Automatic transfer switch (ATS) using programmable logic controller (PLC)

hamdy ashour

Mechatronics, 2004. ICM'04. Proceedings of the ...

Automatic Transfer Switch (ATS) Using Programmable Logic Controller (PLC)

Dr. Hamdy Ashour
Arab Academy for Science &Technology
Department of Electrical & Computer Control Engineering
P.O. 1029 Miami, Alexandria, Egypt
hashour@aast.edu

Abstract:
In the industrial engineering education curriculum, advanced manufacturing technology is so important to provide the students with effective industrial instructions and enrich their practical skills through the continuous development of laboratory industrial resources. Hence, the author has developed an automatic transfer switch (ATS) based on a programmable logic controller (PLC) in the laboratory of the Arab Academy for Science &Technology (AAST) as an industrial case study for the students through the course of industrial automated systems. General concepts and practical considerations of the ATS have been discussed. Steps of designing and implementing the proposed setup, including system requirements, sensors, actuators, hardware configuration, software programming and experimental testes, are demonstrated. The proposed setup has been found so effective not only in increasing students industrial knowledge and skills but also can be used as a stand-alone system in commercial and industrial practical fields.

1. Introduction

As new manufacturing technologies become available and since existing manufacturing technologies become more integrated, industrial engineering departments must continuously developed their laboratory resources in order to provide their students with effective instructions [1]. Automatic transfer switch (ATS) is an important component in many electrical power systems. High voltage ATS ratings and selectively features are discussed in [2]-[4]. Currently, many manufacturing functions are automated through the use of computers (PC), micro-controllers (μC) and programmable logic controllers (PLC) [5]. PLCs have become at the forefront of manufacturing automation due to their simple, robust and reliable hardware connections and software programming techniques [6]-[7]. PLCs have been effectively used in process control [8]-[9] and electrical power systems, such as tap-changer, substation control and protection [10]-[13], and etc.

2. General Concepts

Feeding different loads in the low voltage distribution systems, such as residential, commercial and industrial areas, depends on the requirements and importance of each load. Some loads may only be fed from the main source while others could be fed from different backup sources. Figure 1 illustrates a distribution system having different supply sources. The designer may categorize loads according to their importance as follows: -

a- Normal loads: such as lighting and outlets. Such loads are fed from only one source (the main), hence if the main is off, these loads will be off.

b- Emergency loads: such as emergency lighting and lifts. These loads are normally fed from the main source and in case of main power failure; the emergency generator will feed such loads as a backup source through the ATS system till the main source is on again.

c- Important loads: such as hospital operation and intensive care rooms. These loads could be fed from three different backup sources, the main source, the emergency generator and the uninterrupted power supply (UPS). In case of fault in the main source and the emergency generator, these important loads can be fed from the UPS through the transfer switch (TS). Such important loads are off-line fed from the UPS through the TS, hence should accept the small shut down period due to the transition of the TS. This transfer switch (TS) may also be automatic, and in this case static switches are recommended for their fast switching response [14].

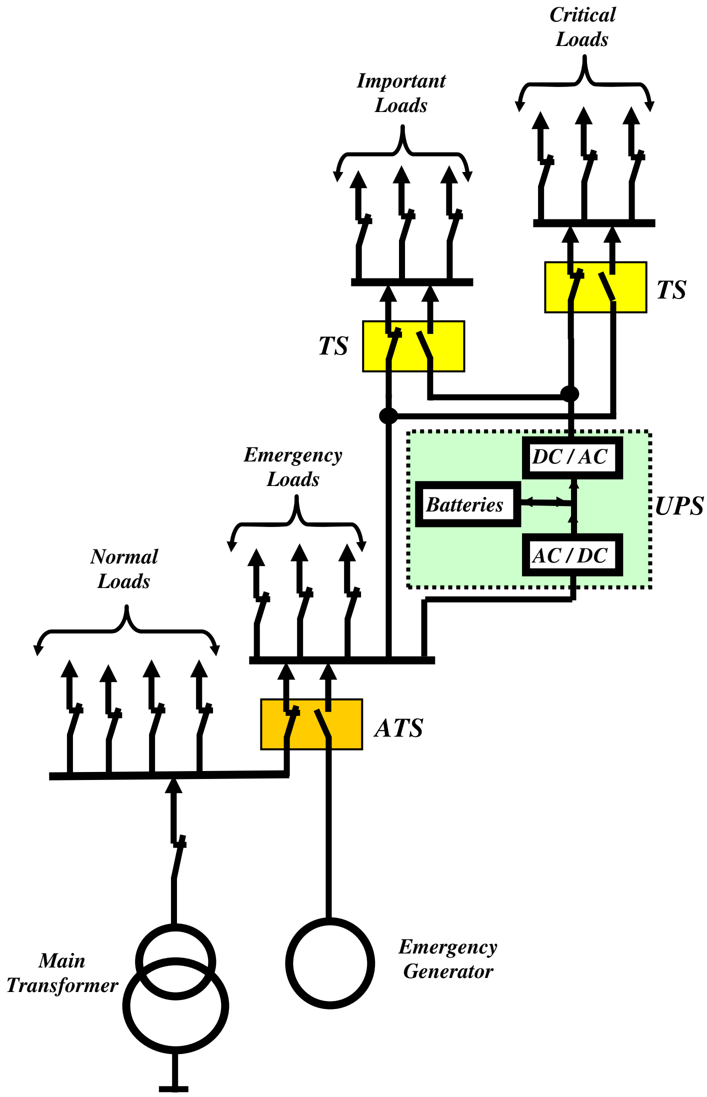


Figure 1: Distribution of loads

d- Critical loads: such as electronic, control and protection equipments. Such critical loads do not accept any interruption in the electrical power; hence they are on-line fed from the UPS. The UPS converts the AC voltage, coming from the main or from the backup generator, to DC voltage (using AC to DC power electronics converter) for charging the batteries bank and feeding the critical loads through the DC to ac inverter. In case of main and emergency power failure, the batteries bank will instantaneously feed the critical loads through the DC to AC inverter without any power interruption. A manual transfer switch (TS) may be utilized in case of maintenance of the UPS unit.

It should be noted that all loads are categorized according to the customer requires and load priorities, hence determining equipment sizes and the overall cost. Transformer size is determined by the sum of all loads while generator size is chosen depending on the sum of emergency, important and critical loads. The UPS capacity should cover both important and critical loads.

3. Practical Considerations

Automatic transfer switches are used to serve a continuous power for the load by automatic transferring between two or more sources when the main source are down or decreased below a certain limit. The ATS automatically disconnects the faulty source and connects the load to the other healthy source. Some practical consideration should be taken into account when ATS systems are utilized, such as:

a- Voltage: The voltage regulation of the back up source should be between the permissible ranges. This could be fulfilled using an automatic voltage regulator (AVR) unit to automatically control the excitation of the generator, hence the output voltage. In the UPS, the DC to AC inverter is controlled to match voltage requirements.

b- Frequency: The generator frequency is determined by the speed of the driving engine, which is provided by a closed loop speed control system to supply the electrical loads with the standard frequency. The UPS normally operated at a fixed output frequency (50 Hz or 60 Hz according to the country standards).

c- Synchronization: In case of the utilization of more than one backup sources, such as two emergency generators or the main it self consists of main transformer and main generator, synchronization conditions (same voltage, frequency, phase sequence and phase shift) should be considered before transferring the power through the ATS.

4. Implementation

Steps of the design and implementation of a digitally controlled industrial system could be summarized as: -

1- Specify system general requirements.
2- Verify the suitable controller, sensors and actuators.
3- Connect the power and control circuits.
4- Write down the software algorithm.
5- Test practically the whole system.

Such design steps for the proposed ATS using PLC will be discussed through the following sections.

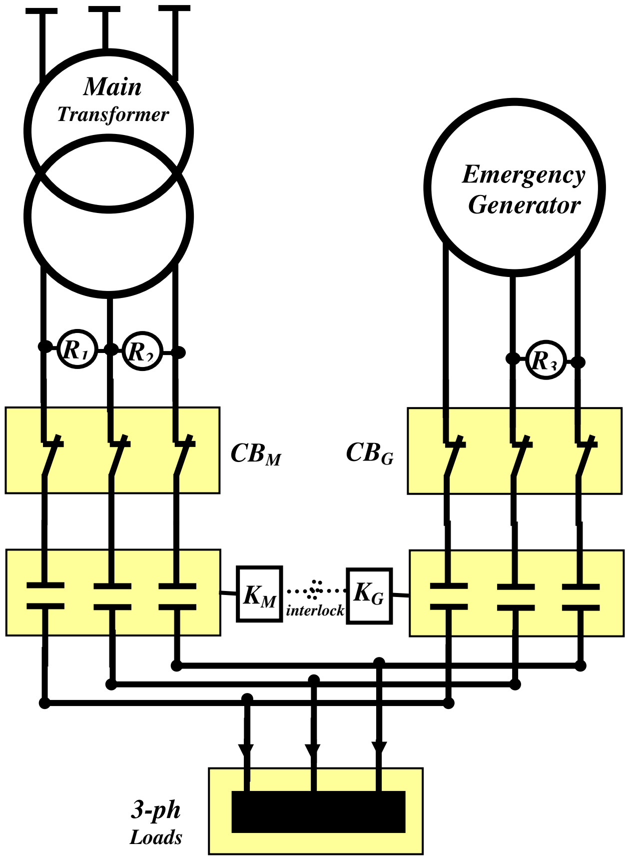


Figure 2: Connection of power circuit

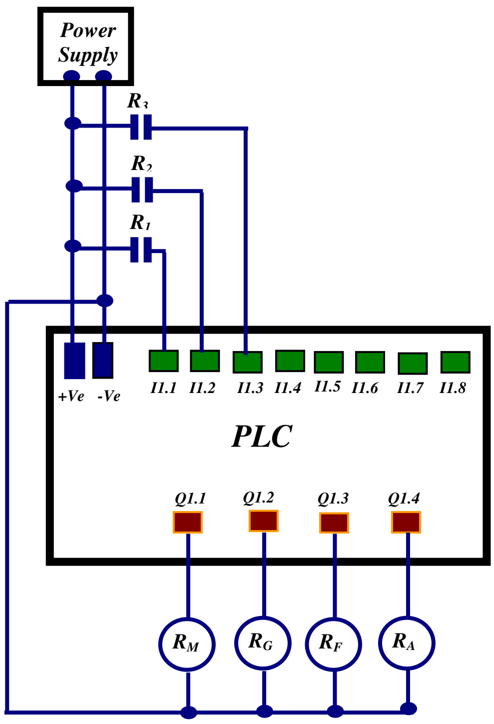


Figure 3: Connection of control circuit

4.1 System Requirements

The basic function of the proposed ATS is to transfer the loads to the generator incase of main failure then back to the main in healthy condition. The sequence of operation can be summarized as:

1. Incase of main source failure detection, disconnect the loads from the main.
2. Start the generator engine unit.
3. If the generator output voltage is stable and reach the required value, then connect the loads to the generator.
4. If the main is back and stable, disconnect the loads from the generator then connect them back to the main.
5. Stop the generator unit.

4.2 Sensors and Actuator

Sensor: The main and emergency voltage signals should be monitored by the PLC. Simple relays are proposed to detect these voltages as their coils are connected to the line voltages while their contacts are connected to the control circuit (the inputs of the PLC). R_1 is for main voltage $V_{M\ (R\text{-}S)}$, R_2 is for main voltage $V_{M\ (S\text{-}T)}$, and R_3 is for generator voltage $V_{G\ (R\text{-}S)}$.

Actuators: Two contactors, mechanically and electrically interlocked, are proposed (K_M and K_G). The coils of these power contactors are tripped through the control relays (R_M and R_G) as outputs of the PLC. Other two PLC output signals (R_F and R_A) are required to start the engine and build up voltage from the generator. Two circuit breakers (CB_M and CB_G) should be provided for protection of the power circuits.

Practically, the engine may require ignition signal and fuel feeding signal. However, in the proposed laboratory setup, no engine was valid, and a DC motor with a DC power electronic speed control unit is utilized to drive the synchronous generator. Hence the two relays (R_F and R_A) are now used for the field and armature of the DC drive unit.

4.3 Hardware connections

Power circuit: Connections of the power circuit are shown in figure 2, where the 3-ph loads can be fed either from the main or the emergency generator through the contactors (K_M and K_G) and circuit breakers (CB_M and CB_G).

Control circuit: A PLC is utilized to control the system to achieve the requirements. Connections between the PLC and all sensors and actuators are shown in figure 3.

4.4 Software programming

The sequence of operation for the proposed setup can be summarized as:

Fault condition:

If any phase of the main source is out (***R_1 or R_2 is OFF***):

1- instantaneously, disconnect the main source through its contactor (***R_M is OFF***).

2- after time delay (***T1***), start the generator (***R_F is ON***).

3- after time delay (***T2***), built up voltage from the generator (***R_A is ON***).

4- check for the generator output voltage (***R_3 is ON***).

5- if yes and stable for time period (***T3***), connect the generator through its contactor (***R_G is ON***).

Normal condition:

If non of the main source phases is out (***R_1 and R_2 are ON***)

1- if yes and stable for time period (***T4***), disconnect the generator through its contactor (***R_G is OFF***).

2- after time delay (***T5***), connect the main through its contactor (***R_M is ON***).

3- after time delay (***T6***), shutdown the generator unit (***R_F and R_A are OFF***).

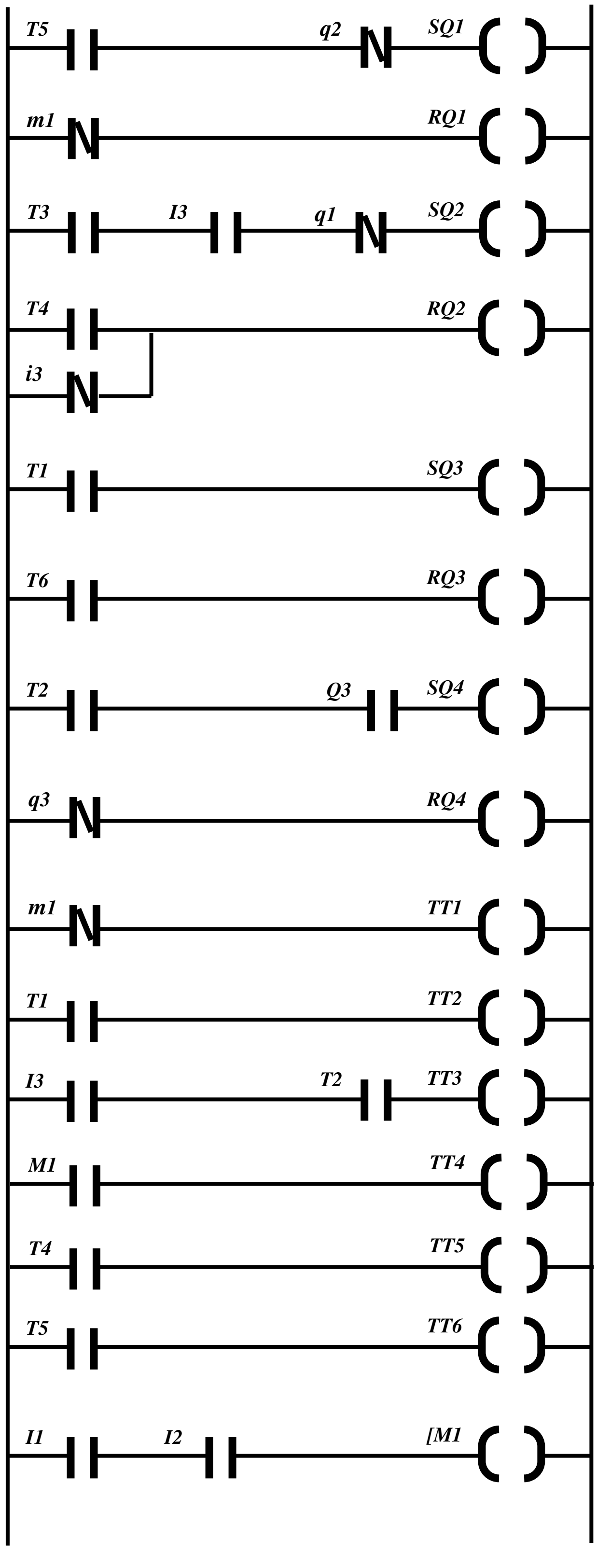


Figure 4: Ladder diagram of the PLC program

The ladder program, shown in figure 4, has been developed using PC software provided with the PLC. Program symbols are listed in table1. The program has been simulated then downloaded to the PLC using the provided PC program. It should be noted that timer values could be individually set according to system requirements and restrictions.

Symbol	*Type*	**Comment**
I1	Input	Main voltage ($V_{M\,(R\text{-}S)}$)
I2	Input	Main voltage ($V_{M\,(S\text{-}T)}$)
I3	Input	Generator voltage ($V_{G\,(R\text{-}S)}$)
Q1	Output	Main contactor
Q2	Output	Generator contactor
Q3	Output	Star the generator unit
Q4	Output	Generator voltage build up
M1	Marker	$\overline{Fault}$ / Normal condition
T1	Timer	To disconnect the main and start the generator
T2	Timer	To build up generator voltage
T3	Timer	To connect generator
T4	Timer	To disconnect the generator
T5	Timer	To connect the main
T6	Timer	To stop the generator unit

Table 1: List of program symbols

Case	*Figure*	*Load*	*Main*	*Generator*
Normal Operation	*6a*	*from OFF to ON*	*ON*	*OFF*
Main Failure	*6b*	*from ON to OFF*	*from ON to OFF*	*OFF*
Generator Starting	*6c*	*OFF*	*OFF*	*from OFF to ON*
Emergency Operation	*6d*	*from OFF to ON*	*OFF*	*ON*
Back to Normal	*6e*	*ON*	*ON*	*from ON to OFF*

Table 2: List of experimental tests

Figure 5: The experimental setup

4.5 Experimental Tests

The overall setup has been implemented as shown in figure 5. Voltage waveforms of the load, main source and emergency generator are scored using digital storage oscilloscope under the control of the PLC for different cases listed in table 2 and illustrated in figure 6.
From figure6 it can be seen that the proposed ATS using the PLC has effectively fulfilled the required sequence of operation in order to supply the load with power from two different backup sources under normal and fault conditions. The system has been implemented as a practical case study though the course of *industrial automated system* and has been found so effective and helpful not only in practicing the academy students on the actual industrial systems, but also providing a good example for teaching such industrial courses. It should be noted that the proposed system has been implemented in such industrial form to be directly utilized in industrial and commercial actual applications.

5. Conclusions

This paper demonstrated steps for designing and implementing an automatic transfer switch using a programmable logic controller. The proposed setup has been developed in the Arab Academy for Science & Technology as a part of educational course in order to improve student capabilities and enrich their knowledge of the advanced manufacturing technology applied to the industrial engineering applications. The overall system has been found simple and effective to be used in different educational, commercial and industrial applications.

References

[1] C. A. Chung, "A cost-effective approach for the development of an integrated PC-PLC-robot system for industrial engineering education", IEEE Transactions on Education, Vol.41, Nov., 1998, pp.306-310.

[2] R. A. Simmons and F. J. Salem, "High voltage automatic transfer switch: going beyond normal distribution solutions", 9th Inter. Conf. On Harmonics and Quality of Power, Vol. 3, 2000, pp. 882-886.

[3] R. E. Cousy, "Transfer switch ratings `without fuses or circuit breakers", IEEE Trans. on Power Delivery, Jan., 1990, pp.202-203.

[4] R. E. Cosse, J. E. Bowen and W. H. Nichols, "Is selectivity achieved in critical low-voltage UPS and standby generator power circuits?", IEEE Trans. On Industry Applications, Vol. 37, Jul., 2001, pp 1140-1151.

[5] R. Walter, "A concept of factory automation", IEEE Trans. on Manufacturing Technology, Dec., 1975, pp.56-58.

[6] K. T. Erickson, "Programmable logic controllers", IEEE Potentials Vol.15, Feb., 1996, pp. 14-17.

[7] E. A. Parr, "Programmable controllers: an engineer's guide", Newnes, 1997.

[8] A. Hossain and M. H. Rashid, "The hardware and software interface of a programmable logic controller to an industrial grade process control system", IEEE Annual Conf. of Industry Applications Society, Vol. 2, Oct., 1990 , pp.1862 –1868.

[9] J. E. Wilson and F. Bried, "Application of programmable logic controllers for pipeline local and remote control" IEEE Trans. on Industry Applications, Vol. 24, Nov., 1988, pp.1082–1088.

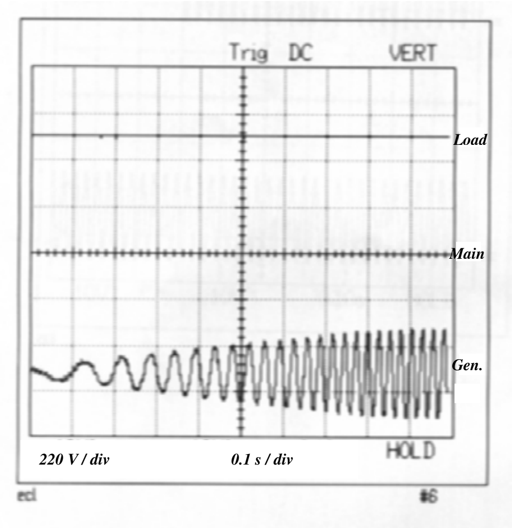
[10] E. Bundesmann and R. Thompson, "Interfacing programmable logic controllers to electrical distribution monitoring systems", IEEE 4th Annual Conf. on Elec. Eng. Problems, Apr., 1993, pp. 46 –55.

[11] D. L. Bassett, "Control of tap change under load transformers through the use of programmable logic controllers" IEEE Trans. On Power Delivery, Oct., 1993, pp. 1759-1765.

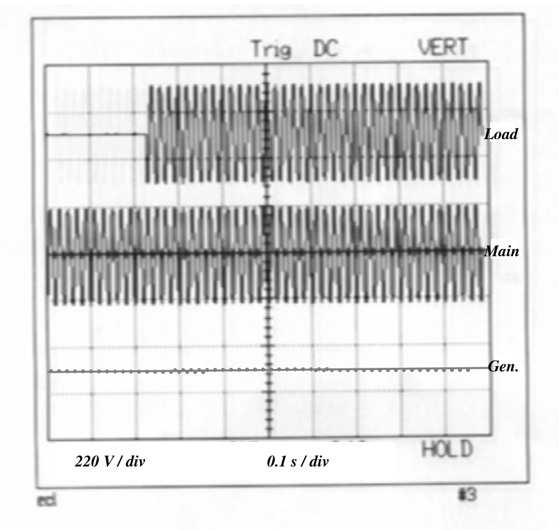
[12] J. G. Gilbert and G. R. Diehl, "Application of programmable logic controllers to substation control and protection", IEEE Trans. on Power Delivery, Jan., 1994, pp. 384-393.

[13] B. Kasztenny, E. Rosolowski, J. Izykowski, M. M. Saha and B. Hillstrom, "Fuzzy logic controller for on-load transformer tap changer", IEEE Trans. On Power Delivery, Vol.13, Jan., 1998, pp. 164-170.

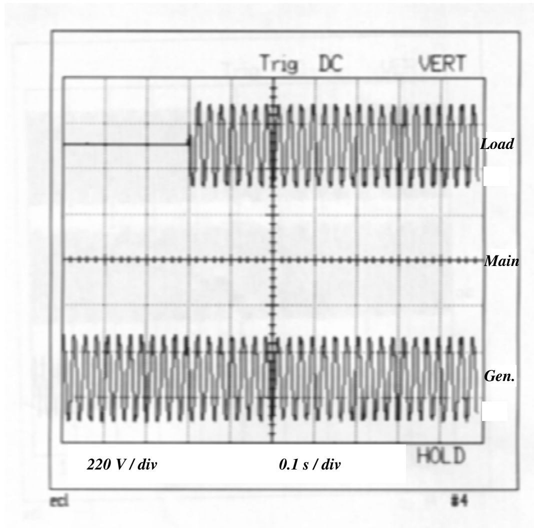
[14] M. Rasihd, "Power electronics: circuits, devices, and applications", Prentice Hall, 1993.



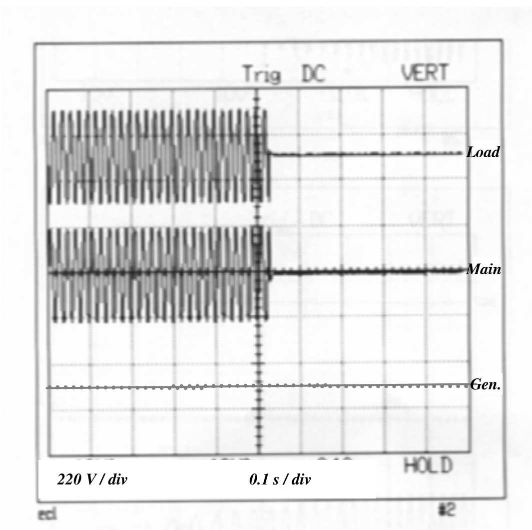
c) Load: OFF
Main: OFF
Gen.: from OFF to ON



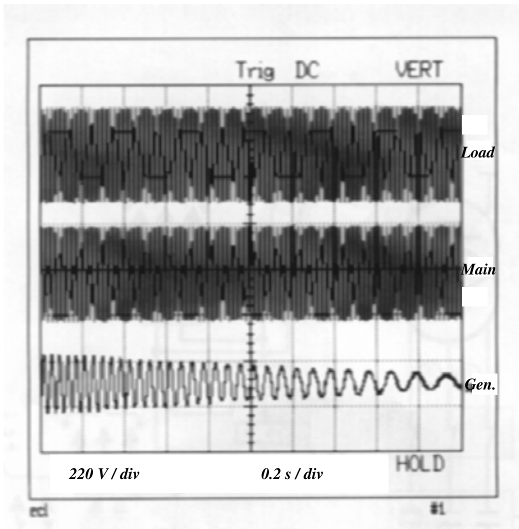
a) Load : from OFF to ON
Main: ON
Gen. : OFF



d) Load: from OFF to ON
Main: OFF
Gen.: ON



b) Load: from ON to OFF
Main: from ON to OFF
Gen.: OFF



e) Load: ON
Main: ON
Gen.: from ON to OFF

Figure 6: Experimental voltage waveforms for different cases of operation