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Prospects and Implementation of Solar Energy Potential in Pakistan: Based on Hybrid Grid Station employing Incremental Conductance technique

Muhammad Hamza Latif [1*], Ayesha Aslam [2], Tahir Mahmood [3]

[1] Department of Electrical Engineering, University of Engineering and Technology Taxila, Taxila, 75290, Pakistan

[1*] m.hamzalatif01@gmail.com

[2] ayeshawajihaaslam18@gmail.com

[3] tahir.mehmood@uettaxila.edu.pk

Abstract: Due to the conventional sources getting scarce over time, the trend of relying on conventional energy sources is changing. In Pakistan, an exponential increase in the power demand has been recorded over last two decades leading to a demand and supply gap. Currently, shedding of load is one of the methods used to counter this problem. Developed countries have long been using solar energy on mass level for generation but in third world countries like Pakistan, the use is still on domestic household level mostly. To eradicate the power shortage, conventional single source grid is not enough. An upgradation to the system is required in the form of source hybridization on distribution sub-station level employing PV. The paper presents a model of hybrid distribution substation designed on MATLAB Simulink based on Incremental conductance technique for implementation and reviews the potential and scope of solar energy in Pakistan. The model is designed for a pre-existing distribution substation present in Rawalpindi. Results of the paper will help understand the scope of solar energy in Pakistan and hybrid distribution substation design

Keywords: Hybrid Grids, MPPT, PV Grids.

I. INTRODUCTION

Pakistan is going through the worst energy crisis in its history with the current deficit of 4500-5000 MW in energy [1]. This demand will touch the figure of 50,000 MW by 2022. Hence, incorporation of solar energy in the power system is the need of the time [2]. Across the world, renewable energy sources are considered as a new way forward in Power Generation due to their emergence as a replacement for conventional generation, reducing the cost factor [3].

The solar energy is now contributing almost about 20-25% of the world's energy demand and has witnessed a growth due to decreased cost and increased efficiency of the PV panels [4]. Pakistan is a country having rich solar insolation having about 3000-3300 hours of average sunshine per year [5]. Solar energy harvesting is feasible in all 12 months. With the average annual solar Irradiation in the range of 5-7 kWh/m^2 and Irradiance average between 800-1200 Watt/m^2, taking into consideration all the technical constraints, Pakistan has a solar potential of 2.9 Million MW [6] [7].

The government of Pakistan is taking steps in order to insure the harvesting of Renewable energy [8]. The provinces of Sindh, Baluchistan and Punjab falls in this optimum range alongside some regions of KPK. On provincial level, Punjab and Baluchistan are amongst the two provinces setting up PV for electricity generation to run the tube wells in Punjab and provide electricity to remote rural areas of Baluchistan that are not feasible to be connected to national grid [10]. Figure 1 represents the solar radiation mapping across the Pakistan for winter and summer. As per STC, the tilt solar irradiation is optimum in the range of 5.0- 8.0 Kwh/m^2.

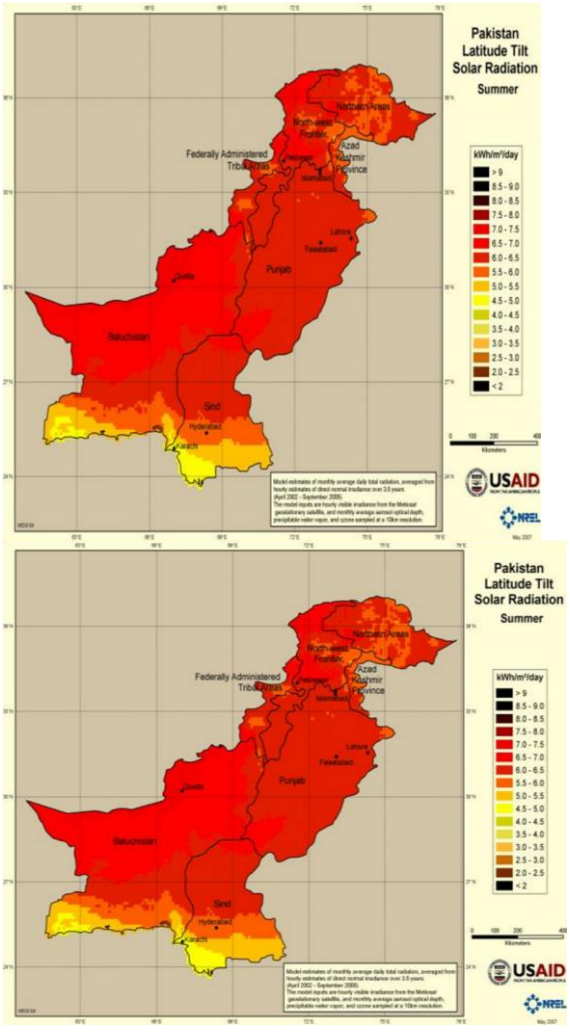

Figure. 1 Solar Radiation Maps of Pakistan [9]

II. PRESENT SITUATION AND FUTURE PROSPECTS OF SOLAR ENERGY IN PAKISTAN

Alternate energy development bureau (AEDB) in the year 2010 has been given the mandate by government of Pakistan to exploit renewable energy resources especially solar energy [1]. Annual report of Punjab energy department indicates the interest of private investors in the field of solar energy. Quaid-e-Azam solar power park is a landmark 1000 MW solar PV generation project in southern Punjab that will be constructed in phases and has already added 400MW to the system [11]. This increased interest is due to the tax exemption given by AEDB on PV panels import. From the year 2007 to 2017, an overwhelming 71 percent increase in import capacity is recorded shown in Fig.2

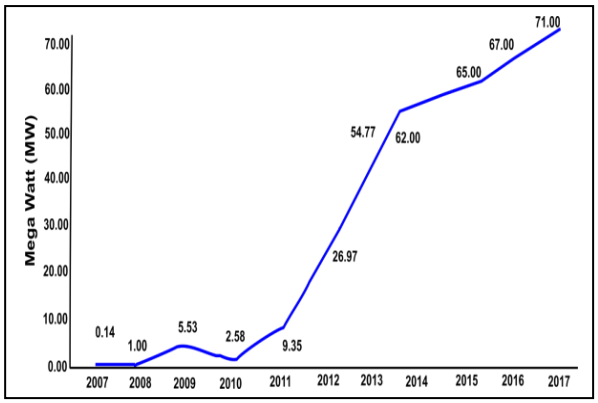

Fig.2 Increase in PV import in Pakistan from 2007-2017 [11] [12]

In the last few years, PV-Grid Integration phenomenon is employed and is considered as a stable one to use for the power system. At Pakistan Engineering Council and Planning Commission, 178 KWh grid connected solar PV parks have been established by the federal government in co-operation with the grant provided by Government of Japan for the implementation of cleaner energy [13].

Table 1. Salient aspects of PV system installed at planning Commission and Pakistan Engineering Council [14].

Characteristics	Planning Commission	Pakistan Engineering Council
Place of Installation	Over Parking Roof	Over a Green Belt Park
Installed PV Capacity	178KW	178KW
Voltage at Grid tying.	400V	400V
Installed Equipment's	PV Panels, Displaying Panels, Systems for data collection	

The government of Pakistan and AEDB are in collaboration with International organizations like JICA and USAID to exploit the maximum solar potential in Pakistan.

Table 2. Existing projects installed with international collaboration.

Project Name and Nature	Capacity	Implementing Organization	Donor
Clean Energy in Pakistan (Grid Tied)	356 kW	PC and PEC	JICA
Solar Pumps (Stand Alone)	4,795 MW (Under Process)	Solar Energy International (US) in collaboration with NUST	USAID
Irrigation and Water Drip Tech (Stand Alone pumping)	Under Process	ZTBL	M/S Shaanxi (China)

In addition to this, the provincial and federal governments both are seeking towards the public-private partnership to promote the solar harvesting. IPPS are very much keen to explore the solar energy resources. Reports by AEDB states that 21 IPPS have signed the LOI with Government of Pakistan of around 400 MW solar parks around the country and expressed it as good omen towards green energy.

Table 3. Projects under Planning and Feasibility phases with private partnerships [16]

Name of Organization	Project Capacity in MW	Location of Implementation
M/S Integrated Power Soln.	50 MW	District Bahawalnagar, Sindh Location: Dharanwala
M/S Jafri Associates	48 MW	District Jamshoro, Sindh Location: Nooriabad
M/S Blue Solar.	50 MW	District Jamshoro, Sindh Location: Nooriabad
M/S Integrated Power	50 MW	District Jamshoro, Sindh Location: Nooriabad
M/S Act Solar	49 MW	Province: Sindh

M/S ET Solar	50 MW	District Attock, Punjab Location: Fateh Jhang Road
	25 MW	District Thatta, Sindh Location: Gharo
M/S Sadiq Energy	45 MW	District Chakwal, Punjab Location: Chakwal
M/S Renewable Energy Solar I & 2	40 MW	Location: Dadu, Sindh

The Government of Pakistan has planned to meet the energy demands by the year 2020 and by year 2030, to start shifting the generation load from costly conventional methods to renewable generation. Fig. 3 depicts the Energy Vision 2030 [15].

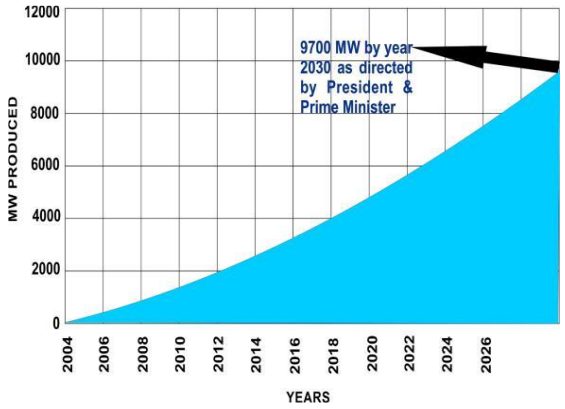

Fig 3. Long Term Renewable Energy Development Vision 2030 [15]

III. EXPLANATION OF THE DESIGNED HYBRID DISTRIBUTION SUBSTATION

Hybrid distribution substations tend to have improved reliability than the single source conventional distribution substations. Renewable energy resources as a backup to the prime source proves to be vital in providing backup to the system to avoid complete breakdown. SAIDI (The System Average Interruption duration Index) is the prime parameter to measure the reliability of a power system [17]. An improvement of 2.1% is achieved in the existing SAIDI figures using PV as secondary source in Hybrid Grids [18].

A comparison between the proposed technique for the design of Hybrid distribution substation that is Incremental conductance to achieve Maximum Power Point (MPP) to Perturb and observe is made on STC. The Incremental conductance algorithm developed is superior to Perturb and Observe. In Incremental Conductance, stable MPP is achieved while in Perturb and Observe, MPP fluctuates fairly than going for stability.

Table 4. Comparative Analysis of Perturb and Observe and Incremental Conductance

Technique	Promptness	Difficulty	Reliability
Inc. Cond (Digital Only)	Medium	Moderate	Medium
P&O (Digital Only)	Slow	Moderate	Low

Incremental conductance also tends to show greater reliability in comparison to perturb and observe [16]. The comparison between two techniques is based on the reliability, implementation level and speed to achieve MPP.

The designed hybrid source grid connected system consists of solar panels, DC-DC boost converters enabling the PV panel voltages to adapt maximum power that's driven by Incremental conductance Algorithm to achieve maximum power point, 3 level bridge inverter controlled by VSC for DC-AC conversion and step up transformer to feed in the grid on working voltage.

A. Geographical Location and Layout of the Simulated Solar Park

The Hybrid Distribution Substation is an upgradation case study of 132KV distribution substation located in Rawalpindi Chaklala Garrison Grid Station. The 500KW solar park is designed in MATLAB Simulink for the Installation at Quaid-e-Azam College Chaklala. The site is opted due to availability of land and also due to less hindrance to solar Irradiance. The site is located at Latitude 33.6" N and Longitude 73.07"E. The winter sunshine estimated at the site is 7 hours/day in winters and 9.2 hours/day in summers [12]. The average tilted solar Irradiation on the site is recorded as 5.23 Kwh/m^2 and Irradiance to be 1000 Watt/m^2 that lies in the optimum window set by STC standards. The solar park is designed for power generation of 500 KW that will occupy 7 acres of the land. The solar panels will be Rack Mounted to save the cells from damage. Each module has 72 cells with 23 series connected modules per strings having a total of 130 parallel strings. The rated efficiency of the PV panels is 17%.

IV. MAXIMUM POWER POINT TRACKING (MPPT)

Due to the change in solar irradiance due to weather conditions, initially PV energy sources were considered as a secondary option for power generation. The weather constraint held back PV development for many years [18]. Maximum power point tracking is technique that optimizes PV panels in order to maximize the

power extraction under carried conditions. MPPT controllers actually tracks down the output voltage to the nominal voltage required at demand end [16]. Maximum power point doesn't lie on a fixed point but rather changes is its position around the P-V curve depending upon the temperature and intensity of light falling on it. Direct and indirect both techniques have been in use to achieve maximum power point. Generally Incremental conductance is preferred over Perturb and Observe as in the later technique, a continuous fluctuation around maximum power point exists especially in changing weather conditions. Also, it has slow response and takes more time to track maximum power point.

A. Incremental Conductance Algorithm for MPPT

Incremental conductance is a preferred technique due to its reliable and improved performance under different climatic conditions. The key point in incremental conductance algorithm is the comparison of PV power (recent) with PV power (previous). The PV power is calculated by measuring the voltage and current. When the difference is calculated to be non-zero between recent and previous, the algorithm will shift left or right in order to find the optimal point on the curve. In case the difference is zero, maximum power is obtained. Incremental conductance is implemented using boost converter that adjusts the duty cycle of PWM. The duty cycle is adjusted so that the maximum power point is achieved. Algorithm is based on following equations [18].

$$\frac{dp}{dv} = \frac{d(VI)}{dv} \quad (1)$$

$$I\frac{dv}{dv} + v\frac{dI}{dv} \quad (2)$$

$$\frac{dp}{dv} = 0 \quad (A)$$

$$i + v\frac{dI}{dV} = 0 \quad (1')$$

$$\frac{-i}{v} = \frac{dI}{dV} \quad (3)$$

By analyzing the above system of equality based on the Algorithm in the flowchart presented in fig. 4, it can be easily determined whether the photovoltaic array used is at the MPP, above it or below it and once determined, steps to regulate are taken to bring back the PV array to maximum power point.

The ratio of differential change of power with respect to differential change in voltage will be greater than zero when the operating voltage of the simulation is less than the voltage that is required for it to be at maximum power point stage. Similarly, the ratio of differential change of power with respect to differential change in voltage will be equal to zero when the operating voltage is equal to the MPP voltage that is the voltage at maximum power point stage. And lastly the ratio of differential change of power with respect to differential change in voltage will be less than zero when the operating voltage is greater than the MPP voltage.

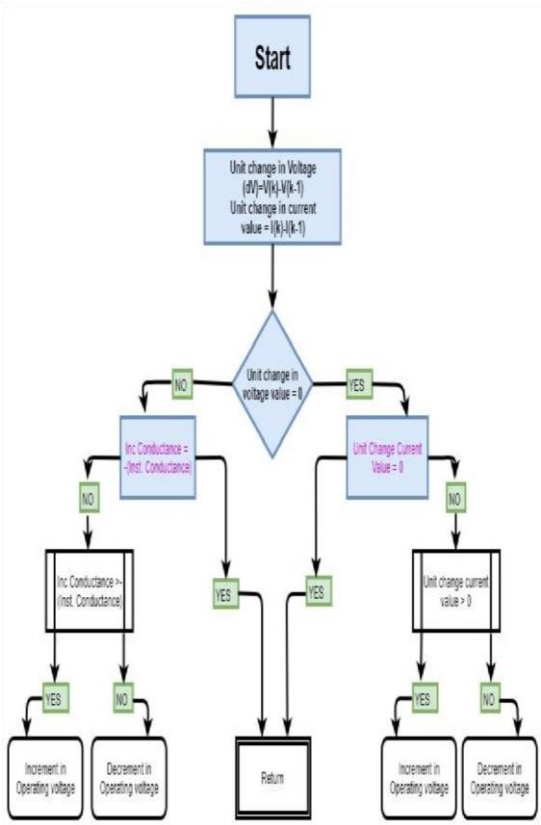

Figure 4. Incremental Conductance Algorithm [18]

V. SYSTEM CONFIGURATION

The configuration system of the hybrid distribution substation employs PV as an additional source to the conventional one. PV panels are attached to the boost converters which regulates the DC output from unregulated state through PWM which is generated by the MPP controller based on Incremental Conductance Algorithm.

The designed system contains:

1 An array of PV panels delivering 500KW maximum at average irradiance of 1000 Watts/m2 with a boost converter of 5-KHz increasing natural voltage of PV to 500 Volts DC.

2 An MPPT controller employing 'Incremental Conductance' technique.

3 3 level- 3 phase converters to converter the output 500 Volts DC obtained from PV to 260 Volts AC and a Utility Grid a 33-kV distribution feeder with a 132kV connected transmission line.

A. PV

Sun Tech STP-270 Module is employed in simulation. For the PV panels used in industries or for the development of Solar Park, the peak efficiency of the solar panel ranges from 9%-20% depending upon the nature and the material of solar panel. The model of Sun tech PV panel has a rated efficiency of about 17.92%. Figure 5 indicates that with the change in the value of solar irradiance, the output voltage and current varies.

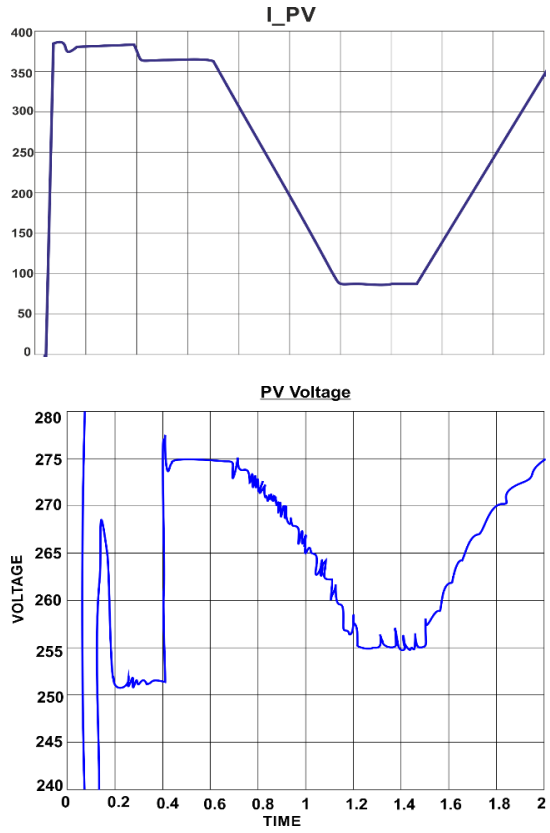

Figure 5. Output Voltage and Current with PV Array

B. DC-DC Boost Converter

Boost converter is the most important part of the system being the main controller of the Unregulated DC input from the PV Panels shown in fig. 6

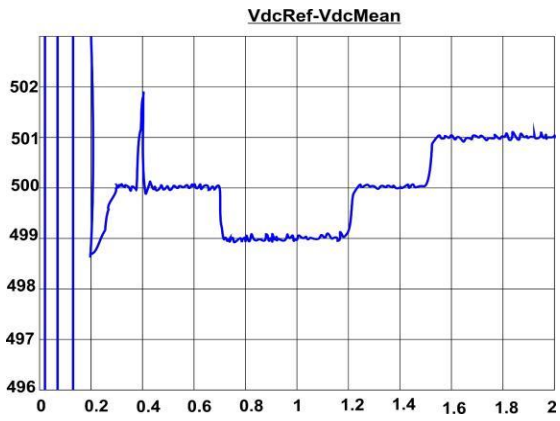

Figure 6. VdcRef – Vdc Measured

It boosts voltage level from 273.5V to 500V. Duty cycle of the Boost converter is generated by the MPP controller designed. The switching device used in the simulation is Insulated Gate Bi-Polar Transistor (IGBT). The output waveform represents that the modulation index keeps on shifting to ensure successful tracking of desired voltage level.

C. DC-AC Inverter

The DC-AC inversion is done through the three level bridge block which has been incorporated in the simulation. The switching devices incorporated in the three level bridge is the insulated gate bipolar transistor. Along with these switching devices, anti-parallel diodes are also connected as well as two neutral damping diodes whose main function is to clear out any irregularities or spikes in the output voltage. Inverter topology comprises of switching devices in series connection. The aim of this inverter is to switch the DC obtained into AC having three levels. This three level formation ensures sinusoidal waveform.

D. Utility Grid

The utility grid is modeled by a feeder, three phase source and a grounding transformer. The distributed line parameters are modeled using a 1.5km feeder. Voltage from the lines is then fed into the 3 phase 47MVA transformer with a nominal frequency of 50Hz. It is used in delta – wye grounded configuration. This is a step up transformer increasing voltage levels from 33kV to 132 kV. Fig 7a represents Voltage and Current profile along the grid and 7b shows output power. The change is due to changing irradiance.

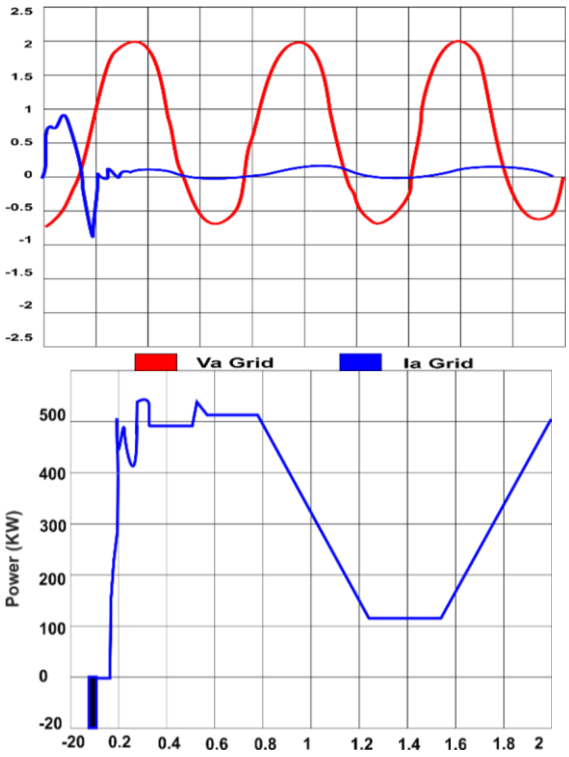

Figure 7a. Voltage and Current Profile (Va Grid, Ia Grid), 7b. Power Waveform

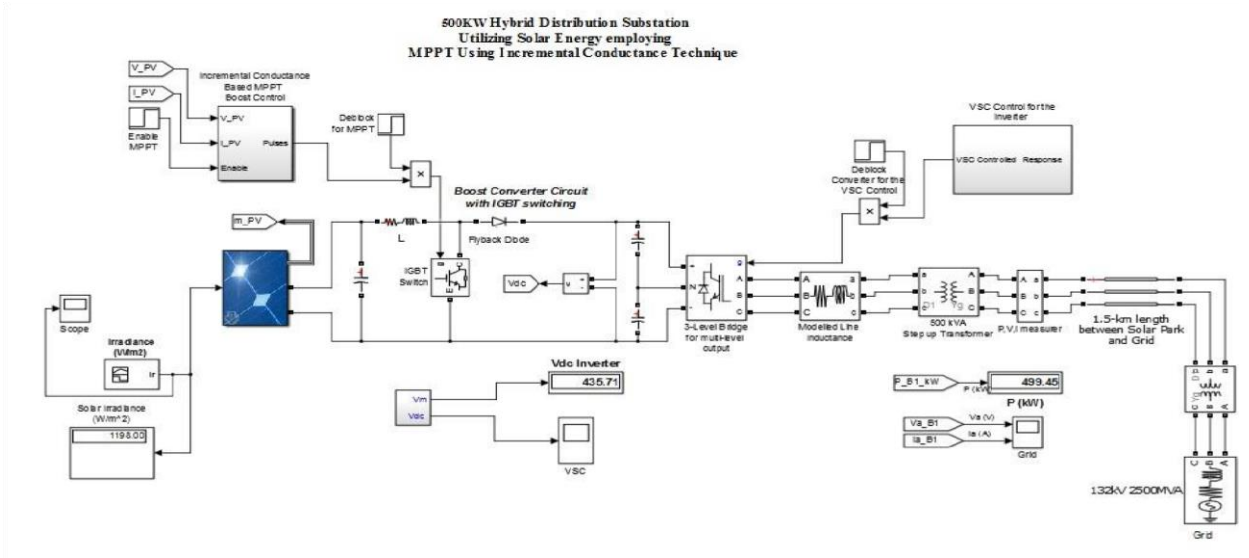

Figure 8 PV Connected Hybrid Distribution Substation Model

VII. CONCLUSION

A Grid Connected PV distribution substation is designed and successfully executed that is confirmed by the simulation results achieved by MATLAB. The setup efficiently employs MPPT controller to increase the efficiency of the system. By this method, maximum power is being tracked from PV system that is supplied to the grid. The paper presents about solar potential in Pakistan and possible implementation of hybrid grid that is need of the hour in this scenario of power crisis employing renewable energy resources.

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