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A Novel Fully Controllable Rotary Switch for Electrical Installation in Buildings

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ABSTRACT. In an electrical installation in buildings, electromechanical switches are mostly used to turn on and off a load. However, sometimes there are two or more switches in the same circuit intended to control the same load. Thus, a conflict can happen between multi-users who are trying to overtake the control of the load (such as turning it on or off). To solve the problem, this paper proposes a novel switch called "Fully Controllable Rotary Switch" (FCRS) in which it can fully control not only the load but also other switches by blocking them or giving them limited or full access over the electrical circuit and the loads. For validation purposes, the utilization of FCRS in buildings is compared to the traditional switches under the same functionality and conditions. Results show that FCRS has the ability to control many electrical loads simultaneously, control other switches in the circuit, increase the satisfaction, security, and privacy of the users. Finally, it reduces the conflict between multi-users and the investment cost by avoiding installing additional switches and protection devices.

Keywords: Rotary switch, Switch, Buildings, Electrical installation, Control loads.

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NOMENCLATURE

1P1T	Single pole, Single Throw Switch
1P2T	Single pole, Double Throw Switch
1PNT	Single pole, N-Throw
2P1T	Double Pole Single Throw Switch
2P2T-R	Double pole, double throw with reverse polarity
DPDT	Double Pole Double Throw Switch
DPST	Double Pole Single Throw Switch
MPNT	M pole, N throw
SPDT	Single Pole Double Throw Switch
SPST	Single Pole Single Throw Switch

1. INTRODUCTION

1.1 Background and motivation

In electrical engineering, a switch is a component that is able to turn on and off one or more electrical elements, connect or disconnect the conducting path in an electrical circuit, divert the electric current from one conductor (or wire) to another, and interrupt the electric current flow in a conductor [1, 2]. Electromechanical device switches are considered the most common switches, which consist of one or more sets of movable electrical contacts connected to external circuits [3, 4]. When the pair of contacts in the switch are touching (also called closed contact), the current flows in the circuit, and the electrical elements are turned on. When the contacts are separated (also called open contacts), the current cannot flow, and the electrical elements are turned off [4, 5].

Different configurations exist for the switches. Switches may have many sets of contacts controlled by the same actuator or knob, and the contacts can operate alternately, sequentially, or simultaneously [6]. Switches can operate manually (e.g., light switch), or using a sensing element (e.g., temperature sensor, motion sensor, etc.) [6]. There are many existing forms of switches such as circuit breakers, relays, reversing switches, push-button switches, mercury switches, rotary switches, and toggle switches [7-9]. Despite the different forms of switches, they function in the same way in which they open or close electrical contacts to control the current flow in conductors. Usually, each contact is connected to only one conductor. Hence, the question that arises, what happens if one electrical contact in the switch can be connected to two or more other terminal contacts instead of just one? Will it give

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more controllability to the user and increase security? Will it facilitate the daily usage of electricity, especially in buildings? What if many users have access to control a certain load simultaneously, which of them will have more privilege than others to control the load? To the best of the author's knowledge, the existing switches cannot answer these questions and cannot meet the requirements of certain users. Hence, a new type of switches should be designed to answer all these questions.

1.2 Literature review

In the field of electrical installation in buildings, switches play an important role in controlling electrical elements by turning them on or off, such as light bulbs, fans, air conditioners, water heaters, and many others [10, 11]. The most familiar form of switches is manual-based mechanical devices with one or more sets of electrical contacts connected to external circuits. A set of contacts is composed of two contacts that can be either connected or not connected. If they are connected, the current flows in the circuit, and we call it "closed". In case they are not connected, we call it "open" since the current cannot flow in the circuit. Fig. 1 presents the difference between closed and open contacts.

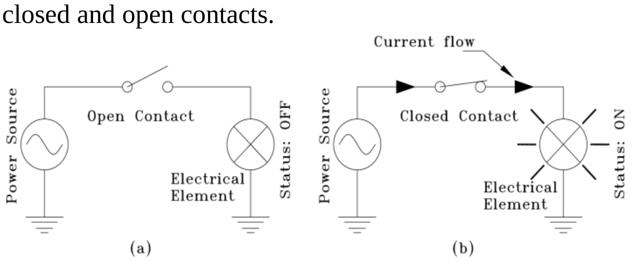


Fig. 1. Open and closed contacts of a switch.

A switch can have many poles and throws. The number of poles is the number of an electrically separate set of contacts that are controlled by a single physical actuator. Fig. 2 shows examples of different forms of switches with a different number of poles. The one-pole switch can be used for a single-phase circuit in which it can only connect or disconnect a phase. A double-pole switch has two separate parallel sets of contacts, which open and close simultaneously via the same mechanism. This can be used to separate the phase and neutral in a single-phase circuit, or 2 phases in a two-phase circuit, etc., [12-14].

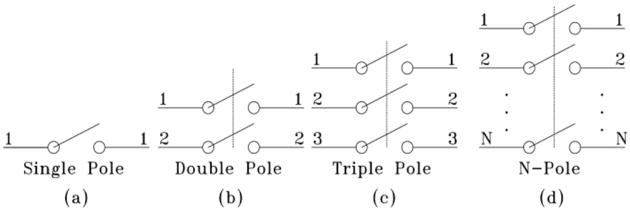


Fig. 2. Different number of poles in a switch.

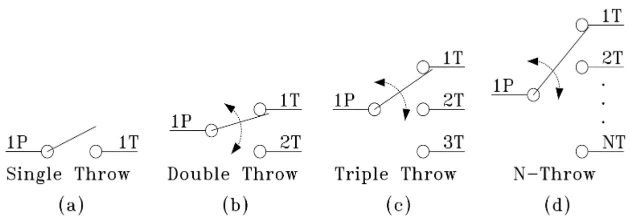
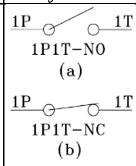
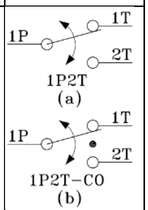
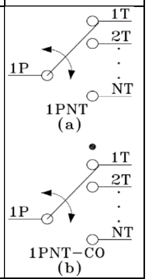
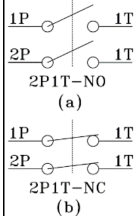
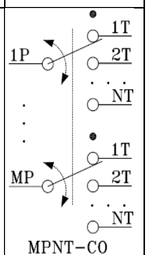
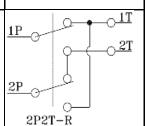


Fig. 3. Different number of throws in a switch.

The number of throws presents the number of available paths for each pole in which the switch can adopt [12-14]. Fig. 3 shows different number of throws in a switch. If a switch has only one throw, it can only control one circuit. If a switch has two throws, it can maximum control two circuits, and the current can flow either in the first or in the second circuit and not both simultaneously.

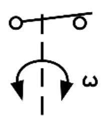
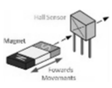
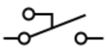
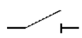
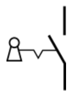
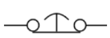
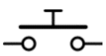
Table 1. Most common switches.

Abb.	Name	Description	Symbol
SPST 1P1T	Single pole, single throw	A simple on-off switch. The two terminals are either connected or disconnected. If the two terminals are normally disconnected, the switch is called Normally Open (1P1T-NO). If the two terminals are normally connected, the switch is called Normally Closed (1P1T-NC), [15-17].	
SPDT 1P2T	Single pole, double throw	Two possible switches can be in this case. (a) 1P2T in which the 1P terminal is either connected to 1T or to 2T. (b) 1P2T-CO has an additional center-off position (CO) in which 1P terminal can rest, and it is not connected to any other terminals (1T nor 2T). So, the possible positions, in this case, are, CO, 1T, and 2T, [15-17].	
1PNT	Single pole, N-Throw	Two possible switches can be in this case. (a) 1PNT in which the 1P terminal is connected to one of the throw terminals, 1T, 2T, …, or NT. (b) 1PNT-CO has a center off position (CO) in which 1P terminal can rest and it is not connected to any other terminals (1T, to NT). The possible positions in this case are CO, 1T, 2T, …, NT.	
DPST 2P1T	Double pole, single throw	Equivalent to two parallel 1P1T switches controlled by a single mechanism. There are two possibilities. (a) 2P1T-NO, in which a set of contacts is in the initial position normally open (NO). (b) 2P1T-NC in which a set of contacts is in the initial position normally closed (NC), [15-17].	
MPNT	M pole, N throw	Equivalent to M parallel 1PNT switches controlled by a single mechanism. There are two possibilities. (a) MPNT, in which the first terminal (1P, 2P, …) is connected to one of the existing N terminals (1T, 2T, …, NT). (b) MPNT-CO, in which the first terminal (1P, 2P, …) can have a rest position and may not be connected to any of the N terminals (1T, 2T, …, NT).	
2P2T-R	Double pole, double throw with reverse polarity	The switch is able to reverse polarity by changing its position. The first position, 1P terminal is connected to 1T, and 2P is connected to 2T. Once the switch is pressed, the polarity is changed and 1P terminal becomes connected to 2T, and 2P becomes connected to 1T, [15-17].	

The number of throws presents the number of available paths for each pole in which the switch can adopt [12-14]. Fig. 3 shows different number of throws in a switch. If a switch has only one throw, it can only control one circuit. If a switch has two throws, it can maximum control two circuits, and the current can flow either in the first or in the second circuit and not both simultaneously.

Table 1 shows the most common switches used in electrical installation in buildings. For lighting, 1P1T (one-pole, one-throw), 1P2T (one-pole, two-throw), and 2P2T-R (polarity-reversal two-pole, two-throw) are mostly used.

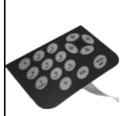
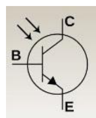
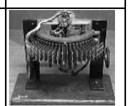
Table 2. Other type of switches Part I.

Name	Description	Picture / Symbol
Centrifugal switch	It operates using the centrifugal force resulting from a rotating shaft (e.g., electric motor,and gasoline engine). It is designed to activate or de-activate as a function of the rotational speed of the shaft[18].	
Company switch	Itis used for power distribution systems in convention centers, arenas, theaters, etc.,that often require panel boards for electrical equipment. It is designed to be easy to use, easily portable, safe and fast[19].	
Dead man's switch	It is a switch designed to be activated or deactivated if the human operator becomes incapacitated (i.e., through death, loss of consciousness, or being bodily removed from control). It can be applied to switch on/off vehicle, machine, computer, etc.[20].	
Fireman's switch	It allows firefighters to quickly disconnect power from high voltage devices that may cause a danger inemergencycases [21].	
Hall effect sensor	It is a type of sensor which detects the presence and magnitude of a magnetic field using the Hall effect[22]. It is used for proximity sensing, positioning, speed detection, and current sensing applications. Usually, it is combined with threshold detection to act as a binary switch. Hall effect sensors are used in industrial applications and in consumer equipment (i.e., detecting missing papers in some computer printers).	
Inertial switch	It is an electrical switch which is firmly mounted upon some equipment such as a vehicle or other mobile device, that triggers in the event of shock or vibration[23, 24]. Once it is triggered, it may either enable or disable some functions such as stopping the fuel pump during a car collision or accident in order to avoid fire hazard.	
Isolator switch	It is used to ensure that an electrical circuit is completely disconnected for service or maintenance [25].	
Key switch	It is a key-operated switch.It is used in situations where access needs to be restricted to the switch's functions such as lunching nuclear missiles [26, 27].	
Emergency switch	It is a safety mechanism used to shut off machinery in an emergency, when it cannot be shut down in the usual manner.	
Latching switch	A latching switch is a switch that maintains its state after being activated.[1] A push-to-make, push-to-break switch would therefore be a latching switch – each time you actuate it, whichever state the switch is left in will persist until the switch is actuated again[28].	
Light switch	It is used to turn on/off electric lights, permanently connected equipment, or electrical outlets. Different types exist including: (a) and remotely controlled switches and dimmers; (b) occupancy-sensing switches; (c) time-controlled switches; (d) dimmer switches that allow controlling the brightness of lamps as well as turning them on or off; and (e) light switch mounted on the socket, base, or in-line with the cord.	
Pull switch	It is actuated by means of a chain or string. Once the string is pulled, one pull is to switch on and next pull is to switch off. Mostly used to turn on/off ceiling lights and fans[29].	

1.3 Other types of switches

There are other types of switches that can have different functionalities. **Table 2** and **Error! Not a valid bookmark self-reference.**show the 20 most used switches in engineering. In addition, we classify the switches into many categories as depicted in **Fig.4**.

Table 3. Other type of switches Part II.

Name	Description	Picture / Symbol
Membrane switch	It is an electrical switch for turning on/off a circuit. It is a circuit printed on Polyethylene terephthalate or Indium tin oxide in which it is mostly used as user-equipment interface utilities that allow for the communication of commands from users to electronic devices such as printer, keyboard, etc., [30].	
Optical switch	It amplifies weak optical signals from the input. Light occurring on an optical transistor’s input changes the intensity of light emitted from the transistor’s output while output power is supplied by an additional optical source. It is mostly used in optical computing and fiber-optic networks[31].	
Piezo switch	It generates electric charge when certain materials are under stress or pressure. It works using Piezoelectric effect. The stress could be a force from compressive pressure that causes the piezo element to bend very slightly like a drumhead and be activated.	
Push button switch	It is a momentary or non-latching switch which causes a temporary change in the state of an electrical circuit only while the switch is physically actuated. An automatic mechanism (i.e. a spring) returns the switch to its default position immediately afterwards, restoring the initial circuit condition [32].	
Stepping switch	It is an electromechanical device that switches an input signal path to one of several possible output paths, directed by a train of electrical pulses[33].	
Time switch	It is a timer that operates an electric switch controlled by the timing mechanism (could be mechanical or electronic). It has several applications, as an example, a sleep timer is a function on many modern televisions and other electronic devices that shuts off the power after a preset amount of time[34].	
Touch switch	It is a type of switch that only has to be touched by an object to operate. It is used in many lamps and wall switches that have a metal exterior as well as on public computer terminals. A touchscreen includes an array of touch switches on a display. A touch switch is the simplest kind of tactile sensor.	
Transfer switch	It switches a load between two sources. It can be manual (by throwing a switch), or automatic (when it senses one of the sources has lost or gained power). As an example, an Automatic Transfer Switch (ATS) is often installed where a backup generator is located, so that the generator may provide temporary electrical power if the utility source fails[35].	

1.3 Contribution

The main problem of the existing architecture of the switches is that they are not able to connect more than one circuit at a time (e.g., 1P terminal cannot be connected to 1T and 2T terminals simultaneously in the switch 1P2T). In addition, they do not give the user a full control of all circuits especially when more than one switch is located on the same circuit. Therefore, an original switch should be developed in order to increase the controllability of many circuits at the same time. For this purpose, a novel switch called Fully Controllable Rotary Switch (FCRS) is designed in this paper, in which it increases the controllability over many circuits simultaneously, increase privacy and security, and reduce the investment cost. For validation purposes, the novel switch is compared to existing switches that are used to control electrical loads in buildings.

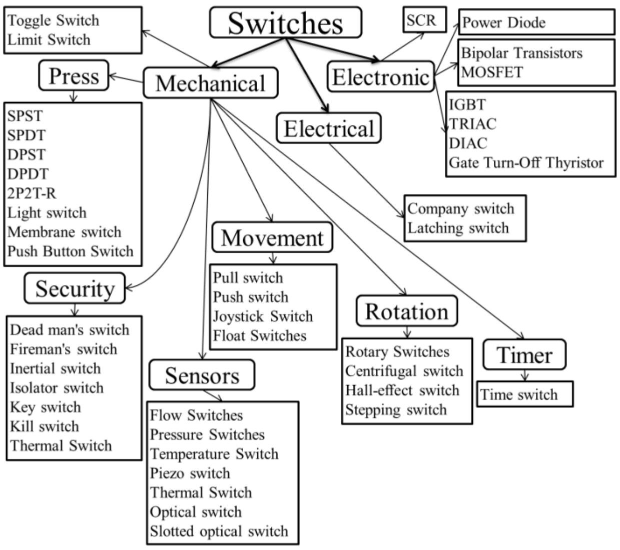


Fig.4. Classification of switches.

2. DESIGN OF A FULLY CONTROLLABLE ROTARY SWITCH

2.1 Mathematical background

The number of terminals and contacts of the Fully Controllable Rotary Switch (FCRS) depends on how many circuits we would like to control and what is the main use of it. Generally speaking, if M and N represent the number of poles and throws of the switch, respectively, the number of possible positions (P) for the contacts in the FCRS is presented in Eq. (1). As an example, if the switch has the form of 1P2T, 3 terminals exist (including the pole terminal), and the total number of possible positions is equal to $2^{(3-1)} = 4$. If the switch has the form of 1P3T, the total number of possible positions or combinations is equal to $2^{(4-1)} = 8$.

$$P = M2^{(T-1)} \tag{1}$$

The rotation angle that should separate the terminals in the switch is described in Eq. (2) and presented in Fig. 5.

$$\theta = \frac{360^o}{2^{(T-1)}} \tag{2}$$

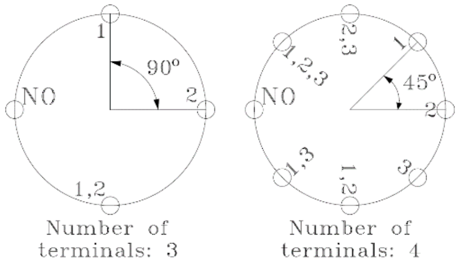


Fig. 5. Rotation angle separating the terminals.

The maximum number of connections (n) between positions is determined by Eq. (3). Where, P is the number of possible positions.

$$n = \frac{P(P-1)}{2} = \frac{M2^{(T-1)}\left(M2^{(T-1)} - 1\right)}{2} \tag{3}$$

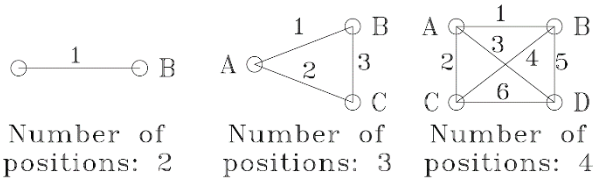


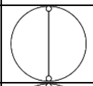
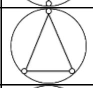
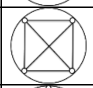
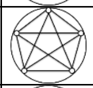
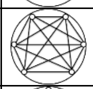
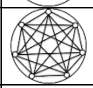
Fig. 6. Number of connections as a function of the number of positions.

The maximum number of configurations C is determined by Eq. (4) and Eq. (5), where C is a function of the number of terminals.

$$C = \sum_{i=0}^{n} \frac{(n)!}{i!\,(n-i)!} \tag{4}$$

$$C = \sum_{i=0}^{\frac{M2^{(T-1)}\left(M2^{(T-1)}-1\right)}{2}} \frac{\left(\frac{M2^{(T-1)}\left(M2^{(T-1)}-1\right)}{2}\right)!}{i!\left(\frac{M2^{(T-1)}\left(M2^{(T-1)}-1\right)}{2} - i\right)!} \tag{5}$$

Table 4. Number of connections as a function of the number of the possible positions.

Number of positions P	Maximum number of connections n	Shape of the switch	θ	maximum number of configurations
2	1		180	2
3	3		120	8
4	6		90	64
5	10		72	1,024
6	15		60	32,768
7	21		41.428	2,097,152
P	$\frac{P(P-1)}{2}$		$\frac{360^o M}{P}$	$\sum_{i=0}^{\frac{P(P-1)}{2}} \frac{\left(\frac{P(P-1)}{2}\right)!}{i!\left(\frac{P(P-1)}{2} - i\right)!}$

2.2 Design of a Fully Controllable Rotary Switch

In this section, the design of a Fully Controllable Rotary Switch (FCRS) is presented, in which only three types are shown FCRS-1P2T, FCRS-1P3T, and FCRS-2P3T. Fig.7 presents the design of a FCRS of the type 1P2T (one-pole, two-throw). Internal connections and the external look of the switch are presented in the figure. There are 4 possible connections in this switch, (a) the switch is off, (b) terminal 1P is connected to terminal 1T, (c) terminal 1P is connected to terminal 2T, (d) terminal 1P is connected to both terminals 1T and 2T. Therefore, the switch gives the user full control over the two circuits (connected to 1T and 2T), which is not the case with any traditional switch. By adding internal barriers (in Fig.7 barriers a, b, c, and d), it is possible to limit the rotation of the switch and forbid it to reach a certain position. For example, if barrier “a” and “c” are activated, the switch cannot reach the position “NO” normally open. Hence, the only states can be:

1) terminal 1P is connected to terminal 1T,
2) terminal 1P is connected to terminal 2T
3) terminal 1P is connected to both terminals 1T and 2T

In case the barriers “c” and “d” are activated, the switch cannot reach the position “1,2”, and the only states can be as follows:

1) the switch is off,
2) terminal 1P is connected to terminal 1T,
3) terminal 1P is connected to terminal 2T

From this place, adding internal barriers can increase the complexity of the switch and give it much more control over all circuits.

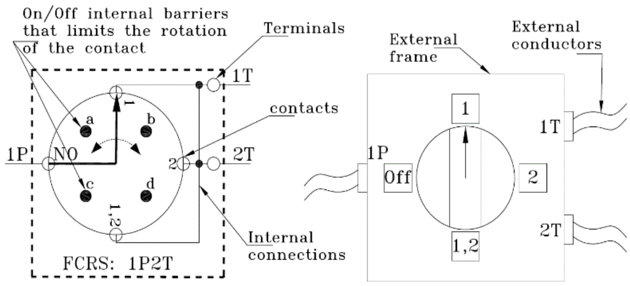


Fig.7. Internal and external design of FCRS-1P2T.

Fig.8 presents the design of a FCRS of the type 1P3T (one-pole, three-throw). Internal connection and external look of the switch are presented in the figure. There are 8 possible connections in this switch as follows:

1) the switch is off,
2) terminal 1P is connected to terminal 1T,
3) terminal 1P is connected to terminal 2T
4) terminal 1P is connected to terminal 3T
5) terminal 1P is connected to both terminals 1T and 2T
6) terminal 1P is connected to both terminals 1T and 3T
7) terminal 1P is connected to both terminals 2T and 3T
8) terminal 1P is connected to all terminals 1T, 2T and 3T

The switch gives the user a full control over the three circuits (connected to 1T, 2T, and 3T) which is not the case of any traditional switch.

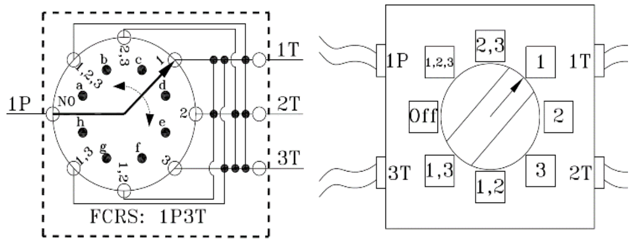


Fig.8. Internal and external design of FCRS-1P3T.

Fig.9 presents the design of an FCRS of the type 2P3T (two-pole, three-throw). Internal connection and external look of the switch are presented in the figure. Similar to the previously mentioned switch 1P3T, there are 8 possible connections for each pole in this switch. Hence, the total number of possible connections is 16 for all poles. The contacts of all poles can be rotated by a single or separate axis. In the case of a single rotating axis, all poles in the switch will be connected to the same terminal positions. In another meaning, if 1P is connected to 2T in the first layer, then 2P will also be connected to 2T in the second layer. However, for a multi-rotating axis, each pole is controlled by its own rotating mechanism and the contact position may not be the same for different poles. In another meaning, if 1P is connected to 2T in the first layer, 2P could be connected to 3T or any other terminal. Hence, this kind of switches gives a full control over all circuits connected to the switch, which is the main originality of this work. With the same analogy, any FCRS-NPMT can be created with “N” Poles and “M” Throws.

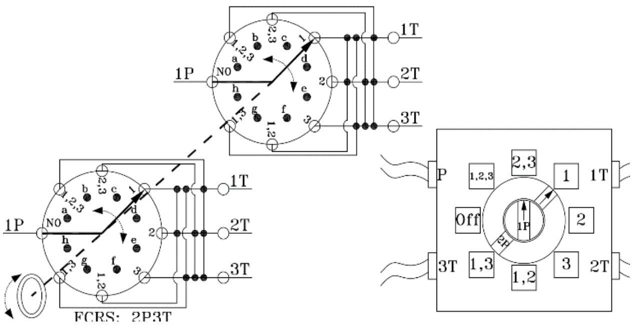


Fig.9. Internal and external design of FCRS-2P3T.

3. APPLICATION OF THE FULLY CONTROLLABLE ROTARY SWITCH IN ELECTRICAL INSTALLATION IN BUILDINGS

In this section, only FCRS-1P2T and 1P3T are chosen and compared to the traditional 1P1T, 1P2T, and 2P2T-R switches in the field of electrical installation in buildings. The main goal is to give the user a full controllability over the electrical elements (such as lighting, machines, etc.), especially when there are multi-users who can also control the same element.

3.1 1P1T Switch vs FCRS-1P2T

FCRS-1P2T can be used to replace the 1P1T switch and it can control the electrical load in the same way as presented in Fig.10. The load is branched to 1T contact in the FCRS. Hence, to turn on the load, it is sufficient to rotate the switch to any position that has the number "1", (such as: "1" and "1,2"). To turn it off, it is sufficient to rotate the switch to any other position (such as" "Off", and "2").

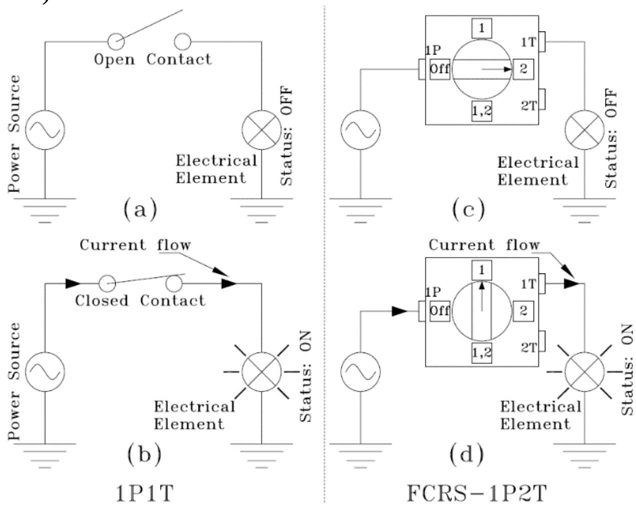


Fig.10. 1P1T Switch vs FCRS-1P2T.

3.2 1P2T Switch vs FCRS-1P2T

Similar to the previous subsection, FCRS-1P2T can replace 1P2T switch as presented in **Fig. 11**. 1P2T switch can either turn on load 1 or load 2. FCRS-1P2T has an advantage over 1P2T switch in which it has more states, such as turning off all loads, turning on load 1, turning on load 2, and turning on load 1 and 2 simultaneously as in**Fig. 11**.

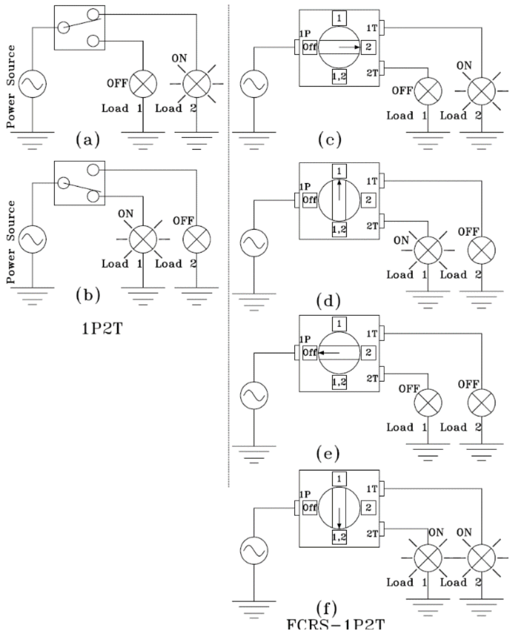


Fig. 11. Example 1, 1P2T Switch vs FCRS-1P2T.

3.3 Two 1P2T switches vs. two FCRS-1P2T

Suppose that two switches are used to control a light bulb in a room as in Fig. **12**. Each switch is located next to a door, one on the entrance and one on the exit. The light can be controlled by any switch and has one of the two states, either on or off.

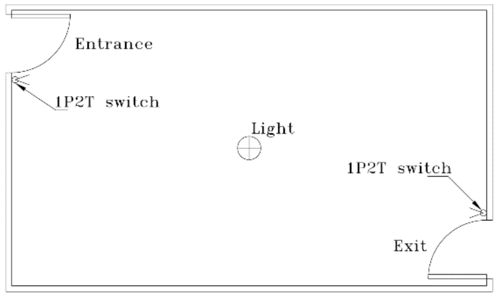


Fig. 12. Controlling light in a room using two 1P2T switches vs. two FCRS-1P2T.

Fig.13 and Table 5 present all possible contact positions for the two switches. It can be remarked that the light is turned on only if both switches are in the same contact positions.

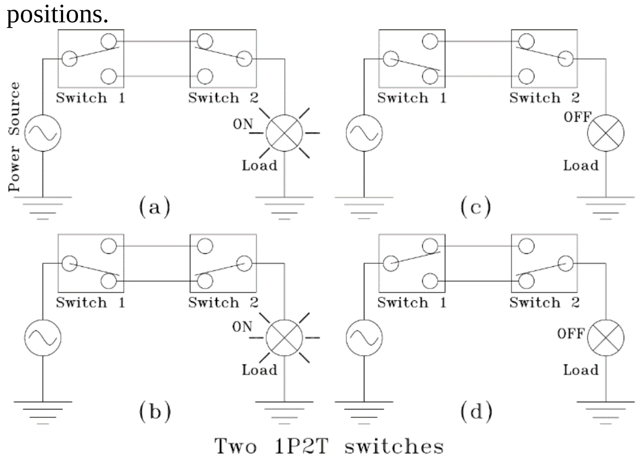


Fig.13. All possible contact positions for both switches of type 1P2T.

Table 5. Possible combination of contact positions of two 1P2T switches.

		Switch 1	
		Position 1	Position 2
Switch 2	Position 1	On	Off
	Position 2	Off	On

For the case of using the proposed FCRS-1P2T, there are lots of ways to control the light, which also depends on the connection type of the terminals of the switch and the configuration of the switches. The control can be divided into six main categories as follows:

- Switch 1 has full control of the load disregarding the contact positions in switch 2, (refer to configuration 1 in Fig.14 and Table 6),
- Switch 2 has full control of the load disregarding the contact positions in switch 1, (refer to configuration 2 in Fig.14 and Table 7),
- Switch 1 and 2 can equally control the load without any preference to any switch, (refer to configuration 3 in Fig.14 and Table 8),
- Switch 1 and 2 can control the load with a slight preference to switch 1, (refer to configuration 4 in Fig.14 and Table 9),
- Switch 1 and 2 can control the load with a slight preference to switch 2, (refer to configuration 5 in Fig.14 and Table 10),
- Other configurations (refer to configuration 6 in Fig.14 and Table 10),

The possible configurations are not limited to the ones presented in Fig.14. There are many other ways to configure the connection; however, only six selected configurations are presented in this section. FCRS allows us to make a large number of different configurations, in which each one operates in a different way according to the needs of the users. Hence, using the proposed FCRS gives much more flexibility to control the loads compared to the traditional switches such as 1P2T.

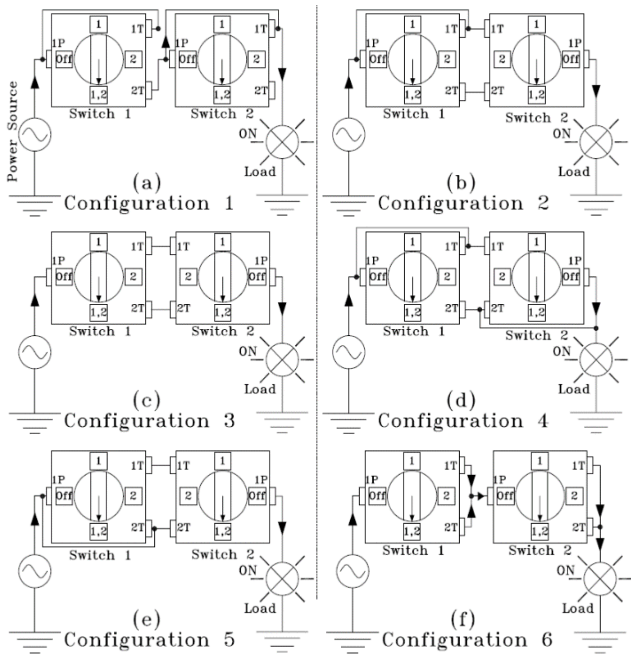


Fig.14. Six selected configurations of connecting two FCRS-1P2T switches.

Table 6. Possible combination of contact positions of the two FCRS-1P2T switches for configuration 1.

		Switch 1			
		Off	1	2	1,2
Switch 2	Off	Off	Off	On	On
	1	Off	Off	On	On
	2	Off	Off	On	On
	1,2	Off	Off	On	On

Table 7. Possible combination of contact positions of the two FCRS-1P2T switches for configuration 2.

		Switch 1			
		Off	1	2	1,2
Switch 2	Off	Off	Off	Off	Off
	1	On	On	Off	On
	2	Off	Off	On	On
	1,2	On	On	On	On

Table 8. Possible combination of contact positions of the two FCRS-1P2T switches for configuration 3.

		Switch 1			
		Off	1	2	1,2
Switch 2	Off	Off	Off	Off	Off
	1	Off	On	Off	On
	2	Off	Off	On	On
	1,2	Off	On	On	On

Table 9. Possible combination of contact positions of the two FCRS-1P2T switches for configuration 4.

		Switch 1			
		Off	1	2	1,2
Switch 2	Off	Off	Off	On	On
	1	On	On	On	On
	2	Off	Off	On	On
	1,2	On	On	On	On

Table 10. Possible combination of contact positions of the two FCRS-1P2T switches for configuration 5.

		Switch 1			
		Off	1	2	1,2
Switch 2	Off	Off	Off	Off	Off
	1	Off	On	Off	On
	2	On	On	On	On
	1,2	On	On	On	On

Table 11. Possible combination of contact positions of the two FCRS-1P2T switches for configuration 6.

		Switch 1			
		Off	1	2	1,2
Switch 2	Off	Off	Off	Off	Off
	1	Off	On	On	On
	2	Off	On	On	On
	1,2	Off	On	On	On

3.4 Controlling an electrical load from three locations

Suppose that three switches are used to control a light bulb in a room as in Fig. **15**. Each switch is located next to a door, one on the entrance, the second on exit 1, and the third on exit 2. The light can be controlled by any switch and has one of the two states, either on or off. In the case of traditional switches, two 1P2T and one 2P2T-R switches are needed. In the case of the new switches, two FCRS-1P2T and one FCRS-1P3T are needed. Fig.16 and Table 12 present all possible contact positions for the three conventional switches. Fig. **17**, Table 13 and Table 14 present a simple configuration of the proposed FCRS in a circuit and all the possible combinations of the contact positions. It is important to mention that such kind of circuits can have many different configurations which allow a more controllability of the electrical loads. However, in this section, just one configuration is presented as an example.

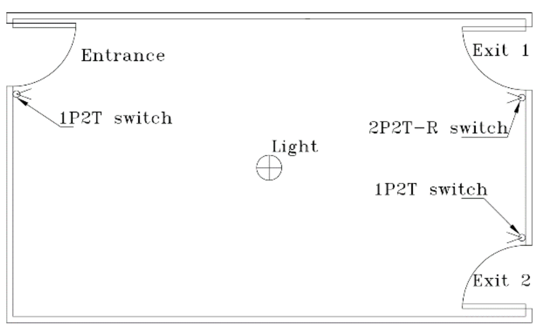


Fig. 15. Controlling a light in a room using two 1P2T and one 2P2T switches vs. two FCRS-1P2T and one FCRS-1P3T.

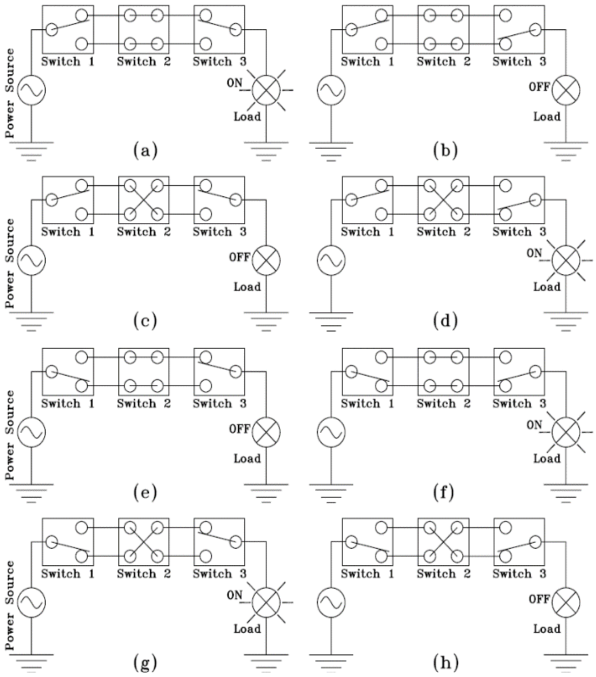


Fig.16. All possible contact positions for both switches of type 1P2T.

Table 12. Possible combination of contact positions of two 1P2T switches.

Switch 1	Switch 2	Switch 3	Light status
Position 1	Position 1	Position 1	On
Position 1	Position 1	Position 2	Off
Position 1	Position 2	Position 1	Off
Position 1	Position 2	Position 2	On
Position 2	Position 1	Position 1	Off
Position 2	Position 1	Position 2	On
Position 2	Position 2	Position 1	On
Position 2	Position 2	Position 2	Off

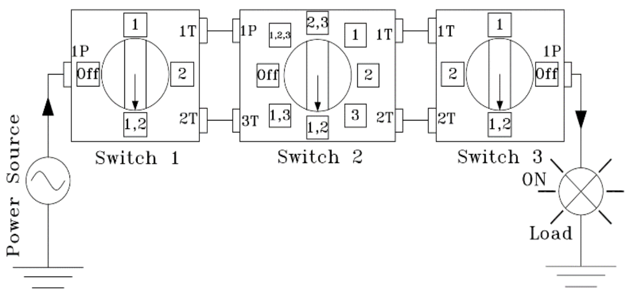


Fig. 17. A simple configuration of the circuit using FCRS.

Table 13. Possible combination of contact positions of two FCRS-1P2T and one FCRS-1P3T switches (Part 1).

Switch 1	Switch 2	Switch 3	Light status	Switch 1	Switch 2	Switch 3	Light status
0	0	0	Off	1	0	0	Off
0	0	1	Off	1	0	1	Off
0	0	2	Off	1	0	2	Off
0	0	1,2	Off	1	0	1,2	Off
0	1	0	Off	1	1	0	Off
0	1	1	Off	1	1	1	On
0	1	2	Off	1	1	2	Off
0	1	1,2	Off	1	1	1,2	On
0	2	0	Off	1	2	0	Off
0	2	1	Off	1	2	1	Off
0	2	2	Off	1	2	2	On
0	2	1,2	Off	1	2	1,2	On
0	3	0	Off	1	3	0	Off
0	3	1	Off	1	3	1	Off
0	3	2	Off	1	3	2	Off
0	3	1,2	Off	1	3	1,2	Off
0	1,2	0	Off	1	1,2	0	Off
0	1,2	1	Off	1	1,2	1	On
0	1,2	2	Off	1	1,2	2	On
0	1,2	1,2	Off	1	1,2	1,2	On
0	1,3	0	Off	1	1,3	0	Off
0	1,3	1	Off	1	1,3	1	On
0	1,3	2	Off	1	1,3	2	Off
0	1,3	1,2	Off	1	1,3	1,2	On
0	2,3	0	Off	1	2,3	0	Off
0	2,3	1	Off	1	2,3	1	Off
0	2,3	2	Off	1	2,3	2	On
0	2,3	1,2	Off	1	2,3	1,2	On
0	1,2,3	0	Off	1	1,2,3	0	Off
0	1,2,3	1	Off	1	1,2,3	1	On
0	1,2,3	2	Off	1	1,2,3	2	On
0	1,2,3	1,2	Off	1	1,2,3	1,2	On

Table 14. Possible combination of contact positions of two FCRS-1P2T and one FCRS-1P3T switches (Part 2).

Switch 1	Switch 2	Switch 3	Light status	Switch 1	Switch 2	Switch 3	Light status
2	0	0	Off	1,2	0	0	Off
2	0	1	Off	1,2	0	1	Off
2	0	2	Off	1,2	0	2	Off
2	0	1,2	Off	1,2	0	1,2	Off
2	1	0	Off	1,2	1	0	Off
2	1	1	Off	1,2	1	1	On
2	1	2	Off	1,2	1	2	Off
2	1	1,2	Off	1,2	1	1,2	On
2	2	0	Off	1,2	2	0	Off
2	2	1	Off	1,2	2	1	Off
2	2	2	Off	1,2	2	2	On
2	2	1,2	Off	1,2	2	1,2	On
2	3	0	Off	1,2	3	0	Off
2	3	1	Off	1,2	3	1	Off
2	3	2	Off	1,2	3	2	Off
2	3	1,2	Off	1,2	3	1,2	Off
2	1,2	0	Off	1,2	1,2	0	Off
2	1,2	1	Off	1,2	1,2	1	On
2	1,2	2	Off	1,2	1,2	2	On
2	1,2	1,2	Off	1,2	1,2	1,2	On
2	1,3	0	Off	1,2	1,3	0	Off
2	1,3	1	On	1,2	1,3	1	On
2	1,3	2	Off	1,2	1,3	2	Off
2	1,3	1,2	On	1,2	1,3	1,2	On
2	2,3	0	Off	1,2	2,3	0	Off
2	2,3	1	Off	1,2	2,3	1	Off
2	2,3	2	On	1,2	2,3	2	On
2	2,3	1,2	On	1,2	2,3	1,2	On
2	1,2,3	0	Off	1,2	1,2,3	0	Off
2	1,2,3	1	On	1,2	1,2,3	1	On
2	1,2,3	2	On	1,2	1,2,3	2	On
2	1,2,3	1,2	On	1,2	1,2,3	1,2	On

3.5 Comparison between the traditional switches and FCRS

In this subsection, a comparison between traditional switches and FCRS is presented in Table 15. FCRS can control many electrical loads simultaneously which is not the case of any other traditional switch. For example, in the case of 1P2T switch, maximum two loads an be controlled and only one of them can be turned on or off. However, FCRS-1P2T can turn off all loads, turn on load 1, turn on load 2, and turn on loads 1 and 2, which is not the case of any other switch. In addition, the FCRS can have a large number of configurations which allow one switch to overtake the control not only on the electrical loads, but also on other switches in the same circuit, which will increase the security, privacy, and satisfaction of a certain user, while reducing the conflict between multi-users who are trying to control the same load using many switches on the same circuit. However, FCRS present complicated configuration that might increase the complexity of the manufacturing and the system, which are considered its main drawbacks. Despite the mentioned limitations, FCRS can replace one or many switches and protection devices, which will reduce the investment cost. Hence, it is more attractive to a specific type of users.

Table 15. Comparison between traditional switch and FCRS.

Description	Traditional switch	FCRS
Control many electrical loads at a time	No	Yes
Control other switches on the same circuit	No	Yes
Increase the satisfaction of the user	Maybe	Yes
Increase the security while repairing the electrical load	No	Yes
Reduce the conflict between multi-users	No	Yes
Increase the privacy of the user	No	Yes
System is less complex	Yes	No
Manufacturing of the switch is less complex	Yes	No
Low manufacturing cost	Yes	No
Reduce the investment cost by reducing the number of installed switches and protection devices	No	Yes
Simple configuration and installation	Yes	No

4. CONCLUSION

Nowadays, electromechanical switches are widely deployed and used in buildings, in which they can turn on and off one or many electrical loads by changing the position of contacts. The most used switches are single-pole single-throw (SPST), single-pole double-throw (SPDT), and double-pole double-throw (DPDT). Despite the utility of these kinds of switches in controlling electrical loads such as lighting, they have many limitations. The most common limitations are low security, low controllability, and low privacy when many users are trying to control the same load. Hence, there is a need to create a novel switch which will give one or more of the users full control over a certain electrical load or circuit. To do so, this paper proposes a fully controllable rotary switch (FCRS) in which it gives single or many users partial or full control over circuits and other switches. Thus, all the mentioned issues are solved, and one user is able to block others from controlling the electrical load, which is not the case of any other conventional switch. The FCRS is a rotary switch that has one pole and many throws (in one or many decks or layers) connected in complicated configurations to give the user full control of the electrical load and to block other users from controlling it even if many switches are a part of the same circuit. The FCRS has many advantages over the traditional switches, such as (a) increasing the security and privacy of the user by fully controlling the circuit even if other switches exist in the same circuit; (b) the user can give limited or no access to other users; (c) reducing the installation cost by avoiding the installation of protection devices such as disconnecting switches, and reducing the installation of additional switches. For validation purposes, FCRS is compared to other existing switches. Results show that installing FCRS in buildings can increase the performance of the user since it can give him full access over the load and also give him a range of priorities that he can choose. In conclusion, FCRS shows many advantages over the traditional switches and needs further investigations in other fields.

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