power, Control Strategy

I. INTRODUCTION

The energy demand in India is continuously increasing which initiate to build up new power generating stations. However, the depletion of fossil fuels shifts the paradigm from the application of conventional energy sources to renewable energy sources for generating electricity [1]. It is been proposed to achieve installed capacity of 175 GW energy from renewable energy sources, including 100 GW from solar power plants by 2022 [1], [2]. The renewable energy sources includes solar and wind (Distributed Generators – DG) for generating electricity, ranging from several KW to hundred MW. Solar PV appears as a reliable; cost-competitive and sustainable electricity source. The solar rooftops and solar Farms are gaining importance in India. As a part of the green corridor project of India, the power lines would transmit 20 gigawatts of power capacity from 34 solar parks across 21 states [2].

The generation of electricity from solar farm is not constant during the all time of day. The PV energy is the function of PV irradiation and temperature, hence the generation is changed according to the condition. The semiconducting materials which are used to make PV panels affects the PV panel efficiency. Design of inverter mainly depends on the semiconductor switches like IGBT, GTO, MOSFET, and SCR for AC power generation. When connecting a large PV Solar system with utility grid Battery Energy Storage Systems (BESS) is not an economical solution [3]. Conventionally solar panels are connected with the inverter using DC – DC converter.

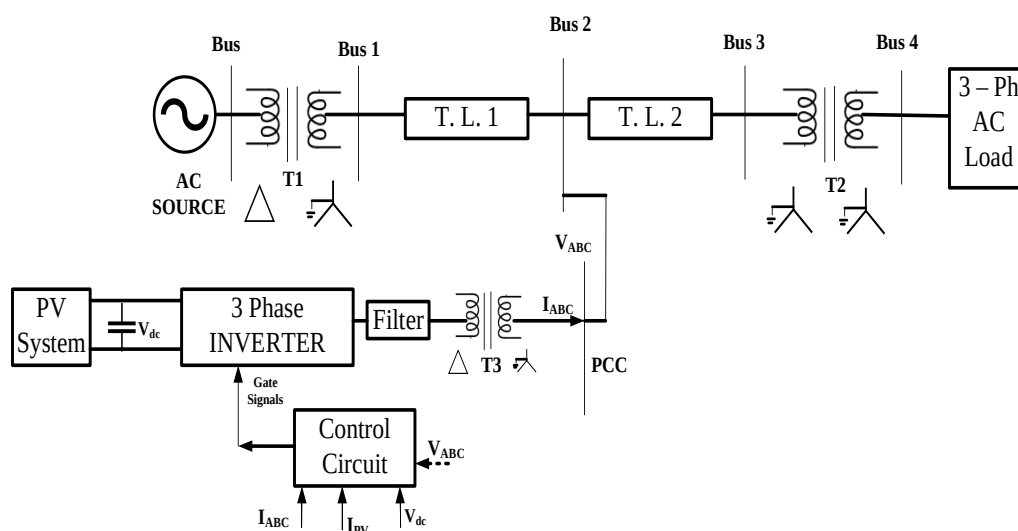
DC converter is used to step up or down the dc voltage level. It is used with MPPT controller to generate gate pulses for dc converter [3]. The integration of PV with grid using inverter is controlled by Power balance theory[PBT]. The templates are used for synchronization and power compensation [4]. Other technique is Synchronous reference Frame[SRF] theory in which Phased Lock Loop [PLL] is used for synchronization [5]. P – Q theory based control scheme do not employ PLL [6]. This technique is costly due to use of dc converter. From [3-8] there are several issues are addressed for grid connected PV system. Some of them are active power generation, voltage and frequency operating limits.

In this paper large PV solar farm is integrated with inverter without any types of dc converter. Due to change in atmospheric condition during day MPPT algorithm is implemented. The control technique for three phase inverter is SRF theory. The proposed control technique maintain unity power factor for the inverter during the all day for the various conditions.

II. SYSTEM DESCRIPTION

The single line diagram of the test system is shown in Fig. 1. It shows a large equivalent generator of 22 kV supplies the power to the 200 km, 400kV transmission line [7]. Here, a 100 MW PV solar farm is connected at the mid-point of the transmission line. Practically large solar DG needs several inverters but for analysis, the single equivalent inverter is considered. Transmission line TL1, TL2 are considered as lumped pi section. Other data is given in the appendix.

The bidirectional voltage source converter is considered as inverter with the DC capacitor. The MPPT technique, Perturbation & Observation is applied to for the PV system. Here DC converter is not used between



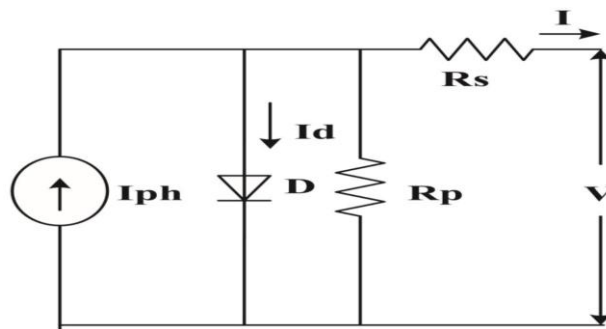
the solar farm and inverter.

Fig. 1 Block diagram of grid integrated PV system

A. PV-System model

The PV panels consists of photovoltaic cells that generate DC voltage. The photovoltaic technology includes PV cells which are connected in series and parallel to increase the voltage and current available from PV cells. Combination of such cells forms PV solar module. Series and parallel combination of PV modules form PV panel [3],[9]. Here only equivalent circuit of solar cell is shown in Fig. 2 .

Fig. 2 equivalent circuit of PV solar Cell



Output current (I) according to Kirchhoff's current law,

$$I = I_{ph} - I_D \quad (1)$$

$$I = I_{ph} - I_0 \left[\exp \left(\frac{V + IR_s}{V_t} \right) - 1 \right] \quad (2)$$

Module output voltage,

$$V^M = I_{sc}^M \left[1 - \exp \left(\frac{V^M - V_{oc}^M + R_s^M \cdot I^M}{V_t^M} \right) \right] \quad (3)$$

Where superscript M is representative of Module.

I_{ph} – Photo generated current

I_0 – Reverse saturation current

I_D – Diode Current

V_t - Thermal voltage of PV module

R_s – Series resistance

R_p – Parallel resistance

I_{sc}^M is the current of short circuited module ($V^M=0$) and V_{oc}^M is the voltage of open one ($I^M=0$).

B. MPPT Technique

As the maximum power operating point (MPOP) of photovoltaic (PV) power generation system changes with changing atmospheric conditions (e.g. solar radiation and temperature). It is used to get maximum power from the PV cell at different conditions. Although the efficiency of this MPPT algorithms is usually high, it drops noticeably in cases related to rapidly decreasing atmospheric conditions[3],[10].

Here Perturbation & Observation (P & O) type MPPT algorithm is employed which is shown in Fig. 3. In the first case, there is a operating point displacement due to perturbation from n-1 to n that leads to $P(n) > P(n-1)$

and $V(n) > V(n-1)$. Increment of generated power after perturbation indicates that the Maximum Power Point (MPP) search is oriented in the right direction, so searching MPP continues in the same direction and V_{Ref} is increased by dv . In the second case, operating point displacement occurs after perturbation and lead to $P(n) < P(n-1)$ and $V(n) < V(n-1)$. Power decrement after perturbation indicates the wrong direction of MPP search, so MPP search direction must be changed and V_{Ref} increased by dv . Operating point Displacement with $P(n) > P(n-1)$ and $V(n) < V(n-1)$ constitutes third case. Increment of the power after perturbation indicates that the MPP search is oriented in a good direction. Therefore, the MPP search direction should be maintained and V_{Ref} decreased by dv . Fourth case is considered by displacement of the operating point after the perturbation from $n-1$ to n with $P(n) < P(n-1)$ and $V(n) > V(n-1)$. The power decreased, so MPP search is oriented in wrong direction and V_{Ref} must be increased by Δv .

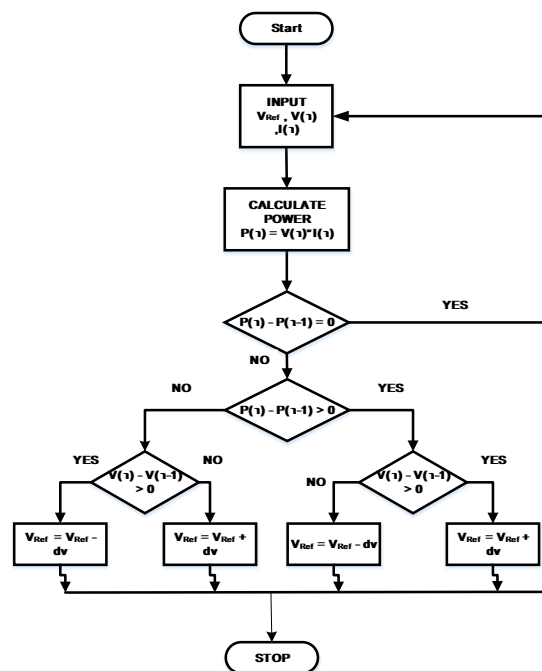
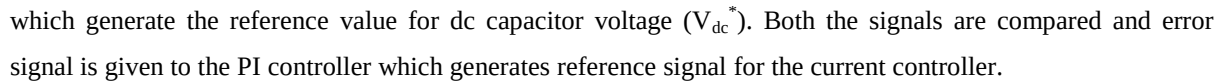


Fig. 3 Flowchart of P & O method

C. Control Strategy

The control scheme implemented for the VSC is Synchronous Reference Frame theory. Here the VSC is works on on Unity Power Factor (UPF) scheme with PLL to synchronize the PV system with grid and maintain system within acceptable limits[11]. Three phase voltage (V_{ABC}) and current (I_{ABC}) measured at PCC are converted into dq0 component according to park transformations (V_{dq0} , I_{dq0})[11]. Here the synchronous rotating frame is 90 behind to the grid source voltage so $V_q = 0$. The operation of VSC at UPF supply only active component of power to the grid. The reactive power supplied by converter is zero.

Here dc converter is not used so, capacitor voltage is maintained constant according to Fig. 4. For capacitor voltage regulation measured value of capacitor voltage (V_{dc}) and output current from PV is given to MPPT



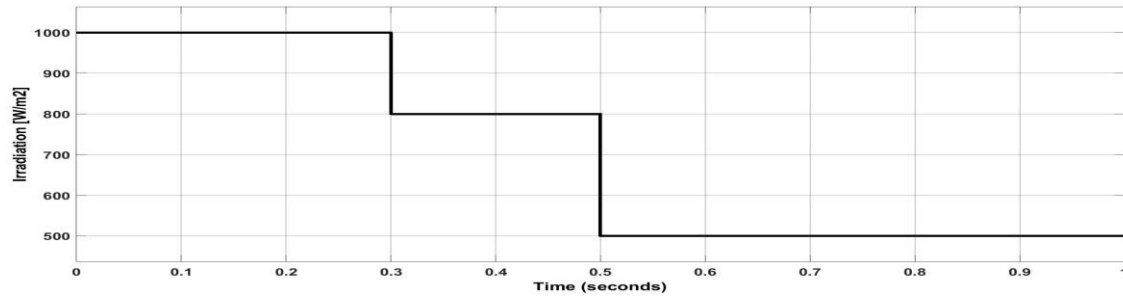
(5) Initial reference value for the dc capacitor voltage(V_{dc}^*) and capacitance for 100 MW solar farm is given by

Where

 I_{VSC_RMS} - RMS value of VSC's current

Fig. 5 Current Controller

$$V_{VSC} = m (V_{dc}/2) \quad (6)$$



III. Results

For the test system, the AC power and supplied current given by PV farm to the transmission grid is measured at the PCC bus. First the ideally at normal condition Irradiation level is 1000 W/m^2 and temperature is 25°C . According to the Fig. 6 irradiation level is changed at constant temperature at 25°C . From $t=0.1\text{s}$ to $t=0.3\text{s}$ irradiation is 1000 W/m^2 and temperature is 25°C AC active power supplied at PCC is 93.68 MW and reactive power is zero is shown in Fig.7.

Fig. 6 Irradiation Level

At this condition generator supplying power active power is 670.70 MW and reactive power is 198.20 MVar. It is shown in Fig. 8. The mid point powers are 754.40 MW and 171.55MVar. The load end powers are 742.52 MW and 133.46 MVar.

Fig. 7 AC Power Supplied by PV at PCC

Fig. 8 Power comparison at different ends

Now from $t = 0.3s$ to $t = 0.5s$ irradiation is changed from 1000 to 800 W/m^2 so active power supplied by PV VSC is changed to 76.18 MW . According to that generator output is also increased to 688.39 MW and 200.60 MVar but there is a little change in reactive power. The mid point and load end powers are almost same as previous values. From , $t = 0.5s$ to $t = 1s$ irradiation level is changed from 700 to 500 W/m^2 so active power supplied by PV VSC is decreased and set at 47.85 MW . Generator supplies 716.32 MW and 203.42 MVar .

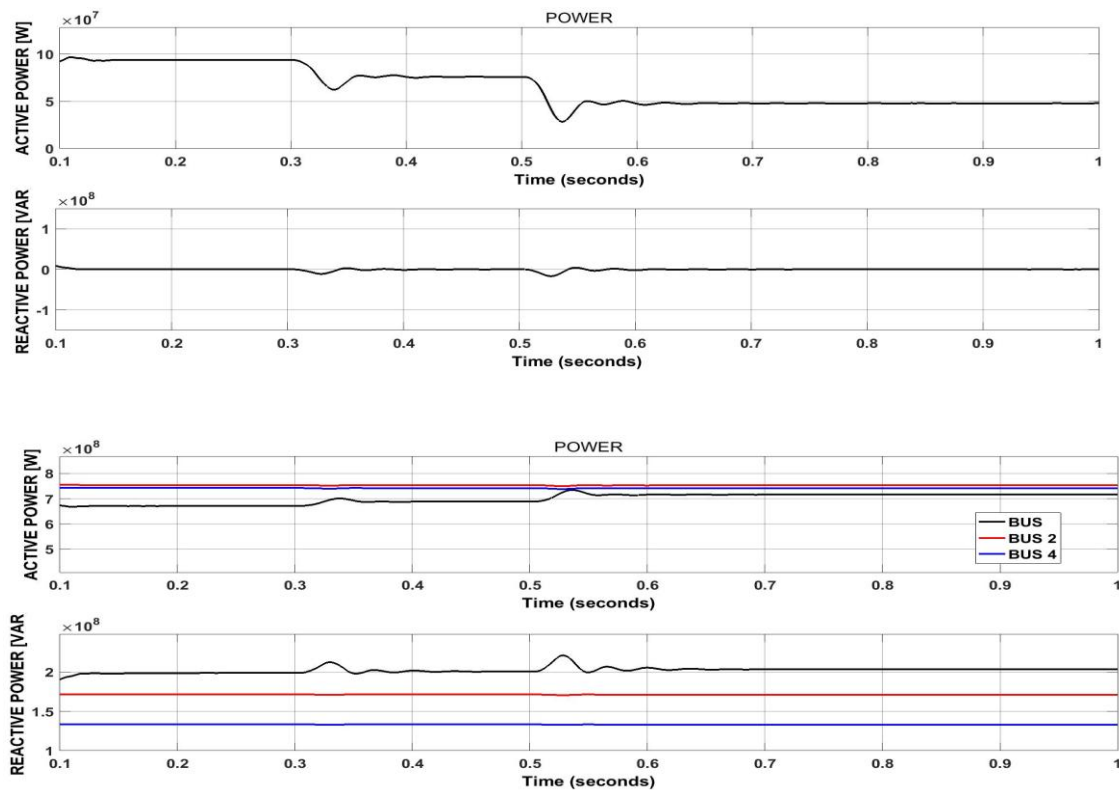
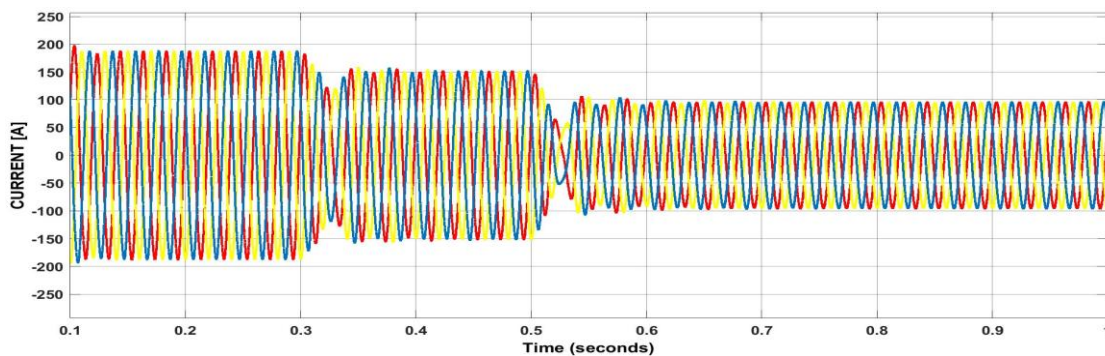


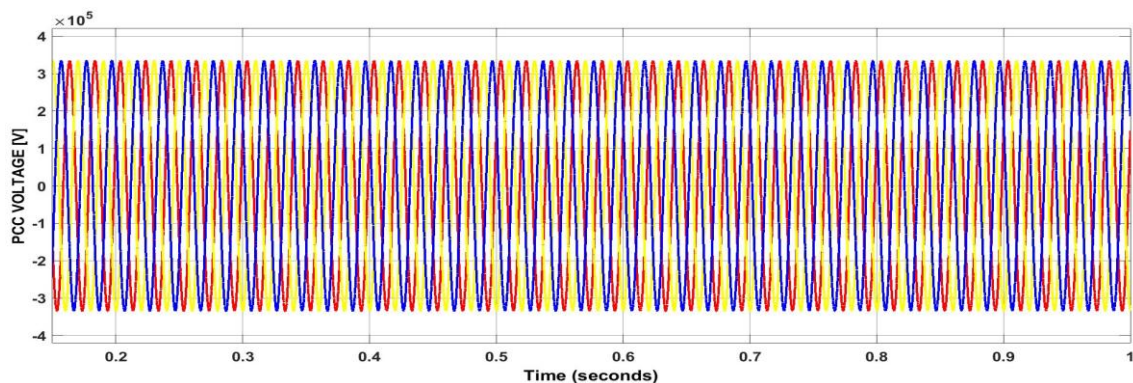
Fig. 9 shows the supplied current from PV converter which is measured at PCC bus. According to irradiation level the output current is change. In Fig. 10 shows the supply voltage at PCC and voltage fluctuation is within limit under $\pm 5\%$ shown at normal operation and changing level of irradiation. The all mechanism, PV with VSC is shunt connected so current level is changed according to condition but it supply constant voltage.

Fig. 9 Current Supplied at PCC

Fig.10 Supply voltage at PCC



When PV is not connected to grid generator supplies power 763.838.25 MW and 208.36 MVar. The



load end power is 739.99 MW and 132.98 MVar. The variable ac load condition of transmission line is shown in fig.11 and its corresponding power at different buses are given in table 1. The ac power supplied by PV VSC is 93.80 MW at irradiation 1000 W/m^2 and temperature is 25°C constant so there is no change in values is shown in Fig. 12.

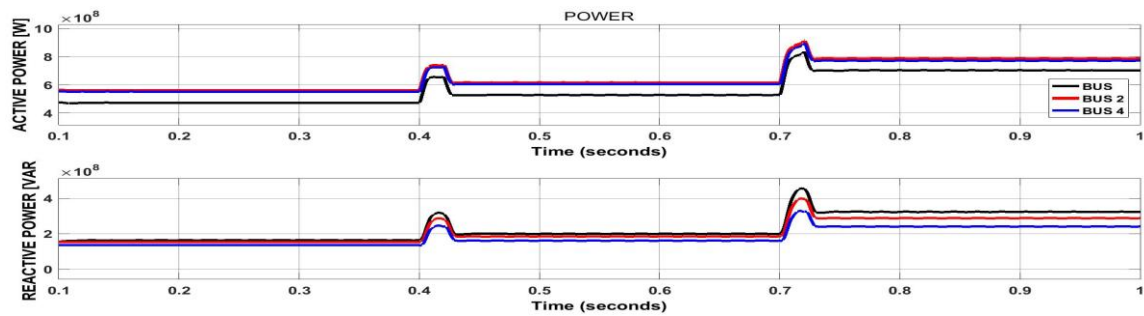


Fig. 11 Variable AC load condition of transmission line

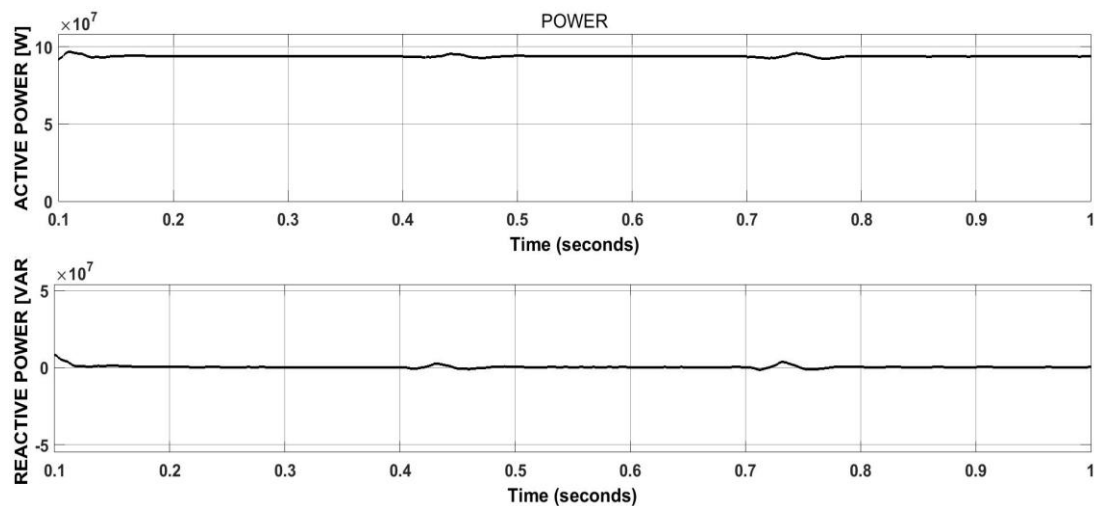


Fig. 12 AC power supplied by PV – VSC at PCC

Table 1

Time (s)		0.1 to 0.4	0.5 to 0.7	0.7 to 1
Generator end power	Active power (MW)	472.55	528.50	704.20
	Reactive power (MVar)	163.38	200.60	323.39
Power supplied by PV-VSC	Active power (MW)	93.90	93.85	93.83
	Reactive power (MVar)	0	0	0
Mid point power	Active power (MW)	560.1	614	786.30
	Reactive power	154	185	288.50

	(MVar)			
Load end power	Active power (MW)	551.80	605	772.45
	Reactive power (MVar)	136.20	160.90	241.49

IV. Conclusion

In proposed strategy large PV farm can be connected to grid. In this strategy PLL is used for grid synchronization of PV. It fulfills the criteria according to IEEE Std. 1547.5. The power supply from DG to the grid is reliable and smooth at different irradiation and loading condition. Active Power generation from PV is decreased according to condition so reactive power generation from generator is increased to fulfill the transmission line reactive power losses at various loading conditions.

APPENDIX

Generator [AC Source]	$V_{L-L} = 22 \text{ KV} ; f=50 \text{ Hz}$
Transformer 1 [T1]	$S = 1110 \text{ MVA}; V_1 = 22 \text{ KV} , V_2 = 400 \text{KV}; f= 50 \text{Hz}$
Line 1 & Line 2	Line 1 Length =100 km; Line 2 Length =100 km; $f= 50 \text{Hz}$ $r_1 = 2*0.01273 \text{ohm/km}$ $r_0 = 0.386 \text{ohm /km}$ $l_1 = 0.4*10^{-3} \text{ H/km}$ $l_0 = 4*10^{-3} \text{ H/km}$ $c_1 = 2*10^{-9} \text{ F/km}$ $c_0 = 2*10^{-9} \text{ F/km}$
Transformer 2 [T2]	$S = 1110 \text{ MVA}; V_1 = 400 \text{ KV}; V_2 = 230 \text{KV}; f=50 \text{Hz}$
Transformer 3 [T3]	$S = 50 \text{ MVA}; V_1 = 400 \text{ KV}; V_2 = 400 \text{V}; f=50 \text{Hz}$
AC Load	$V_{L-L} = 230 \text{ KV}; f= 50 \text{Hz}$
Converter	$S = 100 \text{MVA}$ Carrier Frequency = 5 kHz
PV SYSTEM	Power = 100 MW
1 Module Data	$P_{\max} = 345.043; V_{oc} = 46.7 \text{ V}; V_{\max} = 38.9 \text{ V}$ $I_{sc} = 9.142 \text{ A} ; I_{\max} = 9.142 \text{ A}$
	Cells per module = 72 Series-connected modules per string = 20 Parallel strings = 14490

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