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Performance evaluation of a variable speed DC compressor

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ABSTRACT

Direct current compressors are strong candidates to be employed in energy-efficient refrigeration systems, especially for renewable energy powered units, as these compressors do not require additional components such as a power inverter that an alternative current compressor would require. This study represents experimental performance analysis of a direct current type refrigeration compressor implemented in a 79 L refrigerator. Energy usage reduction and operational improvement potential of the direct current compressor via variable speed operation were investigated. Experiments were carried out at variable speed operation and four different constant speed operation modes of the compressor. Temperature, pressure, and power input measurements were obtained every 30 s. The experimental data were analyzed in terms of energy and exergy efficiencies. The comparison showed that variable speed operation of the direct current compressor can be much more efficient than constant speed operation of the direct current compressors, especially at higher speeds.

Evaluation de la performance d'un compresseur à courant continu à vitesse variable

Mots clés : Courant continu ; Froid ; Vitesse variable ; Économies d'énergie ; Exergie

1. Introduction

Improvements and reduction in the energy consumption of refrigerator compressors is crucial for the refrigeration industry. Domestic refrigeration systems have the opportunity to be powered by green technologies such as solar energy. Solar energy can be used in the absorption refrigeration systems or vapor compression refrigeration systems, but in the present study, only vapor compression refrigeration systems have been investigated. Green technologies have been focusing on either decreasing energy usage, or creating environmentally friendly systems worldwide. In the case of refrigeration, there are two different options for powering the compressor which are alternative current (AC) or direct current (DC). A compressor is combination of a mechanical compression part and an electrical motor. An electrical motor converts electrical energy to mechanical energy in a refrigeration compressor. An AC current compressor is powered by alternative voltage such as 120 or 220 V and 50 Hz. Electrical motor of the AC compressor is an AC induction type. On the

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Nomenclature

Roman

A	surface area [m^2]
B_i	bias error [-]
B_R	bias uncertainty [-]
C	command [-]
D	pipe diameter [m]
$\dot{E}x$	exergy rate [W]
ex	specific exergy [J kg^{-1}]
f	friction factor [-]
h	specific enthalpy [J kg $^{-1}$]
I	solar irradiance [W m^{-2}]
I_m	maximum power point current [A]
I_{oc}	open circuit current [A]
I_{sc}	short circuit current [A]
K_L	loss coefficient [-]
K_p	proportional gain [-]
L	pipe length [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
N	number of bits of resolution [-]
Of	offset [–]
P_i	precision error [–]
P_R	precision uncertainty [–]
P_{major}	major pressure losses [Pa]
P_{minor}	minor pressure losses [Pa]
$\dot{Q}$	heat flow rate [W]
$\dot{Q}_{pv\_loss}$	heat flow rate from the PV surface [W]
$\dot{Q}_{cooling}$	total cooling load [W]
R	experimental results [–]
R_k	kth number of resistance [ohm]
Re	Reynolds number [-]
s	specific entropy [J kg $^{-1}$ K^{-1}]
$\dot{S}_{gen}$	entropy generation [W K^{-1}]
U_R	uncertainty in the experimental result [–]
U	total heat transfer coefficient [W m^{-2} K^{-1}]
V_n	nth number of variable [–]
V_w	wind velocity [m s^{-1}]
V_m	maximum power point voltage [V]
V_{oc}	open circuit voltage [V]
T	temperature [K]
$\dot{W}$	power transferred out from the system [W]
$\dot{W}_{comp}$	compressor power input [W]
u	refrigerant velocity [m s^{-1}]

Greek

ε	absolute wall roughness [-]
ρ	density [kg m^{-3}]
ψ	exergy efficiency [–]
τ	transmittance
α	absorptance
γ	efficiency correction coefficient
η	electrical efficiency

Subscripts

act	actual
amb	ambient
cab	cabinet
Carnot	Carnot cycle
cell	photovoltaic cell
COLD	cold side
comp	compressor
con	condenser
cond	condensing
cap	capillary
des	destruction
des_evp	evaporator destruction
des_ext	external destruction
des_int	internal destruction
desr	desired
evap	evaporating
evp	evaporator
HOT	hot side
in	inlet
in_pv	photovoltaic inlet
L	loss
max	maximum
min	minimum
0	reference state
out	outlet
pv_srf	photovoltaic panel surface
ref	reference conditions
sun	sun
sys	system
tot_des,pv	total photovoltaic destruction

Superscript

Q	heat transfer into the system
W	power transferred out of the system

other hand, DC compressor requires low voltage and direct current supply such as 12–24 V. Even though, DC compressor has similar mechanical compression part with AC compressor, it has a brushless electrical motor. Green energy technologies can be used to power a DC compressor directly while an AC compressor requires a power inverter. Energy usage reduction through improved efficiency and use of renewable energy employing DC compressors is an advantage of such systems. There are other uses of small-sized refrigeration systems besides household use. Many vehicles such as trucks, caravans, boats, cars, etc. are often equipped with portable cooling appliances. To improve compressor and refrigeration system efficiency, modulation methods are used. Cooling capacity and cooling demand of a refrigeration system is equalized by using refrigeration capacity modulation methods. According to Qureshi and Tassou (1996), the most efficient method is variable speed capacity modulation. Different studies have been conducted on variable speed refrigeration systems but most of these are related to AC compressors. Qureshi and Tassou (1996) investigated variable speed capacity modulation of domestic size heat pumps. The study focused on different topics with AC compressors such as energy conservation by using capacity modulation, performance comparison with conventional systems, and mathematical modeling of variable speed systems. Results showed that a variable speed capacity modulation method