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PV Powered DC System for Protection Control and Monitoring (PCM) in Sub-Stations

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Abstract: **Energy demand is growing rapidly day by day and to meet this ever increasing energy demand, the dependence on the conventional energy sources is increasing which is resulting in the pollution, green house effect and global warming. About 80% of world's energy demand is dependent on conventional sources of energy [1]. DC power supply is required for protection, control and monitoring (PCM) system in the electric substations. In this paper, a PV based DC system has been proposed for catering the DC Power demand of the protection control and monitoring system in electric sub-stations. Hybrid configuration having solar and grid power is assumed. In the present work, the study of a 220/33 kV electric sub-station located at "Masjid Moth Delhi, India" has been carried out. DC Load and solar resource assessment has been done for the site under consideration and the socio-economic parameters, a techno-economic study is carried out. The results show that the PV based DC system for protection, control and monitoring (PCM) system in the electric substations has huge potential and offers advantages of renewable energy integration, GHG mitigation.**

Keywords: **Protection control and monitoring (PCM), Solar PV system, Load assessment, solar resource, techno-economic study, emission mitigation.**

I. INTRODUCTION

To meet the ever increasing power demand and the concern of global warming have drawn the focus of whole world towards the renewable energy sources. Renewable energy sources like solar, wind, hydro, biomass are considered to be almost free from CO_2 emissions. However, some CO_2 emissions are also associated with all renewable sources on account of its production , manufacturing of equipment, waste disposal, recycling, etc [1] . Renewable energy sources are freely accessible rather than the conventional source of energy which needs to be extracted. Solar power is one of the most preferred renewable source of energy as it is abundance , free and clean , noise and pollution free, low operation and maintenance cost . Solar energy has various industrial applications which can broadly be classified into solar thermal and solar photovoltaic categories. Improvement in the efficiency of the Solar PV cells, decrease in PV module cost and increase in life expectancy of system has made solar PV as one of the favorable renewable energy sources during last decade [2]. As per IEA, 2010 [2], total PV capacity is expected to rise to 872 GW in 2030 from 27 GW in 2010 as shown in Figure 1.

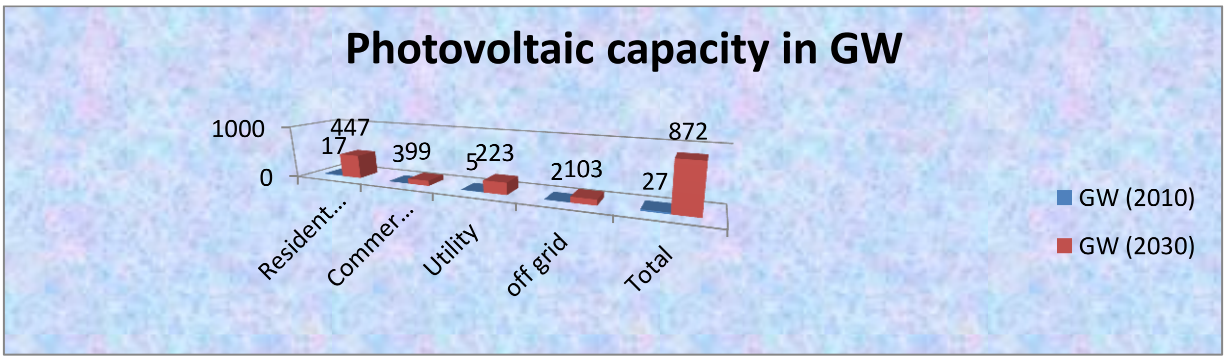

Fig. 1: Worldwide Photovoltaic capacity in GW

DC power supply is required for protection, control and monitoring (PCM) in the substation. Many Renewable energy sources like Photo Voltaic (PV) generator, Fuel cells are the DC generators and directly generate DC power. In many case , inverters are required to convert DC power into AC Power and then again it is converted into DC by using AC/DC convertors for DC applications such as laptops charging , battery bank charging , portable electronic devices , charging of electric vehicles and protection control and monitoring systems etc . The conversion from DC/AC and then AC/DC results is loss of power and it may be avoided if we use Direct DC supply which is generally not available at the substations. As per the prevailing practices, battery chargers alongwith battery banks serve as the source of DC for various DC applications at sub-stations including crucial applications such as protection control and monitoring (PCM). DC power directly for DC applications which has the potential to save 2.5 to 10% of developed energy [3]. Further energy conservation is achieved as the said DC power supply is proposed to be generated using Photovoltaic system.

II. OVERVIEW OF PROTECTION CONTROL AND MONITORING (PCM) SYSTEM

Out of the various DC power supply applications at the substation, the most crucial application is Protection control and monitoring system. Reliable DC power supply is required for protection, control and monitoring (PCM) System. In large capacity substations, redundant DC supply provision is kept to meet the exigency in case of failure of one source of DC supply may be due to ac supply failure, battery charger failure or complete discharging of the battery bank. Auxiliary DC power supply system for PCM is the heart of the substation. Failure of the DC system can cause damage to the substation equipments as protective relays are not able to sense the faulty condition and Circuit breakers are unable to trip for faults. The various indications inside the switchyard and control room also becomes non functional which creates difficulty in proper monitoring, operation and maintenance of the system. The Existing scheme of DC distribution system for Protection, control and monitoring system (PCM) at 220/33 kV sub-station Masjid Moth, Delhi is shown in Figure 2 . In the existing scheme , HT supply at 11 kV, is first transformed into the low voltage AC supply at 415 volts, suitable for battery charger/rectifier with the help of a auxiliary transformer of appropriate capacity . The low voltage AC supply can alternately be obtained from the standby diesel generator set in case of non-availability of grid AC power. The Low voltage AC supply is converted into 48/220 volts with the help of the battery chargers / converters. The function of the battery charger is to supply the DC load as well to charge the battery bank also. The DC power supply is distributed to protection, control and monitoring circuits with the help of the DC distribution board. Battery bank is used to take care of the intermittent load demand, to support the DC load in case of non availability of DC power from the AC/DC converter.

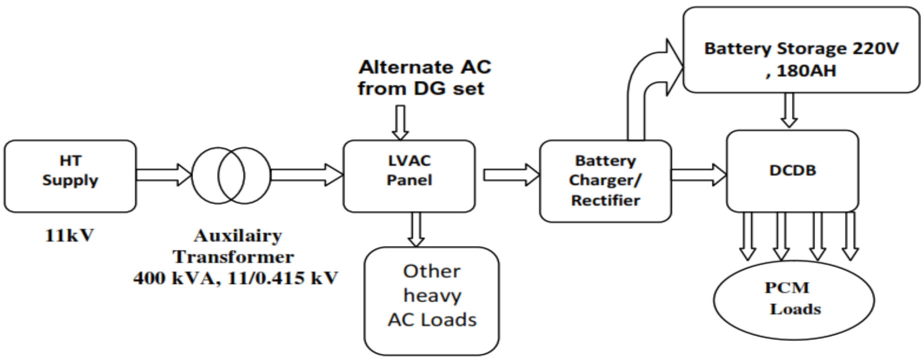

Fig. 1: Existing scheme of DC system for PCM

III. PROPOSED PV BASED SYSTEM FOR PCM

1.1 ***Schematic diagram of proposed PV based system for PCM:***

The proposed system will have photovoltaic module, PV junction box, charge controller, protection system, battery energy storage, Buck/boost DC-DC convertors, charging source selector , DCDB and other associated accessories. Schematic diagram of the proposed DC system is shown in Figure 3.

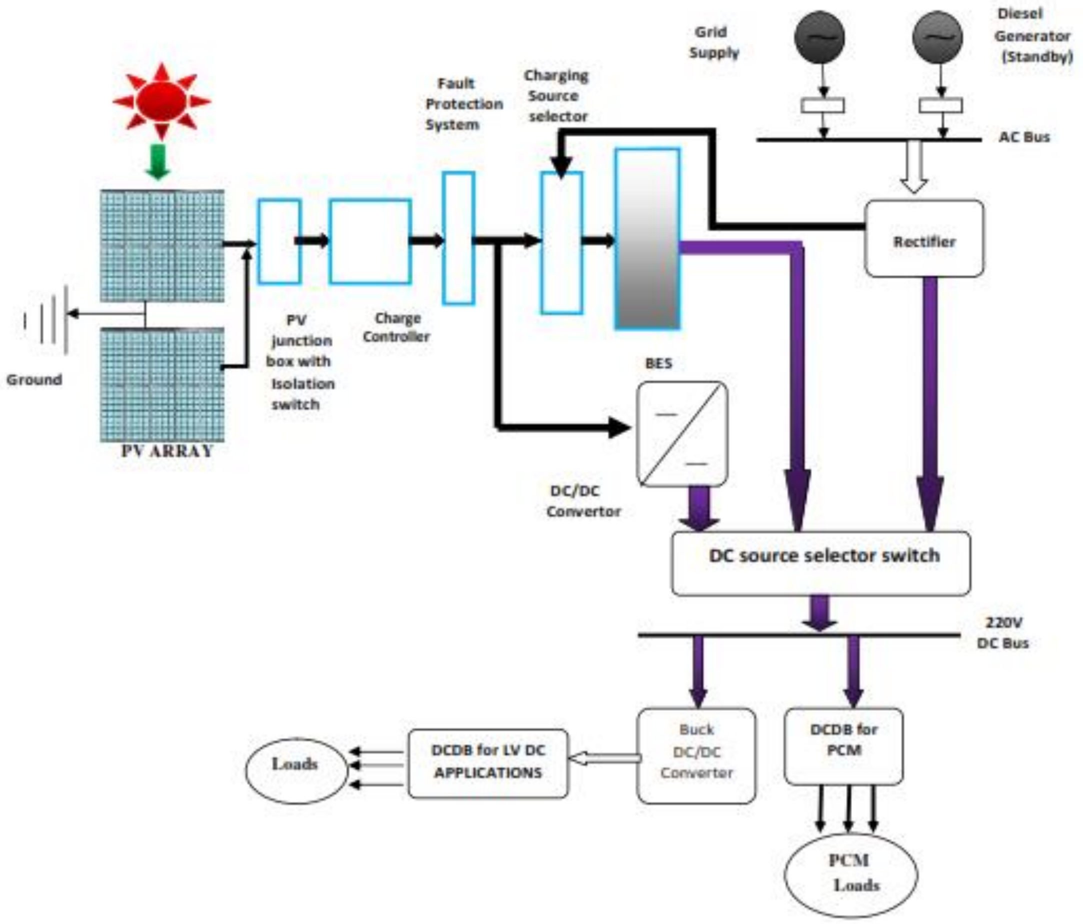

Fig. 3: Schematic diagram of the proposed PV based system for PCM in substations

The integration of PV system for PCM load can be done in two ways i.e. either directly with the battery bank or through DC source selection strategy. The logic table for DC source selection for PCM is shown in table 1.However in this work , we have considered only the first option.

Table 1: Proposed DC Source Selection Strategy

PV	Battery bank	Battery Charger	Power supply to PCM load
0	0	0	Not Desirable
0	0	1	Through Battery charger
0	1	0	Through Battery bank
1	0	0	Through PV
0	1	1	Through Battery charger
1	1	0	Through PV
1	0	1	Through PV
1	1	1	Through PV

1.2 Universal versus Individual PV System:

To supply the DC load either universal PV system of sufficient capacity is chosen or numbers of individual PV system of lesser capacity can be employed. Table 2 provides the comparative analysis of both the systems in respect of various points such as reliability, losses, maintenance etc.

Table 2: Universal PV system versus Individual PV System

S.N.	Parameter	Universal PV system(UPVS) for all DC loads	Individual/Separate PV system(IPVS) for different DC loads
1.	Reliability	Reliability in operation , in case fault/outage of any individual system	Reliability at stake if problem arises in individual system.
2.	Battery energy storage system	Only one BES system is sufficient to maintain the uninterrupted power supply in case of no power from PV system.	Necessity to provide the separate BES to maintain the uninterrupted power supply in case of no power from the PV system.
3.	Power loss and voltage drop	Voltage drop and power loss depends upon the distance of the load from the PV system and more DC/DC converters required.	Voltage drop and power loss can be avoided if IPVS is installed near to load and DC/DC convertors is kept minimum as per requirement.
4.	DCDB, Isolation and protection system	Only one DCDB, isolation and protection system is sufficient to distribute the DC supply from the DC Bus to different loads.	Separate DCDB, isolation & protection system is required for DC supply from the DC Bus to load.
5.	Maintenance	All the loads will be effected during maintenance of the UPVS	All the loads will not be affected during maintenance. Only attached load will be affected.
6.	Short circuit Fault level	Short circuit fault level will be more in case of universal system.	Short circuit fault level reduces.
7.	Protection & safety measures	Stringent protection system is required due to more fault level.	Flexibility in providing protection system.

IV. SYSTEM COMPONENTS

Solar powered DC system consists of following components: PV arrays, power electronic converters (DC/DC and/or AC/DC), battery energy storage system, and the PCM load.

4.1 PV array model:

PV arrays are made from the PV modules consisting of various solar cells. Solar cell is a semiconductor device that has the capability to intercept solar energy and converts it directly into direct current electricity. Photo current produced by the solar cell is directly proportional to the solar radiation. PV system offers non linear relation between I-V and P-V as current and power developed by the PV system depends upon the intensity of incident solar radiation and operating cell temperature. Tracking & temperature effect on PV performance not taken into account for simulation. Economic parameter of the PV system is shown in table 3. Discount rate of 6% per annum and life of PV system considered as 25 years.

4.2 Power Electronic Converters:

Power electronics convertors (DC/DC and AC/DC convertors) serve as the interface between source and the load. PV output voltage is variable as operating conditions are not fixed and are subjected to frequent change , however a constant voltage is required at DC link DC/DC convertor serves this purpose of maintaining the output voltage almost constant over a wide operating range by changing the duty cycle of the switching device .Output voltage is maintained at desired level by controlling the firing angle of the switching devices[4,6]. AC to DC converter is already existing at site, hence its capital cost, replacement cost and O&M cost has not been taken into consideration for simulation.

4.3 Battery energy storage :

A battery energy storage system is required for storing the excess energy generated from the solar PV system during sunshine, to take care of the voltage fluctuations and to supply PCM load during no power from the PV system and the grid. Battery energy storage system is an electro-chemical device that is designed to store the electrical energy in chemical form during charging and convert it back to electrical energy during discharging [5]. For the site considered for study, 180 AH, 220 V Flood lead acid type battery bank is already installed, hence its cost has not been taken into account for simulation.

Table 3: Economic parameters

Item	**Size**	**Capital cost($)**	**Replacement($)**	**O&M cost($/year)**	**Remarks**
PV	1 kWp	1200	960	48	
Battery	220V, 180 AH,	-	-	-	Battery bank and convertor exists at site, hence cost not considered for simulation.
Convertor	5 kW	-	-	-	

V. DATA MODELLING

5.1 *Load Assessment:*

DC power consumption pattern of the DC load pertaining to PCM system has been measured at 220/33 kV substation Masjid Moth, Delhi. The monthly average hourly DC power consumption pattern is shown in Figure 4.

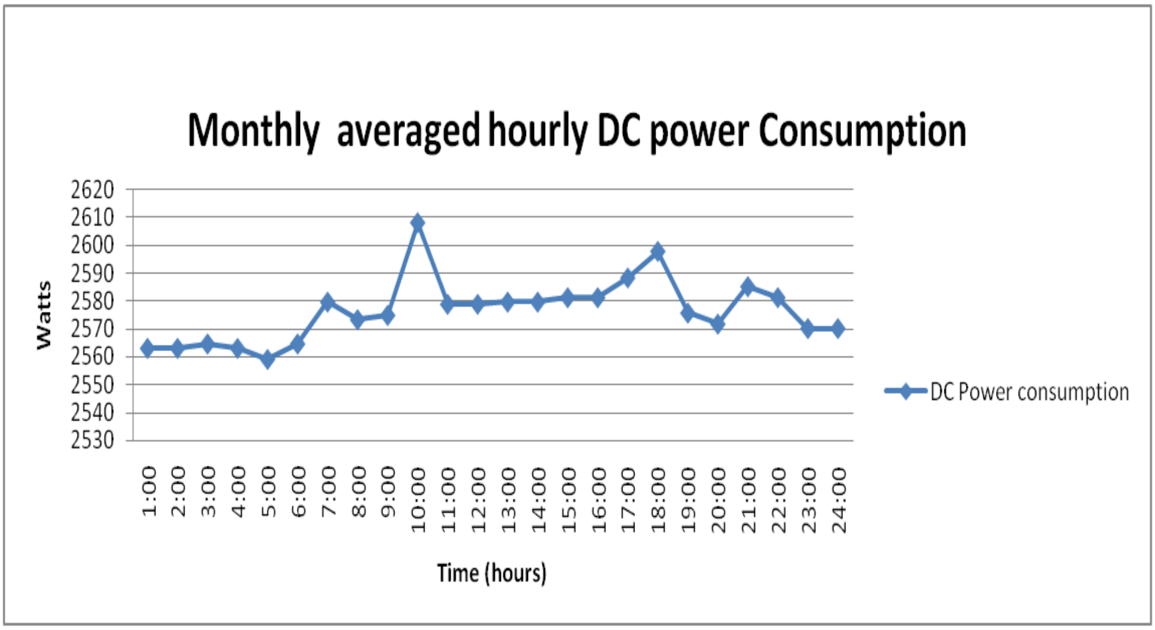

Fig. 4: Monthly average hourly DC power consumption for PCM system

5.2 Solar *resource Assessment:*

Solar resource assessment for the site under consideration has been done to decide the capacity, space requirement of PV system needed to supply the PCM load as electricity generation from the PV system is dependent on the solar insolation, wind speed and temperature profile of the area. The latitude and longitude of the site under consideration (Masjid Moth, Delhi) are N 28.54 degree and E 77.23 degree respectively. In this work, solar irradiance data has been taken from NREL geo spatial tool kit software. Monthly mean daily solar insolation at the site under consideration for this work is shown in Figure 5. Site under consideration has an annual average global radiation of 5.228 kWh/sq.m./day approximately i.e. annual global radiation of 1908 kWh/sq.m. Monthly mean daily solar insolation is lowest (3.246 kWh/sq.m./day) for the month of December and highest (7.049 kWh/sq.m./day) for the month of May. Average clearness index is 0.59.

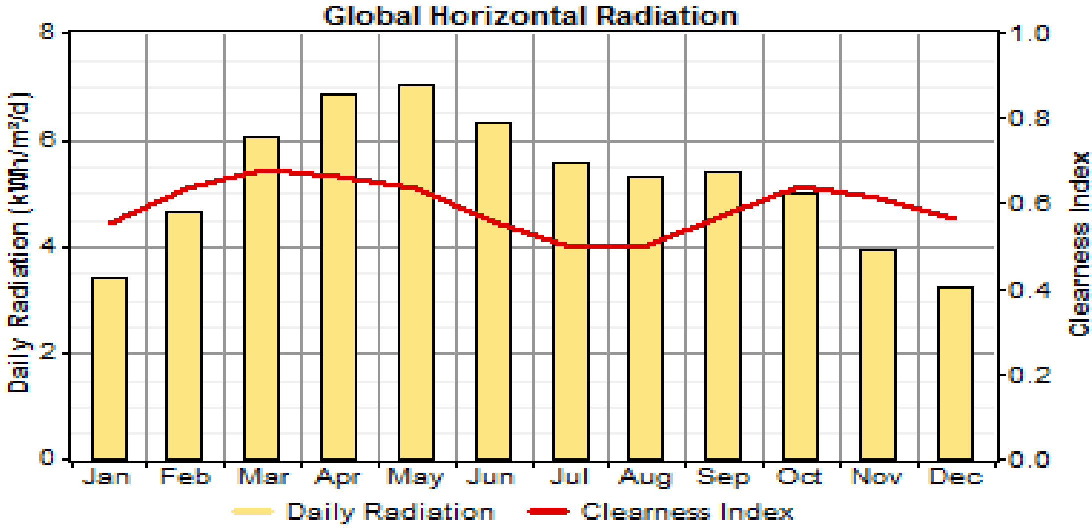

Fig. 5: Monthly mean daily solar insulations

VI. SIMULATION RESULTS AND DISCUSSION

In the preceding sections, load assessment and solar resource assessment have been done. Load assessment data reveals that average DC power requirement for PCM load is ~2.5 kW . A battery storage system is required to store the excess solar energy during day time and supply load during clouds, night when no power is available from PV system. Simulation of PV based DC system for PCM load has been done with the help of "HOMER" software. System components have been shown in Figure 6. System includes the PV system, battery storage system, PCM load 2.5 kW, convertors and grid power supply.E-180 represents the existing 180AH, 220V battery bank. Simulation has been performed without any constraint and rate of power purchased from the grid has been taken as 0.1667 $/kWh including the fixed demand charges and rate of selling power back to the grid has been taken as 0.05 $/kWh. Discount rate of 6% per annum and life of PV system considered as 25 years.

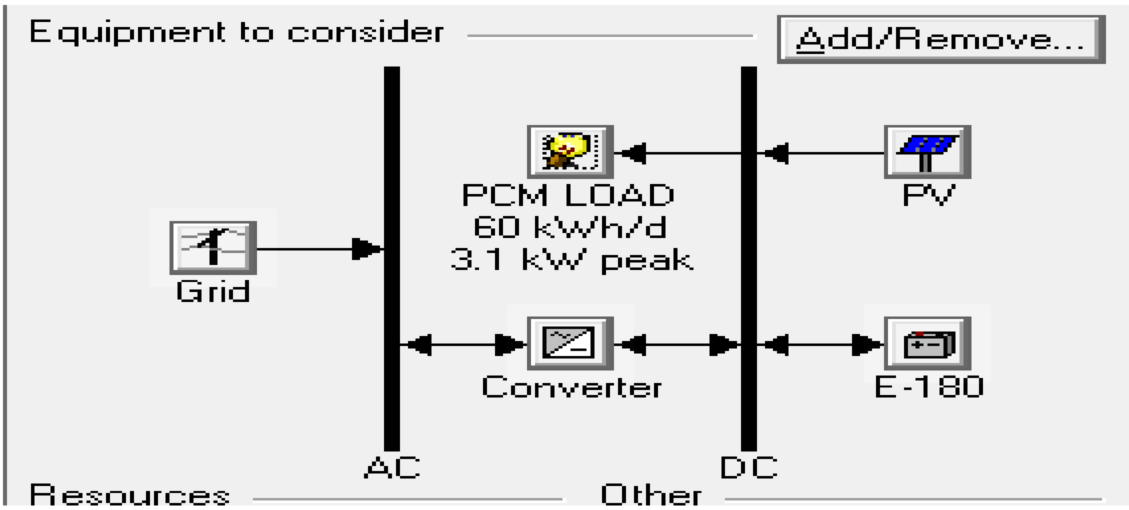

Fig. 6 Configuration of the PV Based DC system for PCM

The optimization results by HOMER are shown in Figure 7. The simulation result suggests PV capacity of 9 kW, 110 batteries, 3 kW convertor capacities. Net present cost (NPC) of the system with single battery storage is $41,477. Initial investment needed is $10800, operating cost of 2400 $/year, cost of electricity (COE) is 0.149 $/kWh. Monthly average electricity production from PV and grid has been shown in Figure 8. Electricity production from the PV is maximum in April, May and least in December and January months. Table 4 gives details of electricity supplied by PV and grid, it can be observed that renewable energy fraction is 54 %. Total energy purchased from the grid is 11,296 kwh/yr. Energy purchased from the grid is maximum in December and minimum for the month of April.

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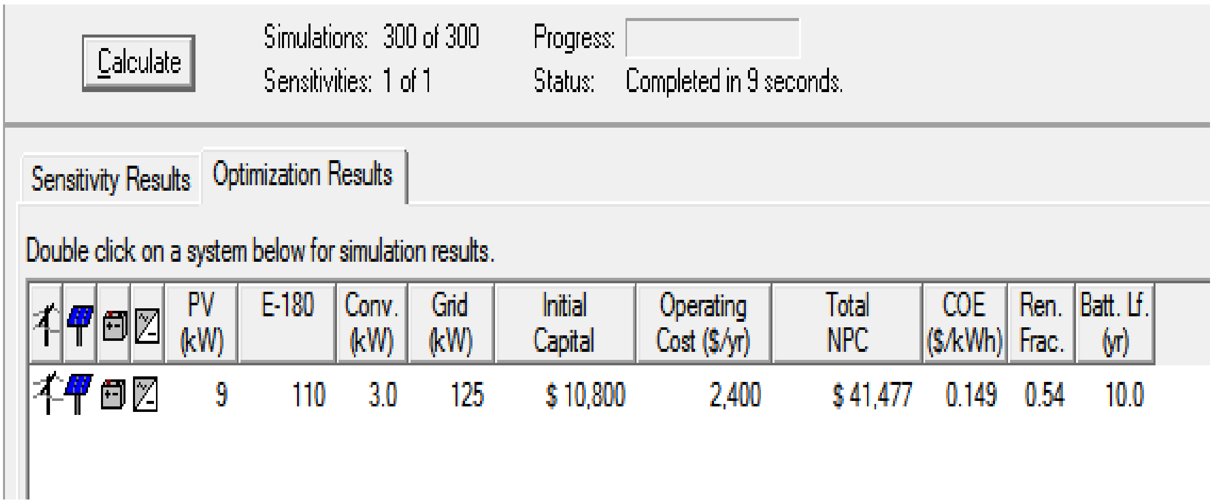

Fig. 7 Optimization results

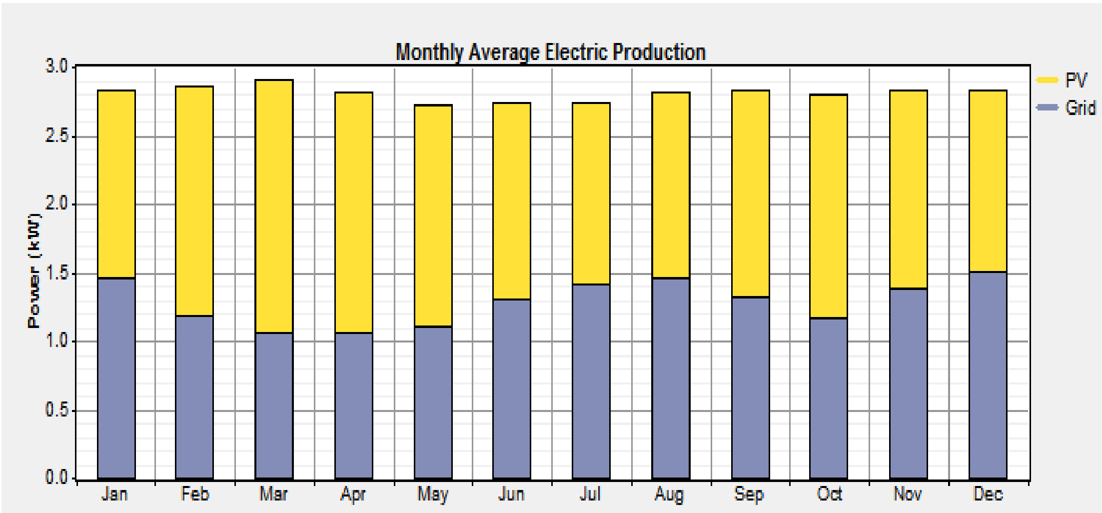

Fig. 8 Monthly averaged electricity production

Table 4: Share of electricity supplied by PV and Grid

Production	kWh/yr	% share
PV array	13,327	54
Grid purchases	11,296	46
Total	24,623	100

Table 5 gives the emissions (kg/yr) with and without PV integration for electricity consumption of 24,623 kWh/yr .The emissions are reduced by 54% with integration of PV system.

Table 5: Emissions mitigation

Pollutant	**Emission factor (g/kWh)**	**Emissions (kg/yr) without PV integration for electricity consumption of 24,623 kWh/yr**	**Emissions (kg/yr) with PV integration for electricity consumption of 24,623 kWh/yr**
Carbon dioxide	632	15561.74	7139
Sulfur dioxide	2.74	67.47	31
Nitrogen oxides	1.32	32.50	15.1

The cost of solar electricity is comparable with grid power because of decrease in initial cost as battery energy storage and convertors are already available at site.

VII. CONCLUSION

DC power supply is required for protection, control and monitoring (PCM) system in the electric substations. In this paper, a PV based DC system has been proposed for catering the DC Power demand of the protection control and monitoring (PCM) system in electric sub-stations. DC Load and solar resource assessment has been done for the site under consideration and simulation has been done with Homer. The results show that the PV based DC system for protection, control and monitoring (PCM) system in the electric substations has huge potential and offers advantages of renewable energy integration, GHG mitigation. The simulation result suggests PV capacity of 9 kW, 110 battery, 3 kW convertor capacity. Net present cost (NPC) of the system with single battery storage is $41,477. Initial investment needed is $10800, operating cost of 2400 $/year, cost of electricity (COE) is 0.149 $/kWh. The cost of solar electricity is comparable with grid power and likely to drop further due to advancement in PV technology worldwide.

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Avneesh Kumar received B. Tech degree in Electrical Engineering from JSS Academy of Technical Education, Uttar Pradesh Technical University, Lucknow, India in 2005. He is pursuing M. Tech in "Energy and Environmental Management" from Centre for Energy Studies, Indian Institute of Technology, Delhi, India. He is working as Assistant Manager (Technical) in Delhi Transco Limited, India with more than eight years of experience in operation & maintenance of 220 kV Sub-Stations.

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APPENDIX - A

Nomenclature

GHG	Greenhouse gas
DG	Diesel Generator
CB	Circuit Breaker
IPVS	Individual PV System
UPVS	Universal PV System
RES	Renewable energy sources
PCM	Protection , control and monitoring
DCDB	Direct current distribution board
DC	Direct Current
AC	Alternating Current
PV	Photovoltaic
PVS	Photovoltaic system
kV	Kilo volts
KWh	Kilo watt hour
kVA	Kilo volt ampere
MW	Mega Watts
MU	Million Unit
GW	Giga Watts
IEA	International energy agency
kW	Kilowatt
GHI	Global horizontal irradiance
NREL	National Renewable energy laboratory
AMP	Amperes
COE	Cost of electricity
NPC	Net present cost