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Application of Process Systems Engineering Tools in Solar and Biomass Technologies

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The abatement of anthropogenic carbon dioxide gas and extensive demand for electricity has motivated cleaner power production from renewable and sustainable sources such as solar and biomass (e.g., palm kernel shell and wood chips). Via photovoltaic (PV) effect, solar irradiation can be converted to electricity, while by nature it can generate and absorb the heat through solar thermal collector. Whereas, chemical characteristics of biomass feature an alternative pathway of fossil-fuel derived hydrogen via thermochemical conversion. This work reviews contemporary applications of process systems engineering (PSE) tools for renewable energy sources, specifically solar and biomass. It can be concluded that a rapid transition of solar and biomass-based renewable energy (RE) technology can be achieved via the assistance of process system engineering (PSE) techniques (i.e digitalisation, computerisation, and artificial intelligent platform). Application of PSE is capable of accelerating the technological sophistication, thus enabling effective exploitation of solar and biomass as a modern RE generation.

Keywords: solar; biomass; PSE; renewable energy; environment

I. INTRODUCTION

The large-scale burning of fossil fuels has significantly increased greenhouse gas (GHG) emissions to the atmosphere, trapping the heat and leading to global climate change (Dimitriou *et al.*, 2018). As a result, renewable energy (RE) technologies have gained great attention as alternative to fossil fuels, aligning with the 2030 Agenda for Sustainable Development (United Nation, 2022) and Circular Economy Action Plan (United States Environmental Protection Agency, 2022). The global energy landscape has witnessed a dramatic shift towards the extensive deployment and utilisation of both solar and biomass-based renewable energy (RE) sources. While numerous commercials RE plants are already on the run, academic research in these fields continues to advance at a rapid pace. This ongoing evolution is driven by the pressing need for technical and environmental interventions to ensure the long-term sustainability, feasibility, and viability of large-scale solar and biomass-based RE technologies. While analysing those two aspects through experimental setups can be challenging, the application of process systems engineering tools can effectively address these limitations. Therefore, this work aims to conduct a mini review of two important renewable energy sources: solar and biomass. These technologies are selected due to their maturity, scalability, and ability to address a significant number of Sustainable Development Goals (specifically SDGs 3, 7, 11, and 13). Solar energy represents a promising avenue in the realm of renewable resources, meeting crucial criteria for sustainable energy solutions. Its abundance and renewable nature, coupled with the continual reduction in associated technological costs, position it as a viable alternative to conventional energy sources. The versatility of solar energy is particularly noteworthy, as it can be harnessed to generate both electrical and thermal energy, two forms critical to maintaining and enhancing human productivity and quality of life. The most available forms of solar energy technology are solar thermal collector, photovoltaic (PV) module, and hybrid photovoltaic-thermal (PVT). Thermal collector absorbs the heat from

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sunlight to produce heat energy. PV module converts solar irradiation to electricity when it strikes the semiconductor layer (on top of the module) via photovoltaic effect. Figure 1 illustrates the common operational mechanism of a photovoltaic (PV) solar cell. Recent innovation in the PVT system is able to fully exploit the use of sunlight by generating both electricity and heat energy simultaneously. This technology evolution features huge opportunity for solar to be a reliable modern RE generation with the assistance of thermal energy storage, such as phase change material (PCM).

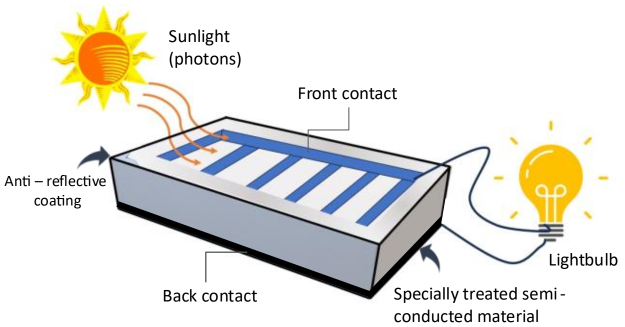

Figure 1. Common operational mechanism of a photovoltaic (PV) solar cell

Biomass residues obtained from the palm oil industry is believed to have the greatest potential as an alternative and renewable fuel source to be used for contemporary energy conversion and features a promising solution in reducing the usage of fossil fuel and energy shortage. General technologies used to convert biomass into fuel can be classified into thermal (direct combustion, incineration), biochemical (fermentation, anaerobic digestion), mechanical and thermal (pulverisation) and also thermochemical. Thermochemical processes include torrefaction, plasma technology, liquefaction, and gasification. Among all processes, gasification is considered the most efficient method for gaseous fuel production. Plus, it has more environmental benefits and can reduce heavy metals and toxic gas formation (Vaish *et al.*, 2019).

Process Systems Engineering (PSE) tools have evidently demonstrated their ability to make significant contributions to the body of knowledge, particularly in three key areas: deciphering complex technologies and systems, predicting operational uncertainties, and addressing challenges faced by industries and investors prior to technology commercialisation. Many reviews have explored the significant contribution of computational efficiency via PSE approach, such as in the area of ionic liquid and biorefineries (Chemmangattuvalappil *et al.*, 2020), materials and molecules reaction in chemical process design (Adjiman *et al.*, 2021; Zhou & Sundmacher, 2021), and process intensification (Tian *et al.*, 2018). Nevertheless, no noticeable review articles have been conducted related to the deployment of PSE tools in the RE area. Thus, the objective of this study is to provide recent progress and highlight the contributions and trends of PSE tools in exploiting the solar and biomass–based RE technology, targeting the operational and control framework. This review encompasses of different types of computational tools and how it plays a part towards experimental output and practical result.

II. APPLICATION OF PSE IN THE SOLAR RENEWABLE TECHNOLOGY

A. Modelling of Solar-based Energy Technology

Solar-based energy technology is forecasted to conquer the global energy sector surpassing the conventional fossil fuel-based energy generation (Manaf *et al.*, 2021). Different materials have been studied to suit the application of the current technology requirement for solar-based RE. Table 1 summarises the materials utilised in the solar cell included in this review paper. This review focuses on the modelling of different types of solar collector and hybrid PVT panels with consideration of phase change material (PCM)-based thermal energy storage (TES) system, due to their market demand and potentiality as a modern RE technology.

There are few types of approaches that can be used to construct and develop a mathematical model of solar collector with/without PCM using various simulation/numerical software, such as computational fluid dynamics (CFD), Matlab, and ANSYS-Fluent.

Wu *et al.* (2020) conducted a numerical study by developing a 3D model of evacuated tube collector (ETC) integrated with PCM using ANSYS-Fluent as simulation software (Wu *et al.*, 2020). In their study, numerical analysis was validated via an outdoor water heating system test rig. It was observed that integration of ETC with composite paraffin-capric acid was able to fulfil the demand for seasonal thermal energy storage (winter and summer), subsequently showed the technical capability of proposed solar water heating system in dynamic climatic condition. Salari *et al.* (2020) used ANSYS-Fluent software to develop a 3D qausi CFD model based on two environmental and technical criteria, which were natural ventilation and power generation, respectively (Salari *et al.*, 2020). Three different solar chimney systems were modelled and simulated, which are solar chimney with PV and PCM, solar chimney with PV panel, solar chimney with PCM and conventional solar chimney. Based on the simulation result, solar chimney with PCM system showed the best performance among other systems from the ventilation viewpoint. Meanwhile, the solar chimney with PV and PCM system outperforms the other systems in terms of power generation, thus suggesting that the technology is more suitable for residential buildings.

Pawar and Sobhansarbandi (2020) conducted a simulation study to investigate the PCM performance integrated with the heat pipe of ETC (Pawar & Sobhansarbandi, 2020). A CFD model was developed to compare the performance of system with and without the presence of PCM using ANSYS-Fluent as simulation software. The simulation result proved that system integrated with PCM showed better performance in term of longer operation time when solar irradiation is inadequate, and the temperature difference was found to be 30˚C between system with and without PCM. A similar software was used to investigate the performance of FPC encapsulated with PCM (Raj *et al.*, 2020). It was observed that the value of liquid fraction was proven to have increased as the heat input increased. PCM was found to melt easily at a faster pace when the flow velocity is low. This scenario was because the heat dissipated to ambient was slower at low water flow rate, hence the PCM in contact with the hot water caused the PCM to melt faster.

An innovative design approach of hot water storage tank for solar water heating system using the artificial neural network (ANN) model was developed in Matlab environment to predict Overall Conductance based on the equivalent thermal resistance (Kulkarni *et al.*, 2021). The developed ANN model was able to mimic the actual solar water heating system with minimal error. Similarly, Diez *et al.* (2019) constructed a flat-plate solar collector which utilised three different working fluid flows via the ANN model (Diez *et al.*, 2019). The developed ANN model was used to predict the outlet water temperature subjected to the input variables, which are solar irradiance, ambient temperature, inlet temperature and working fluid flow. Serale *et al.* (2016) developed a physical–mathematical model of a solar collector integrated with slurry PCM in the Matlab-Simulink environment to compare the performance between solar collector with and without PCM subjected to different variables such as location, orientation, and PCM concentration (Serale *et al.*, 2016). Based on the simulation, the solar collector integrated with PCM showed better performance in term of solar energy exploitation of different magnitude during cold climate.

Szabó *et al.* (2018) developed a flat plate solar collector model based on the actual solar collector available at University of Szegedc (Szabó *et al.*, 2018). The proposed model was simulated with Kolektor 2.2 software while the mathematical model was constructed using Simulink, Matlab environment. It was observed that the amount of heat that absorbed and reflected by the coating featured significant criteria for deficiency of collector. Abu-Arabi *et al.* (2020) had developed a mathematical model for conventional solar still coupled with a flat plate solar collector integrated with PCM using Engineering Equation Solver (EES). Three technical criterias are simulated and evaluated to predict the performance of the proposed system such as wind velocity, solar irradiation and ambient temperature. As solar irradiation increased, the productivity of the system improved about 2.4 times according to the local weather data when integrated with the PCM. Nevertheless, efficiency and productivity of the system did not have any significant impact against the wind velocity and ambient temperature.

Table 1. Summary of PSE utilisation in solar-based energy technology

Modelling software	Material used in studies	References
ANSYS-Fluent	Composite PCMs: CA/62: the combination of capric acid (CA) and #62 paraffin, 48/62: the combination of #48 paraffin and #62 paraffin	(Wu *et al.*, 2020)
ANSYS-Fluent software	SC-PV-PCM: Specialised Solar Chimney with PV and insulated PCM PV cell material: EVA layers, PV cell and Tedlar layer	(Salari e*t al.*, 2020)
ANSYS-Fluent	PCM: Tritriacontane paraffin (C33H68)	(Pawar & Sobhansarbandi, 2020)
ANSYS-Fluent	PCM: Paraffin wax	(Raj *et al.*, 2020)
Matlab/ Artificial Neural Network (ANN)	Insulating Materials: Polyurethane foam, fibre glass, foam glass, calcium silicate	(Kulkarni *et al.*, 2021)
Matlab-Simulink	Slurry PCM as the heat transfer fluid: Fluid is based on the use of the latent heat of fusion/solidification of suspended particles, which alter their aggregation state at the micron scale while maintaining the fluid's liquid state at the macroscopic scale. Kolektor 2.2 software/ Simulink, Matlab	(Serale *et al.*, 2016)
Kolektor 2.2 software/ Simulink, Matlab	Absorber material for solar collector: copper	(Szabó *et al.*, 2018)

B. Control of Solar-based Energy Technology

Kicsiny compared the control performance of actual solar water heating system using proportional (P) and on/off control systems via Simulink Matlab (Kicsiny, 2017). It was observed that the P controller was able to precisely reach the set-point changed for water outlet temperature compared to on/off control system. Similarly, the control analysis of solar water heating system integrated with thermally stratified storage tank was conducted using on/off control system (Araújo & Silva, 2020). The on-off scheme was employed to control the fluid flow and outlet water temperature using a fast computation algorithm developed in Bezanson *et al.* (2017). An auxiliary heater was used as a manipulated variable to control both output variables. The drawback of this conventional control system (on/off) is the operator needs to continuously monitor the system, which may not be feasible for commercial application. An improved work was conducted by Willy *et al.*, where they designed and compared three different flow control configurations to evaluate the performance of solar heating coupled with seasonal thermal energy storage in CFD software (Villasmil *et al.*, 2021) such as high-flow controller (HFC), low-flow controller (LFC) and variable-flow controller (VFC). In their work, an outlet water temperature was selected as the control objective subjected to the minimum storage volume capacity (to attain 100% of annual solar fraction). The simulation result revealed that LFC was able to minimise the storage volume compared to other control strategies. Subsequently, it was evident that the capability of the control system was to preserve stratification.

A model-based optimal control strategy of ground source heat pump system with integrated solar photovoltaic thermal collectors (GSHP-PVT) was conducted in TRNSYS (Xia *et al.*, 2018). Two different control strategies depicted by an advanced control strategy (simplified adaptive models and a genetic algorithm (GA) and conventional control system were evaluated and compared subjected to the set point of supply water temperature during cooling, heating, and transition test periods. It was observed that the proposed advanced control strategy was able to mimic the supply water temperature's set point concurrently reducing the electricity consumption without creating a surplus for the GSHP-PVT system cost. Hansani *et al.* used similar system as (Xia *et al.*, 2018), which is ground source heat pump integrated with solar collector system (GSHP-SC) in CPLEX computational software (Weeratunge *et al.*, 2018). A model predictive control (MPC) algorithm was employed in their study to reduce the operating cost while enhancing the system's efficiency by controlling the intermittent operation of heat source. Based on the simulation result, installing the MPC in the GSHP-SC system resulted in a reduction of operating cost while flexibly stabilised the heat supply of the system.

A control strategy of hybrid CO_2 heat pump with PVT system was evaluated in the Matlab simulation environment (Rullof *et al.*, 2018). The developed control strategy is based on the adaptation of the evaporation temperature by a power-controlled compressor. Their study suggested that the capability of control systems can only be validated based on the real operating behaviour instead of simulation basis.

III. APPLICATION OF PSE IN THE BIOMASS RENEWABLE TECHNOLOGY

A. Modelling of Biomass-based Energy Technology

Simulation software package provides a better understanding for the physical and chemical mechanisms of the biomass gasification process via thermodynamic equilibrium and kinetic models, artificial neural network (ANN) and computational fluid dynamics (CFD). Figure 2 depicts a typical process for biomass gasification simulation using PSE tools.

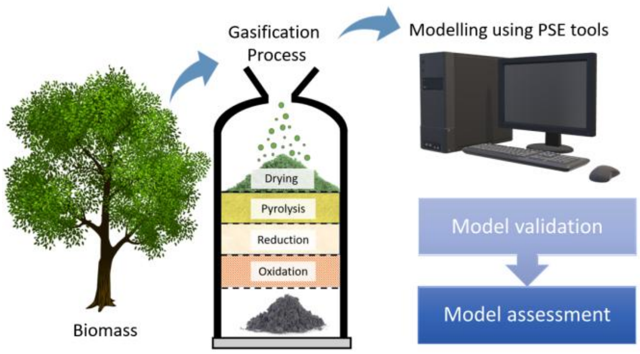

Figure 2. Simulation of the biomass gasification process using PSE tools

Akhator and Asibor (2021) developed a thermodynamic equilibrium model in Aspen Plus software to predict the syngas composition for air-gasification of wood wastes in fixed-bed downdraft gasifier (Akhator & Asibor, 2021). This developed model was built based on the minimisation of Gibbs free energy and the model was validated with both literature and experimental data. Based on the study, CO content was observed to rise with the increase in temperature until the temperature reached 1050 °C while consequently, both CO_2 and CH_4 concentrations were decreased with increase in temperature. As for N_2, it decreased with the temperature incremental until 900°C and then maintained a constant level until it reached 1050°C.

Lan *et al.* (2018) deployed a thermodynamic equilibrium model of biomass gasification-gas turbine combustion for power generation system by using Aspen Plus software with an additional external FORTRAN subunit (Lan *et al.*, 2018). The model was able to satisfactorily predict the significant operational parameters such as gasifier temperature, equivalence ratio (ER) and presence of a catalyst towards the syngas composition and heating value. Forecasted power generation was identified to have minimum deviation with actual data thus provided evidence on the robustness of the developed model. Vakalis *et al.* (2016) also performed a study by utilising wood as the biomass feedstock to observe the effect of ER towards the composition of CO, CO_2 and H_2 by increasing the value of ER from 0.20 to 0.30 (Vakalis *et al.*, 2016). Their study involved the use of thermodynamic equilibrium model approach, which was developed in the Matlab software. It was observed that the composition of CO, H_2 and CO_2 showed the same trend based on the study done by (Akhator & Asibor, 2021) where the value of CO and H_2 decreased with the increase in value of ER while it was the opposite for CO_2.

A study in terms of the moisture content toward the composition of syngas and low heating value (LHV) from Mendiburu *et al.* (2014) has proven that an increase of moisture content from 0% to 20% will lead to an increase in the concentration of CO_2 and H_2 (Mendiburu *et al.*, 2014). However, as for the composition of CO, it tends to undergo a certain reduction towards the increase of moisture content. Nevertheless, the study done by Wu *et al.* (2015) showed that the optimal moisture content of wood is supposed to be less than 20% as any moisture content higher than 20% will lead to the decrease in the composition of H_2 and CO content. On the other hand, several researchers predicted syngas composition/yield as a function of gasification temperature, ER and steam to biomass ratio (SBR) based on different types of gasification reactors using Aspen Plus simulation software (Hussain *et al.*, 2016; Kaushal & Tyagi, 2017; Acevedo-Páez *et al.*, 2020). It was observed that the aforementioned studies featured a similar trend (under different reactors), where production of H_2 is proportional to the temperature elevation. This is because at the higher temperature, increased reaction of char-steam subsequently increases the H_2 production. Contradictory trends exhibited for CO proved when the production of CO was reduced with the increment of gasification temperature. SBR also played a significant role in the H_2 production, where H_2 yield improved with the increase in SBR ratio. This is because at high SBR ratio, the amount of tar was reduced, which contributed to the enhance syngas quality. To address the importance of tar generation towards H_2 production, Kaushal and Tyagi have employed cracking kinetics model to represent the tar formation, which was able to enhance the significant reliability of the developed model (Kaushal & Tyagi, 2017).

A comprehensive analysis has been conducted by Yu *et al.* on the effects of ER, gasification temperature, biomass moisture content and biomass composition on syngas and tar compositions using a kinetic model in Aspen Plus software (Smith *et al.*, 2019). It was observed that the temperature, CO and H_2 concentrations were increased along with the temperature increment. This is due to the water-gas shift reaction, which favoured the forward reaction, and thus CO shift reaction tends to move backward producing more CO. However, the results showed a slight difference from the study conducted by Beheshti *et al.* (2015) where CO showed an increasing trend with ER and then decreased after ER reached its peak value because the CO will then be burnt to produce CO_2.

Artificial neural network (ANN) models are found to be extremely useful with its ability to relate all of the inputs and outputs of a system where all the processes involved are computed through a series of learning and training hence the model itself is able to reduce the loss function to its minimum (Malekian & Chitsaz, 2021). Safarian *et al.* (2020) conducted a study on the ANN biomass gasification of downdraft biomass gasification power production plant (Safarian *et al.*, 2020).

Based on the findings, the relationship between the carbon content and moisture content with the amount of power generated were illustrated in such a way that the increase in carbon content along with the reduction in moisture content of the biomass will facilitate the rate of power generation for the gasification system, thus a higher amount of power will be generated. Mikulandrić *et al.* (2014) performed a study on the process parameter for a biomass gasification process in a fixed bed gasifier by using ANN modelling approach (Mikulandrić *et al.*, 2014). A recent study performed by Serrano and Castelló (2020) had proposed an ANN model to predict the tar generation, composition of the product gas as well as the gas yield of biomass gasification in a bubbling fluidised bed, respectively (Serrano & Castelló, 2020). In terms of tar generation, several tar samples were obtained and analysed from different sampling methods, while the ANN model had successfully predicted the results accurately, which agree well with the literature data. In addition, the total generation of tar is highly dependent on the temperature and ER where a maximum tar generation was observed at the lowest temperature with the lowest ER. Whereas the prediction of gas composition and yield were made under different operating conditions and similar findings was observed, while the ANN model was able to predict the composition of CO_2, CO, CH_4, H_2 as well as the gas yield with high accuracy achieved.

Sezer *et al.* (2022) developed an ANN model to represent the thermodynamic based gasification and solid oxide fuel cells (SOFC) systems) (Sezer *et al.*, 2022). Based on the findings, the ANN model successfully predicted the electrical efficiency, net voltage and current density under the varying operating conditions along with 30 different biomass types as its input parameters, which then indicated that the ANN model has the ability to predict the output with high accuracy. Arumugasamy *et al.* (2020) conducted a study on the gasification behaviour of palm fibre biochar, employed an Artificial Neural Network (ANN) model in conjunction with 11 different algorithms. Their research aimed to predict weight loss, char reactivity, and carbon conversion of the palm fibre biochar during the gasification process

(Arumugasamy *et al.*, 2020). In a similar vein, Shahbaz *et al.* (2019) utilised ANN to analyse the steam gasification of palm kernel shell (PKS), incorporating CaO as an adsorbent and coal bottom ash as a catalyst (Shahbaz *et al.*, 2019). Their findings revealed that the composition of H_2 increases as the temperature rises from 650°C to 750°C, attributed to water gas shift and steam reforming reactions. Conversely, the CO content decreases with this temperature increase. However, only a small variation and amount was observed in terms of the CO_2 production as it was believed to be captured by CaO in the carbonation reaction. According to the aforementioned studies, most of the work utilised the Matlab software as the computation platform for the development of the ANN model.

B. Control of Biomass-based Energy Technology

The major problem of biomass gasification is its bulkiness and inconvenient form of biomass. Most of the biomass have low energy density in comparison to fossil fuel. The low energy density of PKS is 18 MJ/kg, while natural gas has an energy density of 55 MJ/kg (Ahmad *et al.*, 2019). Moreover, biomass gasification is a complex chemical process that involves gas-solid two-phase flow, heat and mass transfer, pyrolysis of biomass material, cracking and subsequent steam reforming of tar vapour arising from the pyrolysis, heterogeneous gas-solid reactions and homogeneous gas-phase reactions. The amount and heating value of the product gas are dependent on many variables, including raw material, gasifying agents, operating variables, design of gasifier, and catalysts. Generated syngas can be directly utilised for power generation in power pallet. Standard industrial control algorithms such as proportional–integral–derivative controller, PID controllers can normally provide satisfying steady-state results but can also lack performance during transition. Additionally, their implementation becomes more complex as gasifier is a multivariable system with a multi-loop. Specific requirements for reaction temperature, gas calorific value and coal gas quality exist during the gasification process, which limits the control actions in the control process. Therefore, more advanced model-based control strategies are being implemented for the domestic and industrial combustion of biomass (Böhler *et al.*, 2020).

Huang and Shen *et al.* (2019) studied the dynamic simulation of the gasifier using Matlab to find the optimal composition of coal, water, and air by following the Taguchi method (Huang & Shen, 2019). The MANFIS–PSO–PID controller was used to maximise the output of syngas from the gasifier by controlling the amount of added water to improve the coal quality. Seepersad *et al.* (2015) carried out a study on the PI controller of steam methane reformer tubes in a gasifier radiant syngas cooler (Seepersad *et al.*, 2015). In their study, both counter-current and co-current flow configurations were compared to obtain the performance objectives. As a result, changing the tube flow rate and the steam-to-carbon ratio affects the tube gas exit temperature and CH_4 slip. To decrease the error and settling time, the counter-current configurations of the control system also seem to be a lot better than the co-current configurations. Pirouti *et al.* (2010) studied a dynamic model for biomass and developed a control strategy of CHP by direct combustion in Simulink Matlab (Pirouti *et al.*, 2010). The study was done to control the pressure of the throttle and the optimal point of the output biomass CHP unit. It was also studied to improve the process control by rejecting the disturbance in the system. The disturbances mentioned are the moisture content of biomass and their composition. The biomass CHP unit shows a slower dynamic reaction than the natural gas and coal. When comparing PI controller boiler follow control and boiler-turbine coordinated control for controlling biomass CHP output power, coordinated control responds faster and more effectively. This approach also enhances the process of identifying and rejecting disturbances. Alves Ribeiro and Meza carried out a study on the multi-objective optimisation design (MOOD) of PID controllers to control the output of the industrial gasifier with various types of load, pressure, and quality (Alves Ribeiro & Reynoso-Meza, 2018). Five inputs and four outputs have been applied in the application that turned it into a MIMO system, while the disturbance was introduced into the system. Unfortunately, the results showed that the MOOD procedure cannot be used because the controller cannot control the disturbance and load changes. Hence, there's was an error in the outputs presented.

Li *et al.* (2018) presented a MPC for biomass/coal co-gasification (Li *et al.*, 2018). This system's inputs are the coal flow rate, O_2 flow rate, and water flow rate, while its outputs are the syngas production rate and H_2/CO ratio. The objective is to control the system of co-gasification to the maximum extent possible within the operating region. The disturbance was applied in the system, which is the biomass flow rate. The results showed that the MPC is able to stabilise the output of the system with all the set-point met. Elmaz and Yücel (2020) carried out a study on the downdraft gasifier to improve the production of energy by using an MPC system (Elmaz & Yücel, 2020). They have developed a time-dependent identification model to predict the outcomes of biomass gasification using non-linear autoregressive with exogenous neural networks (NARXNN). It is used to predict the output of gas compositions and high heating value (HHV) by changing the ER variable. The result showed that the MPC was able to achieve and stabilise the HHV at the desired value. Due to its high consistency with the experiment data and effectiveness as a controller, the MPC strategy for real-time control of the biomass gasification process has achieved a good result.

Böhler *et al.* (2020) compared a MPC controller, a fuzzy model predictive controller, and a PI controller for a wooden pellet gasification on the gasification combustion furnace (Böhler *et al.*, 2020). They found out that the fuel mass flowrate of wet biomass, the primary air from below the grate, and additional air inlet were in charge of controlling the CO formation, emissions at the furnace supply water temperature, the input of flue gas oxygen concentration, and freeboard temperature. When compared to the PI controller, fuzzy model predictive control (FMPC) and linear model predictive control (LMPC), it achieved nearly two times higher stationary performance for the root mean square error. Gong investigated the use of fuzzy neural network control on a biomass gasifier (Gong, 2014), while the process of the gasifier with intelligent control was also researched. The control objectives for this study include the temperature of the gasifier and flue gas oxygen content with the change of material feed flowrate and primary air flow. From the study, it showed that the fuzzy neural network control was more effective than the normal fuzzy control in eliminating the overshoot. When the disturbance was introduced into the system, it did not affect the fuzzy neural network control compared to the normal fuzzy control due to the characteristics of the fuzzy neural network control itself, which had strong anti-interference performance where the system will keep the temperature of the gasifier and flue gas oxygen content at their setpoints. Thus, the fuzzy neural network control has better control effect than the traditional fuzzy control system. Jurado *et al.* (2003) developed a neuro-fuzzy controller for the biomass-based electric power plant to study the operating conditions of the system (Jurado *et al.*, 2003). The controllers were developed based on speed and mechanical power variations. There are two inputs and one output was included in the controller. The mechanical power, which is active power load, reactive power load, and mechanical torque in an asynchronous motor produced by the turbine, and the speed of rotation, which is connected to electrical frequency, are inputs to the controller. The fuel flow is the output from the controller that is fed into the gas turbine model. In comparison to fixed parameter fuzzy controllers and PID controllers, optimum system performance can be obtained by using neuro-fuzzy controllers where the fuzzy controllers are assisted by a neural network under a wide variety of operating conditions.

IV. CONCLUSION

Carbon-based fuels have a negative impact on the environment and contribute to the climate change. As a result, a lot of CO_2 gas is being emitted, especially by the electrical sector. Utilisation of biomass waste to generate power will help to reduce the dependencies of power generation on fossil fuels. This process will help to reduce the use of non-renewable energy and also overcome the problem of the accumulation of waste in landfills. In addition, solar energy is perceived to carry a lot of potentials to be harvested and manipulated as a source of renewable energy due to its abundance in nature. This leads to the development of various studies on traditional solar collector, PV module and PVT systems. Nevertheless, extensive studies related to the commercialisation of these solar-biomass RE technology are demanded due to the limited real data to understand the behaviour and performance of this clean energy. Deeper understanding is needed to study the material existing in solar and biomass-based energy technology. Also, PSE appears to be a significant tool to assist in comprehending the complexity and dynamics of solar and biomass RE technology without the required experimentation in the actual plant. Thus, this preliminary review is expected to provide insight on the contemporary application of multiscale PSE tools, especially towards the exploitation of solar and biomass for modern renewable energy generation.

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