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An Adaptation of Multi-Module Converter of PV Configuration using a Wireless Senser Network

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Abstract

A solar photovoltaic (PV) energy is considered the most promising energy source due to its clean and sustainable energy.As the installed capacity of a PV system is continuously increasing, a new strategy for management and optimal energy harvesting is required. Nowadays, there is a new strategy which depends on a controlling and mentoring PV power plant based on a wireless senser network (WSN). In this paper, Acentralised controller for multi-module converter of PVconfigurationbased on WSNis proposed.A new step decision isdesignedfor this centralised controller to process each PV array individually.This proposal will minimize the cost by reduce number of control compounds of the PV plant and abbreviate the losses by diagnosis the fault early.To assess this configuration, a grid-connected PV system is simulated usinga MATLAB-SIMULINK. The results proved the validity to process many PV modules under variable weather conditions.

Keywords: Photovoltaic (PV), Centralised Controller, Wireless Senser Network (WSN) andZigBee.

1. Introduction

The worldwide warming caused by the massiveness of CO2 in the ambience and the restrictions of worldwide traditional resources as well as increased worldwidepopulation have necessitated urgently to search for alternative sources of energy in order to meet the future demand on electricity. Among the many sources of renewable energy, solar photovoltaic (PV) energy is carefully thought aboutthe most promising and reliable energy sourceowing to its clean and sustainable energy. In other words, it is a low efficiency as well as unreliable source due to mismatching conditional weather such as radiation and temperature which add losses about up to 25% from electricity production [1].Therefore, maximum,and optimal energy production of PV plant with sufficiently high-voltage range has been proposed. To achieve this goal, different topologies of PV panels have been developed to improve the overall performance of small, large solar PV power plants [2].

In general, there are 4 types of topology for PV plant: centralized invertor, string invertor, multistring invertor andmulti-module invertor. Centralized invertor type of PV topology is

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considered the most common for a large plant due to a high-power capacity and low-manufacturing cost. However, there are several limitations such as; a non-flexible design, low-efficiency operations occur in partial shading conditions due to the centralized maximum power point tracking (MPPT) controller as well as higher power loss caused by reverse current blocking diodes [3]. Although, the second type has been prevented a mismatch losses of operated string plant at maximum power point because each string inverter is operated at its own maximum power point (MPP). The extra cost and losses have been elevated by add more power conversion system. The third type is Multi-string inverter which show best performance in case of power losses and efficiency [4]. However, the instilled cost is the highest due to the additional power converters, sensors, and control systems [5].The last topology is multi-Module Converter. This topology consists of two-stage power conversion processes. In the first-stage, PV module relates to DC-DC converter and MPPT individually. In second stage, there is one inverter which converts the DC to AC supply .This type is considered a highest efficiency and most reliability for PV plant even under partial shading condition of weather due to distributed controller on each PV module [6]. However, it has been faced many challenges to build conventional constriction of PV plant such as additional cost and variable steady-state time.

To solve those issues, many researchers suggested that using a smartwireless sensor network (WSN) to be centralised control to make simpler and cheaper implementation fora large PV plant. In addition, using smart WSN helpsto simplify the monitoring of PV plant by using smart WSN for the smart grid. Moreover, this system assists on diagnostic the location of the fault early [8]. Although, there are several types of MPPT method which are used for PV system in literature review such as; Incremental Conductance [9], Fractional Open Circuit Voltage [10], Feedback Voltage or Current [11], Fuzzy Logic [12], Neural Network [13]. APerturb and Observe(P&O) technique is considereda popular method in PV generation owing to a low cost and simple implementation [14] - [15].

The principle of the system work usingPerturb and Observe (P&O) algorithm depends on calculating the PV power using the sensed values of the voltage and current of the PV module and then compared with previous power to adjust the direction of algorithm and updating the DC-DC boost converter by adjust the input voltage reference (Vref,). However, when the algorithm is applied to multiple module systems, the sequence for voltage reference update should be noticed especially in case of suddenly change of conditional weather. This sequence can be happening, when the first module gets to the MPP point, and then the algorithm switch on the second module sequentially. In [16], the author suggested using a centralised controller to send reference voltage to next PV module after the previous PV module reach its MPP point. In this method, each PV module will take time to update Vref, while the next module should wait until the previous PV module reach steady state condition .as result, the MPP tracking speed became very slow. On other hand, the authorin [1] suggested that centralisedMPPT updatesthe reference voltageof each module consequently. However, this method has not discussed coverage time of MPP tracking in case of suddenly change of conditional weather.

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In this paper,a centralised P&O controller is adaptedwithWSNfor a multi module convertor of PV configuration, as shown in Figure 1.Therefore,a new step decision isdesignedfor P&O algorithm to adaptthiscentralised controller. This proposal reduces the oscillation around MPP and avoidsthe system from drift problem. In addition, it is validated to process many PV modules in variable weather conditions.The rest of this paper is organized as follows: Section 2 covers a basic modelling of solar PV system. Section 3 explains the PV configurations. WhileSection 4 presents the applications of WSN in PV configuration. In Section 5, the proposed topology is desired. The results are discussed in Section 6. Finally, Section 7 reports the conclusion.

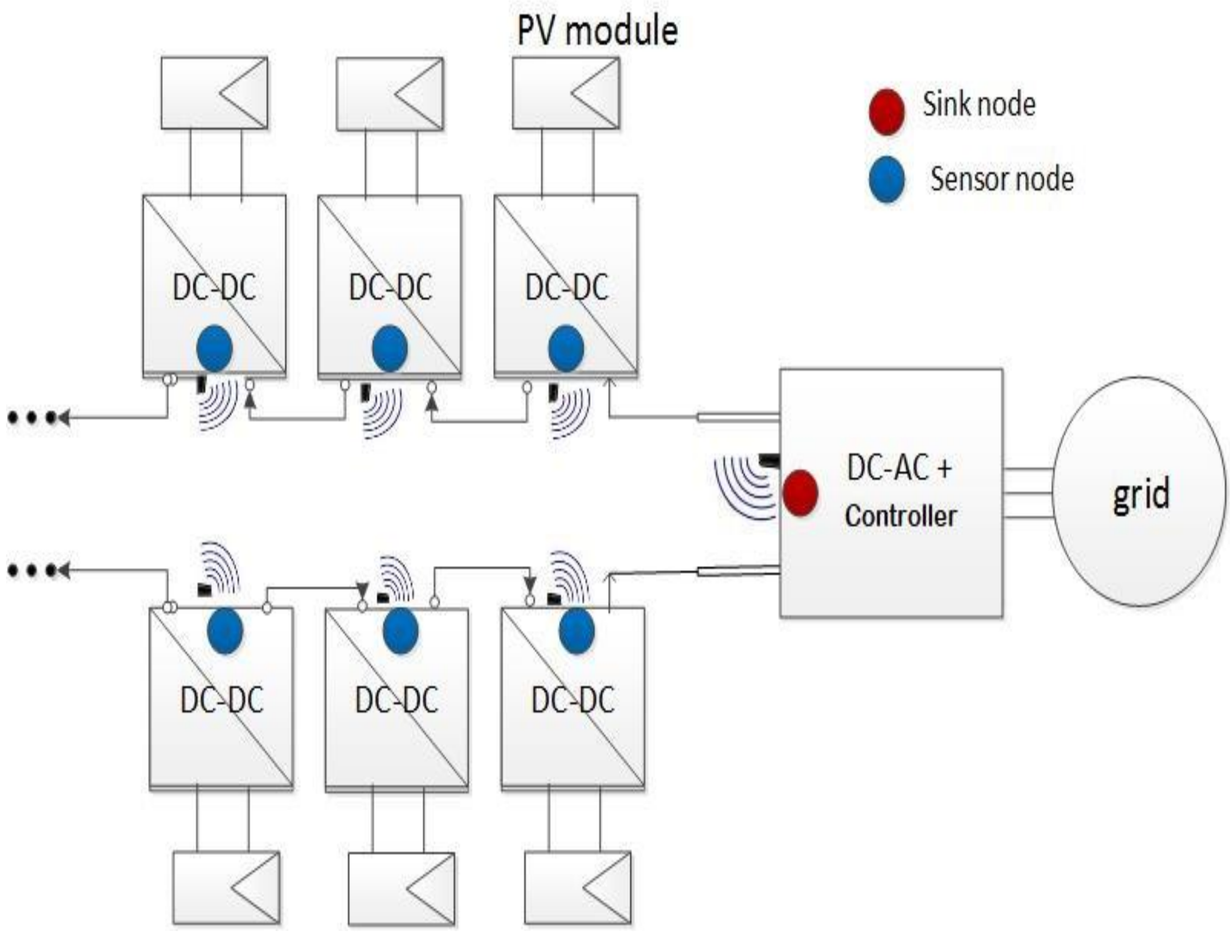

Figure 1.Multi module convertor of PV configuration based oncentralised controller using WSN.

2. PV Generation

In PV generation, the solar cell is considered essentially part to product electricity from the radiation based on a photovoltaic effect. The ideal diode of PV cell is connected in parallel and series resistances to represent the actual PV cell.Thisis because of a magnitude resistance of the PV semiconductor andnon-optimum PN junction diode, resulting in, implementing them, respectively.The Rsh is represent the equivalent shunt resistance with a high value and Rs is represent series resistance with a small. The universal equation of PV generation is given by

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$$I = I_{ph} - i_D \left[\exp\left(\frac{V+I.R_S}{V_T}\right) - 1\right] - \left[\frac{V+I.R_S}{R_p}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where I is the output of cell current, I_D is the reverse saturation current, Iph is the generated current from radiation G, V is the cell voltage, VT is the Thermal voltage (kT/q), K is the Boltzmann constant, T is the temperature operation in Kelvin, q is the charge of electron, $Rs$is the series resistance and Rsh is the parallel resistance. In general, PV generation consist of many cells connect in series and parallel to give different configurations; Firstly, PV module is made from many PV cells which are connected to each other, secondly, PV panel is made of many modules. Thirdly, a group of PV panels make the PV array. The power (P) against voltage (V) characteristic curve of the PV module.A unique and maximum point on the P-V curve of PV cell will generate maximum power. This is known as the maximum power point (MPP) which depends on conditional weather such as the solar irradiance level and the temperature operation surrounding the PV module [17].

3. PV Configuration

To improve the stability, and quality of the PV generation, a conversion system is designed[18]. There are 4 types of the conversion system for a PV plant: centralized invertor, string invertor, multistring invertor and multi-module invertor,[19].The centralized invertor is considered the most common for a large plant due to a high-power capacity and low-manufacturing cost. However, there are several limitations such as; a non-flexible design, low-efficiency operations occur in partial shading conditions as well as higher power loss caused by reverse current blocking diodes. In addition,it suffers from hot-spots during various weather and partial shading conditions of the PV array, high harmonic injunction and voltage rise [20]-[21]. Although, the second type has been prevented a mismatch losses of operated string plant at maximum power point because each string inverter is operated at its own MPP. The extra cost and losses have been elevated by add more power conversion system.

The third type is Multi-string inverter which show best performance in case of power losses and efficiency.This is becausethat the first stage is used to boost the MPP voltage and track the maximum power, whilst the second, converts this DC power into high quality AC power as describe in multi-string configuration. Hence, a DC-DC converter and DC-AC inverter have been designed and connected with generating PV arrays for interfacing with the grid [22]. However, the instilled cost is the highest due to the additional power converters, sensors, and control systems.The last topology is multi-Module Converter. This topology consists of two-stage power conversion processes. In the first-stage, PV module is connected to DC-DC converter and MPPT individually. In the second stage, there is one inverter which converts the DC to AC supply .This is considered to have the highest efficiency and the most reliability for PV plant even under partial shading condition of weather due to distributed controller on each PV module [6]. However, it has been faced many challenges to build conventional constriction of PV plant such as additional cost and variable steady state time.

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4. Application of WSN in PV System

As mentioned earlier, the solar PV energy is considered the most promising energy source. However, the area of this kind of plant are very large regarding to the capacity. Therefore, a new strategy is required to manage the plant sufficiently. Many researchers suggested that the WSN are used in PV system to be monitoring and control it. Most of research work is going on monitoring PV plant which refers to sensing the main parameter of plant such as voltage and current and sending the data to a PC computer or published in website for supervision and monitoring plant. Other researcher study on control of PV plant by using WSN. Control plant based on WSN refers to sensing the data and collecting and sending the data to a control station for decision making and actuate according to the decision. The mostly sensed data are environmental conditions like weather, temperature, wind speed, wind direction, voltage and current.

4.1 Wireless Sensor Network

Recent developing in Nano-Electro-Mechanical system as well as wireless communication technology have made WSN an productive for industrial applications[23]. One of this application is monitoring and controlling PV solar power plant. In general, WSN is wireless networks composed of autonomous and spatially distributed nodes, which collaborate among them to acquire and transmit data, in order to monitor and control large areas. According to of the specific implementation and individual components used for nodes, the WSN has some unique characteristics as: self-conditioning, scalability, robustness, flexibility, and security mechanisms [24]. Moreover, using WSN is possible to cheaply monitor a senior number of variables, such as: temperature, humidity, wind speed, solar radiation, power, voltage, and current, in several points of the plant. Another great benefit of exploiting the WSN approach in PV plants is the possibility to use a single powerful centralized processing unit to process a large amount of data and to implement even quite complex control algorithms.

The hardware of sensor node consists of 4 main units: data acquisition unit, memory & processing unit, communication unit and power unit. A data acquisition unit consists of a set of transducers and Analog to Digital Converter (ADC). The blocks of a WSN are shown in Figure 2. The transducers sense the required signal and the obtained analogy signals are digitized for further processing and storage. In the processing unit, the stored data are further processed for communication with other sensor nodes is involved. Power unit may consist of solar cell or AA sized batteries (maximum of two) or coin cell. Power unit plays an important role in determining the size of the sensor [25].

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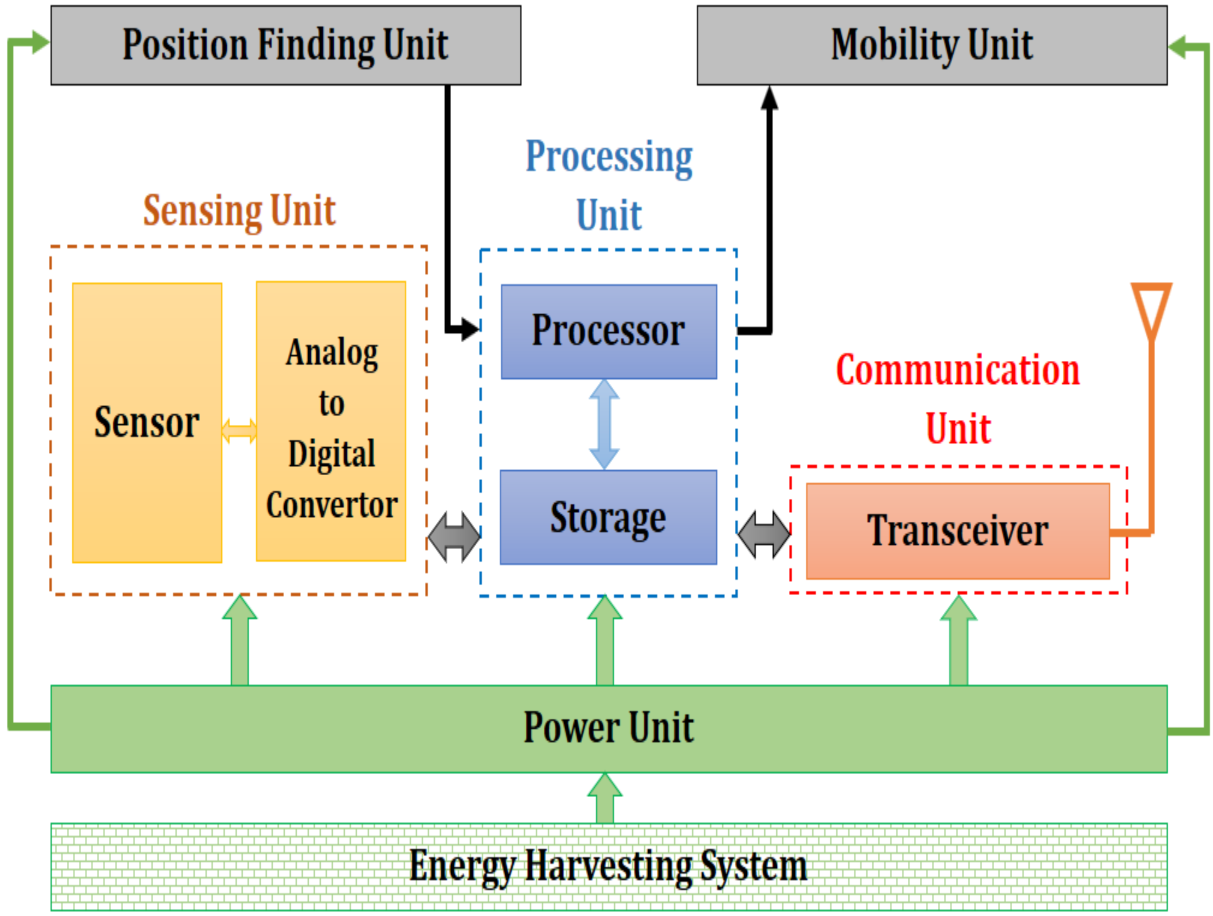

Figure 2. WSN block

4.2 Data Transfer Mechanism

Not very long ago, wired and wireless systems have been used in terms of data transfer mechanism for monitoring and control PV solar power plants. Although wired system has been provided a reliable solution in data transmission, it has been suffered from several disadvantages such as complex physical restrictions of the data cables, high installation and maintenance cost and short lifespan of the system [26]. According to these issues, wireless system is favoured over its cable-based counterpart. For system employing wireless data transmission, there are a different data transmission technology has been presented and each one has advantages and disadvantages. Table 1 summarizesthe most popular WSN in PV plant:

Table (1) explains advantages and disadvantages of different kind of WSN.

No.		Advantage	Disadvantage
1	Bluetooth	-Supportsimple wireless networking.	-Cover short distances. -It is support very shot network capacity of up to 7 nodes and only star topology.

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2	Wi-Fi	-High data transfer rate about 54Mbps.	-The higher cost and power consumption when compared to Bluetooth and ZigBee. -It is support short network capacity of up to 32 nodes.
	ZigBee	-Low-complexity, low cost, low power consumption and slow in transmission speed. -It is support differ topology such as mash, star and cluster head. -It upgradable to support large network capacity of up to 65,536 nodes. -work with most IC manufacturing companies. -Use for large variety of application.	-The transfer rate of ZigBee is much lower compared with Wi-Fi about (250Kbps). -Inefficient in very large-scale distance.
4	GSM/ GPRS	-High reliable with accuracy of data transmission via SMS up to 100%	-High operation and maintenance cost.
5	6LoWPAN	-Low-power. -Low-cost. -High-security.	-More complex. -Support 1500 node only.

4.3 Description of Integrated ZigBee Embedded PV system

ZigBee has been used as animportant technology for wireless sensor networks overcome the limits of Wi-Fi and Bluetooth [27]. ZigBee is considereda popular wireless communication technology in industrial applicationsowing to several future such as a simplestructure,low power consumption, low cost, and slow transmission.In addition, it supportsa differ topology (mash, star, and cluster head) and a large network capacity of up to 65,536 WSN-nodes. Moreover, transmission ranges are up to 100 m indoor and 1.5 km outdoor [26]. Furthermore, it works with the most manufacturing companies and use for different applications such as automation, remote control, security systems, remote meter reading and computer peripherals.

The ZigBee protocol stack consists of four layers as show in Figure 3: the Physical (PHY), Medium Access Control (MAC), the network and the application layers which develop by IEEE 802.15.4 standard [6],[28].While these layers are defined by the ZigBee specification, the PHY and the MAC layers are defined by the IEEE 802.15.4 standard.

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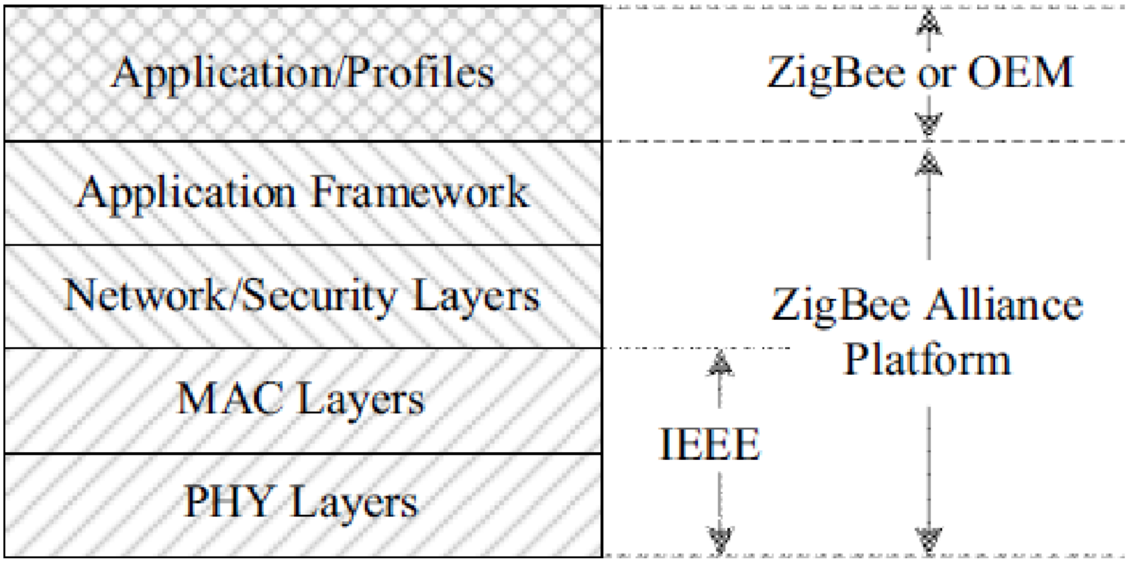

Figure3. Component of ZigBee

ZigBee network consists of three devices: coordinator, routers, and end devices which are described as follows:

1)Coordinator (ZC): The coordinator is the base station. The responsibility of this part is control the networkby storingthe information of the network. There is only one coordinator in the bench system which is reduced-function device (FFD).

2) Router (ZR): The router is the header nodes of the ZigBee network. These devices extend network area coverage, dynamically route around obstacles, and provide backup routes in case of network congestion or device failure which is reduced-function device (FFD). They can connect to the coordinator and other routers, and support child devices.

3) End Devices (ZE): The end devices are the smart nodes. These devices can transmit or receive a message but cannot perform any routing operations. They must be connected to either the coordinator or a router, and do not support child devices which is reduced-function device (RFD). The network of ZigBee is established by network coordinator (WSN-sink) automatically and it forms a multi-hop and self-organizing network system byWSN, to perceive, acquire and process the object information effectively in the network coverage area and send the results to the user terminal Equipment.

There are three network topologies which supportsthe ZigBee network; centralized star, cluster-tree-based and mesh network, as shown in Figure 4.

Star topology is considered a simple topology of ZigBee network.This is because that its coordinator (WSN-sink) is in the center of the network and all other WSN-node is connected to it directly. If any source device wants to send data to other WSN-node will send via WSN-sink because end device cannot send data directly to the other end.

Tree topology is consideredanefficient topology of ZigBee network. However, if any faulthappens in communication link, the system will be stopped and also heavy load is created on the network but tree topology is better as compared to mesh network in term of memory uses.

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Mesh topology is the most popular kind of topology which use in different applications of WSN in ZigBee application related toevery WSN- node can communicate with every sensor node. That means, ZigBee mesh configuration is producing more with less losses than star topology and tree topology because each node can send signal to anotherWSN-node directly.

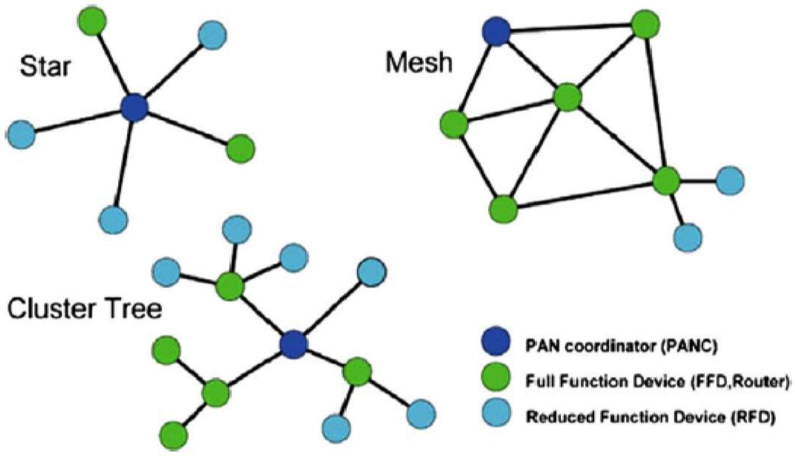

Fig. 4. Topology of ZigBee wireless networks

5. Proposed Configuration

In this work, the multi-module converter of a PV configuration is proposed. The WSN is used to adapt the centralised P&O algorithm. As mentioned earlier, the basic rule of a P&O algorithm set depends on calculating the PV power by using the sensed values of the voltage and current of the PV module and then compared with previous power to fit a new conditionof the algorithm and updating theinput voltage reference of DC-DC boost converter. The reference signal is updated based on following equation:

$$V_{ref.+1} = V_{ref} + \Delta V \ldots\ldots\ldots\ldots\ldots(2)$$

whereVref. and Vref+1 are the reference voltage and next reference voltage of PV converter , respectively and ΔV represents incremental change of reference signal. However, when the algorithm is applied to multiple module systems, the sequence for a voltage reference (Vref.) update should be noticedespecially in case of suddenly change of conditional weather. This sequence can be happened, when the first module gets to the MPP point, and then the algorithm switchon the second module sequentially.To address this issues,centralised controller based on WSNis designed, as shown in Figure 5. Therefore, a new step decision is addedin the end of P&O programto detect the MPP point for each array individually. The historical change of PV powertoPV voltage(**dP/dV**) is designed to detect the MPP by comparing witha positive constant value (**C**)which is set regarding to parameter of PV installed module and the sampling time of the PV controller. When the dP/dV is higher than the value of C, the algorithm will recognise that there is an irradiance change quickly and the algorithm will sent reference voltage to same PV module until reach its MPP point; otherwise P&O algorithm should process the next module. Each PV module will take time to update Vref, while the next module should wait until the previous PV module reach steady state condition.This method is faster and accurate to detect the MPP point individually.To

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detectany fault in the PV systemif any such problems occurred, an externalmodem is required to send an alarm signal to thesystem's operator.

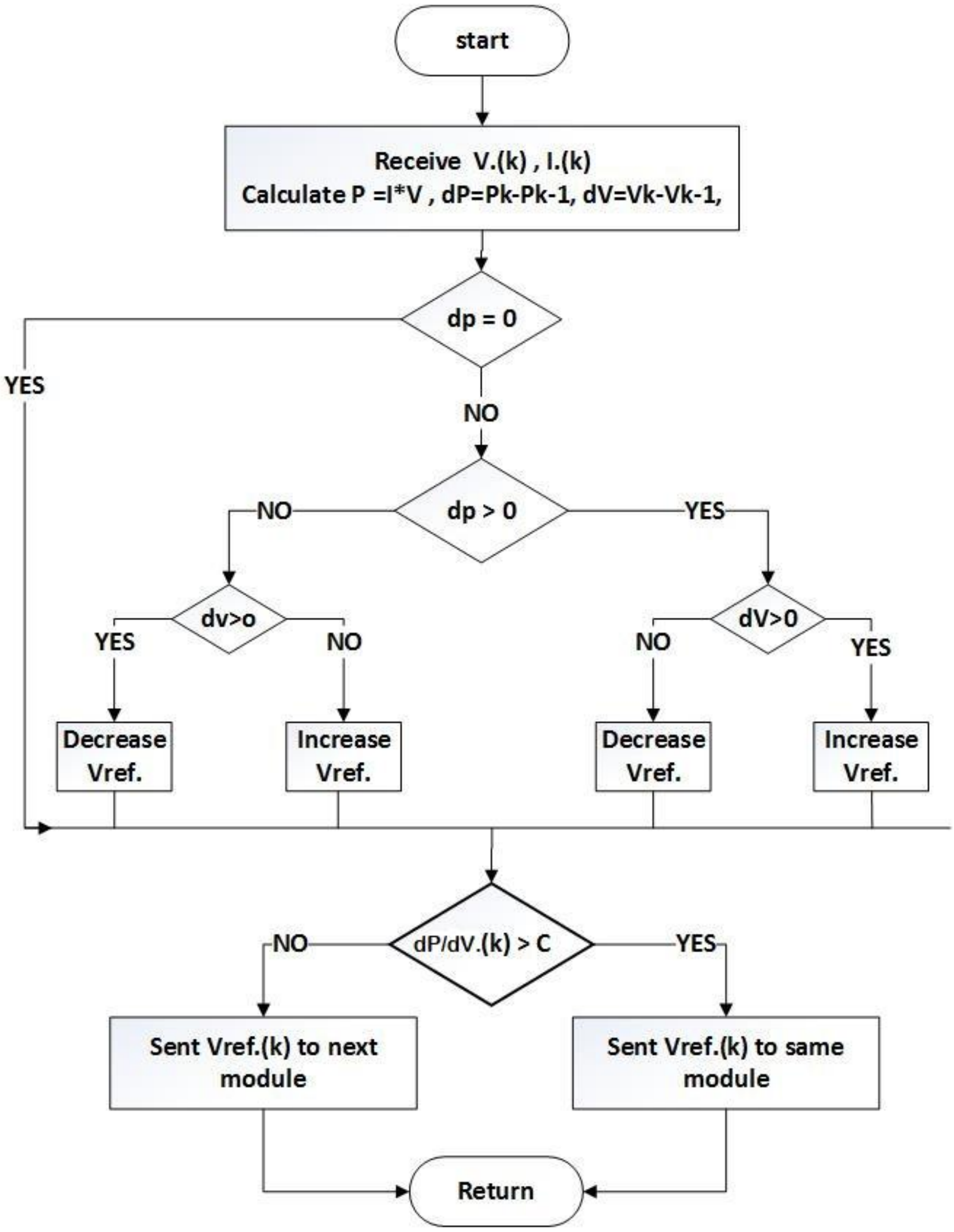

Figure 5. The flowchart of the proposedcontroller

6. Results and Discussion

To test the performance of the proposed configuration, a MATLAB-SIMULINK model for the grid-connected PV system is developedby analysing the effect of a centralised controller on a PV generator. The gird-connected has twostage; in first stage, DC-DC boost converter is controlled through an outer P&O-MPPT loop controller, which is implemented on the central unit to generate a voltage reference signal, which is fed through the WSN to a high bandwidth locally implemented voltage control loop. In second stage, centralised DC-AC inverter is designed based on WSN- sink. The WSN model is implemented based on True Time-tool box.In this application, ZigBee WSN is used in order to control and monitoring the system based on star topology network. This is because that its coordinator device (sink) is in

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the centre of the network and all other WSN-node is connected to it directly. If any source device wants to send signal to other WSN-node will send via WSN-sink because end device cannot send data directly to the other end.
The parameter of a PV system is shown in Table 2. The periodic time of duty cycle is updated every 1ms. To test the performance of the proposed controller, anther PV array is added with same parameters. Theinput radiation was change from 500 to 1000W/m2 at 2 s. It proved that the proposed controller is started from first PV module, and then second module has acquired signal when PV module has reached steady state condition, as shown in Figure 6.

In second case, the wireless controller and wired controller are simulated. The radiation was rapidly changed from 1000 to 500 W/m2 at 0.5 s and then it is changing in to 1000 W/m2 at 1.5 s. As show in Figure7, the output power of the PV generation based on the wired controller drifts away from the maximum power point when the input irradiance increases rapidly, while the WSN controlleravoidsthis issue. However, it appeared to the oscillation around the maximum power point under different weather conditions. This is because of the time delay of the WSN controller.To eliminate this problem, WSN centralised controller is implemented. As a result, the output power of a PV generation was low oscillation around the maximum power point at different weather conditions, as shown in Figure 8.According to those results, theproposal is validated to process many PV modules at variable weather conditions duo to detecting the MPP for each array individually. In addition, it will minimize the cost by reduce number of control compounds of the PV plant by designing one control unit for total PV system and abbreviate the losses by diagnosing the fault early.

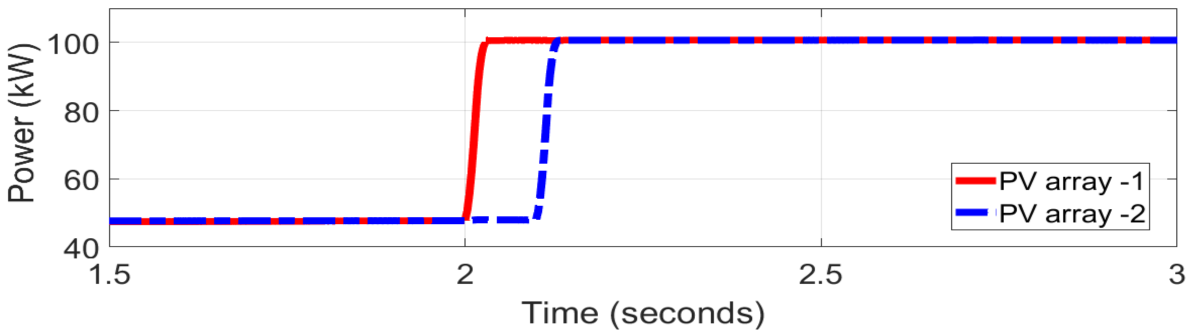

Figure 6. PV power for 2 modules based on proposed controller.

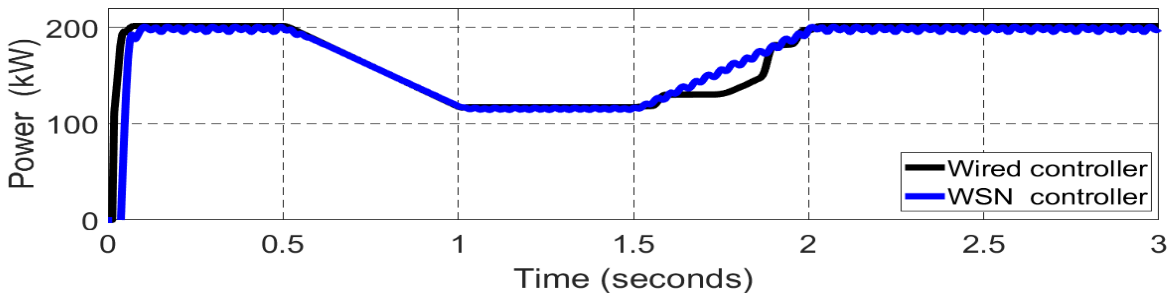

Figure 7. PV power for WSN controller Vs wired controller.

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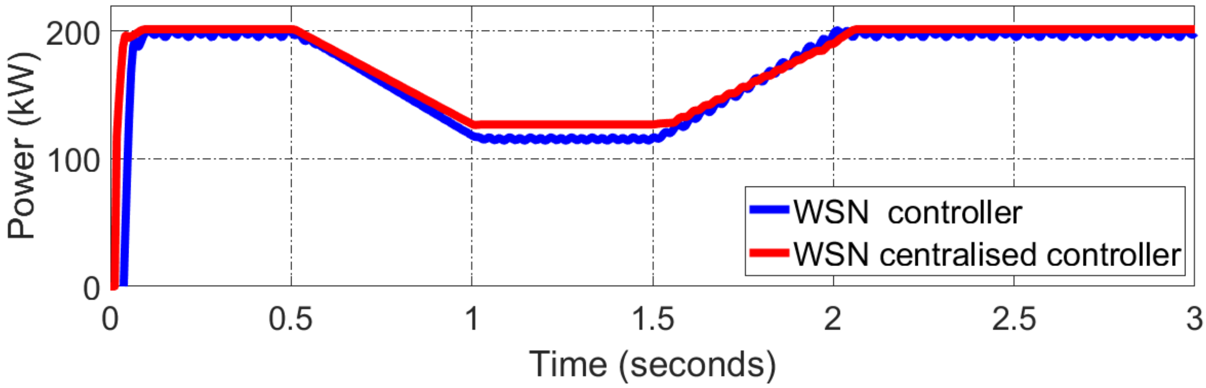

Figure 8. PV power for WSN centralised controller Vs WSN controller.

Table 2. The parameter of PV system

Parameter	Value
PV array power (kw)	100
PV array voltage (V)	270
Switching frequency (kHz)	4
Boost inductor (H)	0.05
Capacitor (mF)	1

7. Conclusion

A controlled by one central place controller for multi-module converter of photovoltaic (PV) configuration based on WSN have beendesigned. It is generally accepted that there are lot of benefits from this proposal such as reduce the oscillation around MPP and avoid system from drift problem. In addition, it is validated to process many PV modules in variable weatherconditions.To sum up, a new step decision has been added for a P&O controllerto detect the MPP point for each array especially in case of rapid change of weather conditions. A grid-connected PV system is simulated by MATLAB-SIMULINKto assess this proposal. The results proved that it is validated to process many PV modules at variable weather conditions. In addition, it will minimize the cost by reduce number of control compounds of the PV plant and abbreviate the losses by diagnosis the fault early.

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