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A Low Cost Microcontroller-Based Automatic Transfer Switch for Portable Generator

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Abstract – **Automatic transfer switch is electro-mechanical controllable apparatus used to transfer electrical supply from utility network to secondary supply such as generating set when utility network supply fails. This apparatus automatically switches its contacts to utility supply if electricity from utility network returns back to normal. Local-made automatic transfer switch for portable generator is not available in the market, however the imported one is offered at costly price. This condition drives people to use manual transfer switches for controlling their portable generators. This paper presents microcontroller-based auto-matic transfer switch for portable generator which is designed to meet cost effective product. The design is based on ATMEL ATtiny2313 micro-controller platform with 2 (two) units of 30-ampere power contactor as actuators so that power capacity of the apparatus reaches 6600 volt-amperes at 220 volt working voltage. Several functional tests conducted in the laboratory show that the apparatus successfully makes transition between the two sources of electricity at the right time.**

Keywords: **automatic transfer switch, ATtiny2313 microcontroller**

I. INTRODUCTION

Automatic transfer switch (ATS) has been used in industrial installations, office buildings, shopping centers, hospitals, etc, to enhance electrical system reliability. During normal condition the ATS contacts connect electrical load to utility network such as PLN network. When utility network fails to supply electricity, ATS transfers its contacts so that the load will be connected to secondary supply such as engine-driven generator or commonly known as generating set (genset). ATS will transfer its contacts back to normal position when electricity supply from utility network returns to normal. Loss of electricity supply duration can be reduced by installing the ATS, hence high reliability electrical system can be achieved.

Behind features offered by the manufacturers, ATS should have 3 (three) basic functions. It must be able to monitor the status of utility supply, the status of genset supply and make transition between the 2 (two) sources of electricity at the right time [1]. Several requirements that should be added to the ATS that will be installed in a high reliable power system have been explained in [2]. For this kind of installation, the ATS must be able to operate under 2 (two) modes of operation, manual mode and automatic mode. Under manual mode of operation, the transition between the 2 sources of supply is made manually utilizing mechanical gear equipped on the ATS. Within automatic mode, the transition is made automatically by the controller unit. The ATS controller may use discrete components such as electromagnet relays and timers or using programmable logic controller. Contacts transition of the ATS may use break-before-make procedure or may use make-before-break procedure. Within first procedure, the ATS contacts connecting electrical load to utility network is firstly open before the contacts connecting electrical load to genset is made to close. Within later procedure, the ATS contacts connecting electrical load to genset is firstly made to close before the contacts connecting ATS to utility network is made to open. Make-before-break procedure is intentionally used in installation that requires high reliability of electricity supply and the installed genset must be equipped with voltage synchronizing apparatus. Other requirement that shall have to be provided in the ATS is the ability to control genset starting and shutting down process.

Portable generator is other type of genset usually used as secondary supply in residential and small business installations. Typical portable generators generate single-phase alternating current with power capacity up to 10 kVA. Like other types of genset, portable generator is equipped with automatic voltage regulator to control generator output voltage and speed governor to control the speed of engine shaft [3].

ATS for portable generator is not common in the market therefore this apparatus is rarely installed. This is due to its costly price felt by common people. For example, the US-made ATS for portable generator, the ASCO ULATS1651001 [4], with power capacity up to 24 kVA in single-phase 3-wire 120/240 volt, 60 Hz installation, is offered at USD 779 [5]. This is as the price of FIRMAN portable generator with power capacity 5 kVA [6]. Because of the above reason, people prefer to use manual transfer switch such as utilizing the cam switches to operate their portable generators.

Publications and patents related with the ATS for portable generator have been searched for. Patent of

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ATS for portable generator which is equipped with features to start and stop the genset is described in [7]. This ATS is controlled by microcontroller and several SPDT type of relays are used as actuators. Other patent is described in [8]. This ATS is also controlled by microcontroller and it uses special electro-mechanical drive to make transition between electricity sources. The ATS describing in these patents are installed in single-phase 3-wire installation complying the NEC standard.

Local made ATS for portable generator is not available in the market, though potential usage of this apparatus is promisingly high due to relatively low reliability of PLN electricity supply at many places in Indonesia. This paper presents ATS for portable generator which is designed by considering low material cost to achieve low price of product. By this concept, the end product will be widely used in residential and small business installations.

II. DESIGN OF AUTOMATIC TRANSFER SWITCH

Low material cost has become constraint that is considered during design phase of this portable generator ATS. Therefore this portable generator ATS is designed to comply with standard type of ATS as explained in previous chapter, i.e. it must be able to monitor the status of utility supply, the status of portable generator supply and to make transition between the sources of supply at the right time. This standard type of ATS is suitable for residential and small business installations since they do not need high reliability supply of electricity. Block diagram of portable generator ATS is shown in Figure 1. Operating principle of the apparatus is explained as follows;

Information about the state of electricity supply either from utility network or portable generator is provided by voltage sensor 1 and voltage sensor 2. The state of the sensors becomes digital input for process controller unit. Other digital input is RESET BUZZER pushbutton switch. Hence totally there are 3 (three) digital input. Process controller unit will control the operation of contactor K1, contactor K2 and buzzer, based on information gained from digital input devices. Hence process controller has 3 (three) digital output, one digital output is used to energize/de-energize contactor K1, one digital output to energize/de-energize contactor K2 and one digital output to energize/de-energize buzzer.

Process controller unit uses ATMEL ATtiny2313 microcontroller [9]. This type of microcontroller is chosen due to its channel capacity enough for controlling the process with 3 (three) digital input and 3 (three) digital output and also this microcontroller is cheaper than other types of microcontroller available in the market.

The microcontroller chip controls the process based on the program embedded in. The BASCOM-AVR language is used for programming ATtiny2313 [10]. The program takes control the process by following the procedure as explained herein. If electricity is available at utility network, the state of voltage sensor 1 output will be LOW. By this input, the microcontroller chip will command to de-energize contactor K2 before commands to energize contactor K1, hence electrical load will be connected to utility network. If electricity is not available at utility network, the state of voltage sensor 1 output will be HIGH, hence process controller unit will command to deenergize contactor K1 and then electrical load will not be connected to utility network. The program continues to read the state of voltage sensor 2 output.

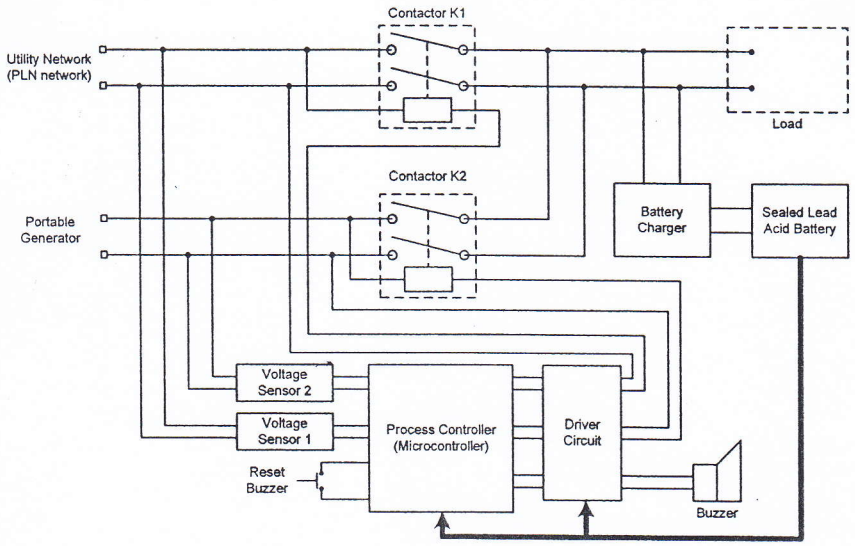

Figure 2. Schematic diagram of voltage sensor circuit

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If the state of voltage sensor 2 output is LOW (which means electricity available at portable generator), process controller will command to energize contactor K2, so that electrical load will be connected to portable generator. If the state of voltage sensor 2 output is HIGH, process controller will command to de-energize contactor K2, and then electrical load will not be connected to portable generator. If both the state of voltage sensor 1 and the state of voltage sensor 2 are LOW at the same time, process controller will energize buzzer to warn the genset operator to stop the engine, contactor K2 will be de-energized after that, and after 10 seconds process controller will energize contactor K1, so electrical load will be connected to utility network. Buzzer will remain sounding until the operator stops the engine and pushes RESET BUZZER switch.

The contactors need 220 volts, 50 Hertz electricity to energize their coil. Coil of contactor K1 is driven by utility network voltage and coil of contactor K2 is driven by portable generator output voltage. Main contacts of both contactors have current carrying capacity of 30 amperes, providing the power capacity of ATS reaches 6600 VA at 220 volts working voltage. This power capacity is maximum load for re-sidential installation type R1 PLN metering tariff [11].

Electronic circuits of the ATS and buzzer is powered by 12-volt sealed lead acid battery with capacity of 7.5 Ah. The 12-volt voltage level is regulated to 5-volt level using linear voltage regulator LM7805 to supply microcontroller circuits. The floating mode battery charger is continuously connected to voltage source to hold 13.8 volts between battery terminals.

III. DESIGN IMPLEMENTATION

The design of automatic transfer switch for portable generator is implemented on ATtiny2313 microcontroller circuit as will be explained herein.

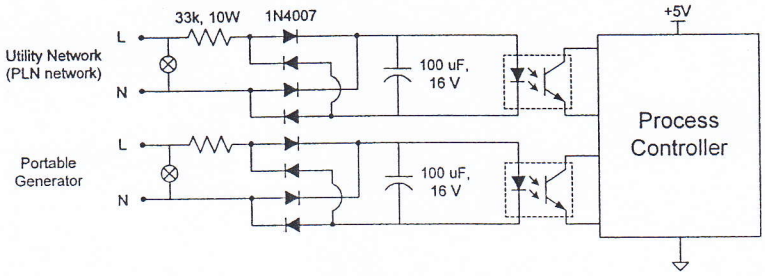

Figure 2. Schematic diagram of voltage sensor circuit

A. Voltage Sensor

The voltage sensors monitor the state of utility network voltage and the state of portable generator output voltage. Sensor circuit is basically a single-phase bridge rectifier with capacitor filter to feed dc current to emitter part of the optocoupler. If ac voltage is available at sensor input, dc current will flow through emitter part and then phototransistor part of the optocoupler will be at conduction state. The input unit of process controller will acknowledge that condition as LOW state input. If ac voltage at input sensor is disappeared then there is no dc current through emitter and phototransistor will be at cut-off state. Process controller will acknowledge the input as a HIGH logic state. Therefore the state of current flowing through emitter part of optocoupler will become digital input to process controller. Schematic diagram of voltage sensor circuit is shown at Figure 2.

B. Process Controller

The process controller unit is an ATtiny2313 microcontroller based circuit. This chip is 8-bit microcontroller product of ATMEL Corporation in DIP 20 pins. ATtiny2313 is chosen due to its input/output channel capacity suiting for the application and the price of the chip is not expensive. ATtiny2313 has 18 programmable input/output channels. This number of channel is enough to control the process with 3 digital inputs and 3 digital outputs. The 3 digital inputs are from voltage sensor 1, voltage sensor 2 and RESET BUZZER pushbutton switch. Those input devices are connected to port D0 (PD0), port D1 (PD1) and port D2 (PD2) respectively through optocoupler circuit. The output devices are driven by port B0 (PB0), port B1 (PB1) and port B2 (PB2). PB0, PB1 and PB2 are connected to the actuators through buffer inverter gate 74LS05 and optocouplers. Schematic diagram of process controller circuit is shown in Figure 3.

ATtiny2313 is programmed with BASCOM-AVR language. The program composes of 3 (three) main processes, they are reading digital input status, data processing and updating output status. Those 3 main processes are executed sequentially and cyclic. Program flowchart is shown in Figure 4 and explained as follows:

At the beginning program reads the states of PD0, PD1 and PD2. Variable M4 is used to state whether PD0 and PD1 are at LOW state at the same time which means electricity available at both utility network and portable generator output. If M4 is at HIGH state then PB2 port will be at HIGH state, hence buzzer which is connected to it will generate sound. Buzzer will stop sounding only if electricity

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supply from portable generator is stopped and RESET BUZZER pushbutton switch is pushed. The program will go to next step to process information from voltage sensor 1. If the state of voltage sensor 1 output is LOW, then variable M1 will be at HIGH state. The program will command to deenergize contactor K2 and after it waits for 10 seconds, PB0 which is connected to contactor K1 coil will be at HIGH state and contactor K1 will be energized, so the electrical load will be connected to utility network. If the state of voltage sensor 1 output is HIGH, then the state of M1 variable is LOW, the contactor K1 will be deenergized, hence electrical load will not be connected to utility network. Next, the program will process information gained from voltage sensor 2 circuit. If the state of voltage sensor 2 output is LOW, then M2 will be at HIGH state, hence the program will command to deenergize contactor K1 and after it waits for 10

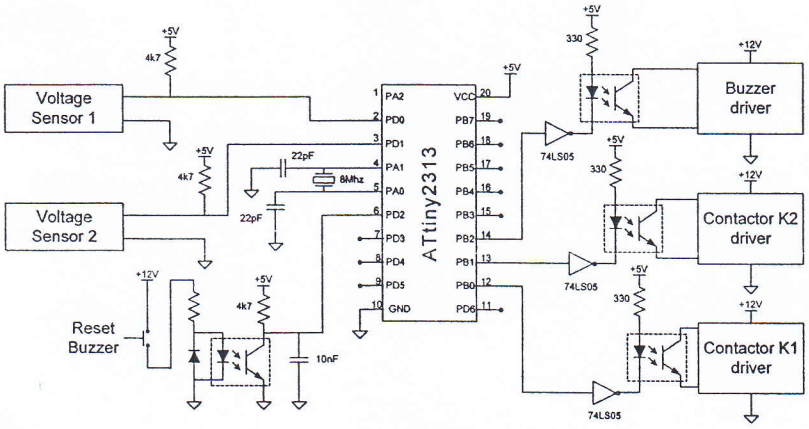

Figure 3. Schematic diagram of process controller circuit

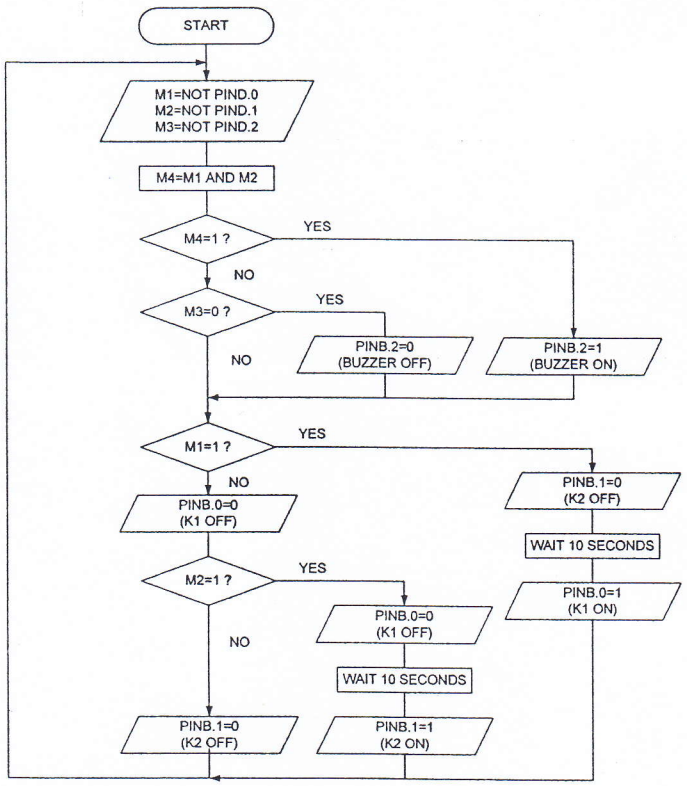

Figure 4. Flowchart for programming ATtiny2313 microcontroller

seconds, port PB1 which is connected to contactor K2 will be at HIGH state, then contactor K2 will be energized and the electrical load will be connected to portable generator. If the state of voltage sensor 2 output is HIGH, variable M2 will be at LOW state, hence the contactor K2 will be deenergized and so the electrical load will not be connected to portable generator. The program will loop back to the first step for next cycle of its process controlling.

C. Actuator Driver Circuit

There are 3 (three) driver circuits to drive 3 output devices. They are contactor K1 driver circuit, contactor K2 driver circuit and buzzer driver circuit. Each driver circuit uses a pcb-mounted relay which is controlled by a pnp transistor switch. The state of transistor base current is controlled by microcontroller digital output. The driver circuit and microcontroller chip is electrically isolated by placement of optocoupler. The driver circuit is powered by 12-volt sealed lead acid battery. Schematic diagram of contactor driver circuit is shown in Figure 5(a) and schematic diagram of buzzer driver circuit is shown in Figure 5(b).

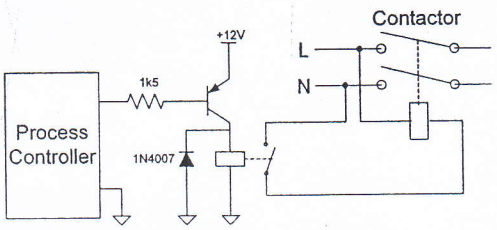

Figure 5(a). Contactor driver circuit diagram

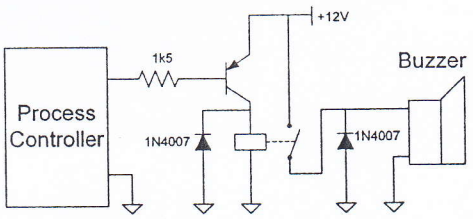

Figure 5(b). Buzzer driver circuit diagram

D. Battery Charger and Power Supply

Electronic circuits of this portable generator ATS is powered by 12-volt sealed lead acid (SLA) battery with 7.5 Ah charge capacity. Charging circuit for the battery uses floating mode which is implemented by continuously hold 13.8 volt between battery terminals. For this purpose, an adjustable voltage regulator LM317 has been used. The LM317 input comes from single-phase bridge connection rectifier through 220 volt/ 15 volt step down transformer. The 12-volt battery voltage is regulated to 5 volt stabilized supply by a fixed voltage regulator LM7805 to feed microcontroller circuit. Schematic diagram of battery charger circuit together with power supply circuit is shown in Figure 6.

IV. RESULTS AND DISCUSSION

The implementation of portable generator ATS on a panel box base plate is shown in Figure 7. There are 2 (two) circuit boards mounted on the base plate. The first circuit board is the ATtiny2313 microcontroller circuit completed with voltage sensors, actuator dri-vers and power supply. Second circuit board is a floa-ting mode battery charger. The assembled portable ge-nerator ATS inside a panel box is shown in Figure 8.

The assembled portable generator ATS has been tested its functionality under several conditions. In the first test the ATS is loaded with a group of six 15-watt incandescent lamps. The reason of using lighting load is that the transition between the sources of electricity can be indicated by its light. The ATS is wired to PLN network as prime source and also wired to portable generator as secondary source. The portable generator is of YAMAWA type YMW4500XE with power capacity of 3000 VA at 220 volt, 50 hertz working voltage. The test bench and its photograph are shown in Figure 9 and Figure 10. The test procedure is explained as follows. First the load is fed through PLN network for 15 minutes, and then the electricity supply is cut out by breaking circuit breaker Q1. And then the load is connected to portable generator by closing circuit breaker Q2 which is installed on portable generator for 15 minutes. And then electricity supply from PLN network is fed to ATS by closing circuit breaker Q1, hence there are 2 supplies available for the lamps. The states of contactor K1, contactor K2 and buzzer are observed and results are presented in Table 1.

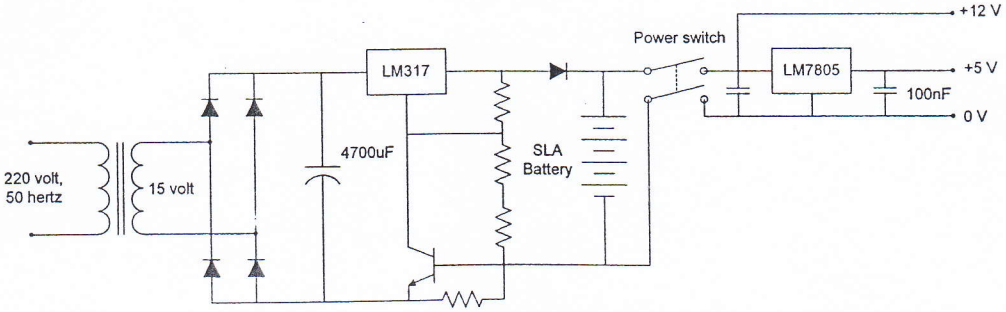

Figure 6. Battery charger and power supply circuit diagram

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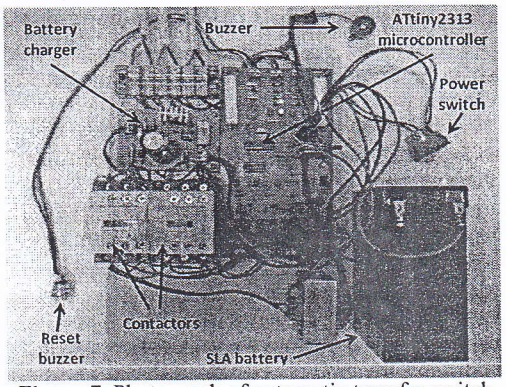

Figure 7. Photograph of automatic transfer switch components

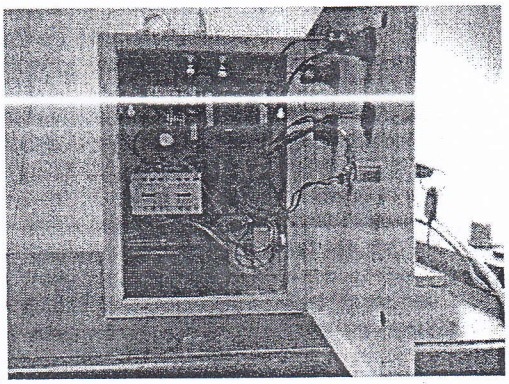

Figure 8. Photograph of assembled automatic transfer switch inside panel box

Observation results presented in Table 1 show that if electricity is available at both utility network and portable generator at the same time, then the ATS will transfer its contacts from portable generator to utility network so that the lamps will be connected to utility network. In this condition buzzer will sound. Buzzer will only stop sounding if the engine is shut down and pushbutton switch RESET BUZZER is pushed for a while.

The second test is ATS functional test using dyna-mic load. A 1.5 hp (1.1 kW) motor compressor has

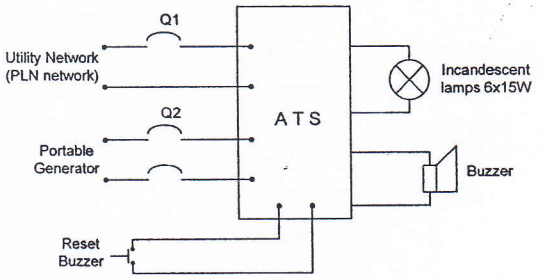

Figure 9. ATS loading test bench using 6x15W incandescent lamps

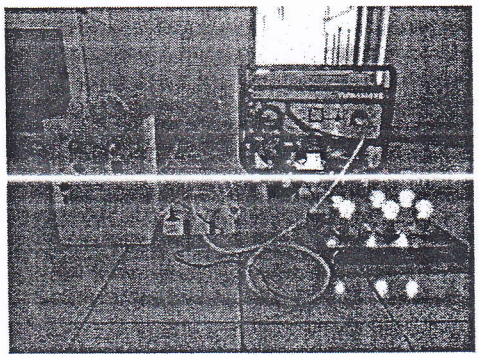

Figure 10. Photograph of ATS loading test using incandescent lamps, electricity from PLN network and portable generator available at the same time.

been loaded to the ATS for this purpose. The test bench with its photograph is shown in Figure 11 and Figure 12. Test procedure is similar to previous test with lighting load. The observation results are presented in Table 2.

Observation results presented in Table 2 show that if electricity is available at both utility network and portable generator at the same time, the ATS will transfer its contacts from portable generator to utility network so that the motor compressor will be connected to utility network. In this condition buzzer will sound and will only be stopped if electricity supply from portable generator is cut out and push-button switch RESET BUZZER is pushed for a while.

Table 1. Result observation of ATS loading test using 6x15W incandescent lamps

PLN supply state	Portable generator supply state	RESET BUZZER pushbutton switch state	Contactor K1 state	Contactor K2 state	Buzzer state	Load state (lighting load)
Available	Unavailable	open	energize	deenergize	deenergize	ON
Unavailable	Unavailable	open	deenergize	deenergize	deenergize	OFF
Unavailable	Available	open	deenergize	energize	deenergize	ON
Available	Available	open	energize	deenergize	energize	ON
Available	Unavailable	open	energize	deenergize	energize	ON
Available	Unavailable	close (pushed)	energize	deenergize	deenergize	ON

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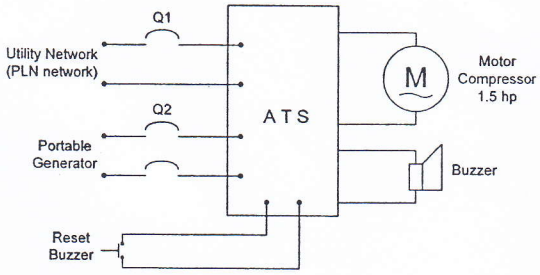

Figure 11. ATS loading test bench using motor compressor 1.5 hp (1.1 kW)

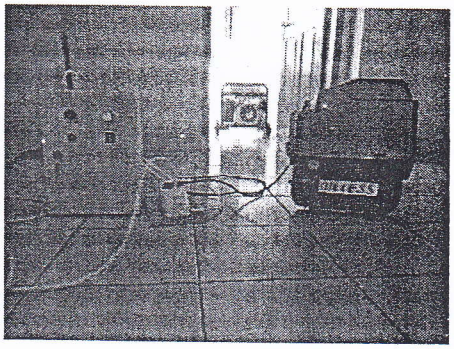

Figure 12. Photograph of ATS loading test using motor compressor 1.5 hp (1.1 kW), electricity supplied from PLN network

Table 2. Result observation of ATS loading test using motor compressor 1.5 hp (1.1 kW)

PLNsupply state	Portable generator supply state	RESET BUZZER pushbotton switch state	Contactor K1 state	Contactor K2 state	Buzzer state	Load state (motor compressor)
Available	Unavailable	open	energize	deenergize	deenergize	running
Unavailable	Unavailable	open	deenergize	deenergize	deenergize	stop
Unavailable	Available	open	deenergize	energize	deenergize	running
Available	Available	open	energize	deenergize	energize	running
Available	Unavailable	open	energize	deenergize	energize	running
Available	Unavailable	close (pushed)	energize	deenergize	deenergize	running

V. CONCLUSION

A 6600 VA rated portable generator ATS was designed and assembled in a compact panel box. The ATS design is made to satisfy standard type ATS which provides only 3 (three) basic functions as they are to monitor the state of utility supply, to monitor portable generator supply and to make transition between the sources of supply at the right time. Low cost ATtiny2313 microcontroller was selected as process controller of the ATS. Altogether with simple voltage sensor circuits and actuator circuits created a cost effective electronic system. Functional tests by loading the ATS with lighting load and dynamic load show that the apparatus is able to transfer its contacts at the right time so that the continuity of electrical supply to the load can be maintained. Bringing simplicity and low cost design, this ATS might be used widely in residential and small business installations.

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