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Power quality improvement by using multiple sources of PV and battery for DSTATCOM based on coordinated design

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Abstract. This paper presented the effect of using multiple sources of photovoltaic (PV) cells and battery on the input dc link channel of voltage source converter (VSC) for distribution STATCOM (DSTATCOM). The first high coordinated design is applied on the input of three-leg VSC for DSTATCOM to provide a continuous voltage over the time without delaying or interruption in the power through the control circuit and Dc to Dc circuit for boost of photovoltaic cell and buck-boost of battery. When there is a large of sun radiation, the generating power of PV is supplied to the three-leg VSC of DSTATCOM for power demand compensation and the surplus power is saved at the battery. In the condition of night or cloudy days the battery is discharged to maintain the sustainability of the VSC DSTATCOM. In addition, the design is used a Star / Delta transformer to isolate three-leg VSC for DSTATCOM to provide a circular path for zero sequence fundamental and then reducing harmonics the neutral current. The purpose of using DSTATCOM is to reduce the harmonics of current source, compensate the reactive currents and compensate the ground currents in the point of common coupled (PCC). The type of algorithm that used to coordinate the compensation process of DSTATCOM is a synchronous reference frame (SRF).

1. Introduction.

In the last years, many researchers have concentrated on the renewable energy sources based on the power quality improvement within the power distribution systems in order to widespread the use of non-linear electronic load [1, 2]. There are many types of micro grids whose comprise photovoltaic cell, fuel cell and wind power [3-5]. Fuel cells and photovoltaic cells are considered the source of low voltages where it is used for providing the sufficient DC voltage input for an inverter as a booster of an alternating voltage source [6]. Solar panel design involves a group of photovoltaic cells that is connected in the series and parallel to provide the rated voltage and current. Since the voltage of solar panel is not constant due to variation in both of radiation and temperature or any of them, therefore it is important to regulate it continuously. The Dc to Dc boost converter can be used to feed the three-leg of VSC with the necessary fixed voltage [7]. Three-leg of VSC are equipped with two sources except the grid source. The controller with high level for the coordination purposes is used so that the priority of the supply from the panel cells.



When there is a shortage in the power of the solar cells, the compensated power is provided from the battery. In case, the power production for the solar cells is exceeded the system power demand so the exceed power will be invested in the battery charging. The charge and discharge executed through the second DC converter known as a Dc to DC buck-boost converter and this kind of processing is called (Hybrid) type [8-9]. Increasing the radiation levels of solar cells during the sunny day that provided the necessary power for inverter at same time the power higher than the production is stored in the battery that is used in the night or cloudy times. The compensation of non-linear loads with external DC sources gives the better results than whether DSTATCOM compensation alone through DC link charging from the grid via the VSC converter [10]. The combination of controllers that are used in the distribution power system known as custom power devices (CPDs) and it extended to provide the solution of power quality problems. The CPDs include the distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) that used for compensating of power. The DVR is proposed for voltage balancing and compensating for voltage harmonic distortions while the UPQC is applied for compensating the load current harmonic, reactive power compensation, power factor correction (UPF) and correcting of non-load current. Some of the industrial and commercial loads contain non-linear property for examples the computer loads, modern welding machines, lighting ballasts and load switch method based power supply etc. The technique of synchronous reference frame theory is suitable for DSTATCOM for compensation and correction [11-12]. Distribution systems of three phases with four wires face many problems of power quality due to non-linear harmonic loads, unbalance in the neutral load, etc [12]. In this paper, the optimization algorithms do not used for Maximum Power Point Tracking (MPPT) just by controlling the Pulse Width Modulation (PWM) to boost of PV power. The current of neutral line is not equal to zero due to inequality of the loading on the feeders let the three wires unbalanced and that lead to random tripping of protective relays, increasing of losses, overloading the equipment of distribution system and the sensitive loads in the system will be affected and may damage or not operated well [13-17]. SVC and STATCOM are considered as solutions to the power quality problems [18]. In this paper, we have presented the simultaneous coordinated design between a two types of multiple power sources (Solar cell and Battery) for DC link channel of the DSTATCOM device in order to obtain the design that provided the most effective performance with faster response to reduce from the above drawbacks [19]. The Isolated Gate Bipolar Transistor (IGBT) type is used for transistor switching in the VSC to give the fast response for inverter at dc capacitor link for DSTATCOM to obtain the required compensation [20]. In addition, the paper presents the advantage of using Star-Delta transformer for providing a circular path within the Delta coils to reduce the neutral currents [21].

2. Methodology

2.1 Design of DSTATCOM with star/delta transformer

The supply power from the circuit of multi-sources (photovoltaic and battery) boost and buck boost converter respectively is fed to the VSC inverter for DSTATCOM with star/delta transformer which is connected to the grid and the non-linear load at Point of Common Coupling (PCC) as shown in Figure 1 [22]. To calculate the value of V_{dc} link of capacitor as follows.

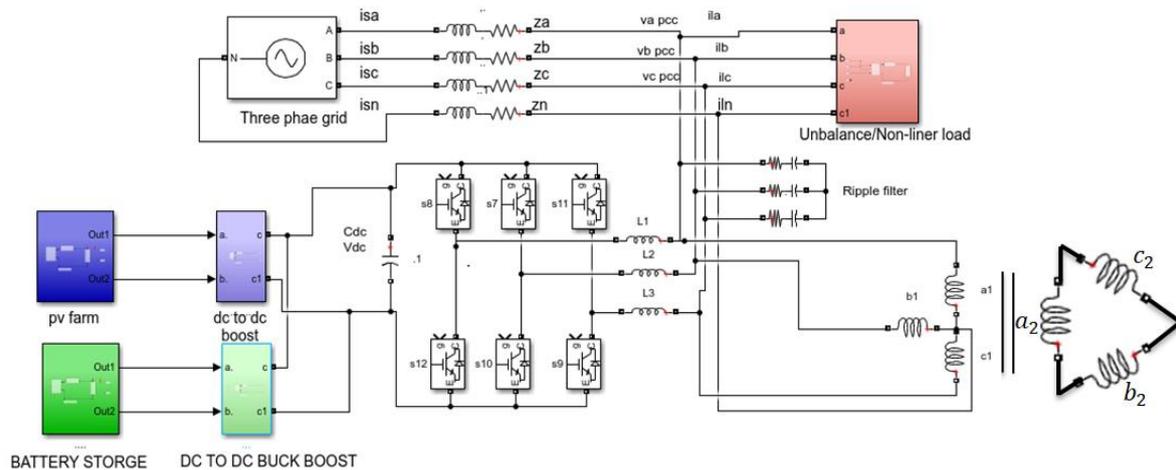


Figure 1. Schematic diagram of the proposed renewable multi sources (PV and battery) for the DSTATCOM DC link channel based on leg VSC with star/delta the transforms.

$$V_{dc1} = \frac{2\sqrt{2} V_{LL}}{\sqrt{3} * M} \tag{1}$$

The value of capacitor voltage (V_{dc1}) in the VSC is calculated by instant power that fed to the DSTATCOM as the following equation (1) [23]:

$$\frac{1}{2} C_{dc} [(V_{dc1}^2) - (V_{dc2}^2)] = 3V(oI)t \tag{2}$$

Also can calculate the value of capacitor from equation (2)[24]. and the value of phase voltage as equation (3):

$$V_{ph} = \frac{V_{LL}}{\sqrt{3}} \tag{3}$$

where: M is the modulation index and equal to 1, (V_{dc1}) is the reference value of dc link voltage equal to (680) volt, (V_{dc2}) is the minimum actual voltage for a DC link of DSTATCOM equal to (677.667) volt, (V_{LL}) is the grid line to line voltage and equal to (415) volt, (C_{dc}) is the capacitor of DC link channel and equal to (3000) μF , (OF) is the over load factor and equal to (1.2), (I) is the phase current of source and equal to (58.13)A, (V) is the phase voltage of source and equal to (240) volt, (V_{ph}) is the grid phase voltage and t is the recovery time of DC link voltage equal to (350) μs .

Figure 2 A and B shows the star/delta connection and phasor diagram for transformer respectively. The primary windings are designed to produce 240 V and line voltages 415 V while the voltage in the secondary windings is set to 240 V. The currents of the transformer depend on the amount of circulation in the delta side of transformer. Another advantage of delta transformer to remove the effect of zero sequence component for current that circulate through it. The ripple filter is used in the circuit to eliminate the ripple voltage that is generated by the VSC switches in the PCC [25].

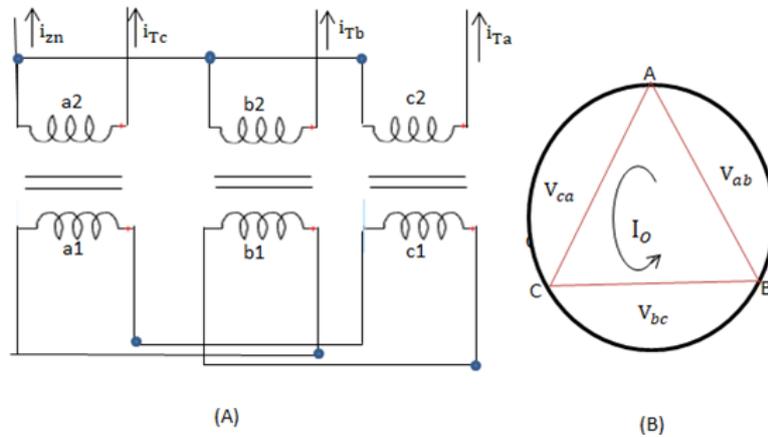


Figure 2. (A) Star/delta connection of transformer windings. (B) Phasor diagram for voltage.

2.2 Modeling of photovoltaic array

The photovoltaic PV consists of several panels (modules) connected in parallel and series method to give the suitable current and voltage for design. The I-V characteristics are listed in Table 1. The PV effect of semiconductor material according to the theory and notion of photovoltaic cell. Figure 3 shows the equivalent circuit of photovoltaic cell. As it known, the generation energy from the solar cell is variable due to the change in the temperature and sun radiation so it must be taken into consideration during the design process to obtain an accurate model. Figure 4 shows the map of solar radiation and temperature variation in a June day at Baghdad city. The amount of solar radiation is variable throughout the year, where it is found that the average value of the solar radiation in Iraq ($6Kw/m^2/day$) as shown in Figure 5 [26].

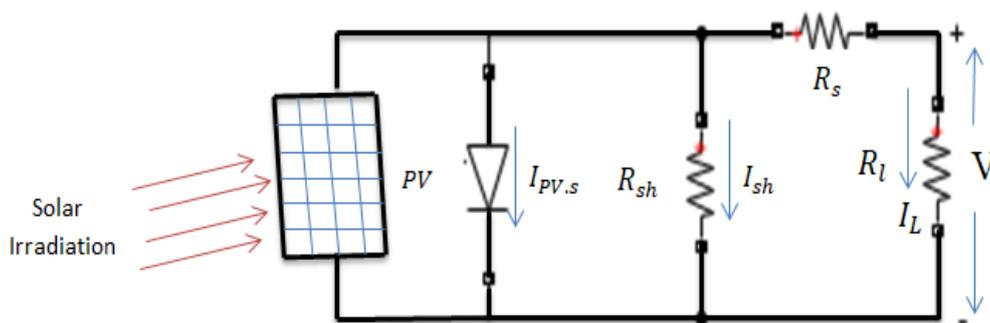


Figure 3. Equivalent of electrical circuit of photovoltaic cell.

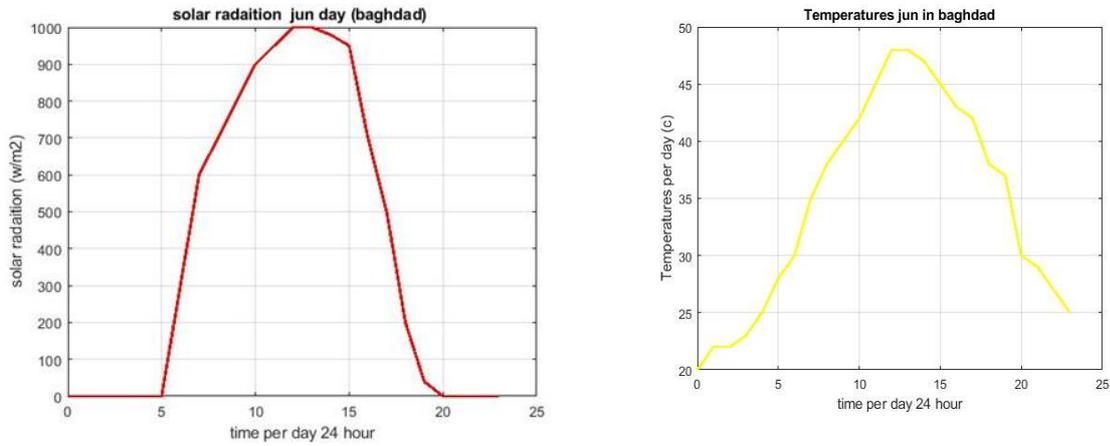


Figure 4. Map of solar radiation and temperature for cell at a June day in the Baghdad city.

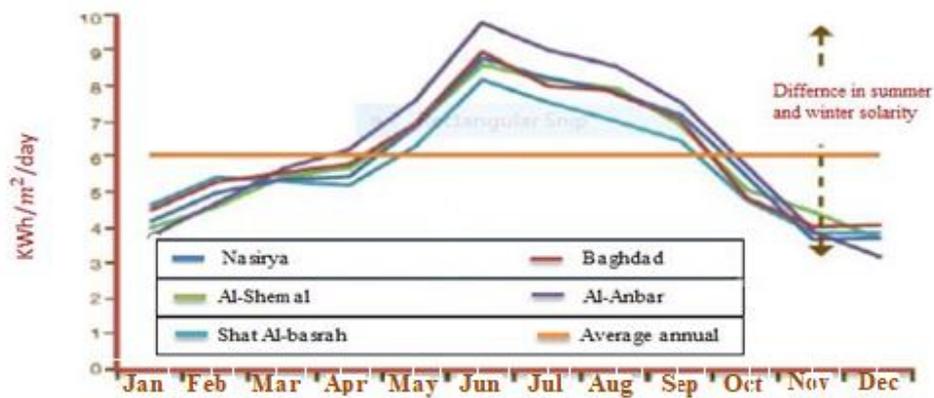


Figure 5. Average solar radiation in the Iraq.

Table 1. Applicable solar panel model information at 1000 W/m² and temperature of 25°C.

Parameters	Sanyo HIT-240HDE4
Maximum power rated (P_{MPR})	240 W
Open circuit voltage (V_{oc})	43.5 V
Short circuit current (I_{sh})	7.37 A
Rated Voltage (V)	35.5 V
Rated Current (I)	6.77 A
Temperature coefficient of short circuit	2.21 mA/°C
Temperature coefficient of open circuit	- 0.109V/°C
Cells per module (Ncell)	60

The (I-V) characteristics of the solar panel that is used in the current work (Sanyo HIT-240HDE4) type which has been drawn by using Matlab-Simulink. Figure 6 shows the relation between constant solar radiation and variable temperature, while Figure 7 shows the same relation but the temperature is constant and solar radiation change according to the equations (4, 5) [21]. A photovoltaic cell of thin layer (HIT) type has been used in the current study. This type of solar cell generated more energy compared to that obtained from crystal solar cell. The current of photovoltaic array mainly depend on two factors, first is the linearity of solar radiation and second is the temperature of solar cells as give in equation (6).

$$I = I_{PV} - I_o \left[\exp\left(\frac{Voc Q}{N_s K T a}\right) - 1 \right] - \frac{Voc}{R_{sh}} \quad (4)$$

$$Voc = V + R_s I \quad (5)$$

The value of $I_{PV,s}$ can be calculated from the equation (7) that is represented the equivalent circuit of Figure 3 [27].

$$I_{PV} = (I_{PV,s} + K_1 \Delta T) \frac{G}{G_s} \quad (6)$$

$$I_{PV,s} = \frac{R_{sh} + R_s}{R_{sh}} I_{sc} \quad (7)$$

where: (I_o) and (I_{PV}) are the diode saturation current and photo current respectively, (N_s) is the number of cells that connected in series, (k) is the boltzmann constant equal to ($1.3806503 \times 10^{-23}$ J/K), (T) is the diode temperature of p-n junction, (Q) is the electronic charge equal to ($1.60217646 \times 10^{-19}$ C), (R_{sh}) represents the shunt resistance of the equivalent circuit array (R_s), is represented the series resistance of equivalent circuit array, (a) is the ideality factor and lies within the range $1 \leq a \leq 1.5$ and choosed 1 in this study ($I_{PV,s}$) is the photo current condition of (STC, 25°C) and 1000 W/m^2 , (K_1) is the short circuit current per temperature coefficients, (ΔT) is the difference between the actual and normal temperatures in kelvin and (G, G_s) are the radation of the device surface and normal radiation respectively.

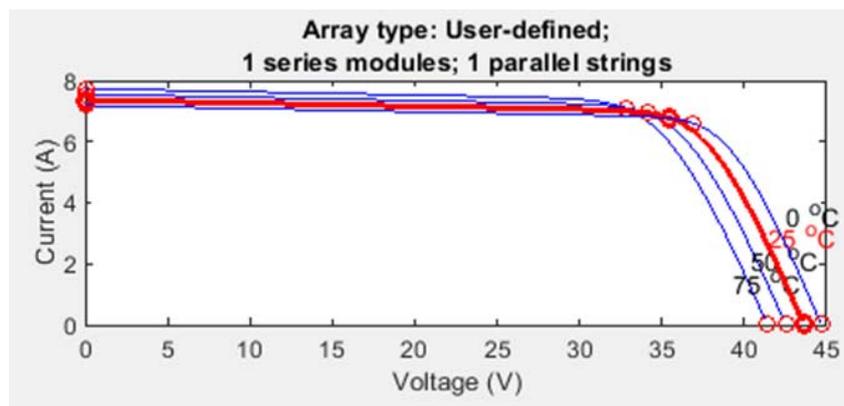


Figure 6. The I-V characteristics of Sanyo HIT-240HDE4 type by Matlab Simulink at constant radiation 1000 W/m^2 and varying temperature.

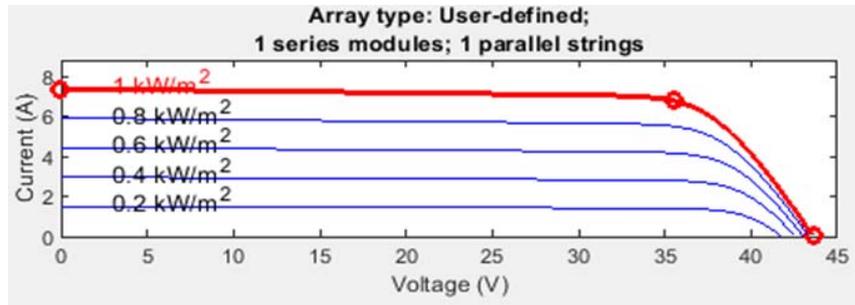


Figure 7. The I-V characteristics of Sanyo HIT-240HDE4 type by Matlab Simulink at constant temperature 25°C and varying radiation.

The work was divided into four situation:

1. Power surplus of panels at day time (high production mode): in this case the out voltage from the photovoltaic cells provides the necessary compensation for dc link of DSTATCOM also charges the battery with overcharging voltage 170 volts. The charging is done through the circuit of DC to DC boost converter for PV and then through the circuit of DC to DC buck converter for battery.
2. Power production equals to the compensation only during day time (Power compensation mode): during this mode the amount of solar radiation is sufficient to generate the power that covered the system compensation only but not enough to battery charging.
3. Fully compensation from battery during the night time (night mode): obviously at night time there is no solar radiation so the full power compensation is drawn from the battery via the boost circuit.
4. Power compensation during the cloudy day (cloudy mode): sometimes the weather is cloudy and there is no solar radiation for this reason the power generation of panels is equal to zero. Therefore, the design takes into account the cloudy day and the power compensation from battery and grid for 24 hours full day.

2.3 Control circuit of DC bus voltage

The control circuit of DC bus voltage includes the following:

2.3.1 PV boost converter Step-up circuit is used for the proper supply for DC Link voltage of VSC according to the load that need to be compensated as shown in Figure 8. The technology that used for cutting in the IGBT gate is the Pulse Width Modulation (PWM) of 25 kHz and the design voltage for converter 850 volts in the case of falling the solar radiation equal to 1000 W/m² will cover a boost circuit. The amount of voltage required for DC link equals 676 volt according to equation (1). The surplus of these voltages sent to the charging circuit (buck converter) that designed to charge the battery from the surplus produced of solar panels as follows in the special equations. This way keep the voltage of the DC link at a constant value for all the time and the parameter of boost design is calculated in equation (8) according to references [28, 29].

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \quad (8)$$

$$D = \frac{T_1}{T_1 - T_2} \quad (9)$$

where: (V_o) is the V_{dc} out of boost converter, (V_{in}) is the voltage of photovoltage solar cells, (D) is the duty cycle of PWM and (T_1, T_2) is ON time and OFF time respectively, corresponding to PWM and calculated in equation (9) .

2.3.2. buck-boost converter of battery. Battery model taken from the Matlab/Electric drive/Extra sources/ Battery library. All details and descriptions about the battery are taken from [30]. The process of producing the energy from solar panels is intermittent due to the climatic conditions as well as changing the load requirements. The lead acid battery (Deep Cycle) is the most common type of battery. The type of lead acid was chosen in this design to preserve the battery life and the control circuit has been designed so that the battery in the charging state is not exceeding 80% from the total charging and in the discharging state (SOC) is not less than 20 % according to reference [28].When the generation power of solar panels increases over the demand, the battery absorbs the surplus power through the buck converter circuit. If the power amount of solar panel generation is insufficient to supply the DC-Link voltage, the circuit of buck-boost converter will regain the power of the battery to support the load as shown in Figure 8. The charging and discharging of lead acid battery model are represented by the following equations [27]:

$$V_{Bat_discharge} = V_s - Ri - K \frac{q}{q-i(t)} (i(t) + t^F) + exp(t) \tag{10}$$

$$V_{Bat_charge} = V_s - R i - \left[K \frac{q}{i(t)-0.1q} \right] i^F - \left[K \frac{q}{q-i(t)} \right] i(t) + exp(t) \tag{11}$$

$$i(t) = \int i d(t) \tag{12}$$

where: ($V_{Bat_discharge}, V_{Bat_charge}$ and V_s) are the battery discharge voltage, battery charge voltage and battery constant voltage respectively (volt), K is the constant polarisation (V/Ah), q is the capacity of battery (Ah), $i(t)$ is the actual charge of battery (A/h) and calculate according to equation (12). i is the current of battery (A), i^F is the filter current (A) and t^F is the filter time (h).

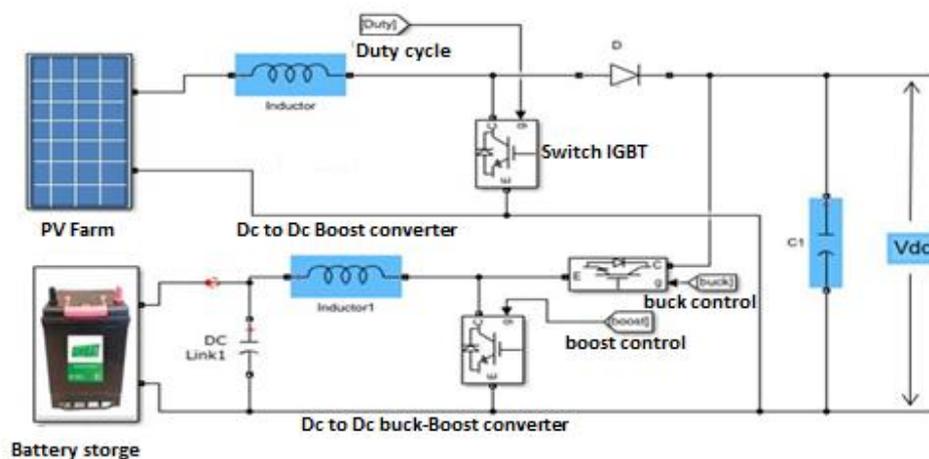


Figure 8. The boost of PV and the buck-boost converter of battery.

2.3.3 Coordination between PV and battery. The control among the power generation of PV panels, the amount of charge power for the battery, the output power of the VSC leg and the percentage of charge

(SOC%) available in the battery requires a high coordination [22]. Therefore, the control circuit is designed to take into account all these variables as shown in Figure 9.

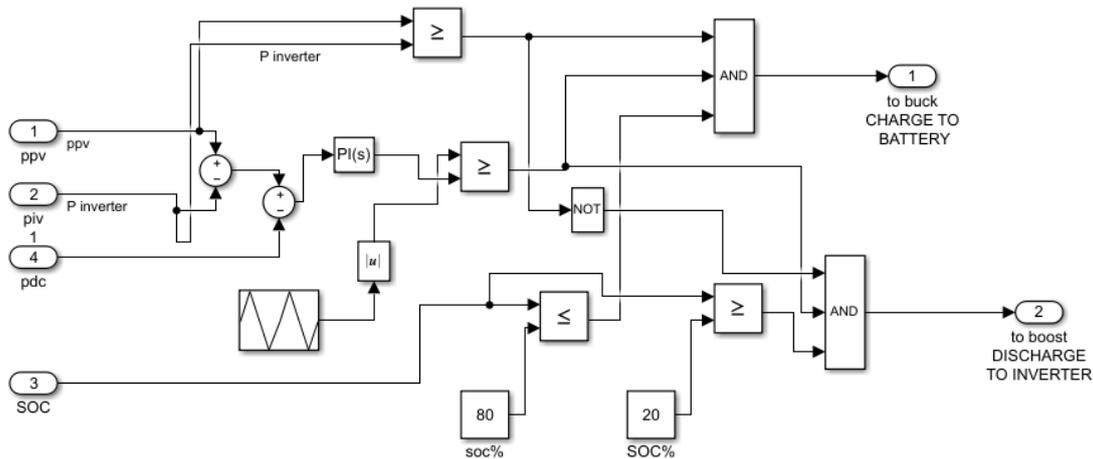


Figure 9. Coordination circuit between battery and PV.

2.4 Control circuit of DSTATCOM.

There are several types of control circuits that used to control the work of (DSTATCOM) :

1. phase shift control [31].
2. decoupled current control [32].
3. Instantaneous reactive power theory (p-q theory)[23].
4. Synchronous Reference Frame theory (SRF) [33].

The control circuit of DSTATCOM is designed based on four types because this type of circuit deals with the compensation currents and since the currents are affected directly by the nonlinear load. Therefore, it required to be treatment by the appropriate selection method for circuit type [23, 34, 35]. The voltages of three phases are taken from (PCC) to be converted into ($\sin \theta$ and $\cos \theta$) values by Phase Locked Loop (PLL) as well as the voltages of three phases for (PCC) are used to determine the amplitude value of these voltages and compared with the reference amplitude to give the error signal and corrected by the PI controller and also converts it to the values of a currents known i_{qa} with fast response according to the training of this controller as shown in the equations (13) and (14). The Park and Clark transformation arrays play an important role in the process of conversion and finding the values of reference current for the control. The load current is measured by a sensor to find the actual current values (i_d, i_q) in the matrix as in equation (15). A DC voltage is also taken by a DC Link Voltage sensor and subtracted from the DC reference voltage to be obtained the differential signal that is processed and converted to a current (VSC switches losses) by a PI controller as in equation (16) and (17). Consequently, the actual current (i_{qa}) add with (i_{qs}) to produce the reference current ($i_{q.ref}$) and the actual current (i_{dd}) add with loss current ($i_{d.loss}$) to produce the reference current ($i_{d.ref}$) as shown in Figure 10. The dq-reference currents need an inverse transformation to obtain the abc-reference currents and then the resulted currents are compared with source currents that affected by harmonic loads in order to calculate the correct signals for gate switches (IGBT).

$$i_{qs(n)} = i_{qs(n-1)} + K_{pq}(V_{Ae(n)} - V_{Ae(n-1)}) + K_{idd} v_{Ae(n)} \tag{13}$$

$$i_{q.ref} = i_{qa} - i_{qd} \tag{14}$$

$$\begin{bmatrix} i_d \\ i_q \\ i_o \end{bmatrix} = \begin{bmatrix} \sin \theta & \sin(\theta - \frac{2\pi i}{3}) & \sin(\theta + \frac{2\pi i}{3}) \\ \cos \theta & \cos(\theta - \frac{2\pi i}{3}) & \cos(\theta + \frac{2\pi i}{3}) \\ \frac{1}{6} & \frac{1}{6} & \frac{1}{6} \end{bmatrix} \begin{bmatrix} \frac{2 \cdot i_{la}}{3} \\ \frac{2 \cdot i_{lb}}{3} \\ \frac{2 \cdot i_{lc}}{3} \end{bmatrix} \tag{15}$$

$$i_{los(n)} = i_{los(n-1)} + K_{pq}(V_{d.ce(n)} - V_{d.ce(n-1)}) + K_{id} v_{d.ce(n)} \tag{16}$$

$$i_{d.ref} = i_{dd} - i_{los} \tag{17}$$

Where: $V_{Ae(n)}$ is the error between reference $V_{s.ref}$ and sensed voltage of grid, $V_{d.ce(n)}$ is the error between reference and sensed Dc bus voltage sampling of nth, (K_{pq}, K_{id}) are the gain of proportional and the gain of integral for PI controller of Dc bus voltage and (K_{pqq}, K_{idd}) are the gain of proportional and the gain of integral of the PI controller for PCC.

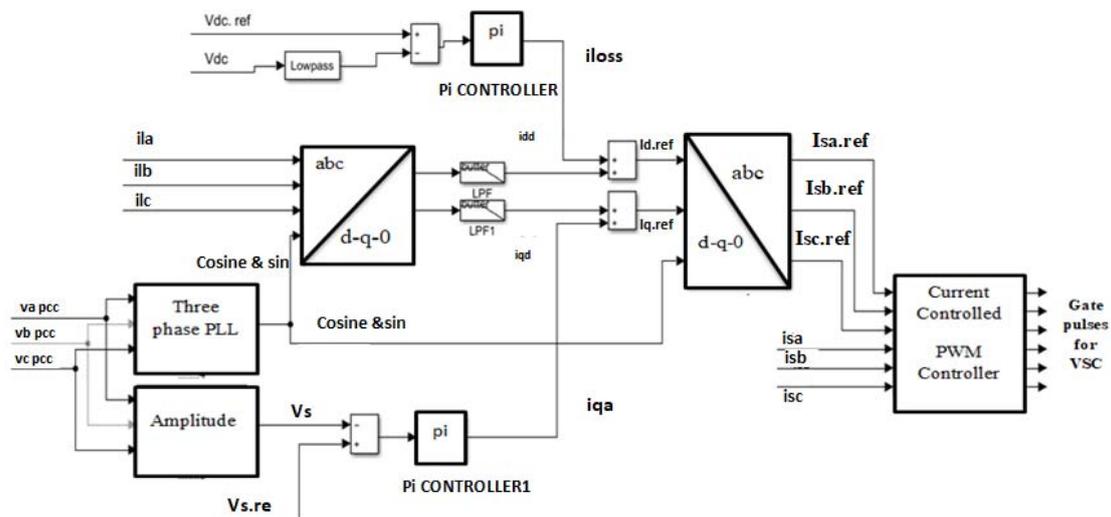


Figure 10. Control circuit of DSTATCOM of three-leg voltage source inverter (VSC).

3. Results and discussion

The buck-boost converter of battery and the boost converter of PV are provided the three-leg VSC with star/delta transformer that connected through the primary side to the output of STATCOM. The simulation of system design is implemented in the MATLAB SIMULINK 2018a. The results and analysis have been compared with the paper [36]. The power system consists of single generator and supplies the power for a non-linear load. Figure 11 shows the voltage of source at non-linear load condition without DSTATCOM compensator.

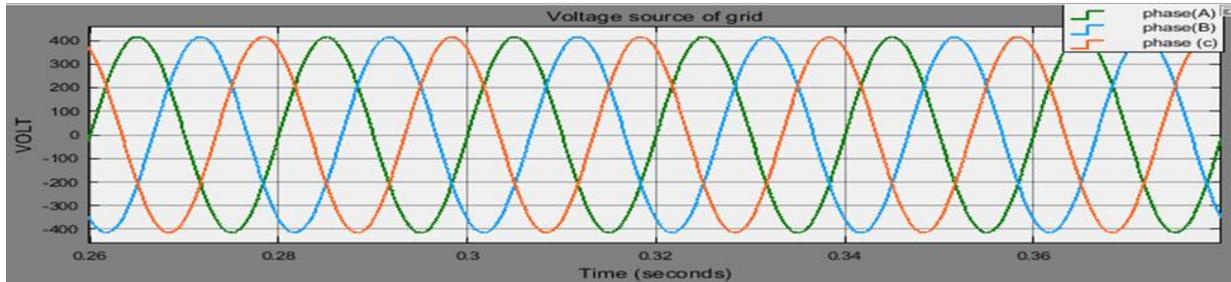


Figure 11. Three phase voltage of source without DSTATCOM compensation.

Figure 12 shows the source current of phase (A) before DSTATCOM compensation, when the load at time between 0.3 to 0.4 second is changed to supply from two phases of source (phase A cut-off wire). From 0.4 second to 0.7 second the source currents become zero (three-phase cut-off wire) and then the load is returning at 0.7 second as shown in Figure 13.

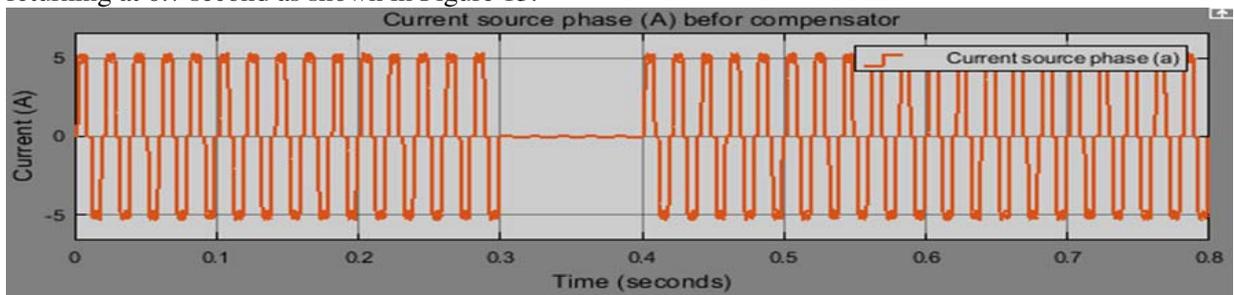


Figure 12. Phase (A) of source current without DSTATCOM compensation.

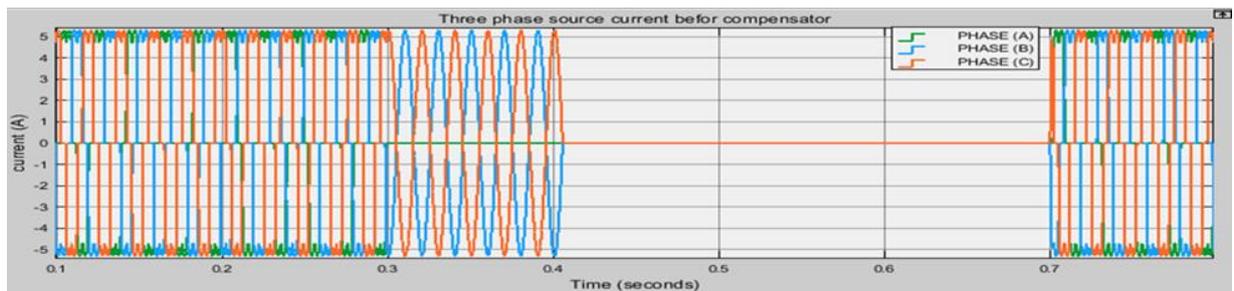


Figure 13. Three phase currents of source without DSTATCOM compensation.

Figures 14 and 15 show the Phase (A) of source current and three phase source currents after DSTATCOM compensation and remain sinusoidal.

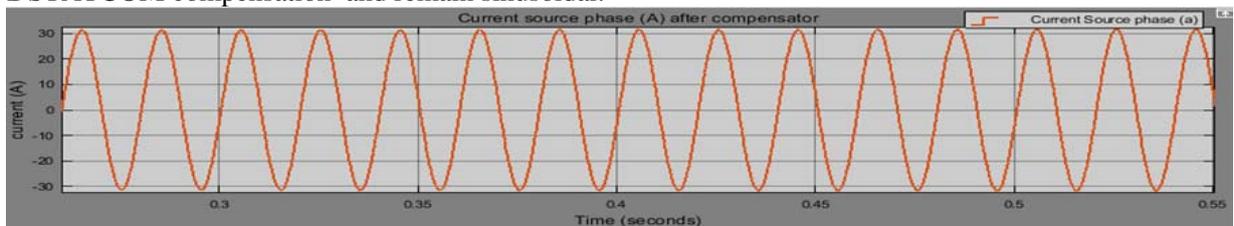


Figure 14. Phase (A) of source current with DSTATCOM compensation.

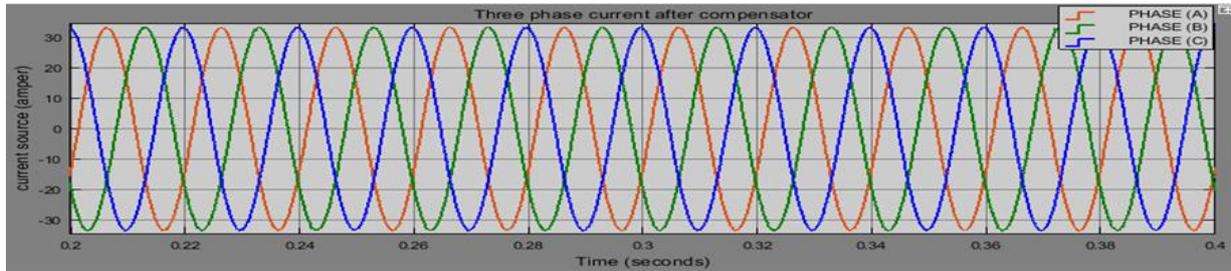


Figure 15. Three phase currents of source with DSTATCOM compensation.

The neutral current after DSTATCOM compensation is shown in Figure 16.

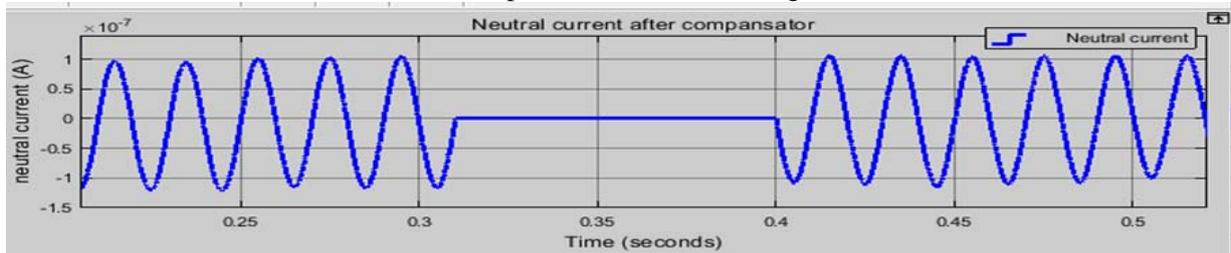


Figure 16. The neutral current of source with DSTATCOM compensation.

Figure 17 shows the Dc link capacitor voltage.

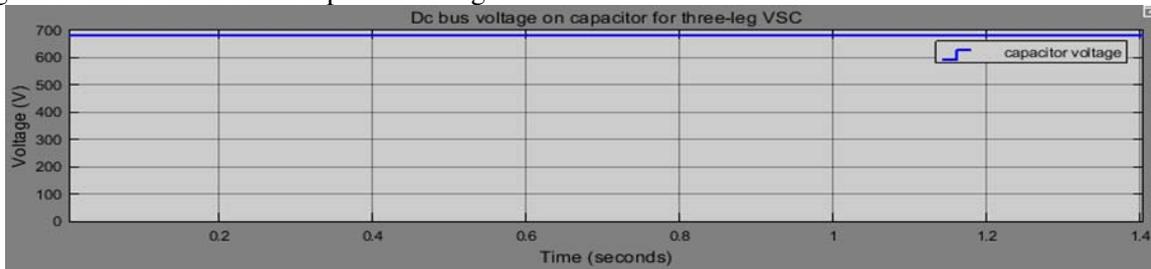


Figure 17. Dc link capacitor voltage.

Figure 18 shows the percentage of Total Harmonic Distortion (THD) before phase compensation (A). Figure 19 shows the percentage of THD after phase compensation (A) with constant irradiation $1000W/m^2$ and constant temperature $25^{\circ}C$. Figure 20 shows the percentage of THD after phase compensation (A) from battery. Figure 21 shows the percentage of THD after phase compensation (A) with variable irradiation and variable temperature. Figure 22 shows the percentage of THD after phase compensation (A) for DSTATCON alone.

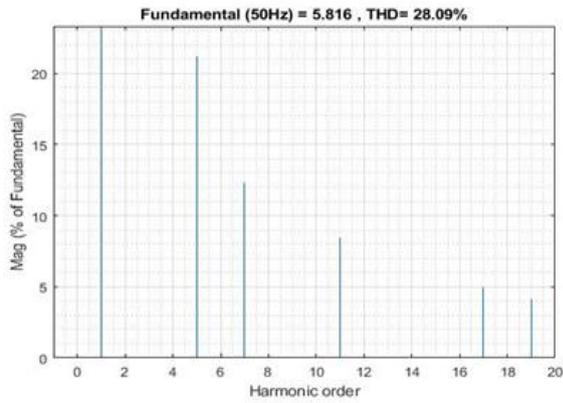


Figure 18. The percentage of THD before phase compensation (A).

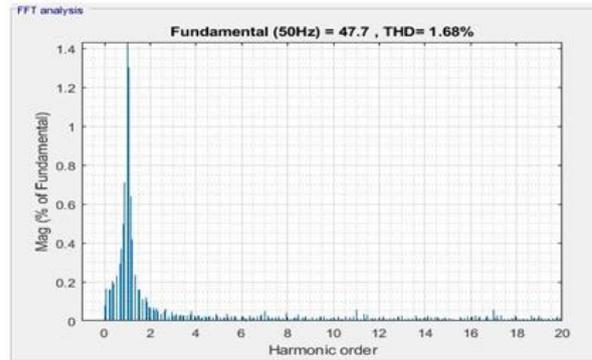


Figure 19. The percentage of THD after phase compensation (A) with constant irradiation $1000W/m^2$ and constant temperature $25^{\circ}C$.

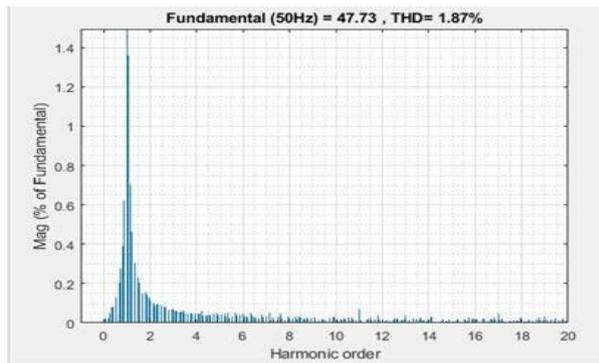


Figure 20. The percentage of THD after phase compensation (A) from battery.

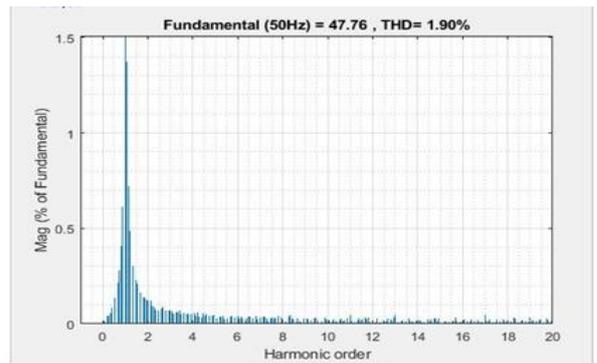


Figure 21. The percentage of THD after phase compensation (A) with variable irradiation and variable temperature.

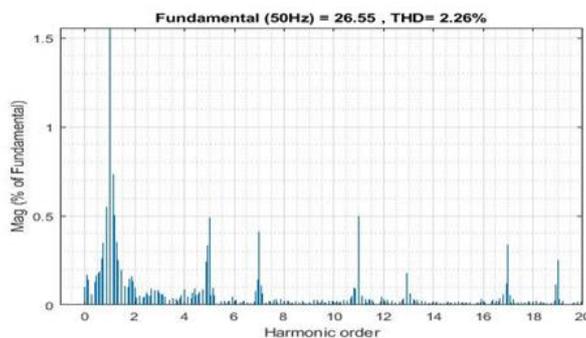


Figure 22. The percentage of THD after phase compensation (A) for DSTATCON alone

The comparison with previous work is listed in Table 2.

Table 2. Comparison THD% for a three-phase current source using (Boost of PV and Buck boost of Battery) of three-leg VSC.

Conditions	THD%		
	Phase (A)	Phase (B)	Phase (C)
Without DSTATCOM compensation	28.09	28.09	28.09
With DSTATCOM compensation alone	2.26	2.26	2.30
With DSTATCOM compensation for constant irradiation (1000W/m ²) and temp at (25°C)	1.68	1.6	1.58
With DSTATCOM compensation for just battery	1.87	1.73	1.69
With DSTATCOM compensation for variable irradiation and variable temperature	1.9	1.85	1.78
Without DSTATCOM compensation [36]	27.59	27.60	27.60
With DSTATCOM compensation [36]	5.38	5.65	5.82

The advantage of this design has more than one source of vdc for input currents to the three-leg VSC. During the day, solar panels feed the inverter and at night the battery operated to supply three-leg VSC. It is noted in the simulation figures the time at 12:00 AM is taken as (0 second) where the battery supply the DC link voltage until (5:00 AM) that represented (0.25s) in the simulation. From the (6 AM) the sun radiation start increasing, the, but the amount of power generation of PV is low. When the sun radiation is increased, the generation of PV starts from (6 AM) until (6.5 PM). It is also noted the amount of charging DC current up to (220 ampere) and the rise of voltage from (40 volt) to (680 volt). Figure 23 shows the charge and discharge process of battery with (SOC%) curve that taken one hour or equivalent to (0.05s) from the simulation time. Figure 24 shows the condition of cloudy at daytime, in this case the compensation is based on the battery within 24 hour.

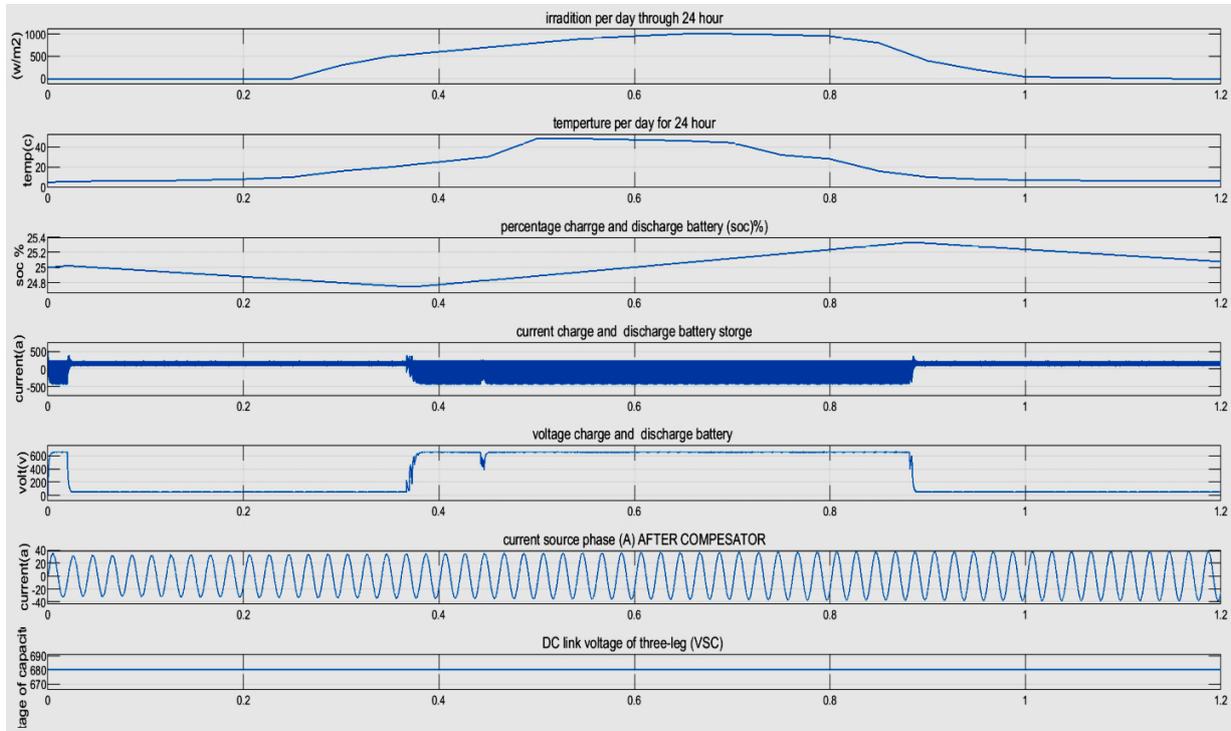


Figure 23. Variable irradiation and variable temperature with SOC% curve through the 24 hour /day.

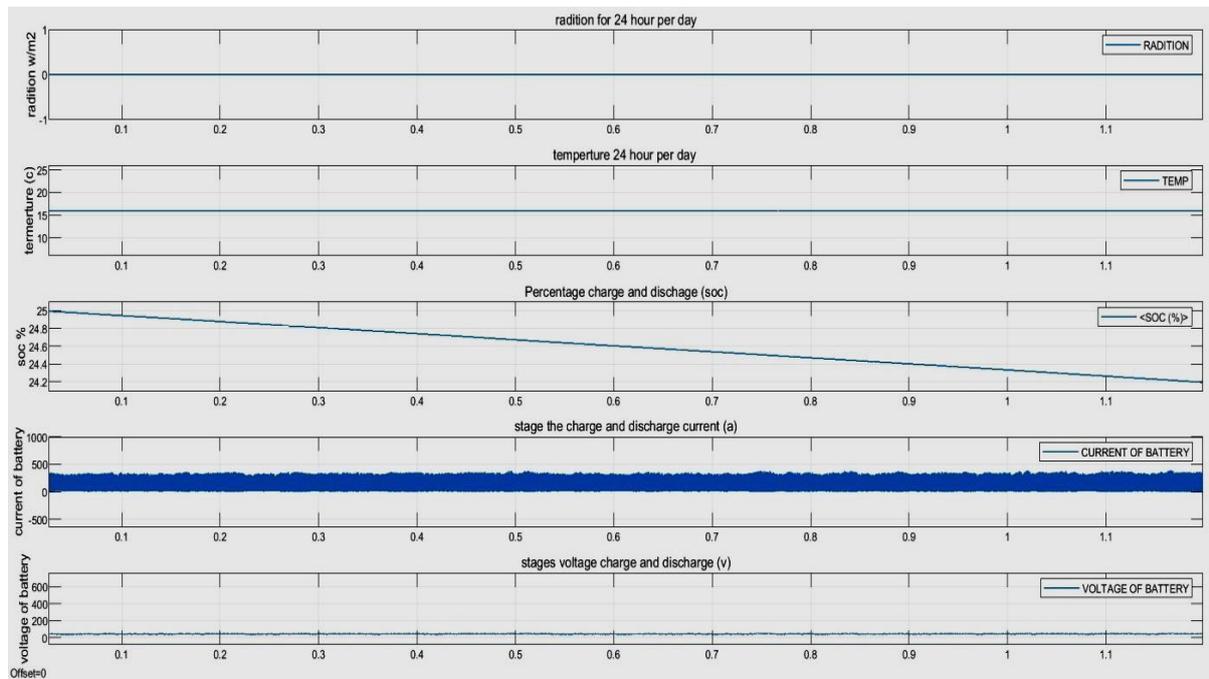


Figure 24. Cloudy day condition and the battery alone to supply the DC link voltage.

It is quite clear from these figures the percentage of THD after phase compensation (A) in the present work equals (1.68%) better than the literature work (5.38%) [36]. In addition, the current of source has been reduced from (60 A) to (32 A) after compensated for the same load. When the compensation of DSTATCOM is alone, the supplying current equal (60A) while the current value will be reduced to (32A) with multi-source (PV and battery) compensation. This mean, the difference between currents (60A) and (32A) equal (28A) that supplied from renewable energy (PV and battery storage).

4. Conclusion

In this paper has been proposed two inputs of DC supply that provided with high-coordination technology for feeding the DSTATCOM in order to ensure the continuity of power throughout the day, night and cloudy conditions via boost of PV and buck-boost for battery. Also, in the Point of Common Coupling (PCC) between the system and DSTATCOM has been connected the star/delta transformer in order to reduce the high current of neutral resulting from unbalanced loads. Synchronous Reference Frame (SRF) algorithm is used to control the DSTATCOM in order to provide the source for harmonics reduction, reactive power compensation, neutral current compensation and high coordination between the PV and battery converters of input three-leg VSC. The results shown the superior performance for the proposed coordination between two input sources of three-leg VSC in terms of better compensation for THD and current in comparison with .

5. References

- [1] Mukhtiar S, Khadkikar V, Ambrish C and Varma R 2011 "Grid interconnection of renewable energy sources at the distribution level with power quality improvement features", *IEEE Trans. Power Delivery* **26**(1).307–15.
- [2] Mahela O P and Shaik A 2016 "Power quality improvement in distribution network using DSTATCOM with battery energy storage system", *Electrical Power and Energy Systems* **83** 229–240.
- [3] Tsengenes G and Adamidis G 2011 "Investigation of the behavior of a three-phase grid-connected photovoltaic system to control active and reactive power", *Electric Power Systems Research* **81** 177–184.
- [4] Jan T, Bialasiewicz 2008 "Renewable energy systems with photovoltaic power generators: operation and modeling" *IEEE Transactions Power Delivery* **55**(7). 2752–8.
- [5] Erkan D and Osma K 2012 "Comparative evaluation of different power management strategies of a stand-alone PV/Wind/PEMFC hybrid power system" *Int J Electr Power Energy Syst* **34**(1).81–9.
- [6] Yong W and Xu C 2010 "DC link voltage optimized control for efficient residential fuel cell converter", *Int J Electr Power Energy Syst.*, **32**(9) 1031–6.
- [7] SK C , TJ L, JF C and S Yang 2007 "Novel high step-up DC–DC converter for fuel cell energy conversion system" *IEEE Trans Ind Electron* **2010** 57(6)–17.
- [8] Prakash N, Balaji V R and Sudha M 2016 "Power quality improvement of grid inter connected hybrid system using STATCOM" *Int J Adv Engg Tech/Vol VII/Issue II/April-June* 1225-1233.
- [9] Adhikari S and Li F 2014 "Coordinated V-f and P-Q control of solar photovoltaic generators with MPPT and battery storage in microgrids" *Trans. on Smart Grid*, vol. 5, no. 3.
- [10] Varma K R, Rahman A S and Vanderheide T 2014 "New control of PV solar farm as STATCOM (PV-STATCOM) for increasing grid power transmission limits during night and day" *Sci. Eng. and Techno.*, vol. 6. No. 2, p **755** – 763.
- [11] Isabel M M, Romero C E, Barrero G F 2007 "Comparison of control strategies for shunt active power filters in three-phase four-wire systems" *IEEE Trans Power Electr* **22**(1):229–36.

- [12] Pandey K A, Shah S and Kumawat P R 2018 "Compensation of neutral current using unit vector template method-based control algorithm for DSTATCOM to power quality improvement" *Int. J. of Sci., Eng. and Techno.*, vol. 6, no. 2, pp. 154-159
- [13] Deepika M, Shailendra J and Gayatri A 2008 "Control strategies for distribution static compensator for power quality improvement" *IETE J. of Research*, vol. 54, no. 6, pp. 421–428.
- [14] Miller M G, III Miller W V, and Chen S E 2018 "Apparatuses and methods for passive fault monitoring of current sensing devices in protective circuit interrupters" *Google Patents*, 08-Nov-2018.
- [15] Prasad V P, Sivanagaraju S and Sreenivasulu N 2008 "Network reconfiguration for load balancing in radial distribution systems using genetic algorithm" *Electr Power Components Syst*, vol 36, no 1, pp. 63–72.
- [16] Lin H C, Kang S M, Chuang J H and Ho Y C "Phase Balancing of Distribution Systems Using a Heuristic Search Approach".
- [17] Hooshmand A R and Soltani S 2012 "Fuzzy optimal phase balancing of radial and meshed distribution networks using BF-PSO algorithm" *IEEE Trans. Power Syst*, vol. 27, no. 1, pp. 47–57.
- [18] Kumar R K and Saxena N 2012 "Review of D-STATCOM using VSC & PWM in power quality improvement" *Int. J. of Elect., Electro.* **1**(2).51-54.
- [19] Varma R K and Salehi R 2017 "SSR mitigation with a new control of PV solar farm as STATCOM (PV-STATCOM)" *IEEE Trans. on Sust. Energy*, pp. 1473–1483.
- [20] J. M and etc 2017 "Overview of power electronics technology and applications in power generation transmission and distribution" *J. of Modern Power Syst. and Clean Energy*, vol. 5, no. 4, pp. 499–514.
- [21] HL J, KD W, CH L and MS H 2008 "Novel power converter topology for three phase four wire hybrid power filter" *IET Power Electron* **1**(1).164–73.
- [22] Kabir N M, Mishra Yand Ledwich G 2014 "Coordinated control of grid connected photovoltaic reactive power and battery energy storage systems to improve the voltage profile of a residential distribution feeder" *IEEE Trans. on Industrial Info.*, vol. 10, no. 2, pp. 967 – 977
- [23] BN S, Rastgoufard P, Singh B, Chandra A and Haddad K Al 2004 "Design, simulation and implementation of three pole/four pole topologies for active filters" *IEE Electric Power Appl* **151**(4).467–476.
- [24] Singh B and Raj Arya S 2012 "Design and control of a DSTATCOM for power quality improvement using cross correlation function approach" *Int. J. of Eng. Sci. and Techno.*, vol. 4, no. 1, pp. 74-86.
- [25] Enjeti P, Shireen W, Packebush Pand Pitel I 1994 "Analysis and design of a new active power filter to cancel neutral current harmonics in three-phase four-wire electric distribution systems" *IEEE Trans. Power Delivery* **30**(6):1565–72.
- [26] Abed M F, Al-Douri Y and Al-shahery Y M 2014 "Review on the energy and renewable energy status" *J. of Renewable and Sustainable Energy*, vol. 39, pp. 816-827.
- [27] Tremblay O. and Dessaint A L 2009 "Experimental validation of a battery dynamic model for EV applications" *World Electric Vehicle J.*, vol. 3, pp. 289-298
- [28] Altas H and Sharaf A 2007 "Photovoltaic array simulation model for Matlab Simulink GUI environment" *Proc ICCEP 07* p. 341–345.
- [29] Jiang W, Zhou Y and Chen J 2009 "Modeling and simulation of boost converter in CCM and DCM" *IEEE Conf.*, pp. 288–291.
- [30] Omar N, Monem M A, Firouz Y, Salminen J, Smekens J, Hegazy O, Gaulous H and Mulder G 2014 "Lithium iron phosphate based battery Assessment of the aging parameters and development of cycle life model" *Applied Energy* Vol. 113 pp **1575–1585**.

- [31] Mazouz N and Midoun A 2011 "Control of a DC/DC converter by fuzzy controller for a solar pumping system" *J Electr Power Energy Syst* **33**(10).1623–30.
- [32] Lara A O and cha A E 2002 "Modelling and Analysis of Custom power Systems BY PSCAD/EMTDC" *IEEE Trans Power Delivery*, vol.17 No.1 pp.266-272.
- [33] Karanki B S and Mahesh K 2013 "Synchronous reference frame based current controller with SPWMS witching strategy for DSTATCOM applications" *IEEE Int. Conf. on Power Electro*.
- [34] Sun J, Czarkowski D and Zabar Z 2002 "Voltage flicker mitigation using PWM-based distribution STATCOM" *IEEE Trans. On Power Delivery* pp. 616-621.
- [35] Bhim S, Jayaprakash P and D Kothari 2011 "New control approach for capacitor supported DSTATCOM in three-phase four wire distribution system under non-ideal supply voltage conditions based on synchronous reference frame theory" *J Electr Power Energy Syst* **33**(5).1109–17.
- [36] Kannan K and Rengarajan N. 2012 "Photovoltaic based distribution static compensator for power quality improvement" *Electrical Power and Energy Systems* **42** 685–692.