Motorized Transfer Switch with Variable Reluctance Stepping Motor Actuator

Budhi Anto,[a,*] Suwitno,[a] and Ambrosius Wahono,[a]

[a)] *Department of Electrical Engineering, Universitas Riau, Pekanbaru, 28293, Indonesia*

*Corresponding author: budhianto.ur@gmail.com

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ABSTRACT

Mechanical transfer switch has been utilized for decades to mitigate outage due to failure in electricity supply. In this paper, we introduce novel method of transfer switch transition mechanism. Traditional transfer switch uses 2 contactors in interlocking mechanism, in that when main contacts of first contactor is at close position, the second contactor is locked at open position and so with conditions reversed. The proposed transfer switch uses variable reluctance stepping motor to drive contacts transition mechanism. The developed stepping motor has 6 poles at the stator and 4 teeth at the rotor. With this construction, the stepping motor will have 30-degree of step angle. The rotor of the stepping motor then directly drives the cam operated switch which has 2 groups of contacts where the first group connects the load to the grid network and the second group connects the load to the generating set. If rotor rotates 30-degree counter clockwise from the neutral position, the load will be connected to the grid network. If rotor rotates 30-degree clockwise from neutral position, the load will be connected to the generating set. By operating the control switches in stepping motor control circuitry correctly, the proposed transfer switch is capable to make transition between 2 sources of electricity safely. Moreover a grip handle mounted onto the rotor shaft allows manual operation of transition mechanism.

KEY WORDS: *transfer switch, cam operated switch, variable reluctance stepping motor*.

NOMENCLATURE

SA	Step Angle or Step Length
N_S	Numbers of Stator Poles
N_R	Numbers of Rotor Teeth

1.0 INTRODUCTION

Transfer switch plays important role in ensuring reliable electrical supply to the load. High reliability installations require reliable grid network and installed back up power source such generating set. When grid network fails to supply electricity, the load will be fed by secondary supply through changing contacts position of transfer switch. When grid network returns to its normal states, transfer switch will retransfer electricity supply to main supply position, so the load is fed by grid network.

Mechanical type of transfer switches are the most ever practised transfer switch in electrical installations for decades. The choice is due to its easy maintenance and low cost equipment. However, it has weakness as it takes long transfer time [1]. Other type of transfer switch is static transfer switch which is based on thyristors circuit [2,3]. Static transfer switch offers faster transfer time ensuring high reliability of electrical supply to the load, however it has weakness due to high conducting losses of thyristors. An attempt to combine the use of mechanical and static type of transfer switch was proposed by Bing Tian to form hybrid transfer switch, where static transfer switch is used during transition period and mechanical transfer switch is used at steady condition [4].

Basically a transfer switch, either mechanical or static type, composes of 2 groups of interlocked contacts, so when first group of contacts is at close position, the second group of contacts is locked at open position, and if second group of contacts is at close position, the first one is locked at open position. There are 2 types of transfer switches, manual transfer switches and automatic transfer switches. The difference between them lies on contacts transition mechanism where in automatic transfer switch (ATS), it is controlled by a dedicated controller which continuously monitors the state of grid supply and the state of generating set supply and perform transition between them at a correct time [5]. For manual transfer switch, the transition between the sources of electricity is done manually using a handle geared on the apparatus.

Mechanical type of ATS usually uses 2 contactors as actuator of transition process where both of them are operated in interlocking mechanism [6]. The controller unit of ATS might use discrete components such as electromagnet relays and timers [7], or might use a microcontroller [8,9], or might use programmable logic controller [10].

ATS installed in a high reliable electrical system must be able to be operated in either manual operation or automatic operation [11]. This requirement will not be satisfied by either contactor based nor thyristor based ATS due to technical difficulties for manual operation. Thus other mechanism that can perform both automatic and manual operation becomes a challenging idea.

In this paper we propose novel method of contacts transition of ATS where the transition mechanism is established by a cam operated switch that directly driven by a variable reluctance stepping motor. Automatic mode of operation is established by stepping motor control circuitry whereas manual mode is performed using a grip handle attached to the rotor shaft of the motor.

2.0 DESIGN OF VARIABLE RELUCTANCE STEPPING MOTOR

Stepping motor is electric motor that converts digital pulses into rotation of its rotor. One digital current pulse fed to its stator winding will cause its rotor to rotate along predetermined angle. This angle is named step length [12] or step angle [13]. One digital current pulse to stator winding will cause the rotor to rotate along one step angle. In order to rotate in a complete one revolution (360 degrees), several current pulses must be fed to stator windings. Hence stepping motor rotates in steps with same step.

Stepping motor has served as actuator element in many control system applications such as in printer [14], disc drive and CNC machines [15]. Application of stepping motor to drive valves is described in [16,17]. Based on its operating principle, Krause classified stepping motors into 2 types. They are variable reluctance types and permanent magnet types. Major difference between them lies on an existent of permanent magnet at axial of rotor shaft [12].

Contacts transition mechanism of transfer switch with variable reluctance stepping motor drive is explained referring to figure 1. This apparatus is basically a cam operated switch with two groups of contacts. The cam is directly driven by stepping motor. The cam has 3 positions, i.e. position **0** or neutral position, position **I** and position **II**. If the cam is at position **I**, electrical supply to the load is maintained by the grid network. If the cam is at position **II**, the load is supplied by the genset. Transition from position **I** to position **II** or from position **II** to position **I** passes through position **0**. Cam motion from position **0** to position **I** is 30 degree counter clockwise rotation, whereas its motion from position **0** to position **II** is 30 degree clockwise rotation. Those patterns of cam motion can be precisely tracked by stepping motor drive, in this case a stepping motor with 30-degree of step angle.

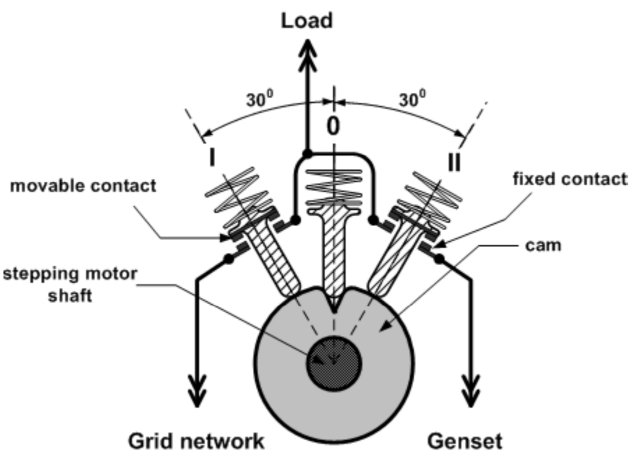

Figure 1: Contacts transition mechanism of new type of transfer switch.

Variable reluctance stepping motor with 30 degree of step angle has been chosen to drive the cam. Basic construction of stepping motor is determined using following equation [13],

$$SA = \frac{|N_s - N_R|}{N_s \times N_R} \times 360^0 \qquad (1)$$

where SA is step angle (in degree); N_S is numbers of stator poles and N_R is numbers of rotor teeth. From equation (1), 30-degree of step angle can be obtained by choosing N_S = 6 and N_R = 4. The construction of variable reluctance stepping motor is shown in figure 2, while figure 3 shows wiring diagram of its stator windings.

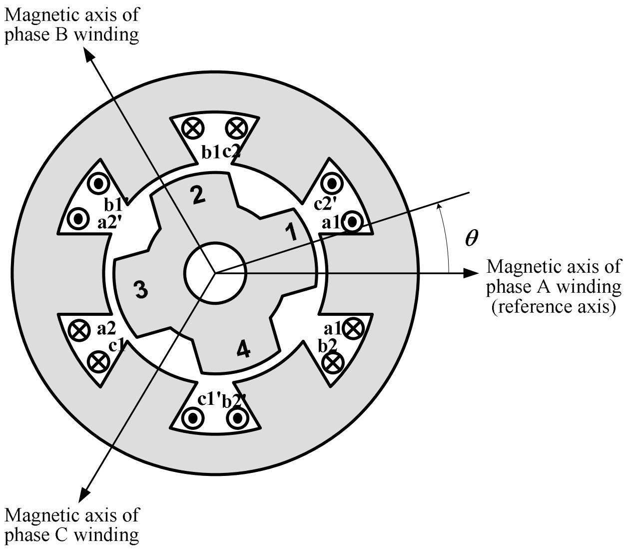

Figure 2: Construction of variable reluctance stepping motor for driving cam switch.

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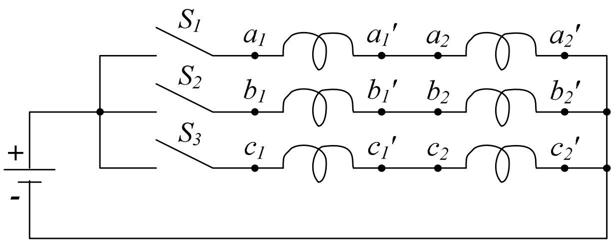

Figure 3: Wiring diagram of stator windings of variable reluctance stepping motor.

Referring to figure 2 and figure 3, phase **A** winding consists of **a1-a1'** winding and **a2-a2'** winding in series connection, phase **B** winding consists of **b1-b1'** winding and **b2-b2'** winding in series connection, and phase **C** winding consists of **c1-c1'** winding and **c2-c2'** winding in series connection. To drive the rotor counter clockwise, phase **A** winding is energized by closing switch S1, opening switch S2 and opening switch S3, and followed by energizing phase **B** winding by closing switch S2, opening switch S1 and opening switch S3. The next step is to energize phase **C** winding by closing switch S3, opening switch S1 and opening switch S2. The process then continues to energize phase **A** again, followed by energizing phase **B**, energizing phase **C** and so on. Counter clockwise rotor motion simulated with MATLAB/Simulink is shown in figure 4 [18].

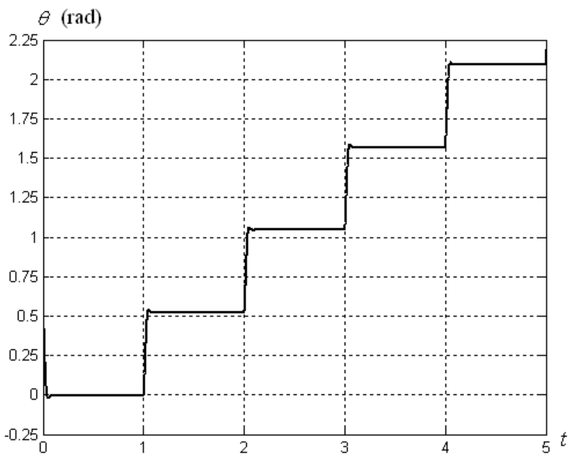

Figure 4: Rotor motion of variable reluctance stepping motor with energizing in sequence, phase A – phase B – phase C. Step angle is 0,524 radian or 30 degrees.

To drive the rotor clockwise, phase **A** winding is energized by closing switch S1, opening switch S2 and opening switch S3, and then followed by energizing phase **C** winding by closing switch S3, opening switch S2 and opening switch S1. Following step is to energize phase **B** winding by closing switch S2, opening switch S1 and opening switch S3.The process then continues by energizing in sequence phase **A** – phase **C** – phase **B**. The simulated clockwise rotor motion under MATLAB/Simulink environment is shown in figure 5 [18].

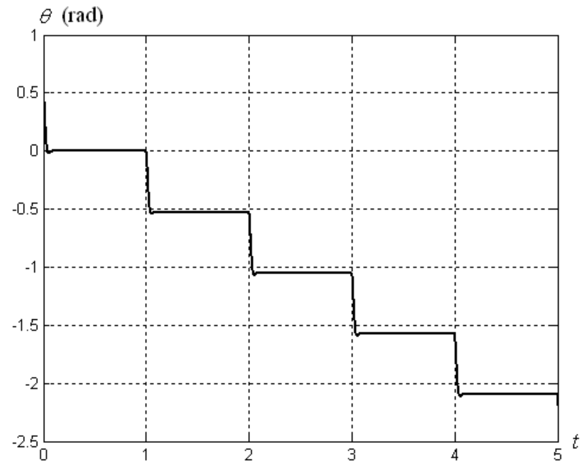

Figure 5: Rotor motion of variable reluctance stepping motor with energizing in sequence, phase A – phase C – phase B. Step angle is 0,524 radian or 30 degrees.

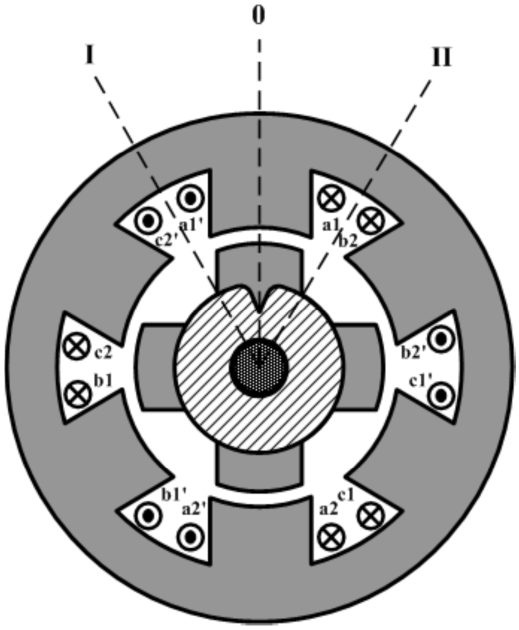

Figure 6: Variable reluctance stepping motor directly drives the cam, there are 3 positions (position **0**, position **I** and position **II**).

The cam that directly driven by variable reluctance stepping motor is ilustrated in figure 6. To drive the cam to position **0**, phase **A** winding is energized, while phase **B** and phase **C** windings is deenergized. To drive the cam from position **0** to position **I** or cam rotates 30 degree counter clockwise, phase **B** winding is energized, while phase **A** and phase **C** windings is deenergized. To drive cam to rotate from position **I** to position **II**, firstly phase **A** winding is energized and then followed by energizing phase **C** winding.

3.0 RESULT AND DISCUSSIONS

The components that assemble the proposed transfer switch are shown in figure 7 to figure 14. The stator and rotor cores are made of thin laminated silicon steel sheets. This material was used as material for the distribution transformer's core. The sheets then scissored in such way to obtain stator and rotor core sheets (figure 8 and figure 9). The stator sheets are stacked to form stator core (figure 10), so as the rotor sheets are stacked to form rotor core. The windings are then installed at stator poles (figure 12). Each winding consists of 700 turns of 0.6 mm copper wire. The rotor core is then installed onto the shaft to form complete rotor part of the stepping motor (figure 11). The rotor part is then installed to stator part to form a complete variable reluctance stepping motor (figure 13). The cam switch is then mounted onto the motor shaft to form an apparatus function as a transfer switch (figure 14).

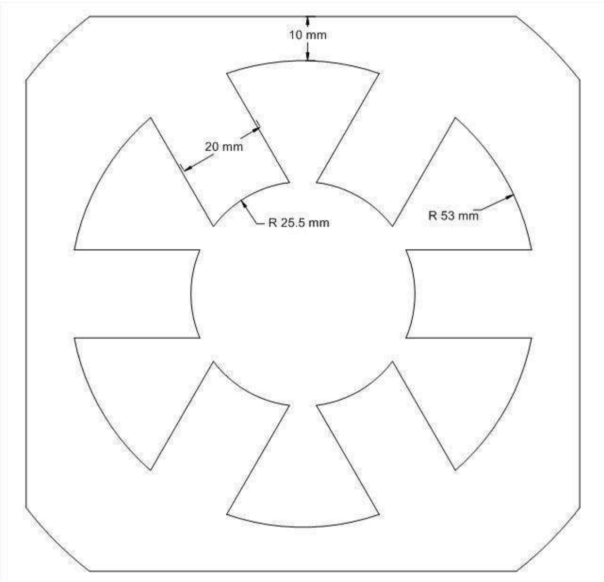

Figure 7: Design of stator core's sheet.

Figure 8: Stator core pattern ready for being scissored.

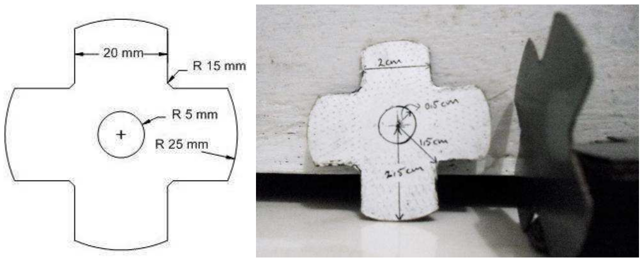

Figure 9: Design of rotor core's sheet (left), The scissored rotor core's sheet (right)

Figure 10: Stator core without windings

Figure 11: The rotor of variable reluctance stepping motor

Figure 12: The Stator of variable reluctance stepping motor

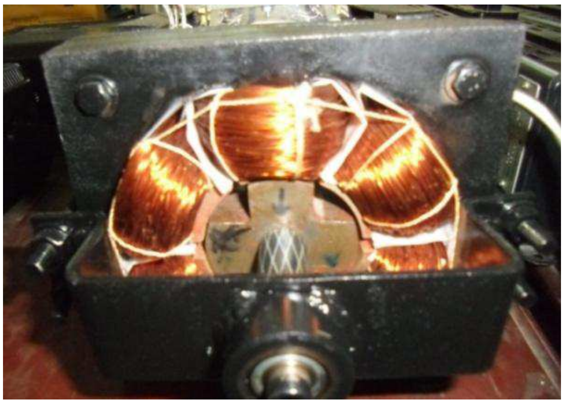

Figure 13: Variable reluctance stepping motor

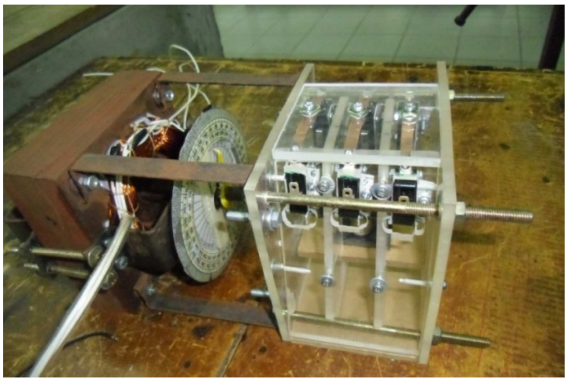

Figure 14: Variable reluctance stepping motor directly drives the cam switch

The variable reluctance stepping motor is driven by 12 volt dc voltage. This level of voltage is chosen in order to be able to drive the stepping motor using a 12-volt battery.

The transfer switch then undergoes functional test using circuit shown in figure 15. The 12-volt dc voltage comes from the rectifier unit. A 2-ohm resistor is used to limit stator currents. To control phase winding energizing, one pushbutton switch is placed at each phase winding path. To measure rotor movement, an angle measurement device is placed between stepping motor and cam switch. The test result is presented in table 1. Figure 16 shows the proposed transfer switch complete with its 12-volt power supply.

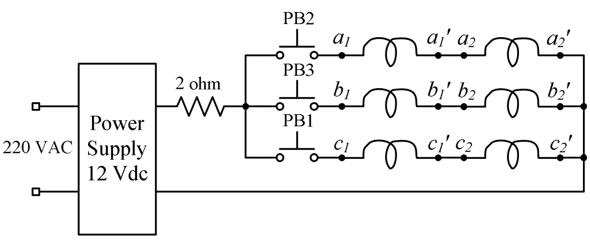

Figure 15: Transfer switch functional test circuit diagram

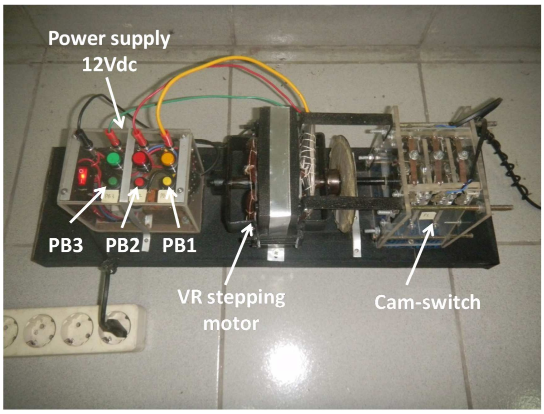

Figure 16: Transfer switch with its power supply and control switches

Table 1: Result of transfer switch functional test

PB1 (pos.II)	PB2 (pos.0)	PB3 (pos.I)	Rotor move-ment	Grid network	Genset
0	1	0	0	Break	Break
1	0	0	-30^0	Break	Make
0	1	0	0	Break	Break
0	0	1	$+30^0$	Make	Break

From table 1, when pushbutton switch PB2 is at close position (1), PB1 is at open position (0) and PB3 is at open position (0), the cam rotates to position 0, so the load will not be connected to either grid network or genset. When PB1 is at close position (1), PB2 is at open position (0) and PB3 is at open position (0), the cam rotates 30 degree clockwise (-30 degree) or the cam rotates to position II. Under this condition, the load is connected to genset supply. When PB2 is at close position (1), PB1 is at open position (0) and PB3 is at open position (0), the cam returns to position 0. When PB3 is at close position (1), PB1 is at open position and PB2 is at open position, the cam rotates 30 degree counter clockwise (+30 degree) or the cam rotates to position I. Under this condition, the load is connected to grid network. Hence by pushing in sequence PB2 and PB1, electrical supply for the load will be transfered from grid network to genset. Also pushing in sequence PB2 and PB3 will transfer electrical supply from genset to grid network. The test result presented in table 1 shows that by operating the control switches correctly, the proposed transfer switch is capable to perform transition between 2 sources of electricity safely.

4.0 CONCLUSION

A new type of transfer switch that uses variable reluctance stepping motor as actuator element has been built. The stepping motor has 6 stator poles and 4 rotor teeth. By this construction the stepping motor will have 30-degree of step angle. The cam operated switch connecting load to either grid network or genset is then mounted onto the stepping motor shaft to form a complete set of transfer switch. The functional test applied to the proposed transfer switch results that by operating its control switches correctly this apparatus is capable to make transition between 2 sources of electricity safely. Further work to make the unit that able to control stepping motor movement based on information of state of supply of the electricity sources is required so the proposed transfer switch will have capability to make transition between the electricity sources in automatic mode of operation.

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