Alternatives Control Strategies for Building Integrated Photovoltaic/Thermal (BIPVT) System

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Abstract: The use of energy in buildings is an ongoing concern, not only in NZ but worldwide. This concern has led to significant growth in the use of solar energy to provide heating and electricity generation. This paper presents the theoretical and experimental results of a novel building integrated solar hot water system; developed using commercial, long run roofing materials. This work shows that it is possible to achieve effective integration that maintains the aesthetics of the building. Building integrated thermal (BIT) system parameters are identified and implemented in the TRansient SYstem Simulation (TRNSYS) modeling environment. Validation result comparing the simulation in TRNSYS and real experimentation show that experimental and simulation responses are close to each other. The coupling of TRNSYS and Matlab/Simulink shows the possibility to use Matlab/Simulink for developing appropriate control strategies for BIT roofing systems. Furthermore in this paper, a Fuzzy Logic (FL) controller is implemented in a Fuzzy Integrated System (FIS) toolbox in a Matlab/Simulink model and linked into TRNSYS building integrated photovoltaic/thermal (BIPVT) system model. Preliminary simulation results are presented, which showed that the FL control strategies improved the energy performance of the BIPVT system and could be an effective way controlling building integrated solar energy systems.

Keywords: BISES, BIT, BIPVT, control strategies, TRNSYS, Matlab/Simulink

1. Introduction

The use of energy in buildings is an ongoing concern, not on in NZ but worldwide. This concern has led to significant growth in the use of solar energy to provide heating and electricity generation. In 2006, an investment of $15.5 million was announced for the first three-and-a-half years of a five-year program to increase the use of solar water heating in New Zealand (Ministry for the Environment, 2007). During that year approximately 35,000 solar water heating systems were installed in New Zealand buildings (Ministry for the Environment, 2007). Although this shows that the future of solar heating in New Zealand is attractive it is still inhibited by high initial costs.

To address the issue of cost, the Solar Engineering Research Group (SERG) at University of Waikato is undertaking research into Building Integrated Solar Energy Systems (BISES): Building Integrated Photovoltaic (BIPV), Building Integrated Solar Thermal (BIT) and Building Integrated Photovoltaic/Thermal (BIPVT) collectors. The developments made to date could result in an up to 50% reduction in the cost of collectors for water heating and lead to a series of high value export products. Since BIPVT is an area that has received only limited attention, therefore the research will be focus on BIPVT.

However, to further strengthen the advantage of this system SERG has identified a strategic opportunity through the development of high level intelligent control systems. Efficient control strategies are essential for the effective operation of BIPVT, and must be considered a fundamental part of the design.

2. Building Integrated Photovoltaic Thermal System

A previous theoretical study and testing of BIPVT collector (Anderson et al., 2009) had been undertaken by the Solar Engineering Research Group at the University of Waikato. BIPVT is a combined system that generates both electricity and hot water.

BIPVT collector was modelled using the TRNSYS PV/thermal collector model (Type 50) available in the

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standard TRNSYS library (see Figure 1). This model is based on modifications to the Hottel-Whillier-Bliss equations that are used for the standard (Type 1) Flat Plate Solar Collector (Florschuetz, 1979). It simulates a combined collector and incorporates both the analysis and work of Florschuetz for flat plate collectors operated at peak power.

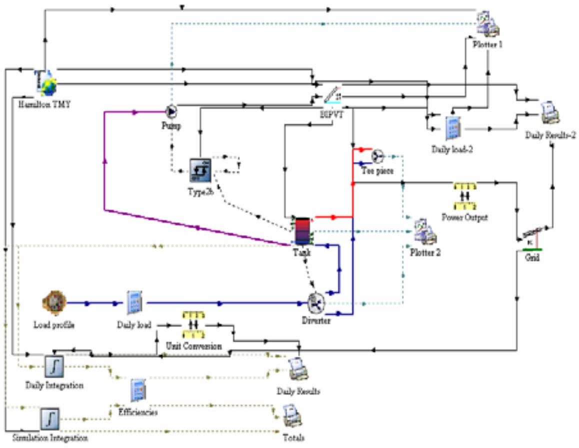

Figure 1: TRNSYS model of BIPVT system (Anderson, 2009)

The historical weather data for Hamilton downloaded from CliFlo. The weather data from the Cliflo was read using the user defined weather function (Type 109). This component serves the main purpose of reading weather data at regular time intervals from a data file, converting it to desired system of units and generating direct and diffuse radiation outputs for an arbitrary number of surfaces with arbitrary orientation and inclination.

The thermal efficiency (η) can be determined directly from the experimental results based on the Hottel-Whillier equation [10]. It is defined simply as the ratio of heat transfer in the collector Eq.1 to the product of the collector area and the global solar irradiance, as shown in Eq. 2.

$$\dot{Q} = \dot{m} C_p \Delta T \qquad \text{(Eq.1)}$$

$$\eta = \frac{\dot{Q}}{A_{collector} G''} \qquad \text{(Eq. 2)}$$

From the experimental data, the efficiency of a solar collector for all conditions can be represented by a linear equation of the form shown in Eq. 3.

$$\eta = \eta_{0A} - a_1 \left(\frac{T_i - T_a}{G''} \right) \qquad (3)$$

Where:

G'' = solar irradiance (W/m^2)

$\dot{m}$ = mass flow rate (kg/s)

C_p = specific heat of the collector cooling medium (J/kg/^{o}C)

ΔT = differences between fluid out temperature, T_o and inlet temperature T_i

$A_{collector}$ = collector area (m^2)

T_i = inlet temperature (^{o}C)

T_a = ambient temperature (^{o}C)

η_{OA} = collector optical efficiency

From the previous experimental data, it was possible to derive the performance of the collectors using a linear least squares regression analysis (Anderson et al., 2009). The data shown in the tables yields two equations that describe the glazed and unglazed collector efficiencies, as shown in Eq. 4 and Eq.5 respectively.

$$\eta = 0.6 - 5.55 \frac{T_i - T_a}{G''} \qquad \text{(Eq.4)}$$

$$\eta = 0.36 - 9.22 \frac{T_i - T_a}{G''} \qquad \text{(Eq.5)}$$

Further, in Anderson (2009) thesis, he suggested to examine control strategies and predictive controllers for energy management from BIPVT system.

2.1 Comparison Between The Best and Worst Scenarios for Glazed BIPVT

It is important to demonstrate with two extreme scenarios to get the best and worst case PV performance of the BIPVT system. There are 2 case scenarios, where the best scenario is system operation with 20^{o}C cold water always flows through the glazed collector and the worst case scenario, where the event of a pump failure of a BIPVT system with stagnating condition. Experimental data for both glazed and unglazed BIPVT from the previous study (Anderson, 2009), were tested for the best and the worst case scenarios. The parameters of the glazed BIPVT collector were identified (see Table 1) and implemented in TRNSYS model.

Table 1: BIPVT System Parameters

Parameters (Type50)	Value
Collector Area	$10m^2$
Collector Fin Efficiency Factor	0.6
Fluid Thermal Capacitance	4.19 kJ/kg.K
Collector plate absorptance	0.875
Collector loss coefficient	5.55 $W/m^2.K$
Cover transmittance	0.89
Temperature coefficient of solar cell efficiency	0.005
Reference temperature for cell	25 C
Packing factor	0.59
Cell efficiency	17.6%

Figure 2 and Figure 3 shows the comparison between the best and the worst scenarios for the glazed collector. In Figure 2, it shows the PV cell temperature for both the best and the worst case scenarios. It is shows that when where the event of a pump failure on a BIPVT system with stagnating condition, the PV cell temperature would exceed 160°C. This is excess of the melting temperature of many common EVA encapsulans. In Figure 3, it is shows how the temperature affect the PV power output generated from the glazed collector for 24 hours period for both case scenarios. From the graph, PV power output for the worst case scenario significantly decreased when PV cell temperature collector gets very hot.

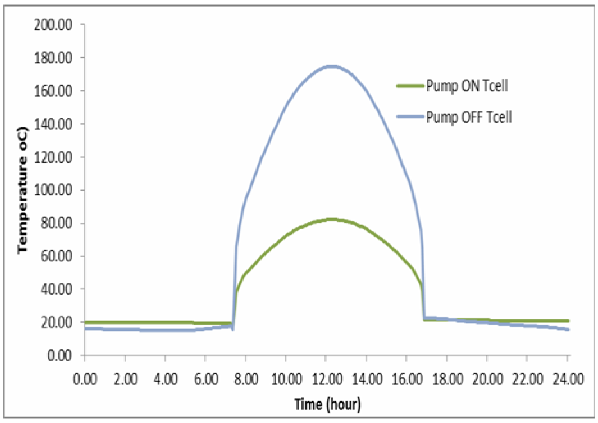

Figure 2: PV Cell temperature for the Glazed System (Pump On and Pump Off)

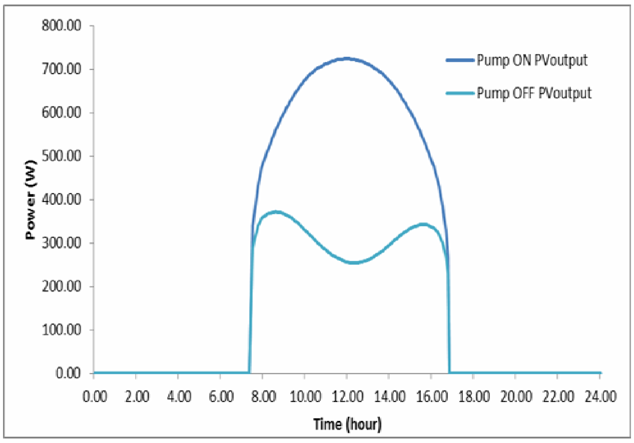

Figure 3: Power output from Glazed System (Pump On and Pump Off)

Furthermore, it is also interesting to see PV energy generated from the BIPVT system. Figure 4 shows the comparison of maximum PV energy generated from the BIPVT system in TRNSYS model. It can be seen that the unglazed system generated 6.3kWh compare to glazed system 5.8kWh. The reason for the difference in the electrical efficiency for the glazed and unglazed collector is due to an increase in the temperature of the PV cells when a glazing layer was added to the BIPVT system.

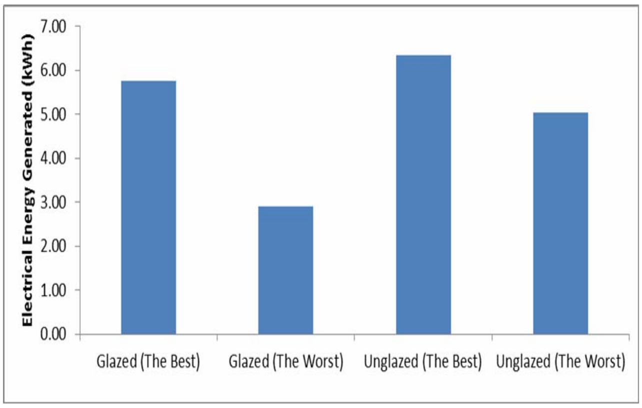

Figure 4: Electrical Energy Generated from BIPVT system

Based on the result from the best and worst scenarios, it is shown that control strategies are important to improve the performance of the BIPVT system.

2.2 Alternatives Control Strategies for Improving BIPVT System Performance

Efficient control strategies are essential for the effective operation of a solar energy system, and must be considered a fundamental part of the design (Candanedo et al., 2007).

In this research, the control strategies were designed and simulated in Matlab/Simulink environment, while the performances of the solar energy system were calculated with a TRNSYS simulation model. The coupling of Matlab and TRNSYS leads to a powerful tool that enables the user to combine the advantages of each program: the modern modeling and solving techniques of Matlab as well as existing and proven, well-validated models and utility routines of TRNSYS.

The coupling of simulation programs TRNSYS with MATLAB/Simulink is to gain profit by the advantages of both programs. The BIPVT system model in TRNSYS and Simulink, on the other hand, is suited for modelling control strategies due to programming with block diagrams. The coupling between TRNSYS type 155 component and Matlab/Simulink can be illustrated as shown in Figure 5.

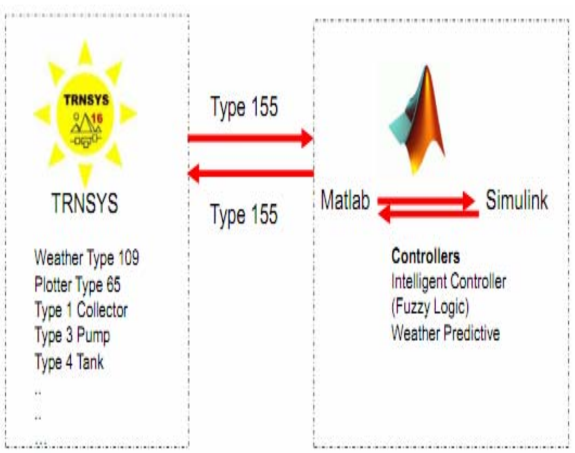

Figure 5: Coupling TRNSYS- Matlab/Simulink

BIPVT collector integrated to the solar hot water (SHW) system. The BIPVT system inputs, variables and parameters of each component (pump, tank, solar radiation data, collector, etc.) were defined, from the experimental data, in the TRNSYS model to perform the simulation. The overall of the schematic diagram of control strategies for BIPVT system is as shown in Figure 6.

In the first instance, a controller for smart appliances was designed using Fuzzy Interface System tool in Simulink environment. The water-use profile (in TRNSYS Type 14) of the system was shown in Figure 7 and is typical of the use in an Australian or New Zealand residence (AS 4234:1994). The hot-water consumption is approximately 360 litres/day for family of 4.

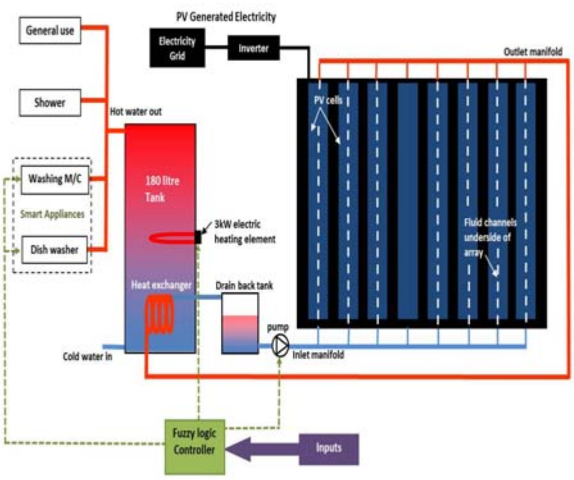

Figure 6: Schematic diagram of control strategies for BIPVT system

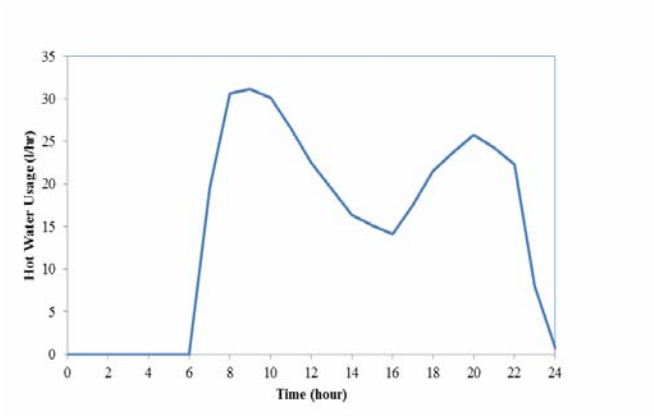

Figure 7: Water Load Profile

National Institute of Water and Atmospheric Research (NIWA) historical weather data on a clear sunny day in summer (24th Jan 2009), with the maximum solar radiation of 1011 W/m2, and with the maximum of 27.9°C ambient temperature were used in Type109 TRNSYS component as weather input in TRNSYS as shown in the graph in Figure 8.

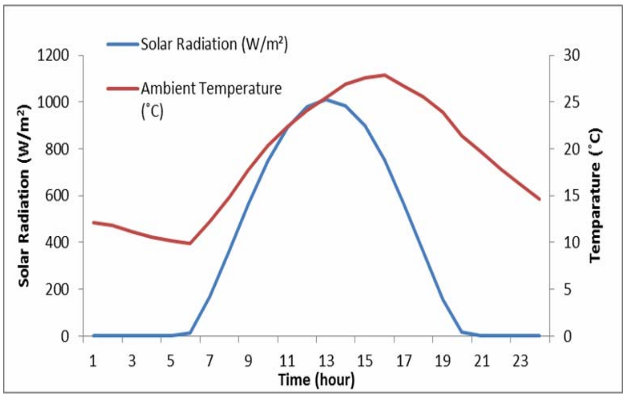

Figure 8: Weather data from NIWA

From the simulation results in Figure 9, it is shows the response of the FLC. When the tank temperature reached the temperature of 65°C, then the controller will be switched ON the smart appliances.

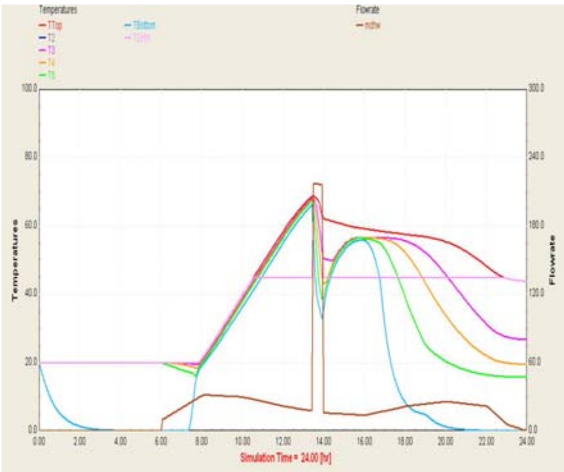

Figure 9: TRNSYS-Simulink Simulation Results

Figure 10, shows the preliminary results in the comparison of useful energy from BIPVT system with standard temperature different controller (Type2b) and FLC.

FLC shows a better thermal energy use compared to the standard controller (Type2b) because it heats the smart appliances (washing machine and dishwasher) plus the load profile whereas the standard controller (Type2b) only provides useful thermal energy for the load profile.

Results show the total of useful energy (thermal and PV) from BIPVT system with FLC is 21.43kWh compare to standard controller (type2b) 15.80kWh is meant improved by 35.58%.

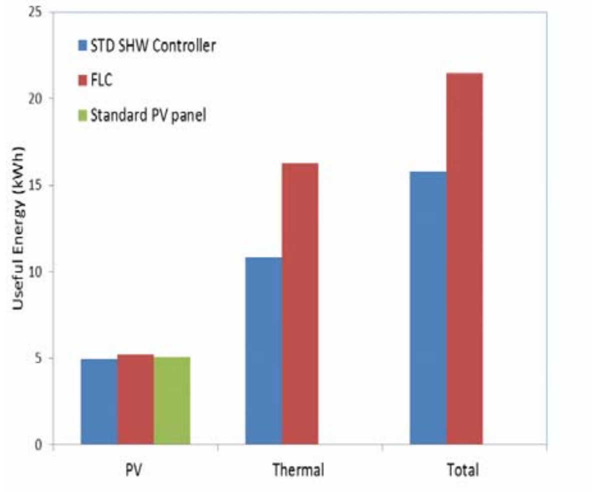

Figure 10: Useful Energy from BIPVT System

3. Conclusions

The PV cell polycrystalline (Type94) in TRNSYS is used in simulation testing to demonstrate actual PV cell and then can predict the performance of the PV cell. From the best and worst case scenarios, it is shown that control strategies are important to control the BIPVT system.

It is shows the possibility to deploy FIS toolbox in Matlab/Simulink by using Type155 for control strategies to improve the performance of the BIPVT system.

Further work is needed to identify and design predictive control strategies for BIPVT system based on weather data forecast, is one approach that could be implemented in BIPVT system.

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