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A Technical Design and Economic Evaluation of DC Solar Air Conditioning

Nopporn Patcharaprakiti[1], Jeerawan Saelao[2]

[1,2]Department of Electrical, Faculty of Engineering, Rajamangala University of Technology LANNA, 99 Moo 10, Sraikao, Phan, Changrai, Thailand
[1]pnopporn@rmutl.ac.th

Abstract: *In this paper propose the design and evaluation of technical and economic of DC Variable flow refrigerant solar air conditioning. The first stage of design is cooling load calculation from size of the room, then 12000 Btu/h is selected. The operation hour of air condition for this room is 4-12 hours which consume power 1025 W and energy from 4100-12300 Wh. The solar energy generation for energize this load and average solar radiation daily 4.0 kWh/m^2/day or 4 Peak sun hour, then solar panels are selected. The battery energy storage are calculated for voltage stabilizing. The solar charger and rectifier circuit is used to charge battery from AC utility. The budgets of solar air condition are estimated and electricity bill are calculated per year. The financial and economic evaluation are calculated. The best case is the number of load operation hour 12 hours/day, the investment cost of system 125,250 Bath, Payback period 7 years, NPV 34323.17 Bath and IRR 14%. This result is useful to planning solar energy promotion in term of air conditioning load consumption to decrease overall peak demand.*

Keywords: *Solar Air conditioning, Brushless DC motor, Variable flow refrigerant*

1. INTRODUCTION

Solar Air condition is one of attractive technology to decrease peak demand and high consumption of air conditioning load depend on temperature by using solar energy which generate from solar radiation and temperature [1-2]. There are two category of solar cooling system for example solar thermal and solar electricity for cooling generation [3-5]. The latter is more convenient, no complex and appropriate to vapor compression air conditioning system which normally use in home, office and building [6-7]. Thus, air conditioning by using Photovoltaic System is studied which composed of two major technologies, firstly the high efficiency and low energy consumption air condition developing is proposed. Secondly, the solar energy from solar radiation and ambient temperature which has proportion relationship with the energy consumption is designed [8]. Then the DC Variable refrigerant flow of vapor compression air conditioner with solar electricity from photovoltaic system is proposed in this paper.

2. PRINCIPLE OF DC VAPOR COMPRESSION CYCLE AIR CONDITIONING

Air conditioning (often referred to as 'A/C' or 'AC') is the process of altering the properties of air (primarily temperature and humidity) to more comfortable conditions, typically with the aim of distributing the conditioned air to an occupied space such as a building or a vehicle to improve thermal comfort and indoor air quality. In common use, an air conditioner is a device that lowers the air temperature. In the most general sense, air conditioning can refer to any form of technology that modifies the condition of air (heating, cooling, (de-)humidification, cleaning, ventilation, or air movement). There are various type of air conditioner such as absorption, thermoelectric and vapor compression air condition [9]. In this article, DC Variable refrigerant flow of vapor compression air conditioner with solar electricity from photovoltaic system is proposed. The vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Figure 1 depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve and an evaporator. The Principle of vapor-compression air condition are shown in Fig.1

The compressors is the main equipment consume energy for vapor compression system, the typically use of compressor in air conditioner are reciprocating, rotary screw, centrifugal, and scroll compressors. Each application prefers one or another due to size, noise, efficiency and pressure issues [10]. Compressors are often described as being either open, hermetic, or semi-hermetic. There are basically 5 types of air conditioner compressor that are commonly used in the HVAC industry Reciprocating, Screw, Centrifugal, Rotary, Scroll. The rotary is appropriate for this speed control application because high efficiency than Reciprocating, Screw and centrifugal type. A refrigerant is a fluid that is used in air conditioners and refrigerators, to take

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heat from the contents of refrigerator or the room (in case of ACs) and throw the heat out in the atmosphere. A refrigerant undergoes phase changes from a liquid to gas (on absorbing heat) and back to liquid (when a compressor compresses it). The choice of ideal refrigerant is made based on: it’s favorable thermodynamic properties (P-H chart), non-corrosive nature and safety (non-toxic and non-flammable). HCFCs (hydrochlorofluorocarbon) are used in most of the air conditioners available in the market even today. But the HCFCs are just marginally better than CFCs (chlorofluorocarbon) as they still contain chlorine which is harmful for the environment. To remove chlorine from the refrigerant, manufacturers created another set of refrigerants called HFCs (or Hydro Fluro Carbons). The most common HFC used in air conditioners is R-410A which is use for this study. This refrigerant is not just better than R-22 in terms of “global warming” potential but is also more energy efficient [11]. The comparison qualification and pressure of both R-22 and R410a are shown in Table1 and Fig.2 respectively.

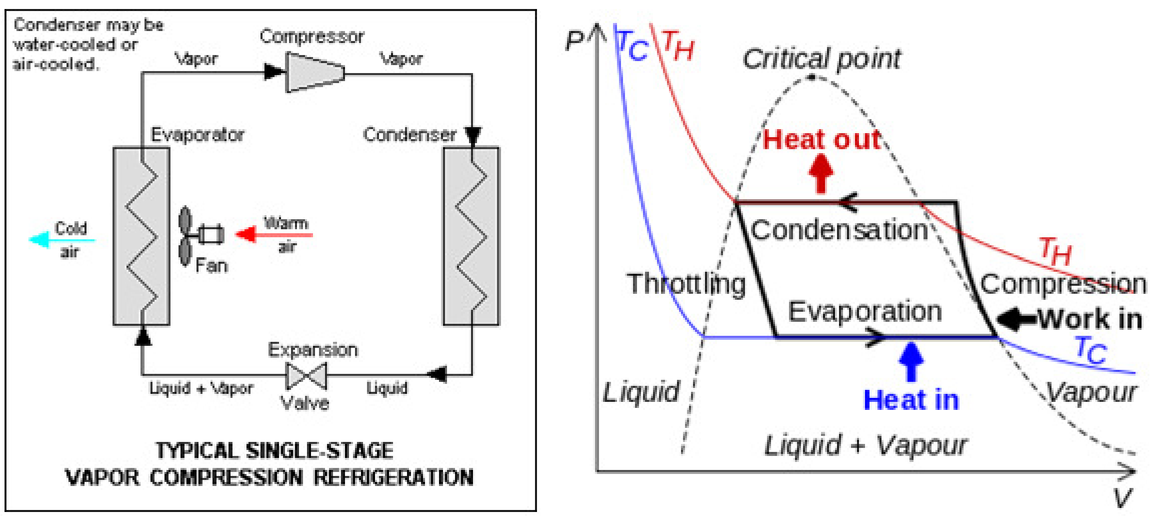

Fig. 1. Principle of vapor compression air conditioning system

TABLE 1: Comparison Refrigerant R22 and R410a

Qualification		
Type of refrigerant	R-22	R410a
Name of Refrigerant	Freon	Puron
composition	Mono refrigerant	Mix refrigerant R32:R125 = 50:50
Ozone depletion potential (ODP)	0.0055 (contribute to ozone depletion)	0 (not contribute to ozone depletion)
Global Warming Potential	1700	1370
Saturation Pressure	150	40
Boiling Point (C)	-40.8	-51.4
Leakage	No change in composition	Composition changes
Recharging	Liquid/Gas/Both (Liquid + Gas)	Must be charged in liquid state
Utilization	discontinued for use in new air conditioning systems	approved for use in new residential air conditioners
Chemical component	hydro-chlorofluorocarbon (HCFC)	hydro-fluorocarbon (HFC)

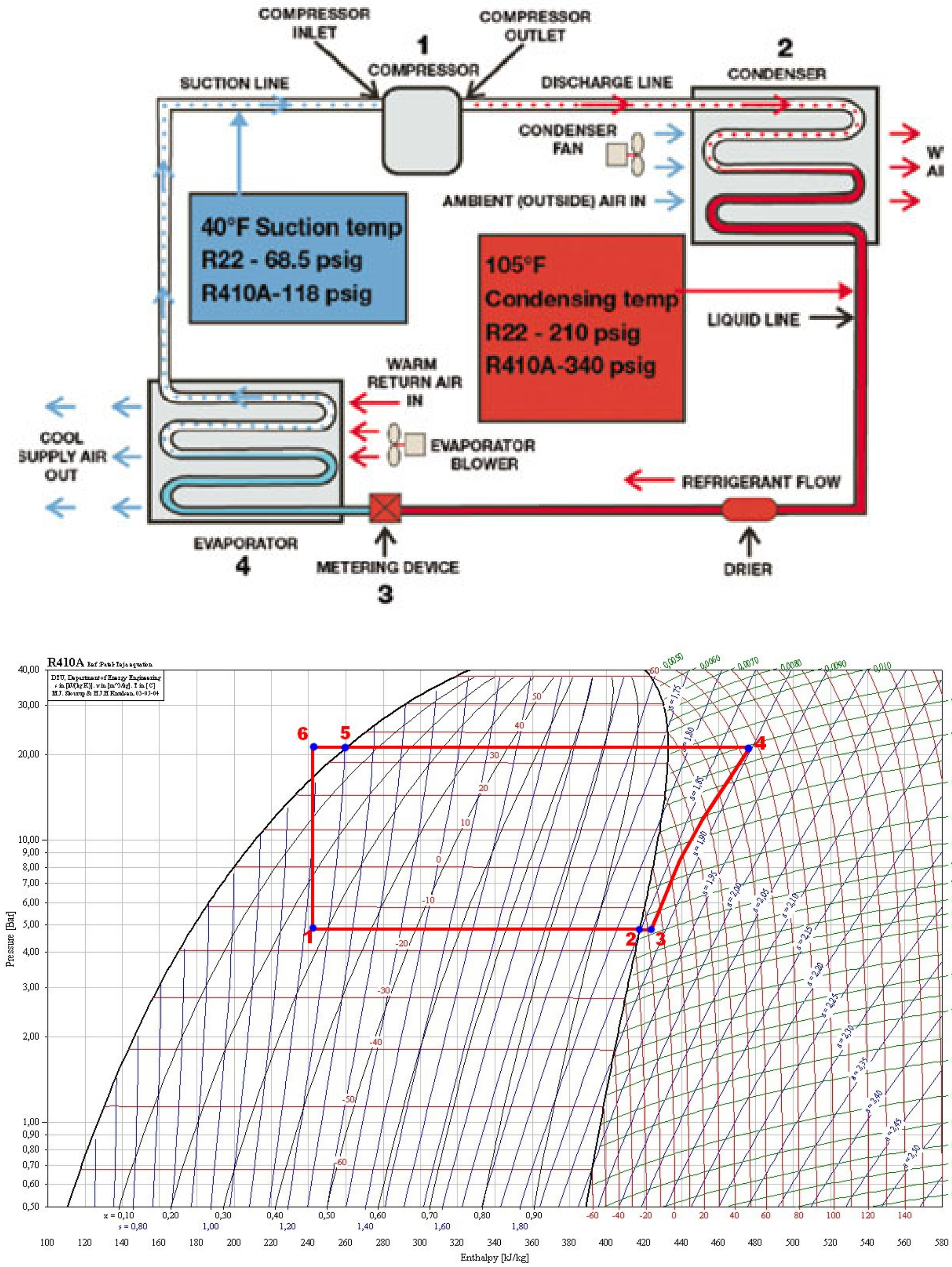

Fig. 2. Comparison Pressure for Refrigerant R-22 and R410A

2.1. VARIABLE REFRIGERANT FLOW (VRF) OF AIR CONDITION

VRF (Variable Refrigerant flow) is one the technique improve from Constant Refrigerant flow instead of is controlled by the thermostat to turn on and turn off compressor for temperature control. This method is used more power and energy for start motor compressor and make the fluctuation of room temperature. Presently, Variable refrigerant flow (VRF) is developed to control temperature by adjust the flow rate of refrigerant via compressor motor speed known as air conditioner inverter. This technique has Energy savings from 30-55% compare with the conventional type [12]. The BLDC motors is suitable for this application because of speed control capability, high efficiency and it can be use DC power from PV module directly. The efficiency of brushless DC motor versus the induction motor can be more than 5%. There are different name of BLDC (brushless direct current) motor follow as BPM (brushless permanent magnet) motor DC (direct current) inverter IPM (interior permanent magnet) motor SPM (surface permanent magnet) motor EC (electronic controlled) motor. The structure of BLDC and advantage comparison with conventional are shown in Fig.3

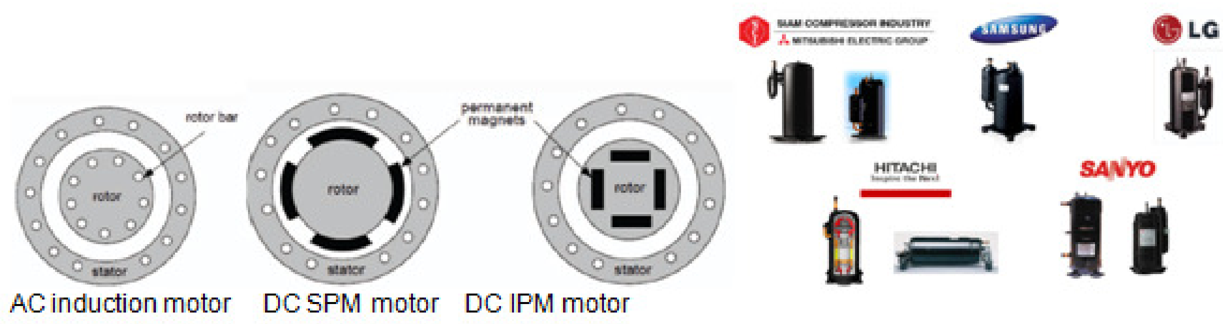

Fig. 3. Comparison Structure of motor for compressor

TABLE 2: Comparison table of BLDC, Brushed and AC motors

Feature	BLDC	Brushed	AC Induction
Maintenance	None	Periodic	None
Life	Longer	Shorter	Longer
Efficiency	High	Moderate	High/Moderate
Power Vs size	High	Moderate/Low	Moderate
Inertia	Low	High	High
Electric noise	Low	High	Low
Cost	High (coming Down)	moderate	Low
Control	Complex	Simple	Simple/Complex
Control requirement	Always requires	Optional	Optional

The speed and torque characteristics of brushless DC motors are very similar to a shunt wound "brushed" (field energised) DC motor with constant excitation. As with brushed motors the rotating magnets passing the stator poles create a back EMF in the stator windings. When the motor is fed with a three phase stepped waveform with positive and negative going pulses of 120 degrees duration, the back EMF or flux wave will be trapezoidal in shape. Brushless DC motors are not strictly DC motors. They use a pulsed DC fed to the stator field windings to create a rotating magnetic field and they operate at synchronous speed. Although they don't use mechanical commutators they do however need electronic commutation to provide the rotating field which adds somewhat to their complexity. The diagram below shows the system for controlling the voltage and speed with the associated current and voltage waveforms superimposed on the circuits [12].

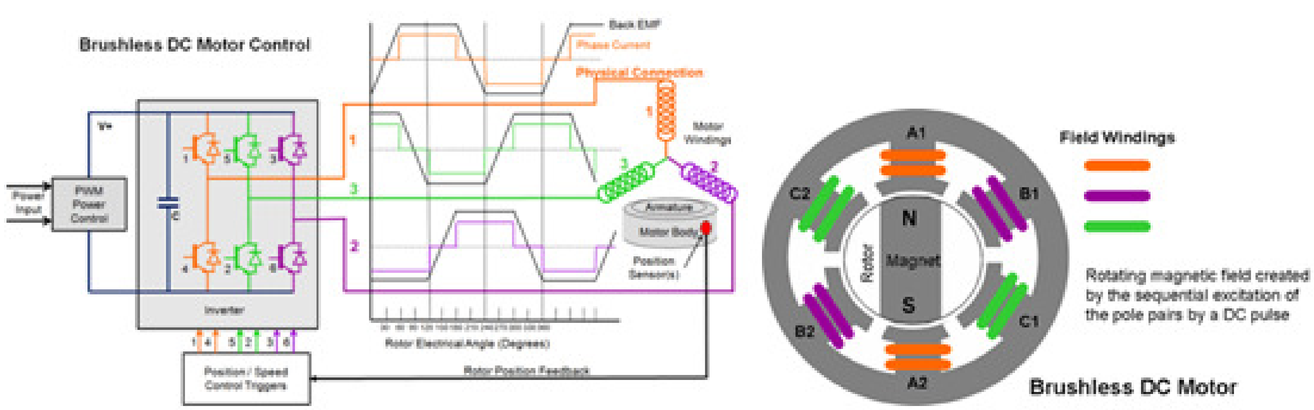

Fig. 4. Principle of BLDC motor speed control [12]

3. SOLAR AIR CONDITIONING DESIGN

The process of solar air conditioner design is follow to air condition diagram Fig.5 The area and size of air condition room is determined and then BTU/h of air condition are calculated or use look up table from Table 2. The second stage is type of air conditioner such as wall type, ceiling floor type, cassette type and so on. The third step is to choose technology of air condition for example non-inverter, inverter (VRF), type of compressor, type of refrigerant. Then choose the air condition brand and installation air condition following to the standard.

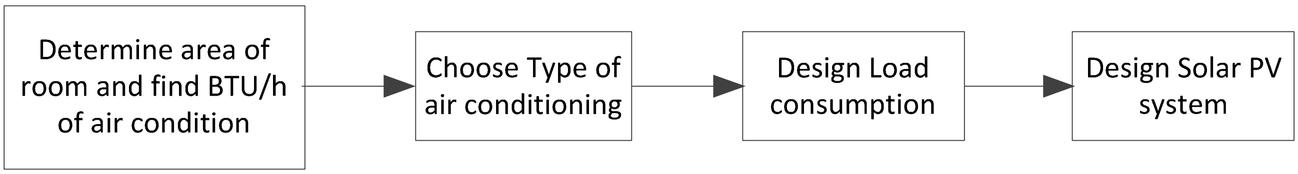

Fig. 5. Air condition design diagram

BTU/h = Room area x heat parameter = (width x length) x heat parameter (1)

= 4 m x 4 m x 750 = 12000 BTU/h

TABLE 3: Heat parameter of each room condition

No	Heat parameter	Type of room
1	700-800	Bedroom with no sunny
2	800-900	Living room with small sunny
3	900-1000	Working room with sunny
4	1000-1200	Restaurant / service room with many people

TABLE 4: specification of DC VRF air conditioner

Parameter	Rated	Parameter	Rated
Voltage DC	48 VDC	DC Power Input (Max)	22 A
Voltage DC range	46-58 VDC	Low Voltage Disconnect	46 V
Max cooling Capacity	13096 BTU	Operating Range (Cooling/Heating)	-6-50C/-12-32C
Max Power Input Cooling	960 W	Outdoor Noise Level	55 dB
Nominal Power Consumption Cooling	< 500 W	Outdoor Fan Motor	Panasonic BLDC
Cooling COP	5.45	Outdoor Fan Input	35 W
Cooling EER	18.61	Outdoor Air Flow	1295 CFM
Max Heating Capacity	13632 BTU/h	Outdoor Unit Dimension (W*D*H)	30"x11.2"x 23.2"
Max Power Input, Heating	1081	Compressor	BLDC Rotary
Nominal Power Consumption Heating	866	Refrigerant	R410A/56.5 oz.
Heating COP	3.69	Pre Charged for Line Set L	23 Ft.
HSPF	9.6	Max Lineset Length/Elevation	66 ft/26 ft.
Indoor Fan Motor	Panasonic BLDC	Moisture Removal	25 G/h
Indoor fan power	30 W DC	Digital Display	F or C
Indoor Fan RPM (Hi/Med/Lo)	1250/900/700	Refrigerant Oil	VG 74/17 oz.
Indoor Fan Flow (Hi/Med/Lo)	412/295/235 CFM	Design Pressure	550/340 PSIG
Indoor Noise level (Hi/Med/Lo)	39/29/26 dB	Liquid side/Gas side	1/4" / 1/2"
Indoor Unit Dimension (W*D*H)	36.3"x 8.6" x 11.5"	*Cooling COP&EER Rated at AHRI 210/240 EV	

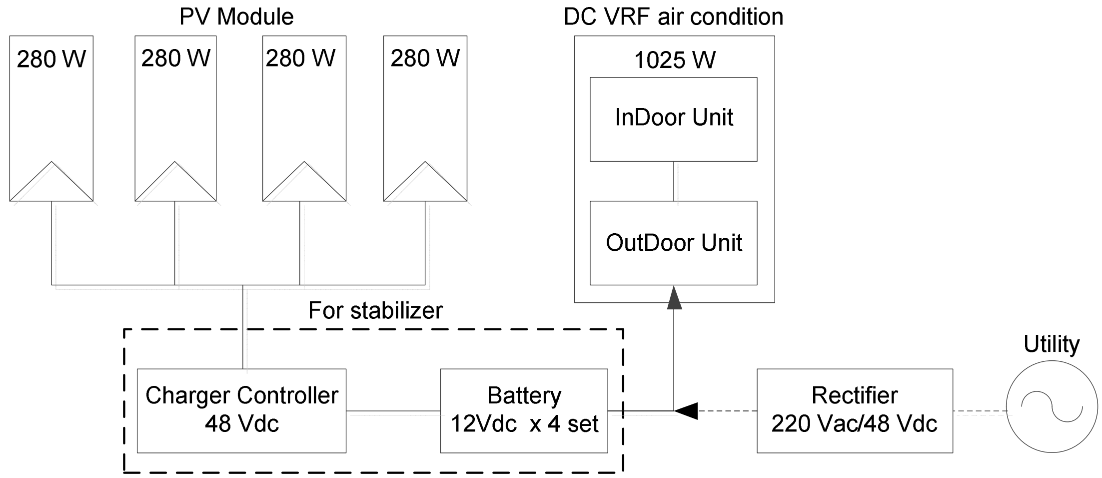

Fig. 6. Diagram of Solar air conditioning connect to the grid

If the ceiling of the room higher than 2.5 meter or high number of people in room or high heat source such computer in the room the BTU/h of air condition should be add more 5% from the conventional. In this design, the commercial DC VRF air conditioner with cooling capacity 12000 BTU rate is selected for the technical and economic evaluation. The DC VRF air conditioner is designed from the ground up to operate on DC power. There is no AC power used inside or needed externally to operate the unit. DC power is connected to the outdoor unit. The indoor unit receives DC power from the outdoor unit. The area of Cool or Heat is up to 16-20 m^2 with Variable Capacity, Anti-Corrosion Technology. The refrigerant of system is R410a which Eco-Friendly to the environment. The air flow fan can adjust in 3 steps with low, medium and high speed with Washable Air Filters. The more advantage of this product is quiet Indoor Unit (As Low As 26dB). The specification of DC VRF air conditioner is described in Table 4.

The DC power is generate from the solar photovoltaic system only for day time load 4 and 8 hours. The high ambient temperature and high irradiance, the air conditioning load has high consumption and in the same time solar panel has also high electrical power generation. The number of solar panels is up to the energy consumption of air condition 1025 Watt and operation hour per days. The 48 V battery storages are used to stored energy when the solar radiation has fluctuated and for load consumption in low radiation and the night time. The diagram of solar air conditioner system is shown in Fig.6

4. ECONOMIC ANALYSIS OF DC SOLAR AIR CONDITION WITH AC AIR CONDITION

In this sector, an economic analysis of DC VRF solar air conditioning and AC conventional air condition with use electricity from the grid is compared. The net investment is the estimate cost of system. The price of DC VRF aid conditioning is similar to AC Inverter technology and the PV system is designed support only daytime load consumption. The battery backup for stabilizing has the lifetime approximately over 5 years. Therefore every 5 years, investment cost is also increase from cost of battery. The three tool for economic evaluation are follow as payback period (PP), Net present value (NPV) and Internal rated of return (IRR) respectively.

4.1. PAYBACK PERIOD: PP

Payback period (PP) = calculated from Net investments / Cost savings per year. (2)

4.2. NET PRESENT VALUE: NPV

The Net present value used for calculate the gains made after the installation of solar water pumping from the decreased use of fuel. The lifetime of the system is 25-year and discount rate of 10% per year. Therefore every 5 year net investment is also increase cost of batteries. The equation 9 is Net present value equation.

$$NPV = \sum_{t=1}^{n} \frac{ES_t}{(1+i)^t} - I_0 \qquad (3)$$

ES_t is cost saving per year (THB), n is lifetime of project (year), I_0 is net investment(THB) and i is inflation rate.

4.3 INTERNAL RATE OF RETURN: IRR

The internal rated of return used for investing in the project can't be negative and that investors have no collections IRR was lower than the rate of inflation over the period of the investment project. The equation 10 is the internal rate of return equation.

$$-I_0 + \sum_{t=1}^{n} \frac{ES_t}{(1+IRR)^t} = 0 \qquad (4)$$

TABLE 5. Investment cost and Economic analysis of Solar Air Condition system

Load operation hour (Day time	4	6	8	10	12
Load Air conditioning (W)	1025	1025	1025	1025	1025
Load Energy Consumption (Wl	4100	6150	8200	10250	12300
Peak Sun Hour (H)	4	4	4	4	4
Solar Energy Power (W)	1025	1538	2050	2563	3075
Number of Solar Panel 250 W	4	6	8	10	12
Charger Current 48 V	21.4	32.0	42.7	53.4	64.1
Rectifier circuit 220 Vac/48 V	40	40	40	40	40
Total Energy from Battery (Ah	40	40	40	40	40
Depth of Discharge (D.O.D) 1	0.5	0.5	0.5	0.5	0.5
Number of Battery	4	4	4	4	4
12 V Deep Cycle Battery	20	20	20	20	20
Daily Energy Cost saving	16.4	24.6	32.8	41	49.2
Monthly Energy Cost saving	492	738	984	1230	1476
Yearly Cost saving	5986	8979	11972	14965	17958
Solar Module	30750	46125	61500	76875	92250
Solar Charger	5000	5000	5000	5000	5000
Battery 1000 B/set, 5 year/rou	20000	20000	20000	20000	20000
Rectifier circuit	4000	4000	4000	4000	4000
Accessorires (Breaker, Cable)	4000	4000	4000	4000	4000
Total Investment cost	63750.0	79125.0	94500.0	109875.0	125250.0
Payback Period	10.6	8.8	7.9	7.3	7.0
Net Present Value	-฿8,558.94	฿2,161.58	฿12,882.11	฿23,602.64	฿34,323.17
Internal Rate of Return	8%	10%	12%	13%	14%

5. CONCLUSIONS

In this paper propose the design and evaluation of technical and economic of DC Variable flow refrigerant solar air conditioning. The first stage of design is cooling load calculation from size of the room, then 12000 Btu/h is selected. The operation hour of air condition for this room is 4-12 hours which consume power 1025 W and energy from 4100-12300 Wh. The solar energy generation for energize this load and average solar radiation daily 4.0 kWh/m2/day or 4 Peak sun hour, then solar panels are selected. The battery energy storage are calculated for voltage stabilizing. The solar charger and rectifier circuit is used to charge battery from AC utility. The budgets of solar air condition are estimated and electricity bill are calculated per year. The financial and economic evaluation are calculated and payback period, NPV and IRR of each configuration are evaluated respectively. The best case is the number of load operation hour 12 hours/day, the investment cost of system 125,250 Bath, Payback period 7 years, NPV 34323.17 Bath and IRR 14%. This result is useful to planning solar energy promotion in term of air conditioning load consumption to decrease overall peak demand.

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