Impacts of a Very Small Scale Biomass Gasification and Small Scale Solar PV Power Plant on Power Systems

K. Hussaro*, J. Intanin, and S. Teekasap

Abstract— *Shortage in fossil fuels and increasing energy demands were a major cause of the energy crisis. Renewable energy has proven to be one of the effective sources of energy that capable of fulfilling the growing demand for sustainable development of society. This research aim to study impacts of a very small scale biomass gasification and solar PV power plant on power quality of power systems, to define guidelines for solving problems of power distribution system, and compared the results from small scale biomass gasification and solar PV power plant for developing net metering system to solve power quality problems of power systems. The experiments were recorded abnormal conditions on electricity generation, and connection to the grid system. It was found that the position of very small biomass gasification power plants has an impact on the electrical network of provincial electricity authority. Lower load reverse current to supply electrical network, new balance of shot circuit, small lips voltage into on-off electrical from the system, low harmonic, and using a capacitor for improving the power factor can be solved these problems. The results showed that the power factor observed was at 0.95 on the small-scale biomass gasification power plant. The 1 MW small solar power plant connected to grid deployed poly-crystalline panels were used as the case study. It was found that the current of on-inverter mode produced more than off-inverter mode at 36.94 %, while the voltage of off-inverter mode was higher than that of on-inverter at 2.63 %. The generation frequency was nearly constant in both on and off inverter connected mode. The development of net metering include smartphone to measure power quality of the electrical network had been studied using recorded power quality data of Provincial Electricity Authority substation for improving power quality in sustainable production and distribution of electricity.*

Keywords— **Biomass gasification, solar PV, power plant, net metering, on-grid, power system.**

1. INTRODUCTION

There are not enough local commercial sources of energy for electric power production to cope with Thailand's domestic demand, at about 60 percent of its total demand were relying on those imported. Thailand's final alternative energy utilization in all sectors (solar energy, wind energy, small hydro power, large hydro power, biomass, municipal solid waste (MSW), biogas and biofuels (ethanol and biodiesel)) has increased continuously. While agricultural wastes from agricultural-based industries are continuously increasing every year. In 2013, about 71 out of 134 million tons of agricultural wastes were used as energy [1]. In 2017, Thailand alternative energy consumption was 11,731 ktoe, shared 14.53 % of the total final energy consumption, with an increase of 6.2 % from the previous year. Heat energy consumption was the greatest share of total final alternative consumption at 62.4 %, followed by electricity and biofuels (ethanol and biodiesels) 21.1 % and 16.5 % respectively. This result in decreasing of energy imports value at 155,788 million Baht, and also decreasing of CO_2 emission at 35.98 million tons, as shown in Fig.1 [1].

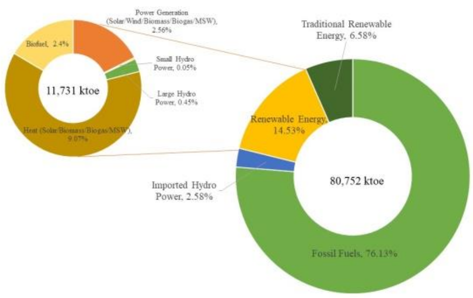

Fig. 1 Alternative Energy Consumption in Thailand 2017

Table 1 presented the total installed of alternative energy based electricity generation capacity at 10,238 MW, increased by 8.5% from the previous year, with gasification biomass power plants took the greatest shared at 30.8% of the total installed capacity, followed by large hydro power, solar energy, wind, biogas, MSW energy and small hydro power at 28.4 %, 26.3 %, 6.1 %, 4.7 %, 1.9 %, and 1.8 % respectively [1].

Thailand set a target for renewable energy power generation to about 19,684.40 MW (5,588 tons of crude oil equivalent) in the year 2036; comprise of 6,000 MW from solar source, 5,570 MW from biomass source, 3,002 MW from wind source, 2,906.4 MW from hydro source, 1,280 MW from biogas source, 680 MW from crops energy source, and 550 MW from multiple solid

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waste (MSW) source. The target aims to significantly replace at least 25 percent of fossil fuels in small-scale power plant (SPP) and very small power plant (VSPP) which leading to more independent country's power supply, and also reduce greenhouse gas emissions and pollutant. Promotions on investment in small gasification and solar power plants technologies are imposed to accelerate project implementation.

Table 1. Total Alternative Energy Based of Electricity Generation Capacity Installed [1]

Energy source	Installed Capacity* (MW)					Growth rate (%)
	2013	2014	2015	2016	2017	
Solar	823	1,298	1,419	2,446	2,697	10.3
Wind	222	224	233	507	628	23.8
Small Hydro Power	109	142.	172	182	182	0.1
Biomass	2,321	2,452	2,727	2,815	3,157	12.2
Biogas	266	312	373	435	475	9.3
MSW	48	66	132	145	192	32
Large Hydro Power	2,906	2,906	2,906	2,906	2,906	-
Total	6,695	7,400	7,963	9,437	10,238	8.5

*Including off grid power generation

Biomass, a sustainable source, is expected to play an important role in future supply to substitute fossil fuels for small and very small power plant through a promising gasification process, a thermo-chemical conversion of solid fuel to combustible syngas. [2-6]. Biomass has a low energy density compared to fossil fuels, with total calorific values ranges between 18 MJ/kg to 19 MJ/kg, which is almost half of natural gas and fuel oil. Thus, cost of transportation is the main barriers for using its in large-scale power plants, however, for small-scale biomass gasification power plant can be used when small adjacent catchment areas are available. New advance biomass gasification technology development in improving system efficiencies, reduce investment and maintnence cost, and require less manpower will make biomass electricity generation become economical ly viable. [7][9][10].

Biomass gasification process depends highly on reactor design and properties of available fuel; heating value, size, moisture content, and ash content. Two types of gasifier reactors are frequency used in biomas gasification power plant, which are fixed bed reactors and fluidized bed reactor. Fixed bed reactors can devined into three types, downdraft or cocurrent gasifiers, updraft or countercurrent gasifiers and cross-draft gasifiers. While fluidized bed reactors can devined into bubbling bed gasifier and circulating bed gasifier. Bubbing bed gasifiers are very simple in construction and operation, and can gasify different kinds of biomass feedstock under high pressure partial oxidation with inert bed materials (sand) as a temperature regulator. While, in circulating bed gasifier, biomass feedstock is partial oxidize under high fluidizing gas velocity and are circulate back to the reactor bed. Normally, gasification technology is selected on the basis of available fuel quality, capacity range, and gas quality conditions. Suitable operation range of various gasifiers are as followed,

fixed bed downdraft gasifiers 1 kW to 1 MW.
fixed bed updraft gasifiers 1.1 MW to 12 MW.
fixed bed cross-draft gasifiers 10 MW to 200 MW.
fluidized-bed gasifiers 1 MW to 50 MW.

Gasify medium (air, pure oxygen, steam/ CO_2, or their mixtures) is one of the main parameter affecting syngas composition. Air has advantage on its great availability at no cost, but its drawback is high nitrogen content, thus, require bigger blower and reactor, and produced lower heating value syngas. Composition of air oxidant syngas were 9 to 10 % H_2, 12 to 15 % CO, 14 to 17 % CO_2, 2 to 4 % CH_4, 56 to 59% N_2, with lower heating value (LHV) at about 3 to 6 MJ/Nm^3.

Pure oxygen has advantage on none of impurity existed, but the drawback is its high production cost. Syngas produced has better heating value, minimize tar content, and contained enrich H_2, CO, and CH_4 gas, and improve carbon conversion characteristics. Composition of pure O_2 oxidant syngas were 30 to 34 % H_2, 30 to 37 % CO, 25 to 29 % CO_2, 4 to 6 % CH_4, with lower heating value (LHV) at about 10 to 15 MJ/Nm^3.

Steam/CO_2 has advantages on its availability at almost no cost for water and using exhaust gas from power plant for CO_2, syngas produced have advantages of H_2 rich and high heating value, and moderate tar. Composition of steam/CO_2 oxidant syngas were 24 to 50 % of H_2, 30 to 45 % of CO, 10 to 19 % of CO_2, 5 to 12 % of CH_4, with lower heating value (LHV) at about 12 to 20 MJ/Nm^3[7][8]. In case steam/CO_2 oxidant, there requires heat supply to maintain endothermic reactions, which can be done through mechanically circulating of hot partially burn biomass, or oxidant preheating directly.

Solar energy has tremendous potential which can produce electricity with zero wastes, zero emission and low system maintenance, Solar energy technologies are consisting of solar heating, photovoltaic (PV) cells, solar thermal electricity and solar architecture which considered significant contributions for solving some of the most urgent energy problems. PV technology has been proven for electricity generation from solar energy with wide range of power production from a few milliwatts to several megawatts (MW) in central power [11].

Solar PV power plants operate on the principle of photovoltaic effect for produce direct current electricity, and mostly deploy modules of crystalline (poly-crystalline and mono-crystalline) solar cell and thin film PV cell. PV cells are made of light-sensitive semiconductor materials, which use photons to dislodge electrons to drive electric current. Thin films are made from amorphous-Si (a-Si), tandem (a-Si/micro-crystalline), CIGS (Copper Indium Gallium Selenide), CdTe (Cadmium Telluride), and Dry- sensitized (TiO_2). Thin film cells offer greater promise for large-scale power generation due to the ease of mass production and lower materials cost, however its conversion efficiencies are lower compared to those of crystalline cells [12][13]. By means of an inverter, direct current are converted into alternating current electricity for suppling to domestic use (stand-alone system) and national/local electric power grid system (on grid system).

There are two main types of solar PV systems; grid connected and off-grid (stand-alone) system. Grid-connected systems are systems that feed power directly into large independent grid, usually public electricity grid. These systems are usually deployed as decentralized grid-connected PV and centralized grid-connected PV. Decentralized grid-connected PV solar electricity production can be of rooftop PV system, where the PV solar modules are mounted on rooftops of buildings for feeding produced electricity to utility grid. Install capacities are usually at the lower range of building power used or few kilowatts. Typical system consists of; (i) solar PV modules, (ii) inverter, (iii) main disconnect/ isolator switch, and (iv) utility grid. While, central grid-connected PV solar electricity production have higher capacities ranging up to several megawatts [12].

Small scale biomass gasification and solar PV power plant are clean form of the use of renewable energy resources available for scattering supply of domestic and commercial electricity consumption. In conventional perceptions, both technologies are expensive compared to retail price of grid provided electricity. Up to now, prices of fossil fuels increase continuously, so electricity tariffs are also continuously raising, thus the cost of electricity from biomass and solar PV can be competed. Moreover, electric power security of adding local scattering electric generation made more interest for the country benefit.

2. MATERIALS AND METHODS

This research aimed to study the impacts of a very small-scale biomass gasification power plant and small solar PV power plant on power systems in power quality, and problem and solution of distribution systems.

Data Collection on Small Biomass Gasification Power Plants and Small Solar PV Power Plants

Survey and experiments data from less than 1 MW of small biomass power plants have been done at operation and maintenance division, Provincial Electricity Authority (Region 1, Central), Suphanburi Province, and Phranakhon Si Ayutthaya Province, Thailand.

Data collection of 1 MW PV power plants have been done at Provincial Electricity Authority (Region 1, Central), Phranakhon Si Ayutthaya Province, Thailand, and Royal Thai Navy, Rayong Province, Thailand.

Survey data were collected through indepth-interview from biomass power plant and small solar PV power plant engineers, provincial electricity authority substation controller, technical personnel of other related agency. Collecting data consist of the following items; electricity and grid connection system (voltage, power factor, power quality, power and energy, and field harmonic conditions), production capacity and process, fuel and fuel preparation, cleaning system, heat exchangers, type and size of internal combustion engine and generator, control systems, protection system, system efficiency, and schematic diagram of circuit breaker., and to record the electricity, as followed; abnormal condition on generator, abnormal condition on the connection to the system, and editing of electrical system.

Experimental design and set-up

This study aimed to establish a practice set of information for analyse and solve power quality problems in biomass and PV power plants electricity production systems. These information will help for comprehensive insight uderstanding to the design of small scale power plant (less than 1 MW). Instrument and equipment used in this study are computer set, mobile phone, network adapter, power supply, and main board connected to main curcit beaker (MBD box) for measured electricity quality. Main board sent real time data via internet to computer for interlligence analze electricity systems, which was been defined normatively as the integration of power, communications, and information technology for an improved electric power infrastucture serving loads while providing for an ongoing evolution of end use application, new technical term for this is “Net metering“.

Net metering are independently controlled distribution networks capable of operating in power plant, as shown in Fig. 2. This enables them to present a single, more stable interaction with the grid, and offers resilience if the grid fails. Where, there is collecting electricity quality and loads within a single network and implementing an intelligent management scheme, the intermittent nature of any biomass gasification and solar PV can be mitigated and a single, more consistent load can be presented with the centralized paradigm.

Analytical methods

The electricity quality (kW-h, voltage, power factor, power quality, and harmonic) was measured by electrical measuring instrument and ABB monitoring and communications (VSN700 Data logger) as shown in Fig 3. All actual data were collected from site measurement. All small-scale power plants (biomass gasification and solar PV) were equipped with the latest Supervisory Control and Data Acquisition System (SCADA). Parameters such electrical energy production were recorded by the data logger. The recorded data were stored in a computer system using peripheral interface with a SCADA communicator through a computer.

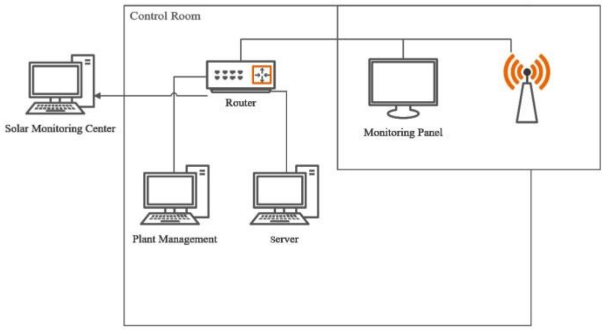


Fig. 2 Net Metering Configuration (Simplified).

Fig. 3 Electrical measuring instrument and ABB monitoring and communications.

3. RESULT AND DISCUSSION

Electricity production from Small Biomass Gasification Power Plant about 1 MW output connected grid

In developing countries, several kinds of biomass feed stocks can be utilized for gasification, particularly from agricultural wastes, such as, corn cobs, rice husk, palm oil shell, coconut shell, palm kernel shell, empty fruit bunch, and grass waste. The 1 MW biomass gasifier-based power plant was operated with circulate fluidized-bed gasifier with gas cleaning and cooling system and has been installed and commissioned in Suphanburi Province, Thailand. Biomass feedstock has particle size from 30 mm to 80 mm with 15-20% of fixed carbon and water content (by weight) after drying. The biomass is conveyor feed into gasifier 6 tons/day. Reactor temperature is at about 700-900°C. The biomass was mixed with hot bed materials (sand 15-20 kg and catalyst 7-8 kg). Syngas come out from reactor together with particulate matter and tar contaminants is fed into the gas cooling and cleaning system to condition the syngas to a suitable level engine operation. Proximate syngas contained 40% H_2, 22 % CO, 21 % CO_2, 9% CH_4, 2% N_2, and 6% of others, [6]. Schematic gasifier system is shown in Fig. 4.

Fig. 5 presented electricity generation from producer gas engine generator set, which was measured using a kWh meter on the control panel and repeat checked with the voltage and ammeter (clamp meter) recording. The power factor was found to be around 0.95. It is important to recognize that the entire power package (V, kWh, and A) were at continuous and constant load. Some of the lower loads recorded are due to the grid failure and reloading the system. During the grid failure, the entire system was operated on the internal load without stopping either the engine or the gasification system.

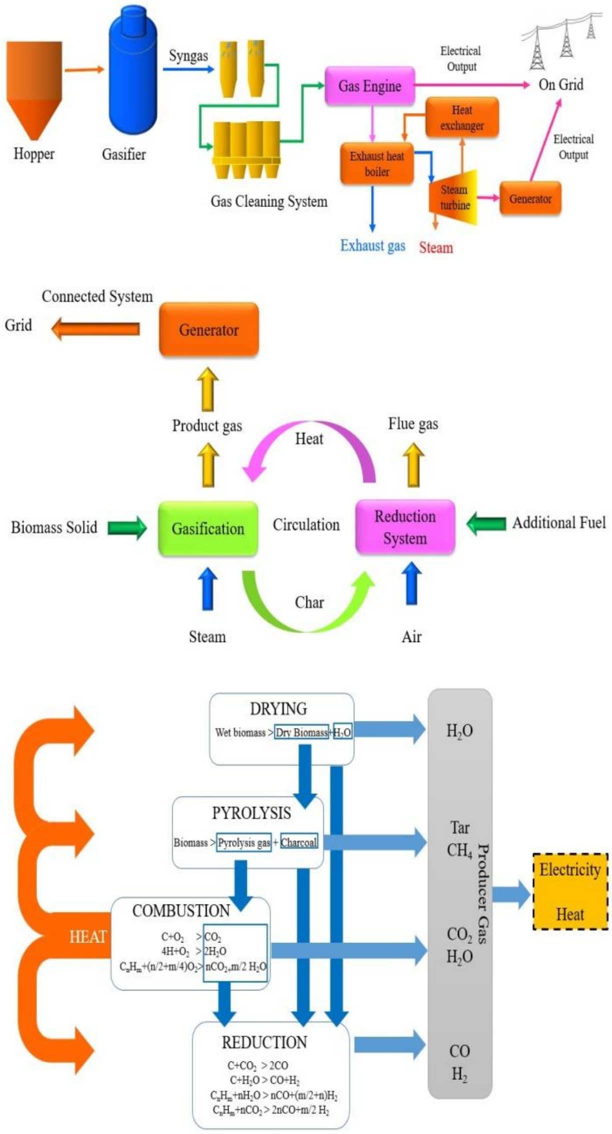


Fig. 4 Schematic diagram of small scale biomass gasification power plant [6][14].

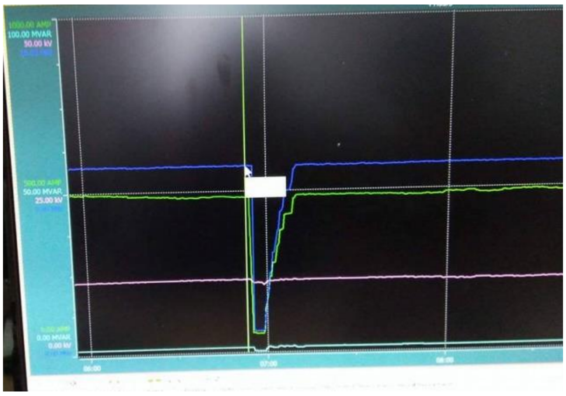


Fig. 5 Electricity generated by producer gas engine generator from small scale biomass gasification power plant

Electricity production from Small Solar PV Power Plant about 1 MW output on-grid

The case study of 1 MW on-grid small PV solar power plant system was shown in Fig. 6. The project was focus in designing a small solar PV power plant to match the consumer load requirement. The system components consist of 7 major parts: (i) solar poly-crystalline panels (specification shown in Table 2), (ii) power conditioning grid tie inverter of 20 kW, three phase, and 50 Hz, with suppressing harmonics control (iii) utility grid system, (iv) DC array junction box, (v) control room with main distribution board (MDB, 380 V with 3 phase), SPD 20kA (MAX 40kA), and 1000 VDC as an lightning protection devices, (vi) cables, and (vii) SCADA. To minimize impact on devices in the system, uncontrolled voltage and current flowing into the system are diverting to ground by a grounding system.

Fig.7 present electrical quality in on-grid and off-grid connected mode. Current was nearly constant at approximately 253.4 A of on-Inverter mode, while solar PV at off-Inverter was decreasing to 93.6 A due to power swings in this mode. From this result, current of on-inverter mode had more than off-inverter mode approximately 37 %, voltage was nearly continuous and completed at about 389.1 V of on-inverter connected mode (Fig. 7(b)), while off-inverter connected mode, the voltage has increasing to approximately 400 V, thus 2.63% of voltage at off-inverter mode was higher than that of on-inverter mode. One of on-grid major problem is frequency stability, it was found that the frequency generated were nearly constant in both modes, at 49.992 Hz for on-inverter connected mode, and 49.993 Hz for off-inverter connected mode (Fig. 7(c)).

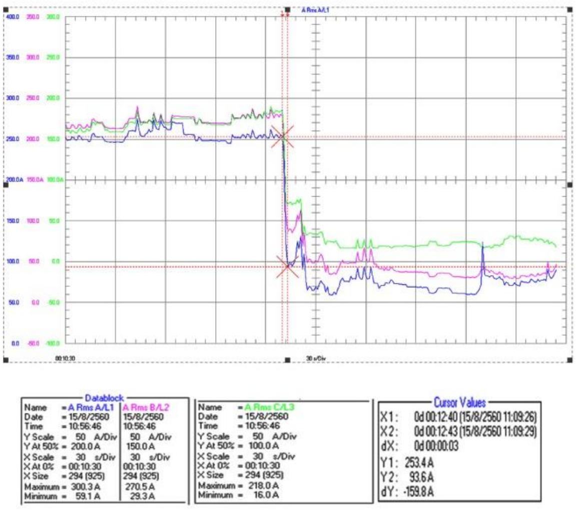
When analyzing quality of current, voltage, and frequency of the on-inverter connected grid, the current had nearly constant, but voltage vary in a range of reduction (voltage sag), (Fig. 8) due to some phase to ground problem as followed; (i) electrical faults in transmission and distribution systems, (ii) not proper switching actions in the system, (iii) use of nonlinear devices in the systems, (iv) some natural phenomena, such as branches across power lines, and (v) incorrect grounding.

Table 2. Solar Panel Specifications

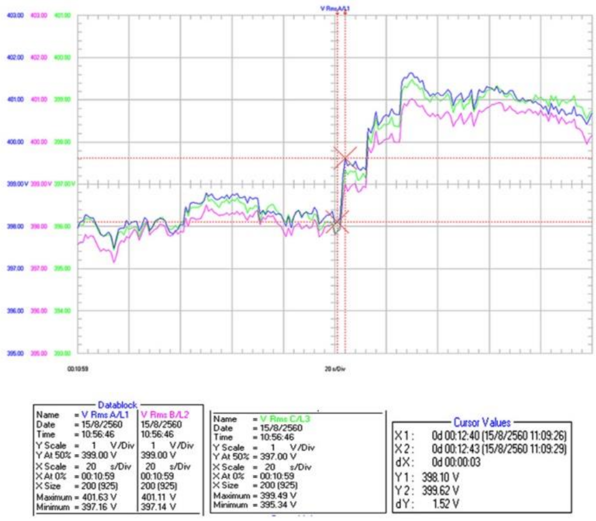
Model Number	GKPC 305-24/Ve
Rate Maximum Power (P_{max}), W	305
Output Tolerance, %	±3
Current at P_{max} (l_{mp}), A	8.43
Voltage at P_{max} (V_{mp}), V	36.2
Short-Circuit Current (l_{sc}), A	8.89
Open-Circuit Voltage (Voc), V	44.7
Nominal Operating Cell Temp. (T_{NOCT})	45 ± 2°C
Weight, kg.	25.8
Dimension, mm.	1956 x 992 x 40
Maximum System Voltage, V	1000
Maximum Series Fuse Rating, A	20
Cell Technology	Poly-Si
All technical data at standard test condition	AM=1.5 E=1000 W/m^2 T_c=25 °C

Fig. 6 Schematic of small scale solar PV power plant.

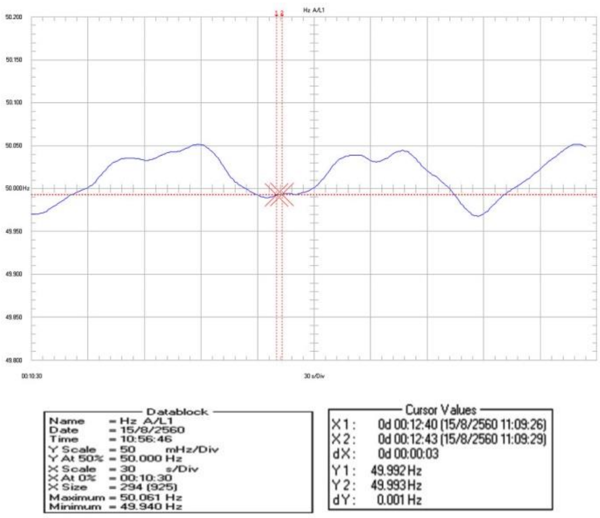
The current harmonics in on-inverter connected mode was higher than that of the off-inverter connected mode as shown in Fig. 9. It was found that, are some there are some effect on grid protection system of PEA when connecting small power plants to the grid. Therefore, there is need to installation protective circuit breaker at the power station to cut of current backwards flow if short circuit happened. While operate at reduce load, backwards flow might occur, in this case, short circuit breaker will cut off the circuit.



(a) Current at on-off inverter

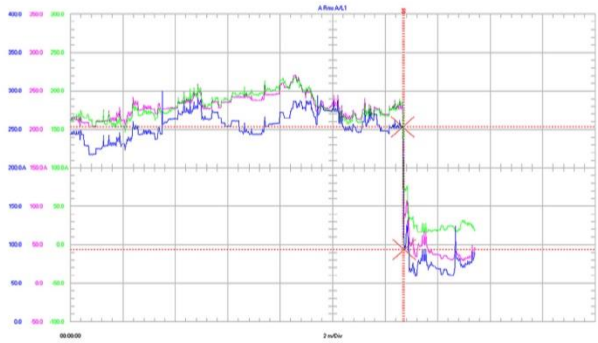


(b) Voltage at on-off inverter

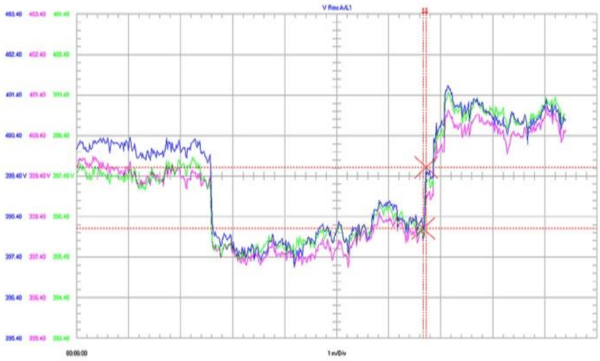


(c) Frequency at on-off inverter

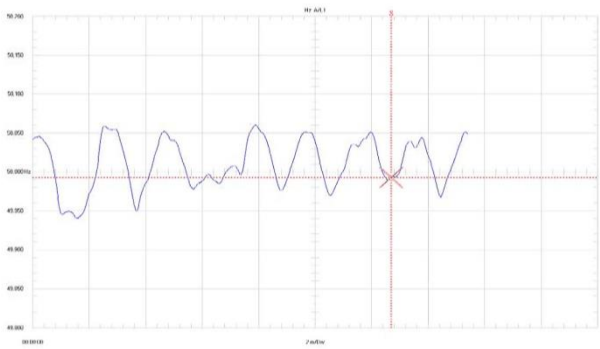
Fig. 7 Quality of current, voltage, and frequency of small-scale solar PV while on-off inverter connected mode.



(a) Current



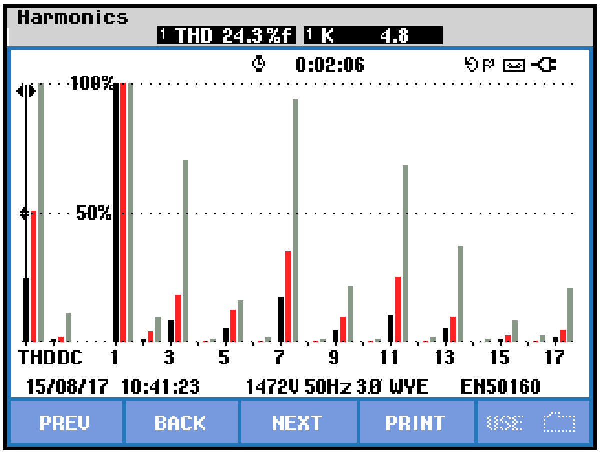
(b) Voltage



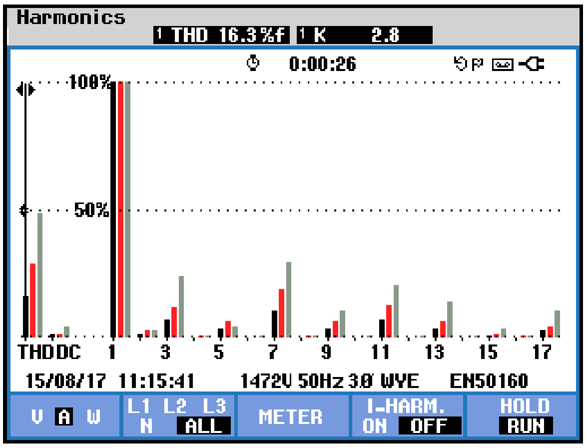
(c) Frequency

Fig. 8 Comparison of on-inverter connected mode on current, voltage, and frequency of small-scale solar PV power plant.

Caution for small power plant grid connection are as followed; (i) Location of the power plant should be in vicinity to customers for reducing power loss, (ii) Power flow must be regulated and set up a circuit protection system. (iii) Voltage must be regulated at not more than 10% variation. (iv) Some renewable power plant cannot produce electricity at all time, so there are needs for electrical backup system. (v) Power quality should be considered; for biomass power plant synchronous generator provide better power quality than that of induction generator. For solar power plant, select correctly type of inverter is essential, and finally (vi) Connection of small power plant and electrical networks need reliable and effective communication between small power plant and main station for possible cure existing problem in real time. Concept of mini-smart grid via net metering system was developed to solve these problems for sustainable production and distribution of electricity in the power grid.



(a) On-Inverter



(b) Off-Inverter

Fig. 9 Current harmonics of on and off inverter connected mode.

Power Quality from Net-Metering of Small Solar PV Power Plant

Smart grid and net metering utilized all kinds of available distributed sources to provide reliable power supply. Power quality of small solar PV power plant with net metering on-grid connected, were measured based on power output and power factor on main meter, sub meter, and solar meter. Current of feeder (customer) was measured via net metering though mobile phone and computer, as shown in Fig. 10.

The maximum variation in power level is found to be 139.5 kW at solar meter. The highest recorded daily power produced occurred during 11.00-15.00 hr. Due to solar PV power panels produced power more than the building load needed; the left power is fed into grid supply system to the system. On contrast, if solar power PV panels can't produce enough power needed for building due low solar radiation during 18.00-06.00 hr., the rest of load needed will be used power from PEA grid. Among power generation metering during 8.00-17.00 hr, it was found that solar meter recoded higher power (positive value) than sub meter and main meter, that is too must solar radiation on this time. The highest power factor (PF) measurement recorded 0.99 pu on solar meter during 8.00-17.00 hr which showed good power quality at load point.

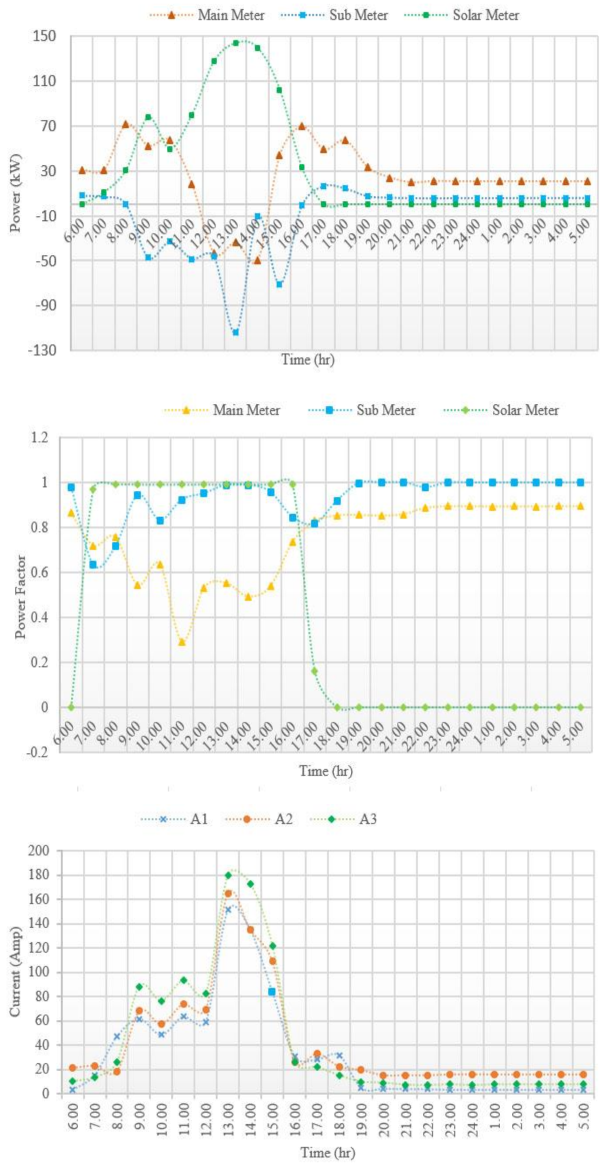


Fig. 10 Power quality of small solar PV power plant with net metering on-grid connected and on feeder

4. CONCLUSION

In this article report impacts on power systems of very small-scale biomass gasification and solar PV power plant (less than 1 MW). Experimental tests on power quality consist of current, voltage, frequency, power factor, and current harmonic has been done. It was found that the power factor of biomass gasification and solar PV power plant were 0.95 and 0.99, respectively. On-inverter connected grid of solar PV power plant, current record was nearly constant, but voltage varied at a range of reduction (voltage sag) due to switching actions, electrical faults in transmission and distribution systems, natural phenomena such as branches across power lines, and incorrect grounding. Therefore, the building electrical system should install nonlinear devices. The net metering system was developed to solve backward electricity flow when the protection system fails. Net metering of the on-grid inverter on solar PV power plant was operated with learning capacities that can be done and evaluate over this framework. A system with a distributed controller can also be recording using this application.

ACKNOWLEDGMENT

The authors wish to express our thanks to the GÜssing Renewable Energy GmbH, Nongbua, Suphanburi Province, Thailand, and Provincial Electricity Authority (Region 1, Central), Phranakhon Si Ayutthaya Province, Thailand, Royal Thai Navy, Rayong Province for sharing some biomass gasification power plant data and allowed us to collect some experimental data on small scale solar power plant. This research was financially supported by Rajamangala University Technology Rattanakosin, Salaya, Phutthamonthon, Nakhon Pathom 73170, Thailand.

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