Simulation of photovoltaic station interfacing scada within transmission line

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ABSTRACT

In this paper, a developed simulation of a photovoltaic (PV) station that includes a PV module, a grid-connected inverter, a maximum power point tracking (MPPT) system, and a DC link capacitor was discussed. The MPPT uses a proportional integral derivative (PID) incremental conductance controller. Due to make it simple to control and monitor the PV station, Simulink dashboard is used to develop an interface that resembles a supervisory control and data acquisition (SCADA) system. Then the faults circumstances were simulated on one of the circuits of the double circuit transmission line using the faults combo box that is accessible in the interface. Then the cases were developed to examine the impact of various faults on the operation and control of the solar station. The developed cases namely normal circumstance, single-phase to ground fault circumstance, double-phase fault circumstance, and three-phase to ground fault circumstance, respectively. Three-phase voltage and current at given fault conditions have been measured to control voltage sag and swell. The active and reactive power are also measured due to obtain that they are injected or absorbed the power from and to the transmission line and maintain toward their setpoint values as indications while the faults occurred.

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1. INTRODUCTION

In the previous couple of decades, photovoltaic (PV) plants have been interconnected into the grid utility at a certain point common coupling (PCC). The troubleshooting that occurred, such as small-scale or large-scale PV power plants connected to the transmission line, was likewise overcome. A network, whether wired or wireless, that connects every device on the PV station is then considered to have been applied. In the PV power plant system, it not only connects the remote stations with the master and enables data transmission back and forth, but it also permits communication between the many networked equipment. These networks, typically known as the supervisory control and data acquisition (SCADA) networks, are integrated using fiber optic (FO) connections SCADA. Since PV farms often cover a sizable geographic region, FO is chosen as the cable used for utility PV projects. FO is the best option due to its extraordinarily long transmission distance and tolerance to electrical noise. Even though the devices are a mile or more away from the substation, it is absolutely astonishing to see tracker or inverter data populate in less than a second [1]. SCADA performance through transmission line required rapid speed of the networking devices. It also needs to consider the construction and material cost involved with installation such as trenching, cable-laying, termination, and testing. The widely used of SCADA in the network utility system, which has traditional energy resource structure have been adjusted and modulated. Initially, several studies that related to SCADA is presented and summarized well in reference [2]. Then several PV companies namely, circutor in Spain [3], nor-cal control in North America [4], and applied technical systems joint stock company in Ho Chi Minh City, Vietnam [5].

The utility problems, namely voltage distortion, power optimization, and faults must consider as well. To the long-distance transmission line, any of those problems could occur and brings impacts toward the electrification system. To decrease voltage distortion and active-reactive power control, many studies have been conducted, namely laboratory-scale experiment-based [6]–[8], power utility simulation textual and graphical programming such as MATLAB/Simulink [9]–[12], or field-case studies [13]–[15]. In the grid utility, whereas PV as distributed generator (DG) is connected, PV source should inject the active power and absorb the reactive power due to its interconnection within the transmission line. Khan and Yun [16] whenever PV plant connects into a grid, it requires voltage control, which poses two significant issues. Firstly, the voltage must be maintained within a permittable limit; secondly, PV plant must meet the grid system operator's capability curve. Voltage regulation and reactive power control are some of the methods for controlling the voltage. Somehow, the similar statement also provided in reference [17]. Normally, PV system that has the maximum power point tracker (MPPT), which is part of the overall control of the inverter, is managing the active power. However, MPPT cannot resist power curtailment, power reserve, or ramp rates. As the result, this tracker should consider not just the maximum power point but also the active power reference provided by the transmission line. On the other hand, when managing reactive power, the point to consider is if the active power is preferred above reactive power or vice versa. Since a large-scale PV power plant is located within a transmission line, then PV system must be upgraded to control PV power generation.

The SCADA is used to manage and monitor voltage distortion, active and reactive power in order to meet additional transmission system requirements despite changing environmental conditions, i.e., ambient conditions, without the use of additional devices. Several studies have been carried out to mitigate the role of SCADA in grid-connected PV systems, particularly in transmission lines. Hazrat [2], it described in detail how SCADA functioned as the central of remotely control the electrical network components, monitoring and diagnostic capabilities provide by the power plant as the electrical power generated at generating station is transmitted to the loads with the use of transmission and distribution substations. It also doing the parameter checking, and fault diagnosis. Nevertheless, the most importantly, SCADA also supports in managing system voltage levels and reactive power flow to achieve efficient distribution grid operation. It helps to reduce system losses, and peak demand using various voltage reduction techniques. The capability of SCADA in managing the mentioned system is provided in reference [18]. Although the integration of SCADA into PV power plant, there are several steps that need to be considered, namely, configurating it to the PV system, communicating it through certain protocols and addressing the variables such as voltage, current, power and relay status into the testbed.T system is tested to handle the problem of continuous supply when the power of the loads is varied. The developed testbed works appropriately in simulating the algorithm in the PV system. The case study of SCADA in the transmission line that have been deployed, can be seen in reference [19]. The study of SCADA integration into PV power plant due to diagnosis faults has been conducted in reference [20]. SCADA helps the utility respond to the challenge present by deregulation. The criteria for selection of control system integrators, become an extremely important factor in the success of SCADA project in handling faults towards the line. Another study that has been done, though it was a laboratory-based project is cited in reference [11]. SCADA contributes to solving the real-life problems and help understand the concept of automation and also possible to record a laboratory from remote area. SCADA also built protection system based on automation tools and reliable and time saving. Eltamaly *et al.* [10], SCADA supports the real-time monitoring and have a direct impact on the performance of the PV power plants as well as the capability for meeting the target application requirements. From those point of views, a control and monitor of a developed PV station in MATLAB/Simulink by Hussain [21] has been run and analyzed due to mitigate the voltage sag and swell, and also the injection and absorption of active and reactive power to and from the grid. The consideration that have been taken by the authors to only used the developed system in the mentioned reference is to saving time and thoroughly analyze the capability of integrated SCADA into the PV station to overcome transmission faults.

The objective of this study is to see the effect on the performance of PV station as it interconnecting to the grid within the transmission line. The rest of the paper is organized as follow. Section one described the current existing transmission line whereas small- and large-scale PV plant may within the line. It also discussed the capability of SCADA and its integration into the PV station. Several studies also available as well. Section two discussed the grid-connected PV station through PCC (including all PV system components). The control of active and reactive power of the inverter, double circuit transmission line, SCADA interfacing as control and monitor systems, simulink dashboard, and also the faults that occurred within transmission line. Section three described the system configuration that has been built in the MATLAB/Simulink platform. Section four provided the results and discussion that have been gained from the developed case of faults through the transmission line. Last, in conclusion, it concluded the function of SCADA within the PV system; the measured three-phase voltage and the distortion that occurred. The measured three-phase current at normal and fault conditions. The measured active and reactive power toward their setpoint values and the indications that occurred to the system as the normal and fault conditions are being simulated.

2. METHOD

As commonly known that grid is connected to PV station through PCC, that has grid codes to be considered. These grid codes clarify the possibility of connecting/disconnecting the PV systems from the grid whenever faults occurred, and also support fault ride through (FRT) and low voltage ride through (LVRT) [22]. The authors in reference [23] through their studies have pointed out that the potential existence of inverter interfaced sources could possibly utilize to regulate the voltage at PCC of each inverter interfaced sources. The PCC voltage regulation is manageable with inverter interfaced sources by dynamically controlling the amount of reactive power that has been absorbed by the grid. Additionally, another study that has been developed Al-Shetwi *et al.* [24] managed to achieve the desired level of PQ issues at the PCC as imposed by the grid codes [17], [25]. It proved by the achievements of all the power quality issues are modified and degrade to the grid code defined level using efficient controls and compliance strategies [26].

2.1. Grid-connected PV station

All the components of PV station, namely PV module, MPPT, and inverter as one system, are illustrated in the following Figure 1. To generate 100 kW of output power, 6 PV modules must be connected in series to form a string, and 66 strings must be connected in parallel. Omar *et al.* [9] contains all of the set specifications. MPPT reaches out by using a boost converter, which takes the DC voltage and current from the PV array and converts them to different DC voltage and current values. The inverter then begins to convert DC voltage and current to alternating current voltage and current using a three-level bridge circuit and a pulse width modulation control circuit. To control the active and reactive power of the inverter, a cascaded loop control based on the dq0 transformation is used. In order to decrease total harmonic distortion in the AC current from the inverter and smooth current variations, then used the current filter. Finally, the transformer of 100 kVA-260 V/25 kV is used to step up voltage to the required grid voltage.

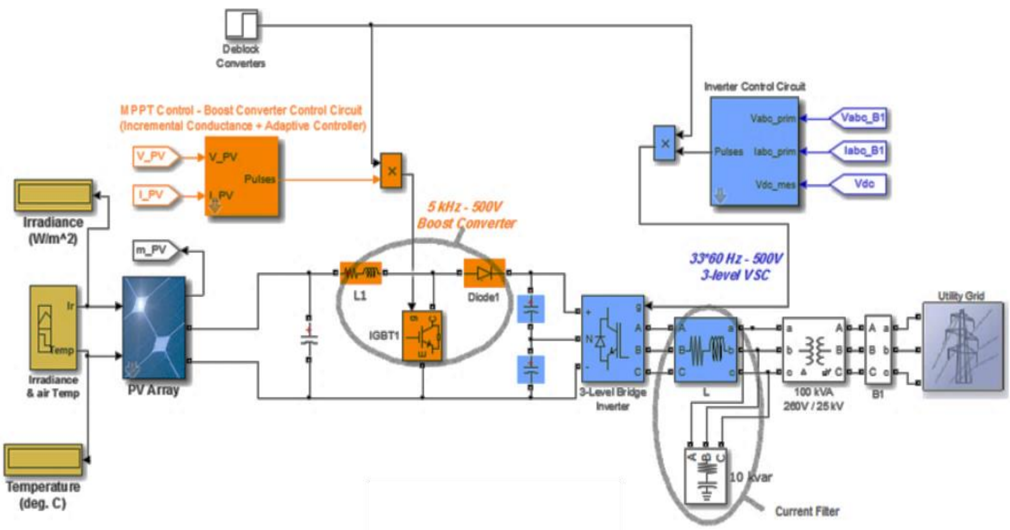


Figure 1. Structure of the PV power station and its components in MATLAB/Simulink [9]

2.2. SCADA

As stated in Eltamaly *et al.* [10], SCADA is used to remotely monitor and control field devices such as sensors, smart meters, remote terminal units (RTUs), intelligent electric devices (IEDs), and so on. Data acquisition units, RTUs, communication networks, and system servers are common components of a SCADA system. Data acquisition units measure and collect monitoring parameters such as voltage, current, temperature, irradiance, and so on, and then send them to the control center via the communication infrastructure. As it represents the core of the SCADA system.

2.3. Simulink dashboard

The simulink dashboard in MATLAB/Simulink is the control and indicator blocks to interact with simulations that combine in certain ways to efficiently model hybrid systems. This type of modelling is particularly useful for systems that have numerous possible operational modes based on discrete events. Traditional signal flow is handled in Simulink while changes in control configuration are implemented in state-flow. It can possibly choose the accurate visualization technique for each modelling and simulation task. Even though to run a file under Simulink Dashboard platform takes longer time than by using Simulink environment and coding in MATLAB, however, the defined data and information is easy to determined and analyze [27]. The system is configured as follow, 100 kW PV module is designed in series-connected module has the I-V and P-V characteristics as seen in the following Figure 2. Array type: user-defined; 10 series modules; 47 parallel strings.

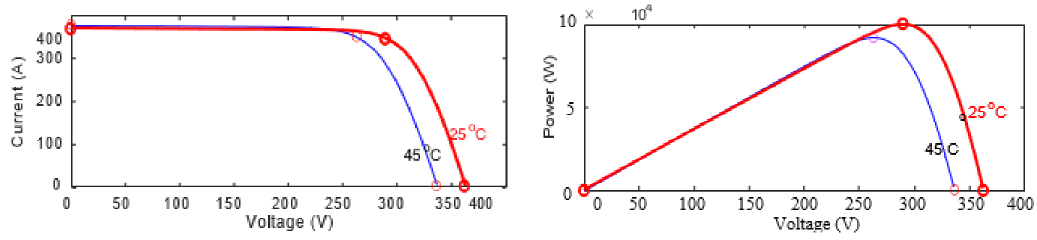


Figure 2. I-V and P-V characteristics of PV module

Although, the MPPT is designed by using boost converter and integral regulator ICT, it is then connected to the inverter and charging/discharging controller for the battery unit. The inverter itself consist of AC and DC voltage controls and PWM control. Additionally, it also has DC link capacitor and a grid connected inverter. A 400 V/25 kV D-Y transformer using a cascaded loop control based on dq0 transformation and power electronic circuits is connected through PCC of the grid utility. The following Figure 3 describes how the mentioned controls are built, and Figure 4 describes the voltage and power control blocks.

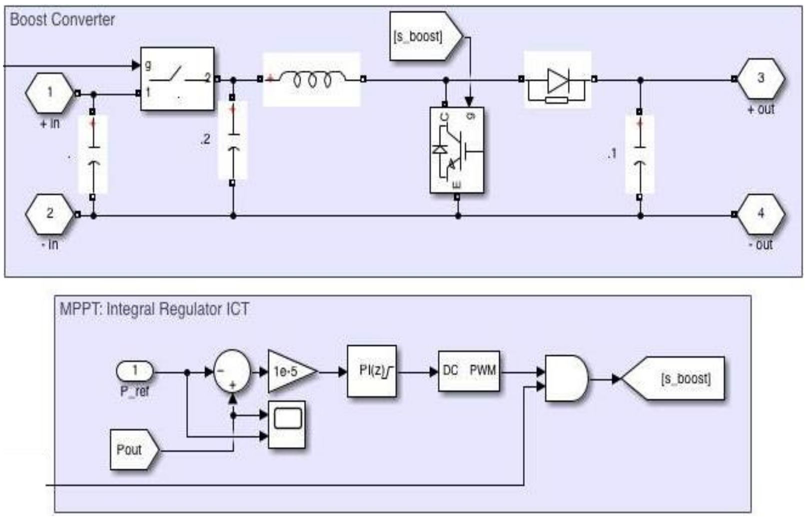


Figure 3. MPPT and inverter blocks

The developed fault cases are: i) normal condition/no faults; ii) during single-phase to ground fault; iii) double-phase fault; and iv) three-phase to ground fault then simulated through the 5 km feeder of one of the circuits of the double circuit transmission line. Hence the developed PV station with SCADA system functions as the interface to control and monitoring the power supplied to the grid and simulates the effect of faults within the transmission line. The following Figure 5 describes how the PCC to transmission line connection is built.

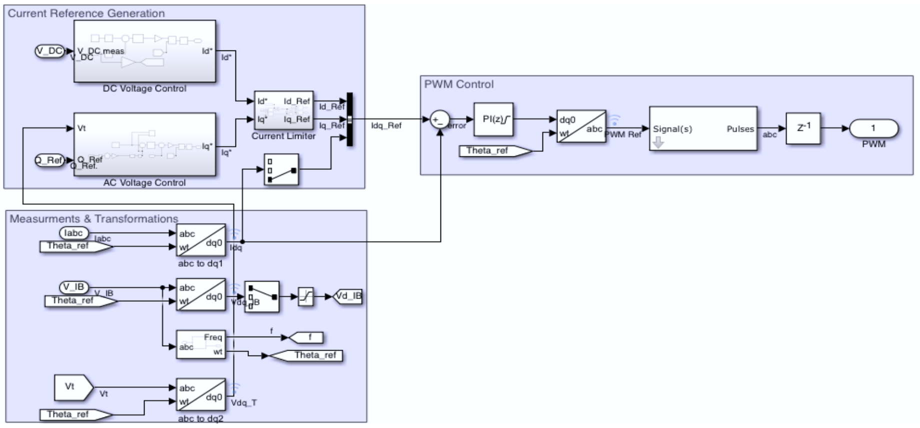


Figure 4. Voltage and power control block

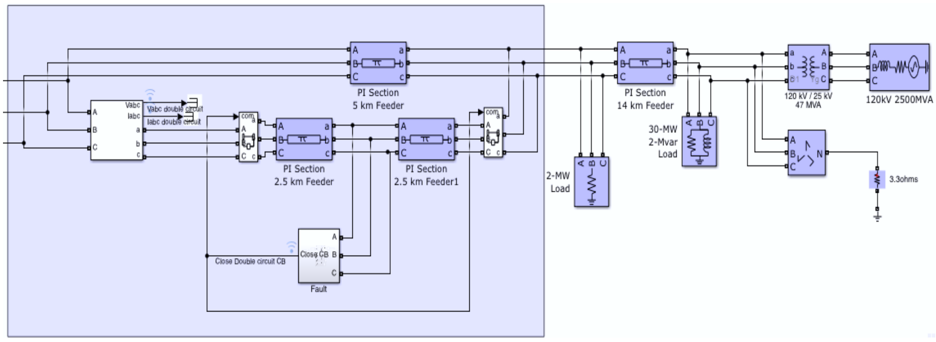


Figure 5. PCC of utility grid

All of the components of PV system then are controlled and monitored through SCADA. The SCADA block itself consists of massive terminals, connectors, and monitors. The entire PV system blocks, and its control and monitor are integrated through SCADA block. The following simulink diagrams that illustrate in Figure 6 is the SCADA of PV system.

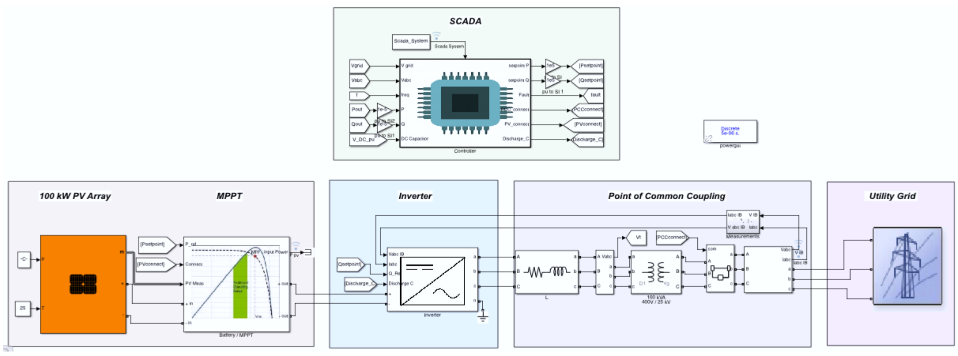


Figure 6. PV system through SCADA

The monitoring system of PV station can be seen in Figure 7. As the simulation run within the limit of voltage and frequency, (±1 pu, ±50 Hz, respectively), the measured output three-phase voltage and current can be determined. The developed cases are namely normal condition (no fault), single-phase to ground fault, double-phase fault and three-phase to ground fault, respectively. Also, the measured active and reactive power, respectively, toward their setpoint value (0.6145 pu, 0.9 pu, and respectively), are illustrated with the similar circumstances.

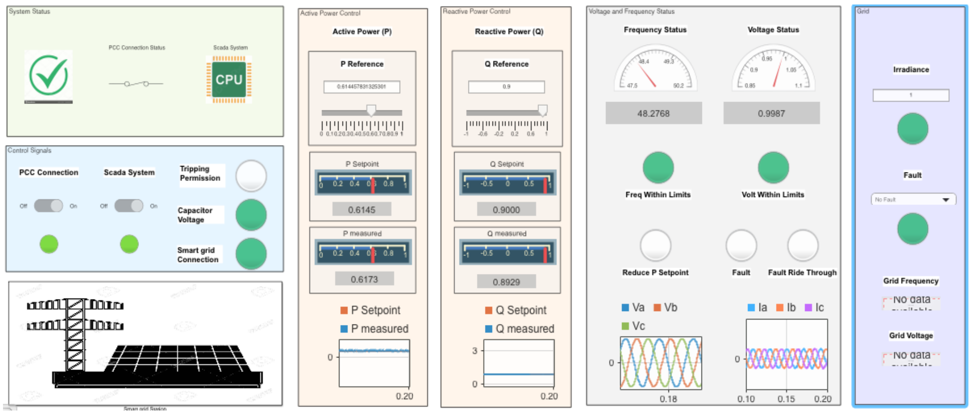
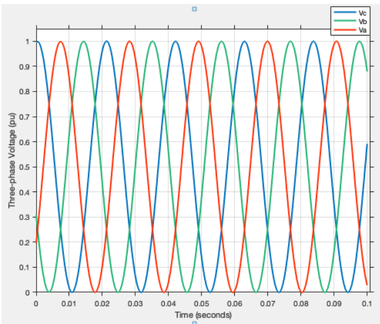


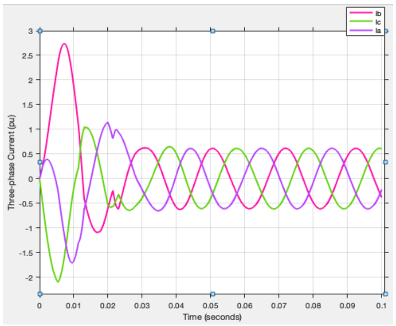
Figure 7. Monitoring system

3. RESULTS AND DISCUSSION

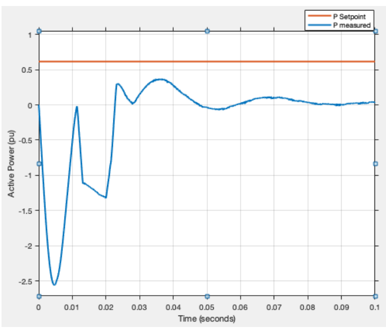
Let us assumed that the simulation runs in 1-minute simulation time for all developed cases. The measured parameters are voltage and current and active and reactive power of the system. The grid frequency is 50 Hz and the reference three-phase voltage of the system is 1pu. The setpoint value of the active and reactive power is 0.6 pu, and 0.9 pu, respectively. These values are the reference values that used through the system. At normal condition (case of no fault), as the system run, it showed steady condition for the three-phase measured voltage and still within its limit. The similar circumstances occurred to the three-phase measured current at two-third of end of simulation time. Figure 8 illustrates the time-plot trend of three-phase voltage and current, measured active and reactive power in pu for no fault ciscumtance. In Figure 8(a), three-phase voltage is on normal condition. Figure 8(b) for the first 0.02 seconds three-phase current show the sag and swell conditions. The active and reacvtive power Figure 8(c) and Figure 8(d), respectively, show the trend of measured active power, which is lower than its setpoint value. It indicates that the active power is injected the power to the grid. The reactive power is lower than its setpoint value that indicates it absorbs the power from the grid.



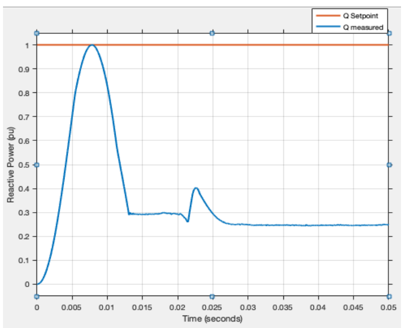
(a)



(b)



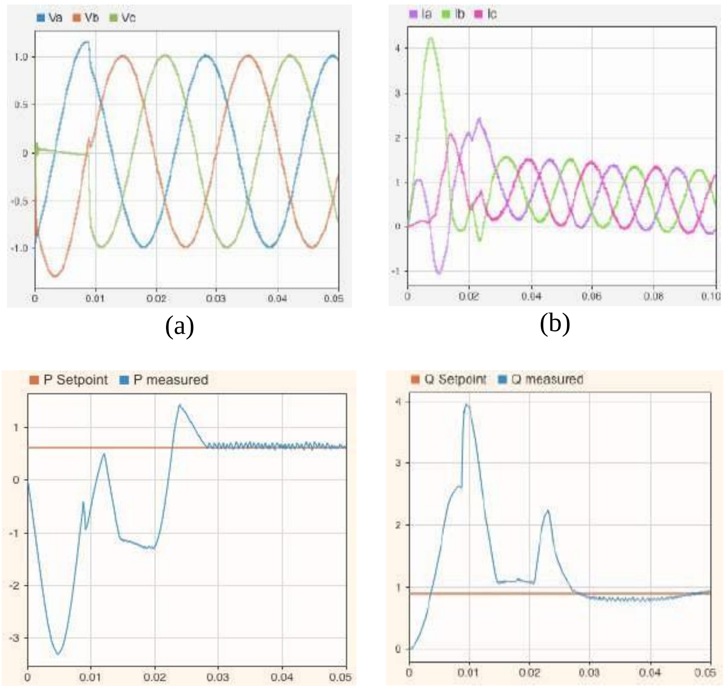
(c)



(d)

Figure 8. Trend of normal condition: (a) three-phase voltage, (b) three-phase current, (c) active power, and (d) reactive power

Figure 9 illustrates the time-plot trend of three-phase voltage and current, measured active and reactive power in pu. Figure 9(a) illustrates the three-phase voltages when the single-phase to ground fault occurred, at the beginning of simulation, the one of three-phase voltages began interrupted at the beginning of simulation time, whereas the voltage distortions (sag and swell) occurred but then it maintained to steady and lie within its limit. The three-phase current in Figure 9(b), started to less significantly ramped-down at two-third of simulation time as it still steady. The active power in Figure 9(c), is lower than its setpoint value, though at a quarter of simulation time, then it rocketed over 1pu, and steady till it reached end of simulation time. This indicates that the process of injecting and absorbing power to and from the grid is unstable at the beginning, and maintained to get steady for the rest of simulation time. While the reactive power in Figure 9(d), though it is below its setpoint, but it is rocketed over at the first 10 seconds, then it began to drop at quarter of simulation time.



(a) (b)

(c) (d)

Figure 9. Trend of single-phase to ground fault: (a) three-phase voltage, (b) three-phase current, (c) active power, and (d) reactive power

Figure 10 illustrates the time-plot trend of three-phase voltage and current, measured active and reactive power in pu. As can be seen in Figure 10(a) when the double-phase fault is being simulated, the interruption occurred at the beginning of simulation (voltage sag and swell occurred) and over their limit values. It is a similar to the single-phase to ground fault when it occurred at one of the double transmission lines, and likewise the three-phase current in Figure 10(b). The active power in Figure 10(c) shows the lower trend than its setpoint value, though at a quarter of simulation time, then it rocketed over 1 pu, and steady till it reached end of simulation time. It means that the active power is being unstable (injected and absorbed to and from the grid) at first, then maintained to inject the power to the grid. The reactive power in Figure 10(d) is rocketed over its setpoint value at the first 10 seconds, then it began to drop at quarter of simulation time, and then steady close to its setpoint value. Figure 11 illustrates the time-plot trend of three-phase voltage and current, measured active and reactive power in pu. Figure 11(a), all of the three-phase voltages are interrupted at 10 seconds of simulation time (voltage sag and swell occurred) and over their limit values. Then maintained within the limit for the rest of simulation time, likewise three-phase current in Figure 11(b). Though the current less significantly increased at two-third of simulation time as it still steady. Figure 11(c) illustrates the active power; the similar circumstance is occurred as the double fault's case. Figure 11(d) illustrates the reactive power at one-third of simulation time addressed similar unstable condition as the case of single-phase to ground fault.

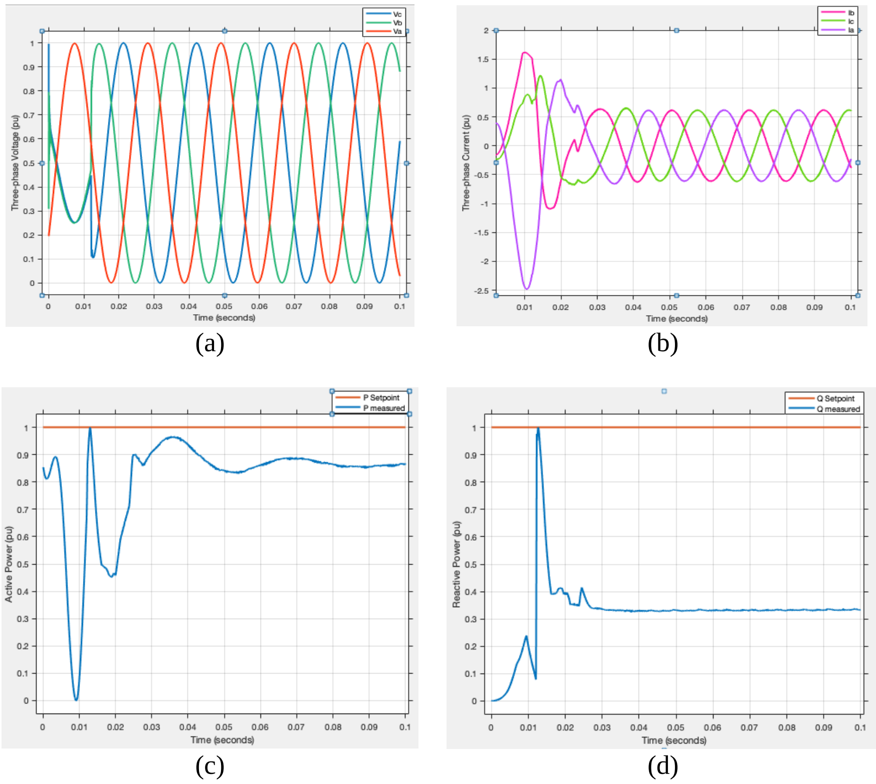


Figure 10. Trend of double-phase fault: (a) three-phase voltage, (b) three-phase current, (c) active power, and (d) reactive power

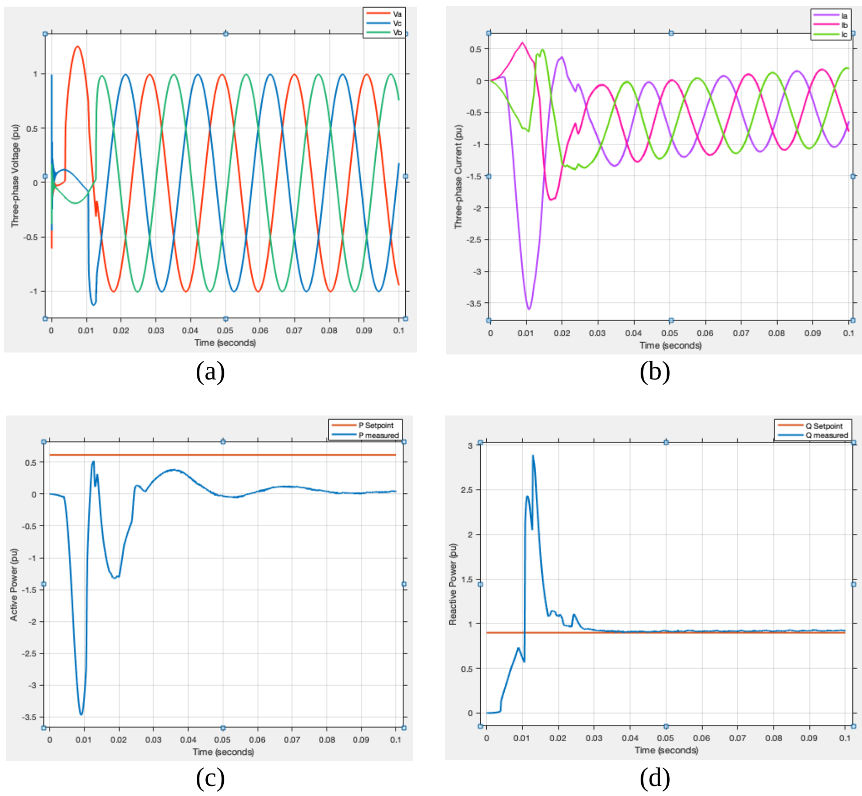


Figure 11. Trend of three-phase to ground fault: (a) three-phase voltage, (b) three-phase current, (c) active power, and (d) reactive power

4. CONCLUSION

A control and monitor of a developed PV station along the transmission line which is integrated into SCADA system using MATLAB/Simulink was analyzed. SCADA supports the real-time monitoring and has a direct impact on the performance of PV power plants as well as their ability to meet the requirements of the target application. The three-phase voltage at a given fault and the station's reactive power are also measured and maintained near their setpoint values as conditions change in order to control voltage sag and swell. Furthermore, the active indications occurred while the faults occurred. The effect on the performance of PV station toward the transmission line can be seen as the transmission line delivers part of the real power to the load, but all reactive power was drawn from the transmission line as itexperienced several faults' condition at peak generation times.

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