Simulation Design & Performance Evaluation of Grid Connected 100 kW Solar Power Plant

Preeti Garg *, Virendra Sharma **‡, Vikas Kumar Sharma***, Aditya Gupta *

* Department of Electrical Engineering, Research Scholar, Arya College of Engg. & IT., Jaipur and 302028, India

** Department of Electrical Engineering, Professor, Arya College of Engg. & IT., Jaipur and 302028, India

*** Department of Electrical Engineering, Associate Professor, Poornima College of Engineering, Jaipur and 302028, India

(vsharmakiran@gmail.com, preetigarg5768@gmail.com, vk.sharma@poornima.org, adityaguptabwr97@gmail.com)

‡ Corresponding Author; Virendra Sharma, Arya College of Engg. & IT., Jaipur and 302028, Tel: +91 9413508455, 8225819180, vsharmakiran@gmail.com

Received: 18.08.2023 Accepted:03.09.2023

Abstract- The article outlines a strategy for maximising the usage of renewable energy because solar energy is becoming more and more in demand as a result of recent developments in photovoltaic (PV) panels. We have connected solar energy to the grid in order to properly monetize and use it. The design and simulation of a two-stage converter system for integrating solar panels with the grid are the topics of this article. It is made up of a PV panel, a boost dc-dc converter to boost the voltage of the PV panel, a VSI to convert dc to ac, and lastly the grid. The Perturbe & observation algorithm is utilized to operate the PV panel at its maximum power point, and the system also functions in a variety of changing environmental circumstances. Reference frame control is used to adjust inverter output in relation to the grid. Three phase PLL is used to lock grid frequency & phase with respect to inverter output. A low pass LC filter is modelled to remove high frequency harmonics from the inverter output which is fed to grid as well as proposed test system of utility network. The power quality enhancement of grid and load parameter profiles in terms of comparative performance improvement (CPI) is evaluated with more than 75% and 22% respectively which shows the effectiveness of proposed research work in all events. All the simulations are carried out in Simulink. The study has been carried out in MATLAB environment**.**

Keywords: RE-sources, Solar Power Plant, Perturb & Observation Algorithm (P&O A), Converter Design (CD), Phase Locked Loop, SRFT control, Grid Interfaced Test system (GITS), PCC.

1. Introduction

This article owing to improvements in PV panel efficiency and the ongoing depletion of non-renewable energy sources, commercialising solar energy in large-scale installations will become more widespread. Power outages, grid instability, power quality degradation, power reliability, etc. may all be readily resolved by integrating PV panels with the grid [1]. A DC-DC converter and a three-phase inverter are required for connecting PV panels to the grid. Because PV panels are expensive, it is best to utilise a dc-dc boost converter to increase the voltage rather than a lot more PV panels. Using a second boost converter has the advantage of allowing for independent control of the PV panels' Maximum Power Point and the inverter's ability to regulate the current fed into the grid. There is a need to investigate the methods which may be implemented at grid level to mitigate the disturbances introduced due to high penetration of variable nature solar energy into the utility grid as 50% by the use of distribution static compensator supported by battery energy storage device in parallel with the dc link capacitor reported in [2-3], in this case the monitoring of battery storage system need to proper selection of custom device, But in proposed work the power quality enhancement achieve more than 75% by using a capacitor bank and its operation easy to manage grid voltage profile. it exchanges only reactive power so problem with capacitor bank storage device, how much rating is required for enhancement of grid voltage profile, this is the main limitation of proposed work. Because to its inherent simplicity, the incremental conductance approach is utilised as the MPPT to extract the most power possible from the solar panels.

A voltage source inverter is used to convert the boost converter's output's dc power to ac (VSI) [4-6]. Here, synchronous reference frame control, or d-q frame control, is employed with pulse width modulation (PWM) technology to control the amount of current injected to the grid. The output of the inverter should also be coordinated with the grid. Hence, the Phase Locked Loop (PLL) approach is used to match the grid frequency and phase. A transformer and an LC filter should both be used after an inverter to provide galvanic isolation and eliminate high frequency harmonics, respectively reported as [7-9].

2. Proposed Test Architecture

Proposed test architecture (PTA) is used for the analysis of grid parameter as well as load parameter on the basis of total harmonics distortions (THDs) by using proposed test system (PTS). The performance was recorded at point of common coupling (PCC) on AC bus which is depicted in Fig.. 1 in the presence of solar power plant penetration with utility grid [10-12]. To enhance the power quality of grid parameters by using energy storage capacitor bank and reduce the impact of grid disturbances when switching is occur in the distribution power system is detailed in this section.

2.1 Proposed Test System

Proposed test system for the analysis of performance of grid connected 100 kW solar PV system to drive a utility loads resistive, inductive, capacitive with penetration of energy storage system supported by capacitor bank is illustrated in Fig. 1. The conventional infinite grid is connected to the AC bus directly for deliver power to the load as per requirement of PTS. All loads have changed the values as per case study proposed in test system of matlab simulink model as [13-14].

2.2 Solar Power Plant

The solar power plant rated at 100 kW is integrated to proposed test system on DC bus using a DC to DC converter. Technical parameters of the solar power plant as reported in [15-16] are used in the proposed study. Output voltage from solar PV plant is 250 V- 300 V which is stepped up to 600 V dc using a dc to dc boost converter. A dc to ac inverter is used to convert 600 V dc into 400V three phase ac Supply which is synchronized with grid voltage by using inverter voltage control technique synchronous reference frame theory (SRFT).

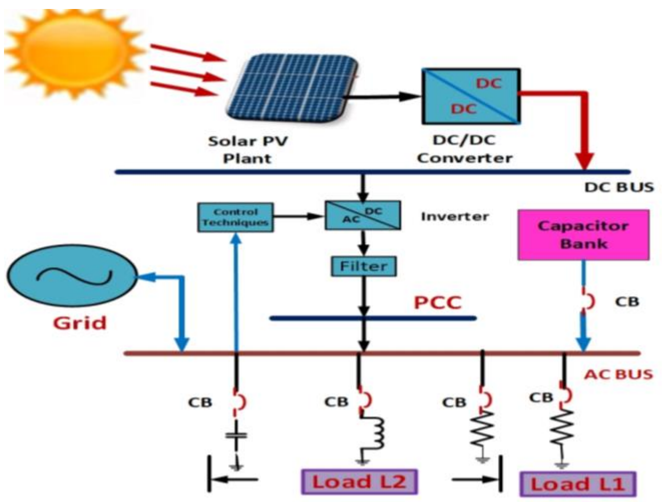


Fig.1 Proposed test system for study of research work

Table 1. Specification of Solar Power Plant

Parameters of proposed work	Units with sysmbol	Value which is used
Solar output voltage	V_O (V)	250 -350
Solar power plant output	P_O (kW)	100
Boost converter voltages	V_{DC} (V)	600
Boost converter switching frequency	F_{BSW} (kHz)	5
Boost converter Inductor	L_{BC} (mH)	1.455
Boost converter Capacitance	C_{BC} (μF)	3227
DC link Capacitor	C_{DC} (μF)	1000
Inverter switching frequency	F_{INVSW} (kHz)	10
Inductor for inverter filter	L_{INV} (μF)	500
Capacitor for inverter filter	C_{INV} (μF)	100
Inverter voltage	V_{IN} (V)	400
Supply frequency	F_S (Hz)	50

2.3 Boost Converter

The output voltage from PV array 300 V to 350 is not sufficient for generation level of desired output, a boost converter is necessary to increase the input voltage to the necessary output voltage which is required to inverter for AC bus of proposed test system. The details of the parameters used in the boost converter of proposed test network are presented in Table 1.

2.4 Inverter Topology

PV array produce a voltage in the form of direct current (DC). But, alternating current AC voltage are required to feed the power to the ac bus as well as grid. The machinery used to convert DC to AC is known as an inverter. The VSC maintains the power at desired output from solar plant while converting the 400 V AC as grid synchronize from output of boost converter voltage 600 V DC. The synchronous reference frame theory is used for getting signal to control of inverter by PWM techniques.

2.5 Capacitor Bank

The capacitor bank (CB) is utilized to enhance the power quality of grid parameter which affect due to renewable energy sources penetration, switching the load as ON/OFF in proposed system of network load bus. It's generally economical and can be effectively introduced any place on the system. The capacitor bank capacity of 100 kVAr is interfaced by circuit breaker to AC bus which supply the reactive power to AC bus whenever load is required as well as enhance the voltage & current profile when transient is occur at the time of event in proposed work.

2.6 Utility Grid

The infinite bus system is used as grid at AC bus in proposed test system for deliver the power whenever required to load as well as it will take the power from solar power plant when utility load is not required the power, it will support to grid and share the power when utility grid is required. The level of 400 V ac phase to phase and 50 HZ source is used for this proposed work.

2.7 Utility Load

Load L1 is pure resistive value of 40 kW very up to 50 kW and load L2 is complex type and it very as per event condition of study for the analysis of performance evaluation are connected to AC bus of PTS. For implementation of proposed work by switching event as described in simulation study to increase the load and measure the performance of proposed grid connected 100 kW solar power plant with the help of circuit breaker.

3. Modeling of Solar Power Plant

In this section, Paper present the simulation steps for the design of grid connected solar power plant (SPP) for the performance evaluation at different load condition by proposed test system. Test network system on which proposed approach is implemented and fulfil the power demand of utility load as well as difference of power provide to grid and vice versa.

3.1 Solar PV Module

A solar power system made by hug number of photovoltaic modules which consists of many numbers of PV cells those are connected in series and parallel. A single solar cell can be modelled by using a current source, a diode and two resistors. The mathematical model equations for this can be found in literature of paper. The circuit representation of single solar pv cell as Fig.. 1 and mathematical equation of (1,2,3,4 and 5) are used for the matlab simulink model of solar PV plant.

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

$$I = I_{ph} - I_o\left[\exp\left(\frac{V+IR_s}{aV_T}\right) - 1\right] - \left(\frac{V+IR_s}{R_{sh}}\right) \quad (2)$$

$$I_{ph} = \frac{[I_{sc}+K_i(T-298)]G}{1000} \quad (3)$$

$$I_o = I_{rs}\left(\frac{T}{T_n}\right)^3 \exp\left[\left(\frac{qE_{go}\left(\frac{1}{T_n}-\frac{1}{T}\right)}{nK}\right]\right. \quad (4)$$

$$I_{rs} = \frac{I_{sc}}{\left[\exp\left(\frac{qV_{oc}}{nN_sKT}\right)-1\right]} \quad (5)$$

Where,

I_{ph} = Phase Current
I_D = Diode Current
I_{sh} = Shunt Current
I_o = Output Current
V = Voltage
I = Current
R_s = Series Resistance
V_T = Diode Thermal Voltage
R_{sh} = Shunt Resistance
I_{sc} = Short Circuit Current
K_i = Cells short circuit current temperature coefficient
T = Temperature
G = Total solar reference radaition at STC
I_{rs} = Series Resistance Current
T_n = Nominal temperature
q = Electron charge
E_{go} = Band gap energy of the semiconductor
n = Ideality factor
K= Boltzmann constant = $1.3806.10^{-23}$ J/K
V_{oc} = Open Circuit Voltage
N_s = Number of cells connected in series

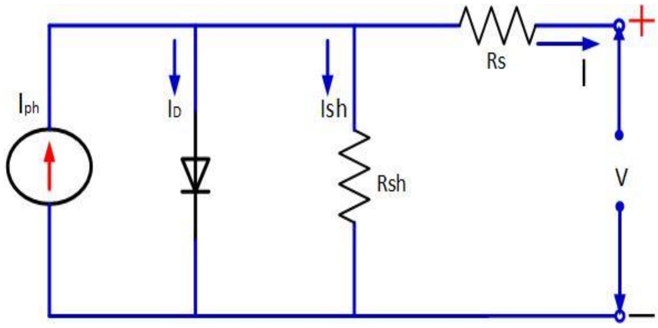


Fig.2 Circuit representation of single solar pv cell for modelling

The Solar Power Plant Simulation Model (SPPSM) is designed mathematically in MATLAB on the basis of standard value of certain variables are taken according to Table 2.

Table 2. Specification of PV array at STC

Parameters of proposed work	**Units with sysmbol**	**Value which is used**
Open circuit voltage	V_{OC} (V)	36.3
Voltage at maximum power point	V_{MPP} (V)	290
Voltage Temperature Coefficient	(%deg)	-0.36099
Short Circuit Current	I_{SC} (A)	7.84
Current at maximum power point	I_{MPP} (A)	345.4
Current Temperature Coefficient	(%deg)	0.102
Cells per modules	Nc	60
1SOLTECH 1STH-215-P	Module	213.15
Parallel String	NP	94
Series connected modules per string	NS	20

3.2 PV Boost Converter

The output voltage from PV array 300 V to 350 is not sufficient for generation level of desired output, a boost converter is necessary to increase the input voltage to the necessary output voltage which is required to inverter for AC bus. A diode, an inductor, capacitor and a high frequency switch device are the main primary parts of a boost converter. The design of boost converter parameter is very complicated as compared conventional boost converter for the desired output of inverter as smooth function of grid connected solar power system as reported in [17]. The output voltage in solar connected boost converter is very from 0 volt to maximum output voltage, so big challenge to evaluate proper value of inductance and capacitor for governing the output voltage by duty cycle ratio. The desired capacitor, inductor and duty cycle ratio got by expression (6,7,8,9,10 and 11) respectively to get desired power from equation (12) at the level of 100 kW as defined by solar power plant is feed to DC bus of PTS. The details of the parameters used in the boost converter of proposed test network are presented in Table 1.

$$L = \frac{V_{ip}(V_{op}-V_{ip})}{f_{sw}\times\Delta I\times V_{op}} \quad (6)$$

$$C = \frac{I_{op}(V_{op}-V_{ip})}{f_{sw}\times\Delta v\times V_{op}} \quad (7)$$

$$D = 1-\sqrt{\frac{R_{MPP}}{R_O}} \quad (8)$$

$$R_{MPP} = \frac{V_{MPP}}{I_{MPP}} \quad (9)$$

$$V_o = \frac{V_i}{1-D} \quad (10)$$

$$I_o = \frac{V_o}{R_o} \quad (11)$$

$$P_o = V_o \times P_o \quad (12)$$

Where,
L = Inductance
V_{ip} = Solar input Voltage
V_{op} = Solar output Voltage
f_{sw} = Switching frequency
Δv = Voltage difference
D = Duty Cycle
R_{MPP} = Maximum peak to peak resistance
V_{MPP} = Maximum peak to peak voltage
I_{MPP} = Maximum peak to peak current
R_o = Output Resistance
P_o = Output Power
V_o = Output Voltage

The PV array produce a voltage in the form of direct current (DC). But, alternating current AC voltage are required to feed the power to the ac bus as well as grid. The machinery used to convert DC to AC is known as an inverter. The VSC maintains the power at desired output from solar plant while converting the 400 V AC as grid synchronize from output of boost converter voltage 600 V DC. The synchronous reference frame theory is used for getting signal to control of inverter by PWM techniques.

4. Control Techniques

The various techniques are used for getting desired output power from proposed test system which are described in this section of paper.

4.1 Maximum DC Power Tracking

Approach for tracking a maximum power tracking ((MPT) from solar power plant which deliver to utility network load in presence of utility grid at different tests are achieved by following process.

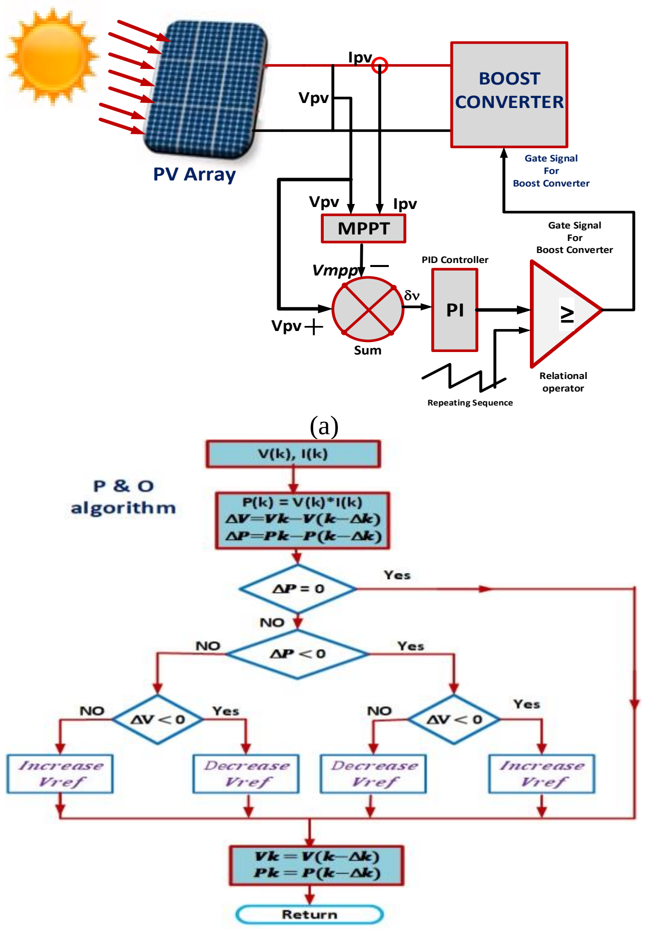
- First select function from Simulink library, Output of the function is duty cycle D.
- Input of the function are Vpv and Ipv from Solar power plant.
- Set initial duty cycle at maximum and minimum duty cycle limit and Change in duty cycle increment or decrement purpose.
- Declare some variables as persistent variable.
- Persistent variables are local to the function in which they are declared. Yet their values are retained in memory between calls to the function.
- In our case persistent variables are old values of V, P and D.
- Initialize these values use if condition with empty such that only during first time values are assigned.
- Calculate P, change in P and change in V.

Check change in P. if not equal to zero then there are four possibilities.

- ❖ dP<0, dV<0 then decrease D
- ❖ dP<0, dV>0 then increase D
- ❖ dP>0, dV<0 then increase D
- ❖ dP>0, dV>0 then decrease D

- If dP is equal to zero then fix D=old value
- If D value violates maximum and minimum values lets fix D=old value
- Update Vold, Pold, Dold values.

That's its P&O techniques for getting maximum output power from solar plant as depicted in Fig. 3 (b) with the help of control structure which depicted in Fig. 3 (a) as reported in [18-19].



(a)

(b)

Fig.3 Maximum DC power tracking approach (a) Control structure for boost converter (b) Flow chart for implementation of algorithm for MPPT

4.2 Maximum AC Power Tracking

Synchronous reference frame theory (SRFT) control technique is used for maximum AC power by getting optimize inverter voltage and it is based on transformation of currents in synchronously rotating d-q frame. Sensed voltage signals are processed by phase locked loop (PLL) to generate sine and cosine signals. Sensed current signals are transformed to d-q frame and filtered. The filtered currents are back transformed to abc frame and fed to hysteresis current controller for switching pulse generation. The currents generated in α–β coordinates are transformed to d-q frame with the help of park's transformation using θ as transformation angle. The mathematical transformation equations (13-15) are used for AC maximum power tracking as control structure depicted in Fig. 4 as reported in [20-21].

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (13)$$

The DC components, i_{ddc} and i_{qdc}, are extracted using low pass filter and are transformed back into α–β coordinates using reverse park's transformation as

$$\begin{bmatrix} I_{\alpha dc} \\ I_{\beta dc} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} i_{ddc} \\ i_{qdc} \end{bmatrix} \quad (14)$$

These currents are transformed to obtain three-phase reference source currents in abc coordinates as

$$\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{\alpha dc} \\ I_{\beta dc} \end{bmatrix} \quad (15)$$

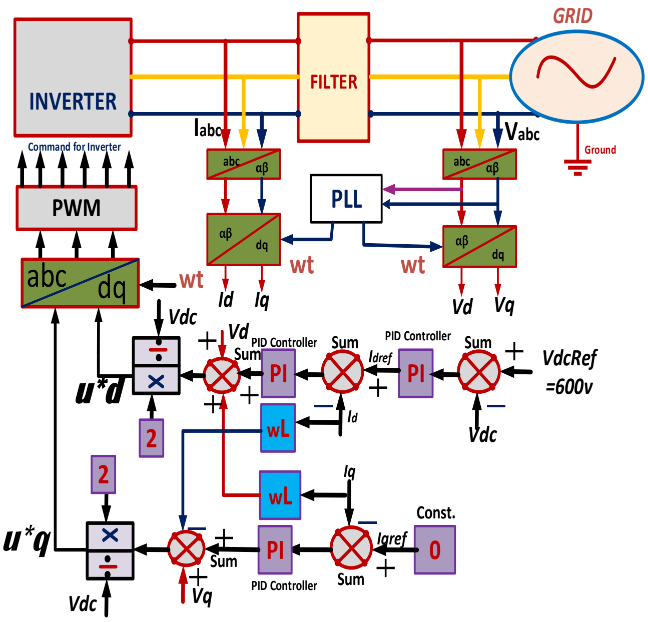


Fig.4 Control structure for inverter voltage control with getting AC maximum power.

5. Simulation Results

This section presents a graphical result with their discussion on the basis of different case study of load switching condition in MATLAB environment by proposed test system for the performance analysis of grid connected 100 kW solar power plant with and without capacitor bank (CB). The case study events include switching ON/OFF of different resistive load, inductive load and capacitive load as per PTS for the study of power contribution of 100 kW solar power plant as well as grid contribution for proposed network load by flow of active and reactive powers, and also disturbance detection impact (DDI) on grid voltage/current and load voltage/current with evaluation of total harmonics distortions (THDs) are investigated with the help of matlab simulation by operation of circuit breaker (c/b) on AC bus of PTS with and without storage of capacitor bank.

5.1 Incremental Small Resistive Load without CB

This study provides the impact of small resistive load switching (SRLS) by increasing load L1 from their original value of 40 kW to 90 kW by switching other L2 of 50 kW for the duration 0.5s from 0.5s to 1s simulation time with the help of c/b with absence of CB on MATLAB platform through PTS. The performance analysis of grid connected 100 kW SPP on the basis of power flow contribution towards grid as well as demand of utility load without contribution of CB, impact of switching event (ISE) on grid voltage/current and load voltage/current profile in terms of disturbance detection impact (DDI) are presents in this subsection.

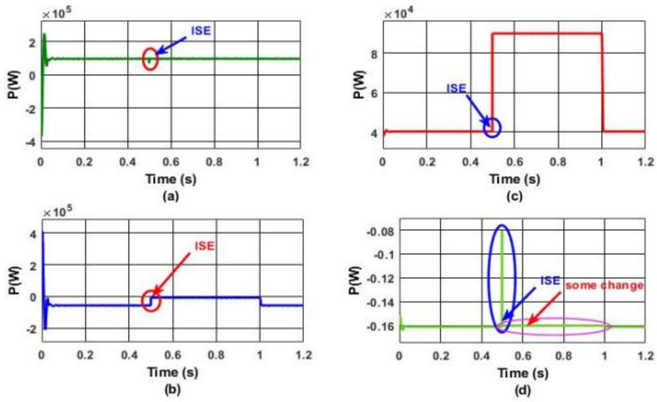


Fig.5 Profile of active powers in PTS without CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

Generated and consume active power by the test system are depicted in Fig. 5. The observation from graphical result of simulation of Fig.. 5 (a) show the performance in constant power generated of 100 kW SPP at STC but impact of switching event (ISE) is also observed at the time of switching the load in PTS. The Fig. 5 (b) provide the grid power contribution toward the switching time as per load proposed in PTS. Power consumed by the load for switching time as event condition of load imposed is shown in Fig. 5 (c). There is no active power exchange by storage capacitor bank device but some disturbance was observed at the time of switching load in PTS as Fig. 5 (d), because only resistive load is imposed.

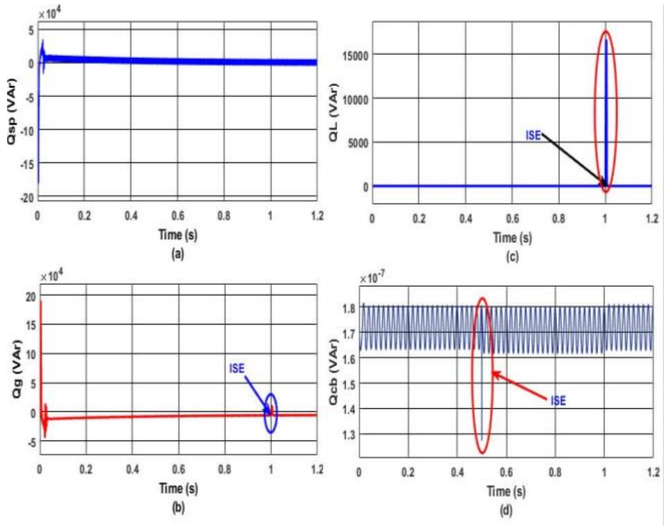


Fig.6 Profile of reactive powers in PTS without CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

The generated and consume reactive power by the test system are depicted in Fig. 6. It is observed that from graphical result of simulation of Fig.. 6 (a) there is no reactive power generated of 100 kW SPP at STC. The Fig. 6 (b) provide the grid power contribution toward the switching time as per load proposed in PTS for internal circuit because there is no need of reactive power for switching load as seen in Fig. 6 (c) but some transient is observed as event condition when load is removed. There is no reactive power exchange by storage capacitor bank device because CB is out of from c/b, but some disturbance was observed at the time of switching load in PTS as Fig. 6 (d).

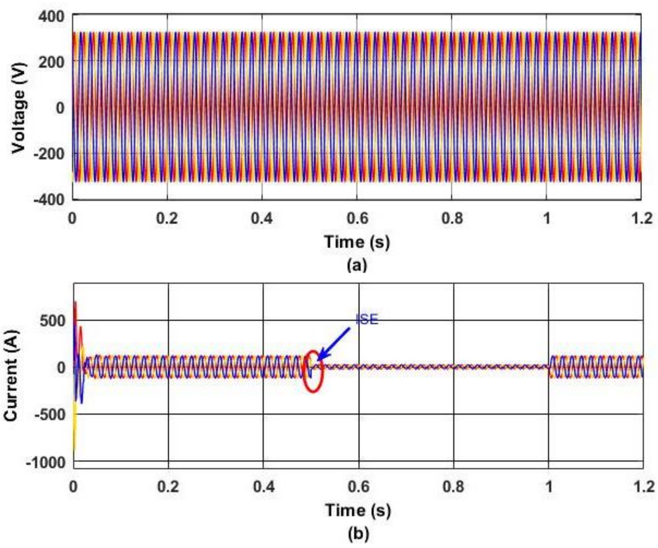


Fig.7 Performance of utility grid parameters without CB (a) Voltage signal profile (b) Current signal profile

The performance of grid parameter was recorded in Fig. 7 (a) & (b) on PCC which is described in proposed test system when increase the load 40 kW to 90 kW by switching another load L2 with the help of c/b without CB. It is showing the effectiveness of proposed test system.

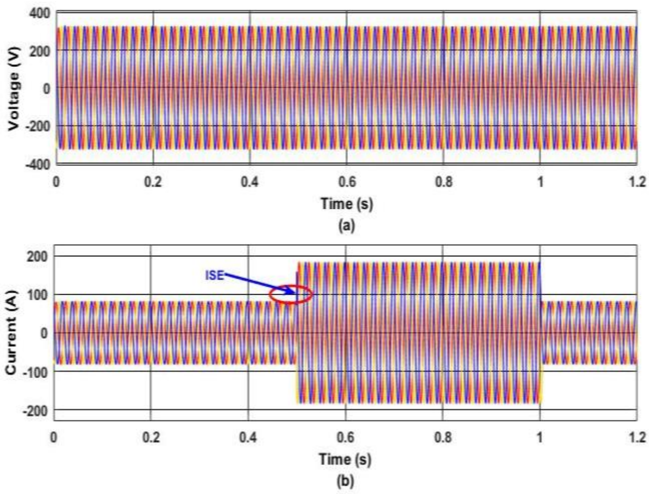


Fig.8 Performance of utility load parameters without CB (a) Voltage signal profile (b) Current signal profile

The performance of load parameter was recorded in Fig. 8 (a) & (b) on PCC which is described in proposed test system when increase the load 40 kW to 90 kW by switching another load L2 with the help of c/b in absence of CB. It is showing the effectiveness of PTS by changing the load current at simulation time 0.5s to 1s because load is increased by c/b operation.

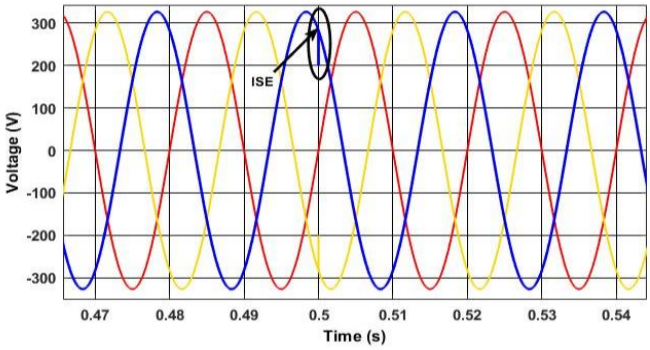


Fig.9 Disturbance detection impact (DDI) in grid voltage signal without CB

Grid voltage waveform recorded on PCC during the event of switching ON the other resistive load in the absence of CB is provided for time corresponds to 0.46s to 0.55s is data recorded in Fig. 9. This is observed that the voltage waveform deteriorates by small magnitude at the moment of switching ON the load takes place.

5.2 Incremental Small Resistive Load with CB

This study provides the impact of small resistive load switching (SRLS) by increasing load L1 from their original value of 40 kW to 90 kW by switching other L2 of 50 kW for the duration 0.5s from 0.5s to 1s simulation time with the help of c/b with presence of CB on MATLAB platform through PTS. The performance analysis of grid connected 100 kW SPP on the basis of power flow contribution towards grid as well as demand of utility load with contribution of CB, impact of switching on grid voltage/current and load voltage/current profile in terms of DDI are presents in this subsection.

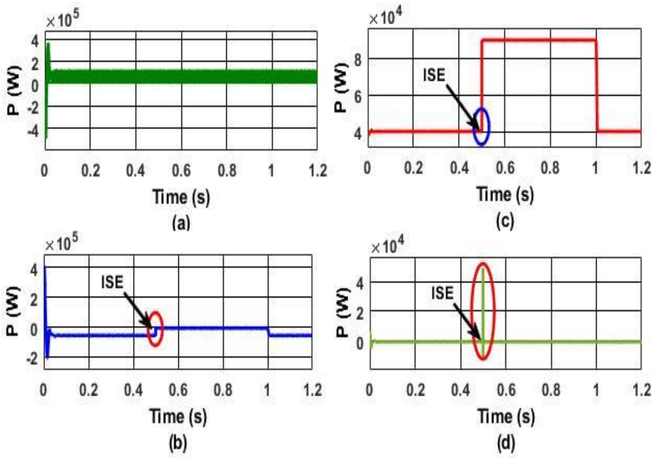


Fig.10 Profile of active powers in PTS with CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

The graphical representation of simulation results those obtained by MATLAB platform for the performance analysis of PTS on the basis of power flow contribution towards grid as well as demand of utility load with contribution of SPP is depicted in Fig. 10 (b), (c) & (a) respectively. There is no active power exchange by storage capacitor bank device but some disturbance was observed at the time of switching load in PTS as Fig. 10 (d), because only resistive load is imposed.

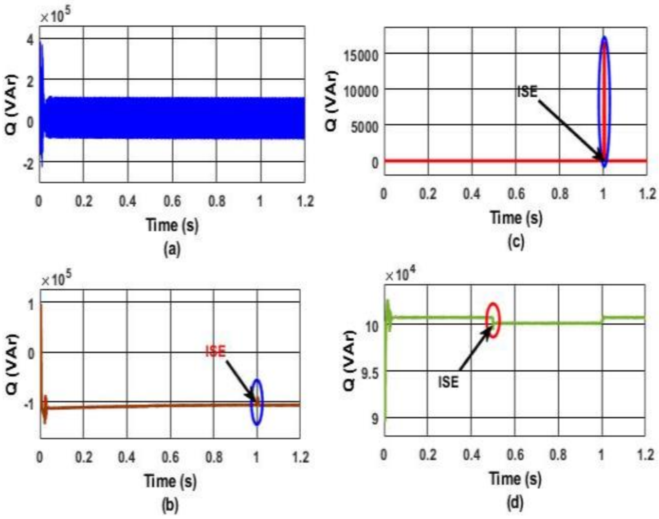


Fig.11 Profile of reactive powers in PTS with CB (a) Solar power (b) Grid power (c) Load power (d) Capacitor bank power

The generated and consume reactive power by the test system are depicted in Fig. 11. It is observed that in Fig.. 11 (a) there is no reactive power generated of 100 kW SPP at STC. The Fig. 11 (b) show take reactive power from storage device of CB as contribution toward the switching time as per capacity of CB proposed in PTS because there is no reactive load in PTS for load demand as seen in Fig. 11 (c) but some transient is observed as event condition when load is removed. The reactive power exchange by storage capacitor bank device to grid as well as enhance the grid vltage/current profile by injecting reacctive power observed at the time of switching the load in PTS as Fig. 11 (d).

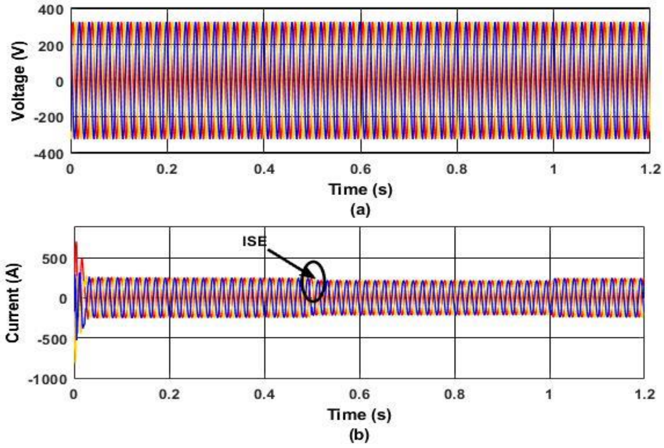


Fig.12 Performance of utility grid parameters with CB (a) Voltage signal profile (b) Current signal profile

The performance of grid parameter was recorded in Fig. 12 (a) & (b) on PCC which is described in proposed test system when increase the load 40 kW to 90 kW by switching another load L2 with the help of c/b with CB. It is showing the effectiveness of proposed CB for PTS.

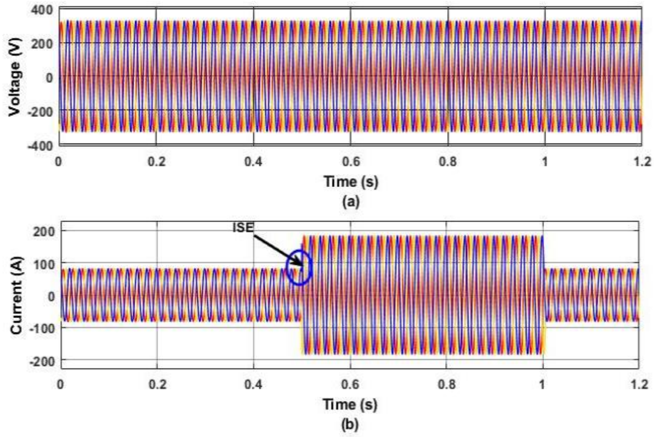


Fig.13 Performance of utility load parameters with CB (a) Voltage signal profile (b) Current signal profile

The performance of load parameter was recorded in Fig. 13 (a) & (b) on PCC when increase the load 40 kW to 90 kW by switching another load L2 with the help of circuit breaker in presence of CB. It is showing the effectiveness of proposed test system by enhance profile of voltage/current signal.

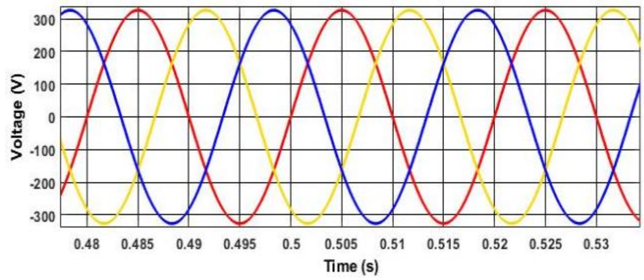


Fig.14 Disturbance detection impact (DDI) in grid voltage signal with CB

Waveform of grid voltage recorded on PCC during the event of switching ON the resistive load in the presence of CB is observed without transient at the switching of load in PTS provided in Fig. 14, which time corresponds to 0.48s to 0.53s of recorded data. This is observed that the voltage waveform of grid voltage signal is improved at the moment of switching ON the load takes place. It shows the effectiveness of proposed work.

5.3 Incremental Large Resistive Load without CB

This study provides the impact of large resistive load switching (LRLS) by increasing load L1 from their original value of 50 kW to 150 kW by switching other L2 of 100 kW for the 0.5s from 0.5s to 1s simulation time with the help of c/b with absence of CB on MATLAB platform trough PTS. The performance analysis of grid connected 100 kW SPP on the basis of power flow contribution towards grid as well as demand of utility load without contribution of CB, impact of switching on grid voltage/current and load voltage/current profile in terms of DDI are presents in this subsection.

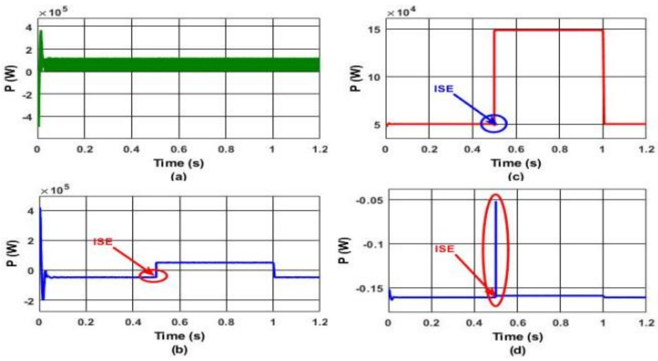


Fig.15 Profile of active powers in PTS without CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

Generated and consume active power by the test system are depicted in Fig. 15. The observation from Fig.. 15 (a) show the performance in constant power generated of 100 kW SPP at STC. The Fig. 15 (b) provide the grid power contribution toward the load proposed in PTS as per switching time condition. Power consumed by the load for switching time as event condition of load imposed is shown in Fig. 15 (c). There is no active power exchange by storage capacitor bank device but some disturbance was observed at the time of switching load in PTS as Fig. 15 (d).

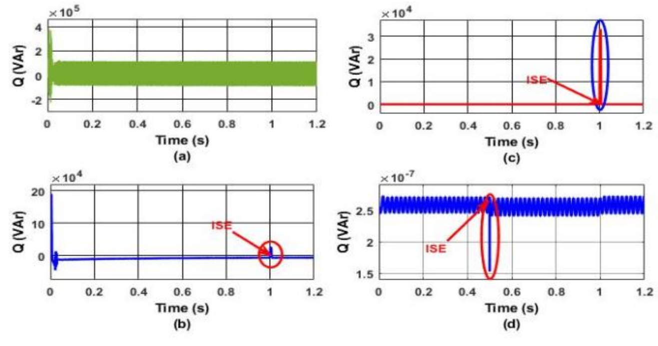


Fig.16 Profile of reactive powers in PTS without CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

All reactive power of the test system is depicted in Fig. 16. It is observed that from graphical result of simulation of Fig.. 16 (a) there is no reactive power generated of 100 kW SPP at STC. The Fig. 16 (b) provide the grid power contribution toward the switching time as per load proposed in PTS for internal circuit because there is no need of reactive power for switching load as seen in Fig. 16 (c) but some transient is observed as event condition when load is removed. There is no reactive power exchange by storage capacitor bank device because CB is out from PTS, but some disturbance was observed at the time of switching load as depicted in Fig. 16 (d).

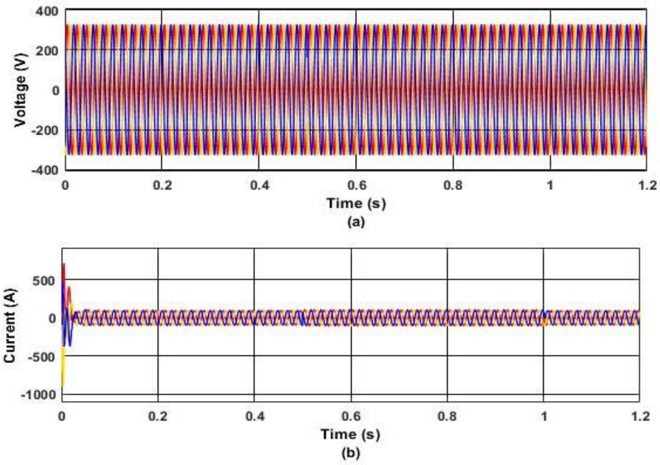


Fig.17 Performance of utility grid parameters without CB (a) Voltage signal profile (b) Current signal profile

The performance of grid parameter was recorded in Fig. 17 (a) & (b) on PCC when increase the load 50 kW to 150 kW by switching another load L2 with the help of c/b in without CB. It is showing the effectiveness of proposed test system.

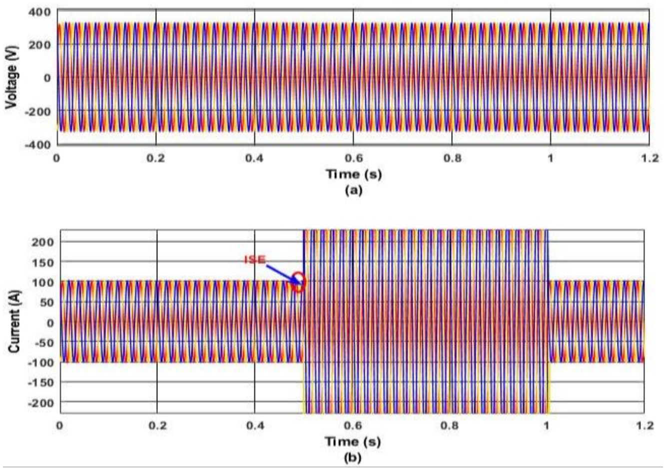


Fig.18 Performance of utility load parameters without CB (a) Voltage signal profile (b) Current signal profile

The performance of load parameter was recorded in Fig. 18 (a) & (b) on PCC which is described in proposed test system when increase the load 50 kW to 150 kW by switching another load L2 with the help of circuit breaker in absence of CB. It is showing the effectiveness of proposed test system.

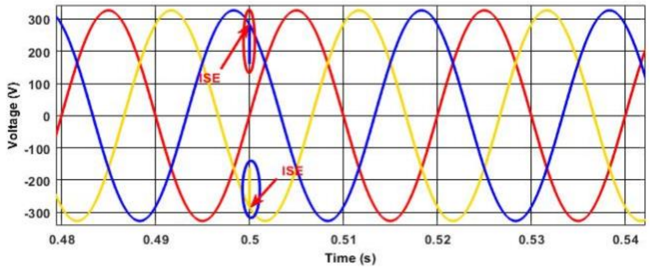


Fig.19 Disturbance detection impact (DDI) in grid voltage signal without CB

The grid voltage waveform recorded on PCC during the event of switching ON the resistive load in the absence of CB is provided in Fig. 19 in which, time corresponds to 0.48s to 0.54s data was recorded and observed that the voltage waveform deteriorates by small magnitude at the moment of switching ON the load takes place.

5.4 Incremental Large Resistive Load with CB

This study provides the impact of large resistive load switching (LRLLS) by increasing load L1 from their original value of 50 kW to 150 kW by switching other L2 of 100 kW for the 0.5s from 0.5s to 1s simulation time with the help of c/b with presence of CB on MATLAB platform through PTS. The performance analysis of grid connected 100 kW SPP on the basis of power flow contribution towards grid as well as demand of utility load with contribution of CB, impact of switching on grid voltage/current and load voltage/current profile in terms of DDI are presents in this subsection.

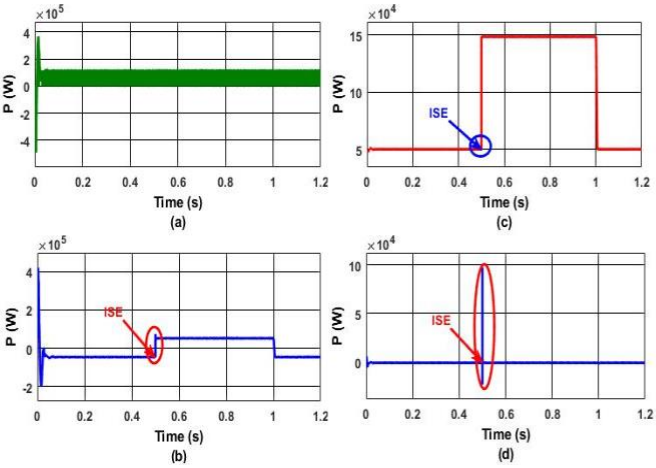


Fig.20 Profile of active powers in PTS without CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

The graphical representation of simulation results those obtained by MATLAB platform for the performance analysis of PTS on the basis of active power flow contribution towards grid as well as demand of utility load with contribution of SPP with presence of CB is depicted in Fig. 20 (a), (b) (c) & (d) respectively. There is no active power exchange by CB device because it exchanges only reactive power as demand in PTS but some disturbance was observed at the time of switching load in as depicted in Fig. 20 (d).

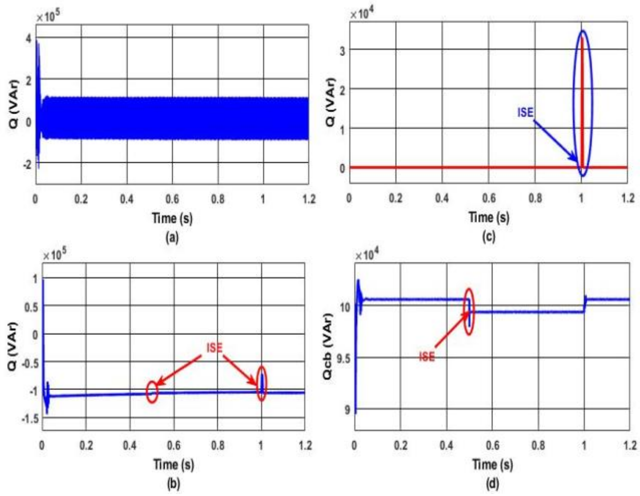


Fig.21 Profile of reactive powers in PTS with CB (a) SPP power (b) Grid power (c) Load power (d) Capacitor bank power

The graphical representation of simulation results those obtained by MATLAB simulation for the performance analysis of PTS on the basis of reactive power contribution towards grid as well as demand of utility load with presence of CB is depicted in Fig. 21 (a), (b) (c) & (d) respectively. There is 100 kVAr reactive power exchanges by CB to grid as per demand to enhance the transient at the time of switching event as seen in Fig. 21 (d).

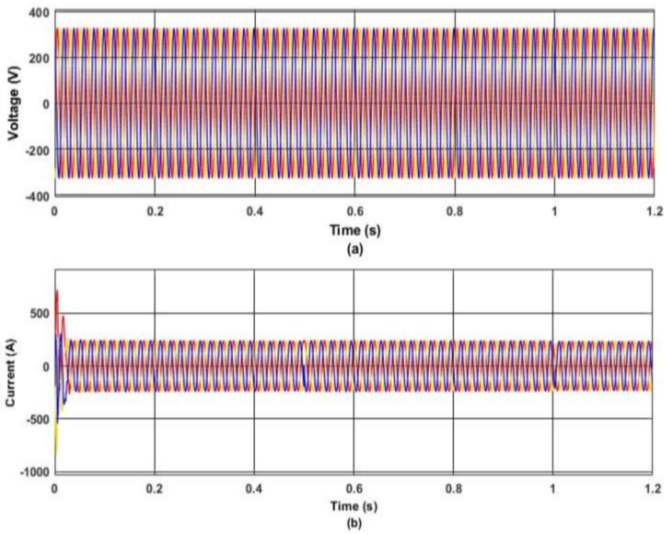


Fig.22 Performance of utility grid parameters with CB (a) Voltage signal profile (b) Current signal profile

The performance of grid parameter was recorded in Fig. 22 (a) & (b) on PCC when increase the load 50 kW to 150 kW by switching another load L2 with the help of c/b in with CB. It is showing the effectiveness of proposed test system.

Performance of load parameter was recorded in Fig. 23 (a) & (b) on PCC which is described in proposed test system when increase the load 50 kW to 150 kW by switching another load L2 with the help of circuit breaker in presence of CB. It is showing the effectiveness of proposed test system.

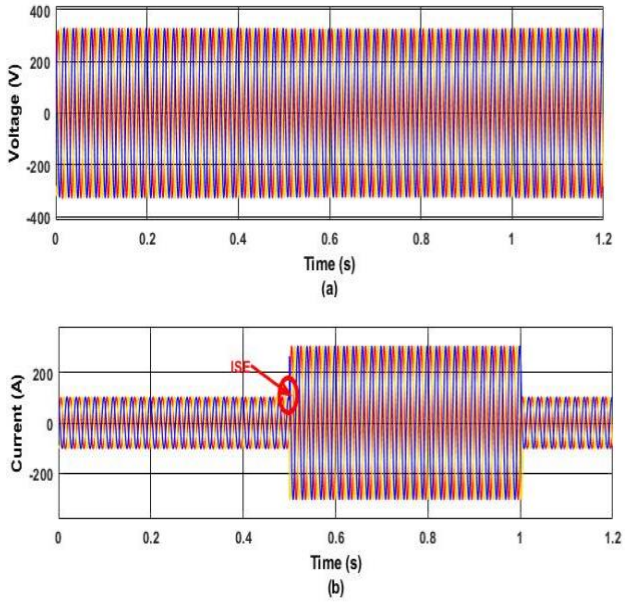


Fig.23 Performance of utility load parameters with CB (a) Voltage signal profile (b) Current signal profile

The grid voltage waveform recorded on PCC during the event of switching ON the resistive load in the presence of CB is provided in Fig. 24 in which, time corresponds to 0.485s to 0.528s data was recorded for keen observation and observed that the voltage waveform is improve as without CB operation but transient of very small magnitude is seen at the moment of switching ON the load takes place.

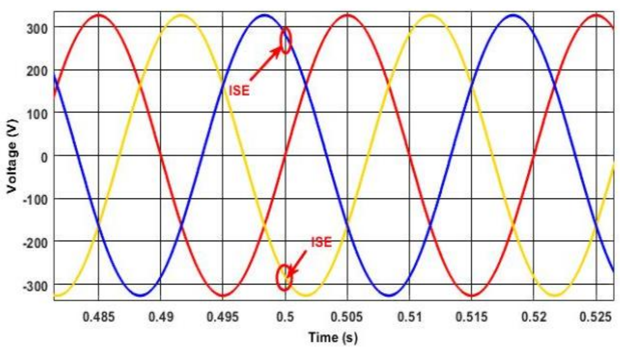


Fig.24 Disturbance detection impact (DDI) in grid voltage signal with CB

5.5 Incremental Inductive Load without CB

This study provides the impact of inductive load switching (ILS) by switching other load L2 of 100 kW & 100 kVAr for the duration 0.5s from 0.5s to 1s simulation time with the help of c/b with absence of CB on MATLAB platform with load L1 has value of 50 kW & 50 kVAr through PTS. The performance analysis of grid connected 100 kW SPP on the basis of power flow contribution towards grid as well as demand of utility load without contribution of CB, impact of switching on grid voltage/current and load voltage/current and DDI profile are presents in this subsection.

The graphical representation of simulation results those obtained by matlab simulation for the performance analysis of PTS on the basis of active power flow contribution towards grid as well as demand of utility load with contribution of solar power plant with absence of CB is depicted in Fig. 25 (a), (b), (c) & (d) respectively.

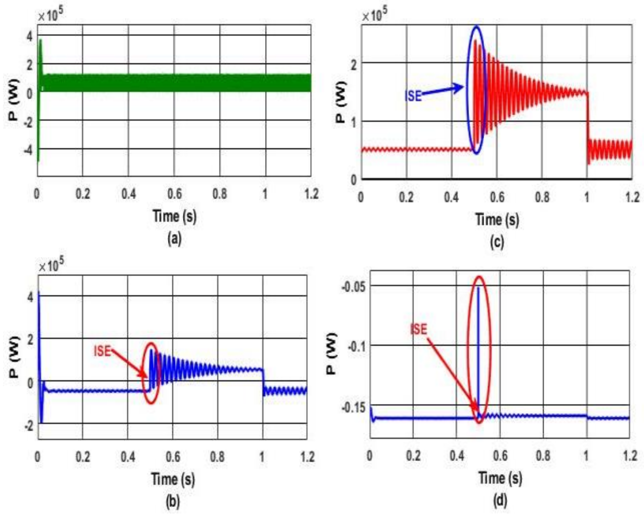


Fig.25 Profile of active powers in PTS without CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

There is no active power exchange by CB device because it exchanges only reactive power as demand in PTS but some disturbance was observed at the time of switching load as depicted in Fig. 25 (d).

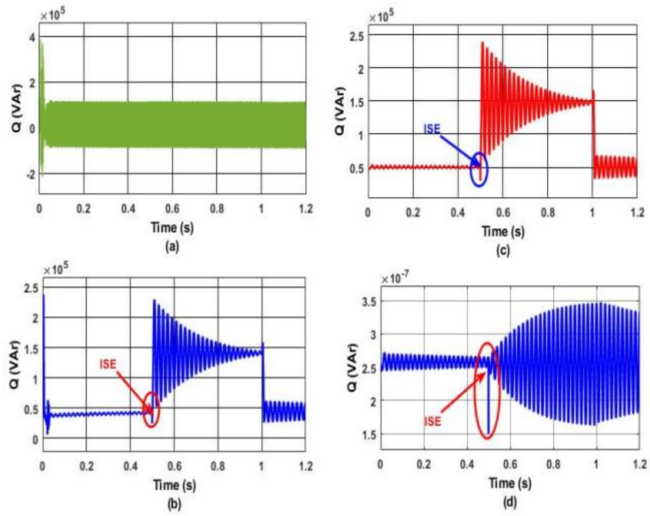


Fig.26 Profile of reactive powers in PTS without CB (a) SPP power (b) Grid power (c) Load power (d) Capacitor bank power

The graphical representation of simulation results those obtained by MATLAB simulation for the performance analysis of PTS on the basis of reactive power contribution towards grid as well as demand of utility load without CB is depicted in Fig. 26 (a), (b), (c) & (d) respectively. There is no reactive power exchange by CB to load as well as grid because CB is out of PTS in this event.

The impact on grid parameter was recorded in Fig. 27 (a) & (b) on PCC when increase the load 50 kW & 50 kVAr to 150 kW & 150 kVAr by switching another load L2 with the help of c/b without CB proposed.

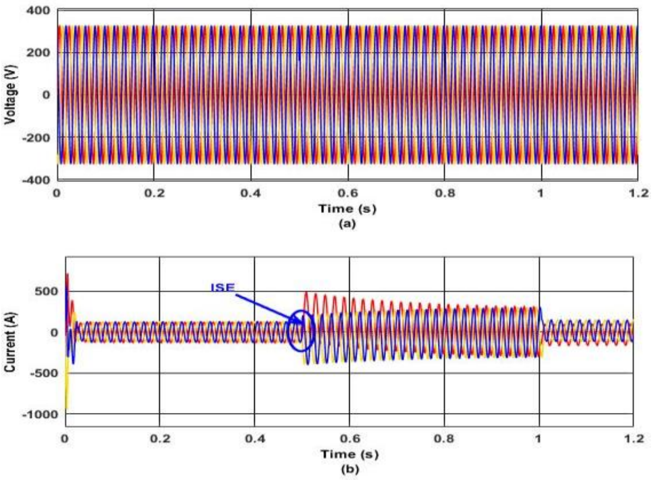


Fig.27 Performance of utility grid parameters without CB (a) Voltage signal profile (b) Current signal profile

The impact on load parameters was recorded in Fig. 28 (a) & (b) on PCC when increase the load 50 kW & 50 kVAr to 150 kW & 150 kVAr by switching another load L2 with the help of c/b without CB proposed.

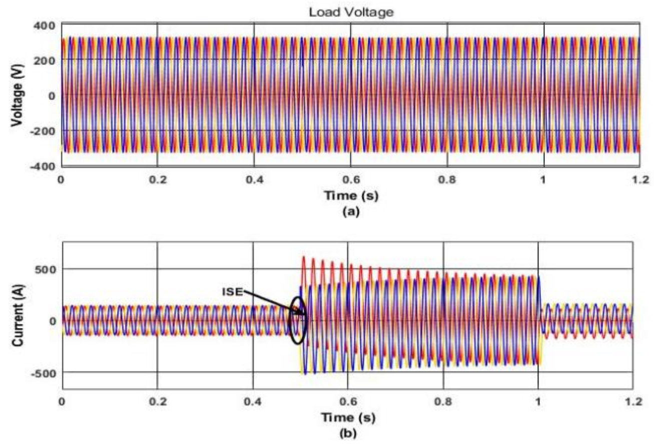


Fig.28 Performance of utility load parameters without CB (a) Voltage signal profile (b) Current signal profile

The grid voltage waveform recorded on PCC during the event of switching ON the inductive load in the absence of CB for the DDI observation is provided in Fig. 29 in which, time corresponds to 0.47s to 0.54s data was recorded for keen observation and observed that the voltage waveform is destroyed at the time of switching as without CB operation, also transient of some magnitude is seen at the moment of switching ON the load takes place.

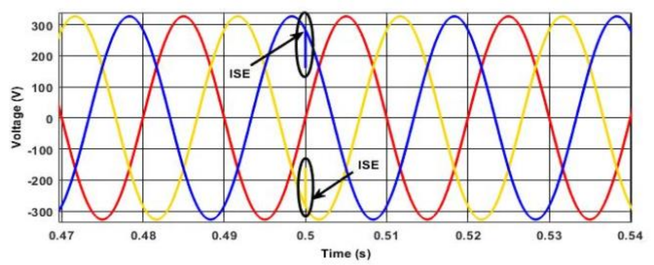


Fig.29 Disturbance detection impact (DDI) in grid voltage signal without CB

The grid voltage waveform recorded on PCC during the event of switching ON the inductive load in the absence of CB for the DDI observation is provided in Fig. 29 in which, time corresponds to 0.47s to 0.54s data was recorded for keen observation and observed that the voltage waveform is destroyed at the time of switching as without CB operation, also transient of some magnitude is seen at the moment of switching ON the load takes place.

5.6 Incremental Inductive Load with CB

This study provides the impact of ILS by switching other load L2 of 100 kW & 100 kVAr for the duration 0.5s from 0.5s to 1s simulation time with the help of c/b with presence of CB on MATLAB platform with load L1 has value of 50 kW & 50 kVAr through PTS. The performance analysis of grid connected 100 kW SPP on the basis of power flow contribution towards grid as well as demand of utility load with contribution of CB, impact of switching on grid voltage/current and load voltage/current profile in terms of DDI are presents in this subsection.

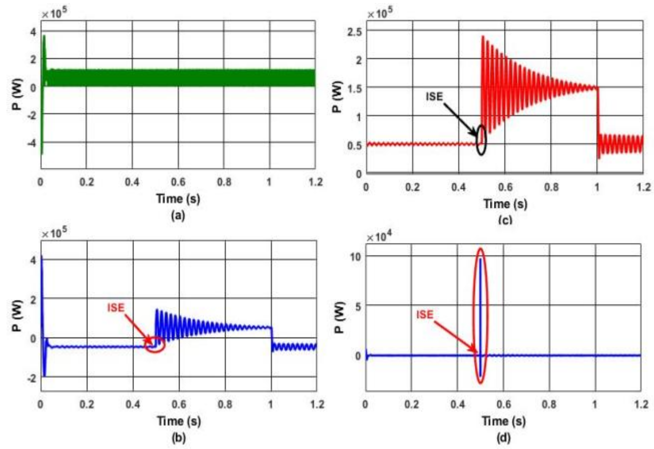


Fig.30 Profile of active powers in PTS with CB (a) Generated power by SPP (b) Grid power (c) Load power (d) Capacitor bank power

The graphical representation of simulation results those obtained by matlab simulation for the performance analysis of PTS on the basis of active power flow contribution towards grid as well as demand of utility load with contribution of solar power plant with presence of CB is depicted in Fig. 30 (a), (b), (c) & (d) respectively. There is no active power exchange by CB device because it exchanges only reactive power as demand in PTS but some disturbance was observed at the time of switching load as depicted in Fig. 30 (d).

The graphical representation of simulation results those obtained by MATLAB simulation for the performance analysis of PTS on the basis of reactive power contribution towards grid as well as demand of utility load without CB is depicted in Fig. 31 (a), (b), (c) & (d) respectively. There is some reactive power exchange by CB to the load as per demand by PTS depicted in Fig. 31 (d). It shows the effectiveness of proposed research work.

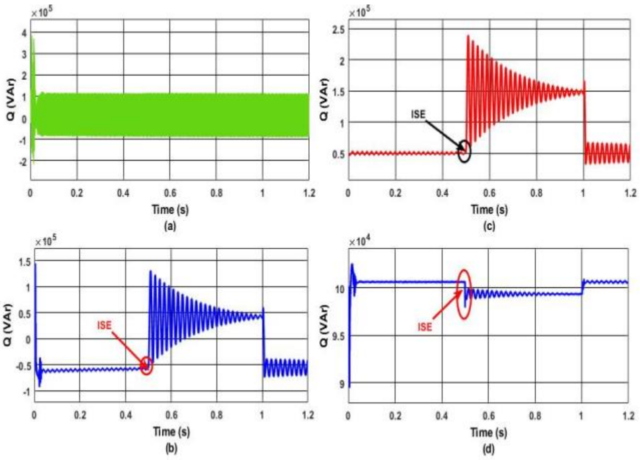


Fig.31 Profile of reactive powers in PTS with CB (a) SPP power (b) Grid power (c) Load power (d) Capacitor bank power

The impact on grid parameter was recorded in Fig. 32 (a) & (b) on PCC when switching other load L2 of 100 kW & 100 kVAr for the duration 0.5s from 0.5s to 1s simulation time with the help of c/b with presence of CB on MATLAB platform with load L1 has value of 50 kW & 50 kVAr through PTS. It is showing the effectiveness of proposed test system.

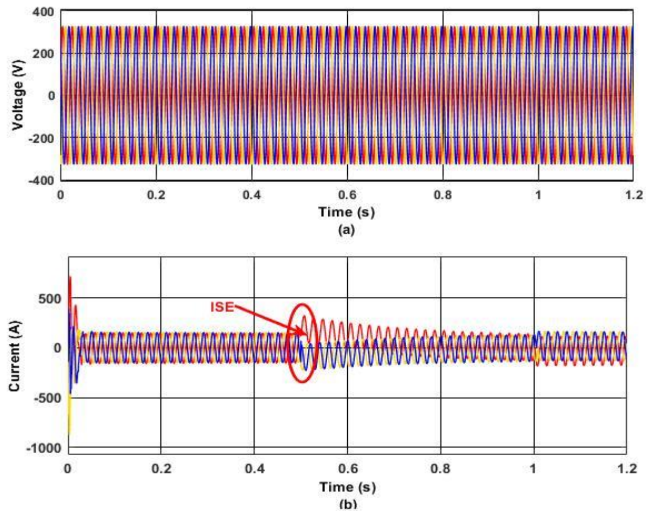


Fig.32 Performance of utility grid parameters with CB (a) Voltage signal profile (b) Current signal profile

The performance of load parameter was recorded in Fig. 33 (a) & (b) on PCC which is described in proposed test system when switching other load L2 of 100 kW & 100 kVAr for the duration 0.5s from 0.5s to 1s simulation time with the help of c/b with presence of CB on MATLAB platform with load L1 has value of 50 kW & 50 kVAr through PTS. It is showing the effectiveness of proposed test system.

The grid voltage waveform recorded on PCC during the event of switching ON the resistive load in the presence of CB is provided in Fig. 34 in which, time corresponds to 0.47s to 0.54s data was recorded for keen observation and observed that the voltage waveform is improve as without CB operation, also transient is removed at the moment of switching ON the load takes place.

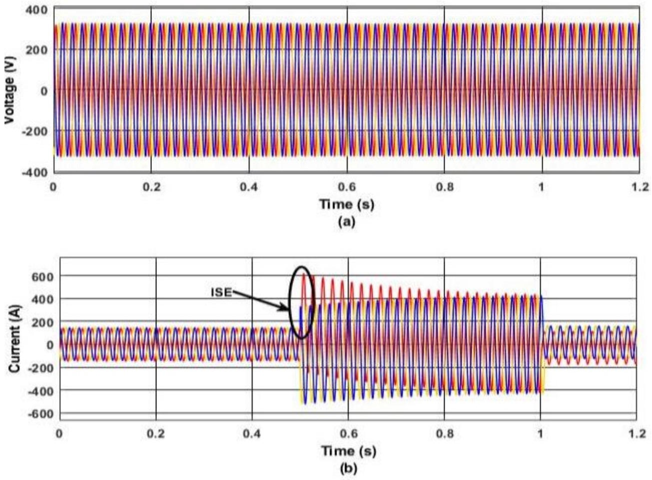


Fig.33 Performance of utility load parameters with CB (a) Voltage signal profile (b) Current signal profile

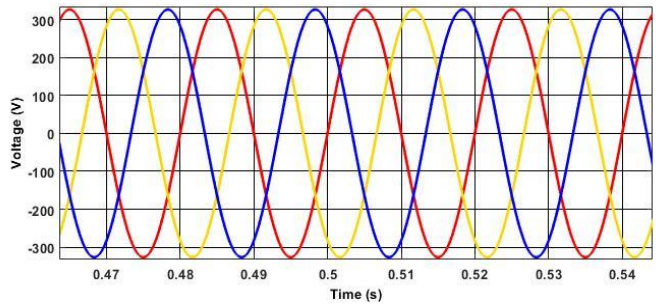


Fig.34 Disturbance detection impact (DDI) in grid voltage signal with CB

6. Comparative Performance

Comparative performance of grid connected 100 kW solar power plant with storage of capacitor bank on the basis of power contribution towards the utility demand load as well as grid contribution is present with different study of work through proposed test sustem on simulink of matlab, also evaluated the total harmonic distortions (THDs) presence in grid parameters like voltage & current by event with and without storage capacitor bank with the help of c/b. The comparative performance index (CPI) is evaluated using expression (16) for validation of result as proposed existence vs alternative improvement.

$$CPI = \frac{THDACB - THDPCB}{THDACB} \times 100\% \qquad (16)$$

Where THDPCB is the THD in the presence of capacitor bank storage and THDACB is the THD in the absence of capacitor bank storage. Due to limitations of pages, graphical representation is presented only three events with and without storage system CB. However, this proposed method is performed for different cases of study such as switching ON and OFF of domestic/industrial aspect with load variability on utility grid. The THD of grid/load parameter signals are provided in Tables of 3, 4, 5 and 6.

Table 3. Grid Voltage Signal THD

Name of Events	% THD		% CPI
	ACB	PCB	
Resistive Load is increased from 40 kW load (L1) to 90 kW by switching 50 kW load (L2) in PTS	0.11	0.02	81.8
Resistive Load is increased from 50 kW load (L1) to 150 kW by switching 100 kW load (L2) in PTS	0.18	0.02	88.8
Inductive Load is increased from [50 kW and 50 kVAr (+ve)] (L1) to 150 kW and 150 kVAr by switching 100 kW and 100 kVAr (L2) in PTS	0.18	0.03	83.3

Table 4. Grid current Signal THD

Name of Events	% THD		% CPI
	ACB	PCB	
Resistive Load is increased from 40 kW load (L1) to 90 kW by switching 50 kW load (L2) in PTS	73.37	16.26	77.8
Resistive Load is increased from 50 kW load (L1) to 150 kW by switching 100 kW load (L2) in PTS	117.57	29.14	75.2
Inductive Load is increased from [50 kW and 50 kVAr (+ve)] (L1) to 150 kW and 150 kVAr by switching 100 kW and 100 kVAr (L2) in PTS	202.12	39.05	80.6

Observation from Table 3 and 4 investigated operational tests such as ON/OFF the utility load by help of c/b on PTS, THD generated in Grid voltage/current waveform improved by interfacing of CB with grid connected RE source as SPP. Comparative improves in the values of total harmonics distortions (THDs) presence in voltage/current signal is calculated to be more than 75% in all test.

Table 5. Load Voltage Signal THD

Name of Events	% THD		% CPI
	ACB	PCB	
Resistive Load is increased from 40 kW load (L1) to 90 kW by switching 50 kW load (L2) in PTS	0.16	0.11	31.2
Resistive Load is increased from 50 kW load (L1) to 150 kW by switching 100 kW load (L2) in PTS	0.28	0.20	28.5
Inductive Load is increased from [50 kW and 50 kVAr (+ve)] (L1) to 150 kW and 150 kVAr by switching 100 kW and 100 kVAr (L2) in PTS	0.33	0.30	9.09

Table 6. Load current Signal THD

Name of Events	% THD		% CPI
	ACB	PCB	
Resistive Load is increased from 40 kW load (L1) to 90 kW by switching 50 kW load (L2) in PTS	26.66	23.69	11.1
Resistive Load is increased from 50 kW load (L1) to 150 kW by switching 100 kW load (L2) in PTS	25.94	21.98	15.2
Inductive Load is increased from [50 kW and 50 kVAr (+ve)] (L1) to 150 kW and 150 kVAr by switching 100 kW and 100 kVAr (L2) in PTS	31.02	22.74	26.7

Also, this is observed from the Table 5 and 6 that in all the investigated operational events such as ON/OFF the utility load, the THD generated in load voltage/current waveform improved by interfacing of CB with grid connected 100 kW SPP. The comparative improvement in the values of total harmonics distortion (THDs) presence in voltage signal is calculated to be more than 22% CPI in switching condition. Also, CPI in terms of THDs in load current signal is calculated to be more than 17%.

7. Conclusions

This research paper provide a performance of grid connected renewable energy as solar source, capacity of 100 kW in terms of active/reactive power contribution to the utility load which is demand by test condition those proposed in test system with the help of circuit breaker operation with and without storage system of capacitor bank, Also improve the grid voltage/current and load voltage/current profiles with more than 75% and 22% CPI respectively which shows the effectivenes of proposed research work in all physical test condition. This is the key point to improve power quality of grid connected RE sources by reserchers in field of power system.

Acknowledgements

All the authors are grateful to Arya College of Engineering & IT for their great efforts in support for this work.

References

[1] P. Akash Pattanaik, Naresh K Pilli and S K Singh, “Design, Simulation & Performance Evaluation of three phase grid connected PV panel”, IEEE Power, Communication and Information Technology Conference (PCITC), Bhubaneswar, India, 15-17 October 2015.

[2] Virendra Sharma and Lata Gidwani “Optimistic Use of DSTATCOM Controlled Battery Energy Storage System to Mitigate Grid Disturbances with Solar Energy Penetration”, 10th International Conference on Computing, Communication and Networking Technologies (ICCCNT), IIT Kanpur, India, 06-08 July 2019.

[3] Virendra Sharma and Lata Gidwani, “Minimization Impact of Grid Disturbances on performance of utility grid with wind energy penetration using battery energy storage devices”, International Conference on Computing, Power and Communication Technologies (GUCON), 27-28 September 2019.

[4] G. Bal, S. Oncu, N. Ozturk and K. Unal, “An Application of PDM Technique for MPPT in Solar Powered Wireless Power Transfer Systems”, IEEE 10th International Conference on Renewable Energy Research and Application (ICRERA), Istanbul, Turkey, 26-29 September 2021.

[5] S. Vadi, F. B. Gurbuz, S. Sagiroglu and R. Bayindir, “Optimization of PI Based Buck-Boost Converter by Particle Swarm Optimization Algorithm”, IEEE 9th International Conference on Smart Grid (IC Smart Grid), Setubal, Portugal, 29 June 2021 - 01 July 2021.

[6] M. K. Amaehule, R. Uhunmwangho, N. Nwazor, Ekene S. Mbonu, and K. E. Okedu, “Investigation of the Impact of Soot on the Efficiency of Solar Panels using a Smart Intelligent

Monitoring System", International Journal of Smart Grid, DOI: https://doi.org/10.20508/ijsmartgrid.v7i1.269.g255, Vol.7, No.1.

[7] F. M. Wulfran, D. N. S. Raoul, M. R. Jean Jacques and K. T. Saatong, "A Technical Analysis of a Grid-Connected Hybrid Renewable Energy System under Meteorological Constraints for a Timely Energy Management", IJSG, DOI: https://doi.org/10.20508/ijsmartgrid.v7i2.278.g260,Vol.7,No. 2.

[8] A. Belkaid, I. Colak, K. Kayisli, R. Bayindir, "Improving PV System Performance using High Efficiency Fuzzy Logic Control", IEEE 8th International Conference on Smart Grid (IC Smart Grid), Paris, France, 2020.

[9] S. Ram Ola, A. Saraswat, S. Kumar Goyal, V. Sharma, B. Khan, OP. Mahela, H. Haes Alhelou, P. Siano, "Alienation Coefficient and Wigner Distribution Function Based Protection Scheme for Hybrid Power System Network with Renewable Energy Penetration", MDPI Energies, DOI: https://doi.org/10.3390/en13051120, Vol. 13, pp. 1120.

[10] Alaa Najem Abed, Hazim H. Hussain, Naseer K. Kasim, "Performance Analysis of Grid-Connected CIGS PV Solar System and Comparison with PV Syst Simulation Program", International Journal of Smart Grid, DOI: https://doi.org/10.20508/ijsmartgrid.v3i4.57.g64, Vol.3, No.4.

[11] B. Kasniya, T. Kanumuri, V. Shrivastava, V. Sharma, "A Review of Li-Ion Battery's Thermal Runway Mitigation Strategies with an Eye towards a Smarter BTMS", IEEE 10th Power India International Conference (PIICON), New Delhi, India, 25-27 November 2022.

[12] S. Kenu, R. Uhunmwangho, K. Okedu, "Harnessing Solar and Wind Power for Hybrid Stand-alone Energy System: The Case of Coastline Communities in Delta State of Southern Nigeria", International Journal of Smart Grid, DOI: https://doi.org/10.20508/ijsmartgrid.v7i1.268.g257, Vol.7, No.1.

[13] Sharma V., Gidwani L., "Frequency regulation of grid with wind power using Energy Storage System" International Journal of Grid Distributed and Computing, DOI: http://dx.doi.org/10.14257/ijgdc.2015.8.3.26, Vol. 8, PP. 267-274.

[14] Virendra Sharma and Lata Gidwani "Optimistic Use of Energy Storage System to Mitigate Grid Disturbances in the Hybrid Power System" AIMS Energy, DOI: https://www.aimspress.com/article/10.3934/energy.2019.6.688, Vol. 7, Issue 6, PP. 688–709.

[15] V. Sharma, Virendra Sharma, P. Kumar Choubey, A. Kumar, L. Gidwani. "Optimal generation capacity mix in microgrid to meet demand" International Journal of Advances in Applied Sciences (IJAAS), DOI: http://doi: 10.11591/ijaas.v10.i3.pp271-282, Vol. 10, No. 3, pp. 271-282.

[16] A. Gupta and Virendra Sharma, "Performance prediction by modelling 5KW solar penetration in power system", Materials Today: Proceedings (Elsevier), DOI: https://doi.org/10.1016/j.matpr.2022.09.321, Volume 69, part 2, pp 569-575.

[17] J. Verma, V. Sharma, G. Jain, N. Kumar Garg, V. Shrivastava, P. Garg, "Power Management & Quality Analysis of Battery Storage Based Renewable Energy Generation System for Utility Bus", 10th IEEE Power India International Conference, New Delhi, India, 25-27 November 2022.

[18] V. Sharma and L. Gidwani, "Recognition of Disturbances in Hybrid Power System Interfaced with Battery Energy Storage System Using Combined Features of Stockwell Transform and Hilbert Transform", Journal of AIMS Energy, DOI: https://www.aimspress.com/article/10.3934/energy.2019.5.671, Vol. 7, Issue 5, pp. 671-687.

[19] R. Zafer Caglayan, K. Kayisli, N. Zhakiyev, A. Harrouz and I. Colak, "A Review of Hybrid Renewable Energy Systems and MPPT Methods", International Journal of Smart Grid, DOI: https://doi.org/10.20508/ijsma , Vol.6, No.3.

[20] V. Sharma, J. Verma, P. Sonwane, H. Sharma, A. Gupta, P. Kumar, "Power Management and Voltage Regulation of Self-Governed Hybrid RE-Source Microgrid System for Distribution Load," 6th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Kedah, Malaysia, 1-3 December 2021.

[21] Irfan Ali, Virendra Sharma and P. Chhawchharia, "Control techniques for active power filter for harmonic elimination & power quality improvement", Journal of International Conference on Energy, ISSN:2320-2084, Volume-4, Issue-10, pp 25-36.