Cooling System for HV Switching Personnel in Arc Flash Suit

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***Abstract*—High Voltage switching is very dangerous and has caused many fatalities or damage to equipment. Two of the most common sources of HV switchgear accidents are a lack of following safety protocols and an insufficient understanding of the HV electrical systems; just as car drivers can avoid accidents with proper understanding of driving, so can HV personnel. But because HV switching accidents do happen, Switching Personnel are required to wear Arc Flash suits. Butthe experience of Switching Personnel in equatorial Malaysia is that theysweatprofusely even after a minute of wearing such a suit. The reason is because these suits aredesigned and manufactured in temperate countries wherewarm armor like this will be welcomed. To solve this, in this research an air conditioning system was built to enable blowing cool air within the Arc Flash suits via a pipe going up from the bottom of the suit to the chest level. The robust car air conditioner system was driven by a 2 HP motor and a long flexible pipe will enable the switching personnel to reach many HV switchgears. One such system should be permanently placed in each substation.**

Keywords—Arc Flash Suite, HV switchgears, air conditioner, safety system

I. INTRODUCTION

The Arc Flash Suit cooling system (AFSCS) of Fig. 23 was built-up after much iteration of the design and testing.

A car air conditioning system was utilized and not a home air conditioner because the former were designed to withstand the rough movements in case it needs to be moved to a rural substation to enable switching operations. The car industry has continually developed the car air conditioner since 1935 when Ralph Peo of Buffalo, New York applied for a patent for it [1]. The system built in this research will not be expensive if the car air conditioner system was acquired from scar scrap yards. As can be seen from Fig. 18 and Fig. 23 the cool air from the evaporator portion of the air conditioner system is funneled via a 6 m flexible pipe to the chest level of the Switching Personnel (SP). At that point there is an air valve which the SP can use to control the air flow within the Arc Flash Suit (AFS).

The car air conditioner was driven by a 2 HP, 3Φ motor. The whole system was mounted on (4' X 4' X 3 mm) X 3 pieces of plywood screwed together. Wheels were installed underneath it, but it was discovered that with wheels below the plywood base without a handle, it was still difficult to move the system, therefore the whole system was placed on a standard folding cart as shown in Fig. 23.

3Φ power is needed which is available in all substations and in case an emergency switching is needed to be performed and the 3Φ socket point is not available a direct tap from LV lines can be done as shown in Fig. 19, using the Local Earthing clamps [2].

The case study of an HV switching accident which can help to justify this project is when an 11 kV oil circuit breaker (OCB) was switched in Sibu, Malaysia in 2015. The SP noticed from the gauge that the oil level was low but was in a hurry so switched it anyway. He got second degree burns and was admitted to the ICU (intensive care unit) of the Sibu hospital. After he recovered a little, his employer, which was the electric utility of the state, gave him a warning letter for not wearing the AFS [3][4][5]. At that time this author was teaching 30 staff of the electric utility who were mostly SP. They were askedwhy they wouldrefuse to wear safety gear and all 30 agreed that it is just too warm to wear it in Malaysia [6]. As depicted in Fig. 2, the higher category AFS covers the SP more, making it warmer for them. A typical AFS cost about USD 4,500 in Malaysia and are mostly made in temperate countries where SP would welcome the warmth they provide.

This research is done since even the main electrical utility of Sarawak, Malaysia cannot find a cooling system or their SP [7]. Online search also reveals that there are none working on a system such as this. This must be due to the fact that engineering innovations are mostly concentrated in temperate countries. But such a cooling system should be a boon for people who need to work in even warmer countries such as in the Middle East [8]. The Guardian news outlet of the United Kingdom published an article in 2023 that up to 6,500 workers from India, Pakistan, Nepal, Bangladesh and Sri Lanka died during the construction of the facilities required for the football World Cup finals held there. Many of the deaths are related to "heat-related illnesses" [9]. The system built in this research can be further improved to beutilized by workers in warmer countries. For air conditioners, large establishments have for a long time been using centralized systems with chillers and so forth. But with the decrease in home size and cost of air conditioners (split units), increasingly large businesses are realizing that the many home air conditioners can replace a centralized air conditioner. The logic of that thought process is that there are normally only a few centralized air conditioner vendors in any country because of the high cost of such systems. They can therefore charge whatever they want for the initial system as well as for maintenance. If split units are used, there is competition for the initial price as well as service personnel [11][12]. A study by UniversitiTechnologi Malaysia (UTM) indicated that changing the whole university to split units would be very advantageous. For example, the electric bill for Universiti Malaysia Sarawak (UNIMAS) was USD $ 2,900,000 per year. It was calculated that if split units were installed, that electric bill amount can be used to purchase split units for all classrooms and offices

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and the bill can drastically reduce after that. Often during breaks large areas are kept cool while there are no humans around at UNIMAS [13].

Projecting this scenario, would it be possible for each human wearing an air conditioning system to be a saving compared to even a split unit air conditioning in a classroom for example. If such a system is developed and miniaturized, working in hot deserts will cease to be a problem.

II. Literature Review

There are coolers available in the market that are operated by 5V batteries and measure just a few inchescube,but they cannot cool the SP sufficiently in a warm AFS [14].

Other options currently available in the market are body cooling ice vests which have many pockets where ice packs are placed. People whohave used such systems have a problem with flexibility and it takes up to three hours to get the chemical back to solid to ice state once body heat warms them up. The ice also adds weight for the SP to carry around. Therefore, bulkiness and flexibility are the main complaints of users of such systems [15][16].

There are many systems in Malaysia which are just copies of those in temperate countries where most of the world's engineering developments take place. The most infamous case is the train station of Kuala Lumpur which was designed and built during the British colonial period to withstand three meters of snow. Builders of roads also just copy designs from temperate countries not considering that Malaysia has five times more rainfall (157"/year versus 31"/year in temperate countries) [17]. Comparatively there is a road called Maxwell, built before 1963 which is still good. This road slopes to both sides and there are big drains on both sides of the road. Today roads are built with embankments on both sides causing the roads to be ponds after heavy rains.

HV switchgear accidents do not happen often but in the majority of cases it is a slight skipping of procedures that caused them. AFS is designed to protect the SP despite making this small dangerous mistake [17]. This is analogous to the days of wars with swords, high skills as warriors were critical but armors were required if the skills were lacking and mistakes were made.

Officially the air conditioner was invented by Willis Haviland Carrier in 1902 [19]. It is an incredible invention that requires the inventor to think of four things at one time. Air conditioners and refrigerators work with the same principle and are termed heat engines. Scaled up heat engines (refrigerators) are the LNG (liquified natural gas) plants of which the largest is in the USA at Sabine Pass which produces 55.4 million metric tons per annum (MTPA) of LNG [20]. As an indication of the size of such heat engines, the LNG plant located in Bintulu, Malaysia is 4.4 km long and produces only 30% of what the Sabine Pass plant produces.

Fig. 1 depicts the schematic of an air conditioner system. There are four principal components in the schematic located on four sides of the schematic, the condenser, the evaporator, the compressor and the expansion valve. A coolant which has a boiling point as low as -29^{o}C through all these four components to achieve cooling of the area surrounding the evaporator and deposits this heat in the area surrounding the condenser.

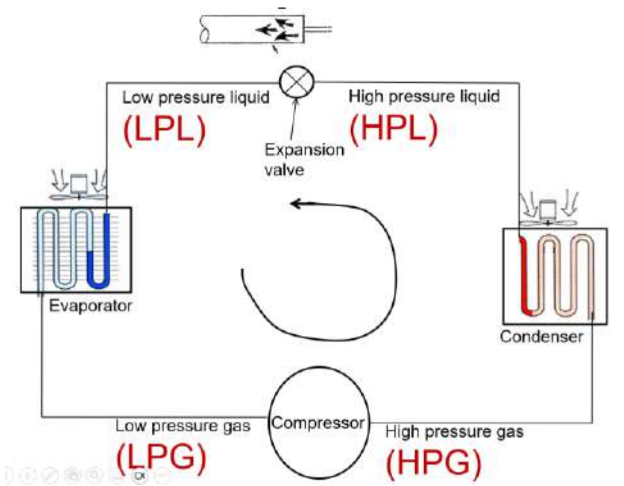

Fig. 1. The air conditioner cycle schematic [22]

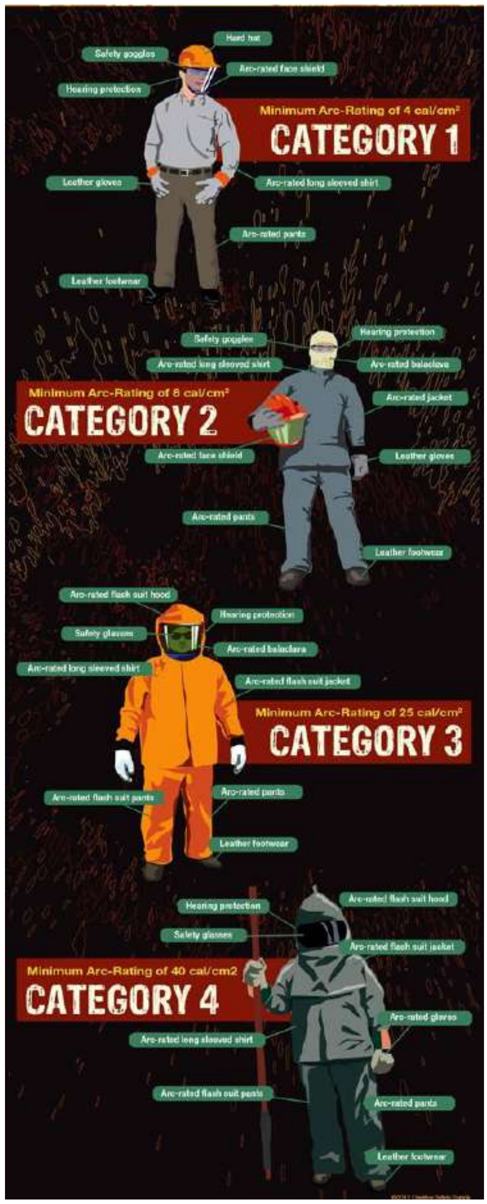

Fig. 2. Four types of AFS, as can be seen, the SP will get increasingly warmer as the protection is increased [23]

The condenser and the evaporator do the opposite things. The condenser changes the coolant's state from gas to liquid while the evaporator changes the state of the coolant from liquid to gas. In both the condenser and the evaporator, the coolant is made to move in a spiral of tubes to increase the surface area of coolant as the spiral is blown by fan as shown in Fig. 1 left and right, top. The logic of this is like the heat sinks placed on microprocessors, its shape is to increase the surface area that is blown by the fan above it. The alveoli of the lungs also increase the surface area of the lungs to aid O_2absorption. In the latest battery technology, the cathode and anode are also designed to increase their surface area as much as possible to increase battery capacity.

Similarly, the compressor and expansion valve do the opposite things. The compressor increases the pressure of the coolant in gaseous state while the expansion valve decreases the pressure of the coolant in liquid state.

In the expansion valve the high-pressure liquid coolant is suddenly released from a small diameter pipe to a large diameter pipe thereby decreasing the pressure of the liquid. The compressor is a pump that compresses the coolant in gaseous state.

It is easy to remember the schematic if one realizes that it is hard for a pump to compress liquid so the input and output of the pump must be in gaseous state. Then remember a cold soft drink in a tin on the table of an eating shop is the condenser; the bubbles of water forming on the tin is what happens in a condenser [21].

III. METHODOLOGY

The project started with a purchase of all components of a car air conditioner. The next thing done was to purchase an induction motor and a VFD (variable frequency drive) to drive it. The original designed concept was that the VFD can control the motor's speed and thereby the coolness of the air coming out to the satisfaction of the SP. The purchased car air conditioner parts are shown in Fig. 3. The next thing was to purchase an induction motor of size 1 Φ, 1 HP as shown in Fig. 4. A VFD was then purchased online. But when it came a month later, it turned out to be a 1 Φ in and 3 Φ out one as shown in Fig. 5. Therefore, the 1Φ, 1HP motor was replaced with a 3 Φ from the local shop which did not charge extra for it. This 1 HP, 3 Φ motor is shown in Fig. 6. The control circuit of the car is normally run by the 12 V car battery plus alternator system. Therefore a 12 V SMPS (switch mode power supply) power supply was purchased as shown in Fig. 7.

A base was than built to install the whole system. 10 mm thickness plywood is sold at a fixed 8' X 4' length which is difficult to carry in a car therefore 3 mm X 4' X 4' plywood was purchased as shown in Fig. 8. 1.6 mmself-driving screws were used to join up the 3 X 3 mm plywood to reach a thickness of 9 mm. Since in the mounting of the air conditioner component on this plywood will require screws and nuts to go below the plywood, four wheels were installed below the plywood.

A setup was built to enable the induction motor to turn the compressor, replacing the car engine. This was built by a local vendor for free since it was for research. This setup is shown in Fig. 9.

A mechanic was then engaged to assemble the systemsince this author have never dwelt with an air conditioner system.The mechanic helping in assembling the air conditioner system is shown in Fig. 10.

But there was a problem, the compressor ran slowly, and the induction motor started getting quite hot. As shown in Fig. 11, the cylindrical metal will go in to engage the impeller of the pump upon switching on the air conditioner switch which is located on the evaporator unit.

The next thing tried was to purchase a 2 HP capable VFD and a 2 HP, 3 Φ induction motor as shown in Fig. 12 and Fig. 13. This was tried but though it ran better, the compressor pump did not run fast enough. It must be noted that this new VFD of Fig. 12 and the previous one of Fig. 5 takes in 1 Φ and generates 3 Φ output power.

The next plan was to try using 3 Φ directly from a supply to run the system. So, the system was installed properly as shown in Fig. 14 and Fig. 15 to be brought to the university power lab which had 3Φ power. Here it ran perfectly as shown in Fig. 16. Cool air came out of the evaporator unit.

Many layers of flexible garbage bags were used to funnel the cool air from the evaporator unit to initially the orange hose shown in Fig. 17 left. This orange hose is designed to handle air flow. But after explaining to the vendor that high pressure air is not required, he suggested using the flexible gray hose shown in Fig. 17 right. A 6 m length of this hose was purchased to enable the SP to move to many HV switchgears upon using the AFS.

Now that the VFD is not used, an air control ball valve was purchased and installed as shown in Fig. 18. This simple method of attaching the air flow control pipe was determined to be the best method i.e. using a galvanized iron (GI) metal wire which is coated with plastic. This GI wire is easily available in hardware stores and therefore easy for the SP to replace when needed.

In substations where a 3 Φ socket point is not available the local earthing wire shown in Fig. 19 can be used to derive 3 Φ power to run the system.

Data was then collected of the temperature within the AFS. A thermostat shown in Fig. 20 was used to measure the heat. In Fig. 20, the top hand is holding the display, and the bottom hand is holding the thermostat probe. But because of the high cost of the AFS, a raincoat was used to get the heat data as shown in Fig. 21 where heat data was collected first in the lab and later in the outside hot environment. It must be noted that the entire research budget for this research can purchase only one AFS with only a little money left over.

Before connecting the hose to the evaporator unit the original plan was to get the hose to send cool air to various parts of the human body via a big hose to small tubing as shown in Fig. 22. But this was determined to be not user friendly for the SP.

Table 1 illustrates the environment temperature within the AFS without the cooling system, with the cooling system and the delta of temperature caused by the cooling system. The temperature was taken every one minute for 18 minutes. The initial readings show a negative temperature improvement because the AFS is initially worn, the temperature will go up and is later cooled by the air conditioning system.

Fig. 3. The car air-conditioner system purchased

Fig. 4. 1Φ, 1 HP motor initially purchased

Fig. 5. The first VFD purchased, 1HP, 3Φ

Fig. 6. 3 Φ, 1 HP motor that was subsequently purchased

Fig. 7. The 12V SMPS used to power the air-conditioner system but not the induction motor

Fig. 8. Four plywood pieces and screw used to join them to form the base of the system; later four wheels were attached to the bottom of the base

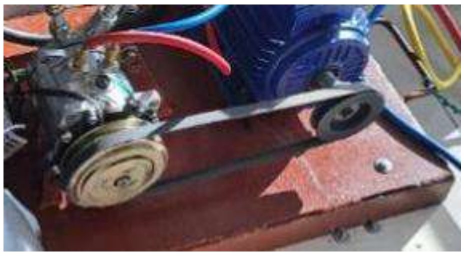

Fig. 9. The metal setup to enable the induction motor to turn the compressor

Fig. 10. The Sibu car mechanic showing how to connect and operate the system

Fig. 11. The first try with the original inverter purchased from eBay also showing the electromagnet engage of the pump (cylindrical metal)

Fig. 12.：The VFD with specs 2HP, 3Φ, below is the nameplate of the 2 HP, 3Φ motor

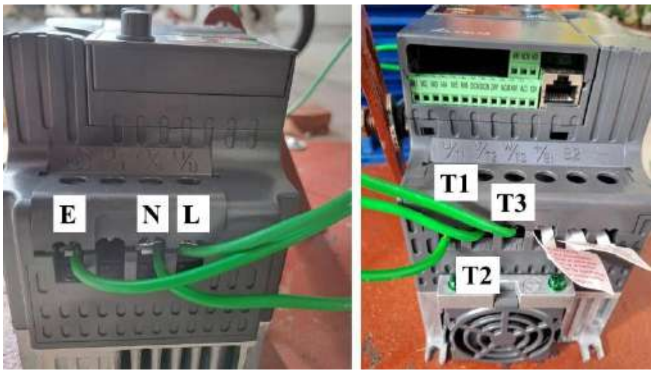

Fig. 13. The method of connecting the 1Φ to 3Φ VFD

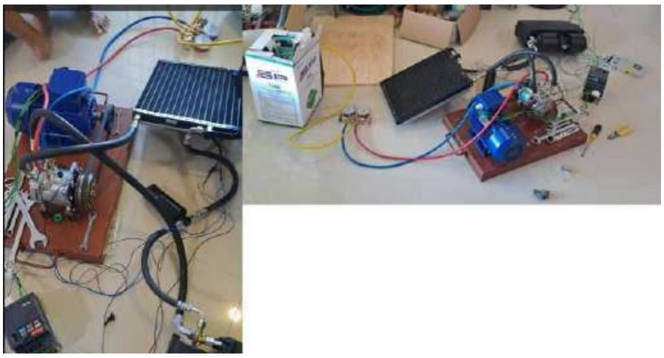

Fig. 14. Testing the system

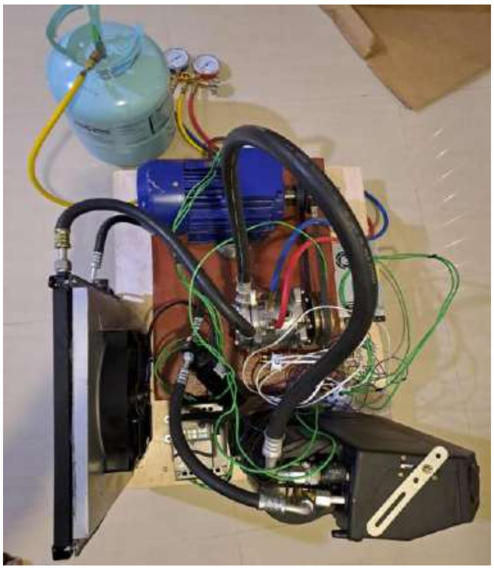

Fig. 15. Final built up system

Fig. 16. The system running perfectly in the power lab of UTS

Fig. 17.：Orange hose which was initially used as the outlet and later the flexible and much longer gray hose was used

Fig. 18. An air flow valve replaced the VFD in controlling the air flow of cool air out of the system

Fig. 19. This method can be used to get 3Φ power from the LV side of substations

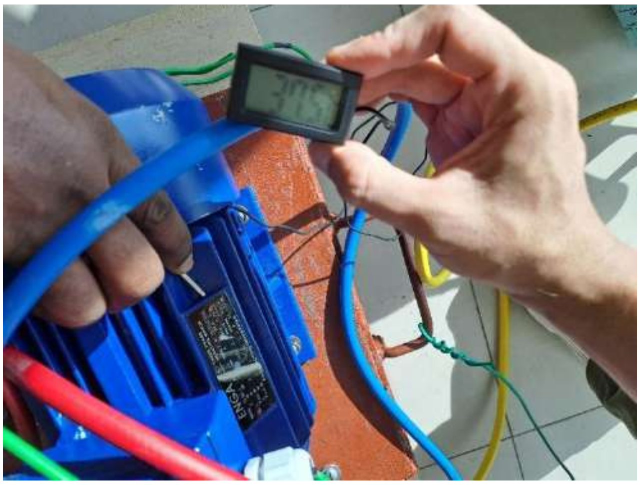

Fig. 20. The Thermometer Used to Take Heat Measurements

Fig. 21. Testing in the UTS laboratory and later testing outside in the sun, simulating conditions of a substation

Fig. 22. Initially the outlet hose was forced to send cool air to many tubes, but it did not work

Fig. 23. the complete setup place on a standard

TABLE I. THE ENVIRONMENT TEMPERATURE RESULTS WITHIN THE AFS

Time (min.)	Environment temperature within AFS without cooling system (°C)	Environment temperature within AFS with the cooling system (°C)	Δ of environment temperature within the AFS (°C)
1	35.5	35.6	-0.1
2	36.7	36.9	-0.2
3	36.7	36.8	-0.1
4	36.8	36.3	0.5
5	36.7	36.2	0.5
6	36.8	36.1	0.7
7	36.9	36.7	0.2
8	36.8	36.1	0.7
9	37	35.8	1.2
10	36.9	35.6	1.3
11	36.8	35.9	0.9
12	36.7	35.9	0.8
13	36.7	35.9	0.8
14	36.8	35.9	0.9
15	36.8	35.9	0.9
16	36.8	35.7	1.1
17	36.8	35.6	1.2
18	36.9	35.5	1.4

IV. CONCLUSION

This research is a success with the final built-up system depicted in Fig. 23. In the attempt to achieve the success, three induction motors were purchased, a 1 Φ, 1 HP one, a 3 Φ, 1 HP one and a 3 Φ, 2 HP one. Two VFD were also purchased, a 1 Φ to 3 Φ, 1HP one and a1 Φ to 3 Φ, 2HP one.

With such a cooling system the SP will not be reluctant to wear the AFS in warmer countries. The system is practical and economical because car air conditioners can be acquired from car scrap yards for cheap prices. This will make it feasible to purchase one of these units for each substation. Car air conditioners are also built to be robust and suit a high movement work that may be required in substations operation work. Comparatively home air conditioners were designed to be installed once and not moved.

Various methods were suggested to get the cool air-conditioned air into the AFS but the method eventually chosen as depicted in Fig. 17 is the most appropriate considering that SP may sometimes be in very rural substations without access to hardware stores. Aplastic-coatedGI metal (won't stain the SP's shirt) wire is used to hold the cool air output valve at the chest level, pointing at the head of the SP. The sensation of claustrophobia is mostly accentuated by heat in the head of the SP.

The initial hose used for the output air-conditioned air to flow is shown in Fig. 16 left image but was later changed to the gray flexible hose shown in Fig. 16 right image because high pressure air is not used. This indicates that it is useful for researchers to work closely with vendors who have more knowledge of what is available in the market. The 6 m flexible hose used will enable the SP to reach many HV switchgearsafter wearing the system.

In the final design, the VFD is not used and is replaced by the air flow control ball valve shown in Fig. 17. The original idea was that the VFD will vary the speed of the motor to achieve the appropriate cooling needs of the SP. Thereby replacing a USD 101 VFD with a USD 5 air ball valve. The whole system of Fig. 23 can be moved around and even transported on the vehicle of the SP.

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