A Case Study of Frequency Fluctuation Caused by Fault on MEA's System

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***Abstract-* This paper studies the frequency fluctuation in case of a fault in Metropolitan Electricity Authority's the power system. This paper brings the actual situation in the power station, which received the power from 115 kV power transmission line system of MEA, to study. The study method will consider the effect of frequency changes in the power system by MEA's power system model which used the ATP-EMTP transient analysis program. It is used the fault of 115 V power transmission line system in type of a single phase to ground fault about 8 km occurs at phase R. The result of the power system simulation found that the voltage waveform is changed and shifted. This results in lower frequencies with the lowest frequency at phase R about 41.357 Hz. or decrease 17.286% approximately when compared to the 50 Hz power system frequency.**

***Keyword*: ATP-EMTP, Load Shedding**

I. INTRODUCTION

According to Figure 1, the disturbances in MEA's power transmission lines system may occur several times in each year as a result the power system's protection is malfunctioning. The impact can affect the voltage, power current and frequency of the power system which the cause may vary. However, if considered in the power frequency protection system, the cause of the power generation caused by the fault in the power system and the cause of the harmonic effect of the load on the power system. Therefore, making the power system to stabilize and do not occur power failure due to faulty power protection. From the study, if considering only the effects of voltage and frequency on the system that effect to the load shedding [5] or malfunction of the underfrequency relay [4] to the point that loads are disconnected from the power system. This formed a rationale to study factors that caused electrical disturbances which affected the MEA's power system frequency using a simulation model of the power system using the ATP-EMTP program [1] and [6] based on actual events at the MEA's substations. Changes in frequency of the power system can either be in the form of underfrequency or overfrequency [2]

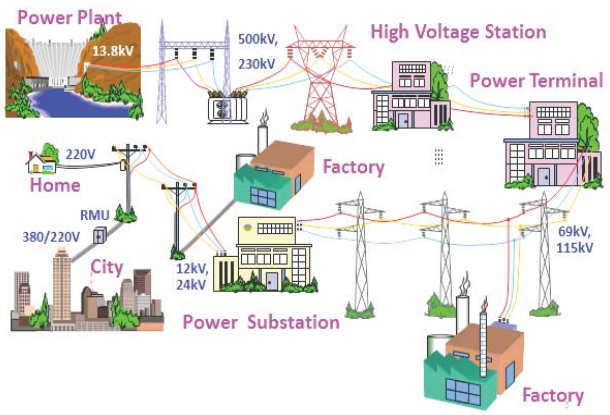

Figure 1. Power System of MEA

II. METHOD

This paper studies the actual problems in the power system which caused the power failure for unknown reasons. This incident was caused by a single phase to ground fault that occurred in ONTT7942 transmission line at Bangchan Station. It was considered by using MEA's power system model using ATP-EMTP transient analysis program. The simulation results examine the frequency of fault in order to determine the effect of the underfrequency relay.

*U*nderfrequency relay

The underfrequency relay is a preventive device used to disconnect loads from the automatic power distribution system. In the case where the frequency is decreased as shown in Figure 2., each step of a load discharge is about 10% of the maximum load and when the underfrequency relay is activiated, the relay will effect a delay of approximately 150ms before disconnecting the load.

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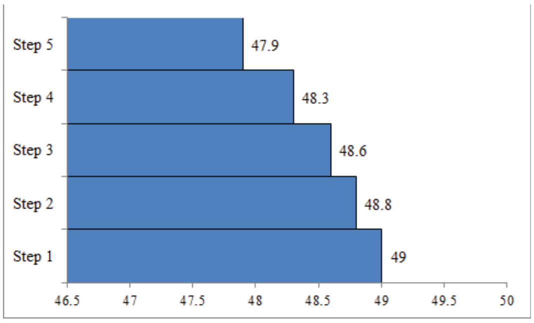


Figure 2. Under frequency setting

Phase shift of the voltage

When a surge occurs in the power transmission system, for example from on/off the circuit breaker specifically during a fault, it will result in a phase shift of the voltage or a vector surge [6]. An event such as this will trigger the underfrequency relay to detect a decrease in system frequency i.e. the period of the voltage waveform during a surge will be greater by Δt as shown in Figure 3 from experimentation, details of which appear below.

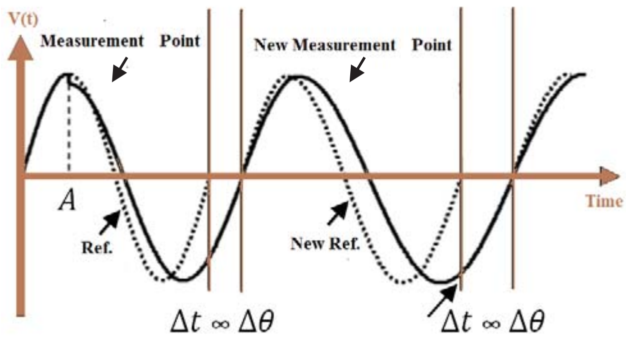
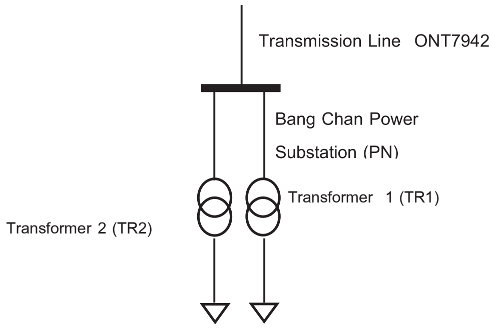


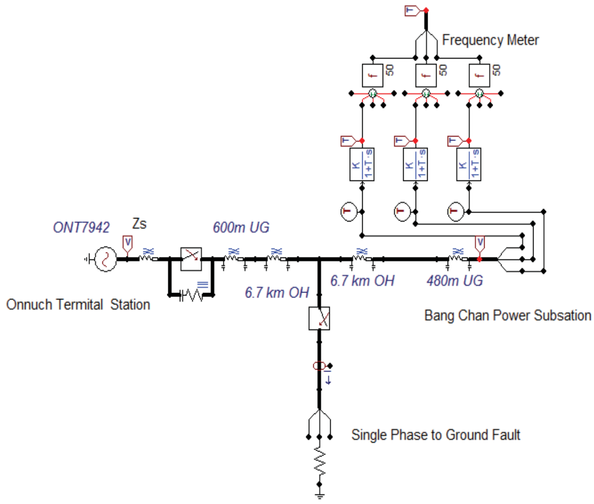
Figure 3. Occurance of a phase shift of the voltage waveforms during a fault.

III. RESULTS

Figure 4a is MEA's power system model which is the incident at Bangchan Substation. This station is powered by transmission line ONT7942 and supply to 2 power transformers. The power system in Figure 4b simulates a single phase to ground fault at a distance 8 km of the overhead transmission line to study the voltage waveform on the 115kV bus B of Bangchan Substation. The voltage measured passed through a low pass filter at the cut off frequency of 150 Hz before measuring the frequency using a frequency meter



a) Bang Chan Power Substation



b) Model of the power system

Figure 4. Model of the power system at the ONT7942 transmission line

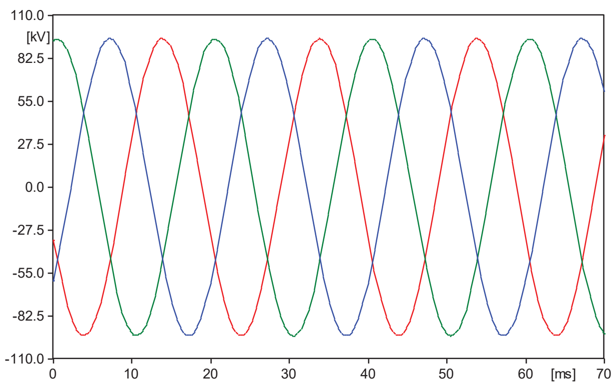


Figure 5 Voltage waveforms (L-N) form ONT7942 transmission line

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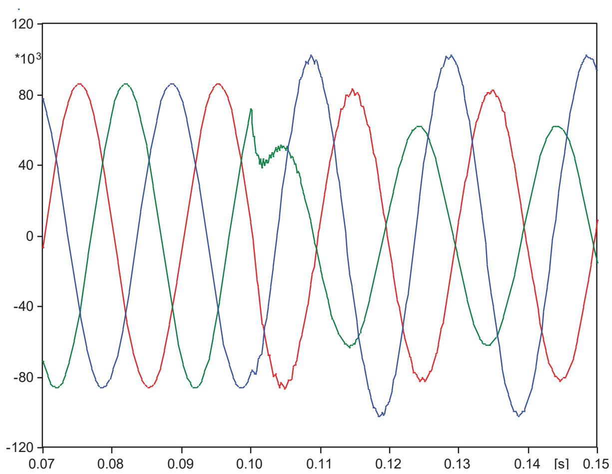
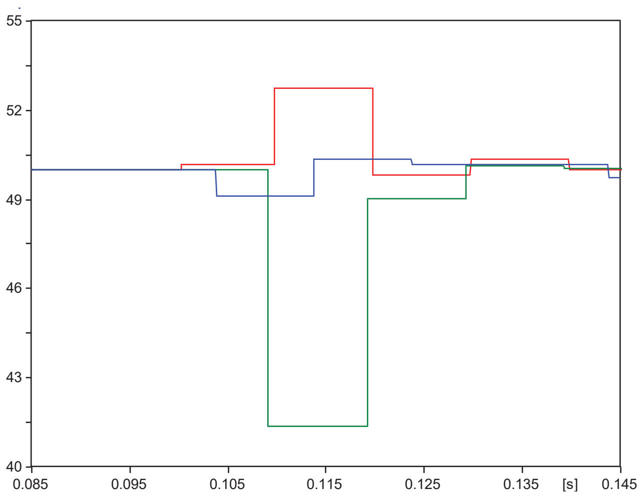


Figure 6 Voltage waveforms (L-N) during a single to

When simulating this incident with ATP-EMTP program, ONT7942 transmission line as shown in Figure 5, and measured the voltage while occur single phase to fault at 0.1 s, it found that the blue waveforms decreased at phase R as shown in Figure 6 and effect to frequency changing which occurred during the fault as well. The result is a frequency shift at 10.21ms with the lowest frequency at 41.357 Hz as shown in Figure 7 which occurs at phase R. The said frequency compared to the frequency of the power system is 50 Hz, the value decreases about 17.286% when compared to the frequency relay setting. This result found that the low frequency at 10.21 s has enough time to make a frequency relay works continuously because the protection system has setting a time delay setting of 150 ms.; therefore, the load shedding cannot working.



.Figure 7. frequency during a single to ground phase fault

IV. CONCLUSION

Nowadays, MEA's power supply system is relatively more complex due to the increasing number of residential customers and the commercial industry. Customers have high expectations for higher quality power. In another side, the electronic technology advances make electrical appliance or industrial equipment is sensitivity to voltage using due to the complexity of the system and its relatively inadequate power quality. Therefore, the study of the impact on the power system or the fluctuation frequency from the fault will make the power system to stability and increase the quality power of the system.

The study of the fault result by power system simulation using a transient analysis program, which studies the faults that cause the fluctuation of the frequency in a short period of time. From this simulation, the value is decreased about 17.286% in 10.21ms. It found that the frequency is actually reduced but the time is less than the delay time of the load shedding or frequency relay that make the system does not work. So, if this incident is occurred, it can be determined that the device of the protection system is malfunction. However, this study is just a simulation of power system using transmission line of Bangchan Substation. In fact, each substation of MEA has different conditions, it depends on the area, such as the type of transmission line, the distance and the electrical equipment. Therefore, the simulation of the power system is a way to determine the causes of the protection system's failure in case of an unknown cause of power failure. This is useful for improving protection system and setting the system in the next abnormal situations.

V. REFERENCE

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Design of Simple Hydraulic System in Hydraulic Prosthetic Knee

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***Abstract*-Currently, hydraulic prosthetic knees are commercial prosthetic knee for transfemoral amputees who wish to remain active. However, while these knees improve the quality of life for transfemoral amputees, they can be prohibitively expensive because the hydraulic system which enables them to operate is particularly complex and uses a lot of parts. Consequently, hydraulic prosthetic knees are beyond the reach of many transfemoral amputees in Thailand. This paper presents a new hydraulic system that has been purposely designed to be simple and cheap. Moreover, it could still adjust knee angle suitably at various walking speeds for each amputee. To simplify the system, we designed a hydraulic cylinder that can be manufactured from a block of material by using a machining process only and other hydraulic components can be mounted in the cylinder by using few parts. This method also resulted in lower cost and compact. The function was determined by Matlab computation program to calculate the performance of the knee angle at five walking speeds for young and adult. The results showed that the system could provide natural knee angle in a narrow speed ranges and suitable speed ranges of young amputee was faster than speed ranges of adult amputee.**

I. INTRODUCTION

The number of transfemoral amputees in Thailand has been increasing continuously over recent years. In 2012 there were 24,798 lower limb amputees with approximately 32 percent of these amputees in the age range of 25-44 years [1]. Apart from the amputation, the body of these relatively young amputees remains the ability or potential to perform a range of mobility activities, such as walking and running. In the K-level grading scale (the rating of the potential level of each amputee), these amputees are graded K3-4, with maximum potential in all levels [2]. The suitable prosthetic knee for these amputees must be one that is able to adjust the friction force according to the walking speed of each amputee [3].

Prosthetic knees with adjustable friction force come in various types. The first type is a pneumatic prosthetic knee that is operated by using air pressure. The advantages of this type are that it is light and easy to maintain, while the air properties vary little at different temperatures [4]. However, the type of knee also has a disadvantage in that it requires an additional mechanism to establish a stability for an amputee [5]. Moreover, it can be used in only a narrow range of walking speeds. The second type is a hydraulic prosthetic knee that is operated by using hydraulic oil pressure. This type of knee has advantages in that it is able to establish stability itself and is suitable for adjusting the friction force in a wide range of walking speeds. However, it is heavier and more expensive than a pneumatic prosthetic knee [4]. Furthermore, the properties of the hydraulic oil change at different temperatures. This problem can be solved by using silicone oil but this will increase the production cost [3]. Finally, the third type is a microprocessor prosthetic knees that uses a computer system to assist in its operation. In this way, it is able to help an amputee to walk naturally and reduce falls [4, 6, 7]. However, this type of knee has disadvantages in that it requires energy from an external source, making it more expensive and more difficult to maintain. From above, it can be concluded that a hydraulic prosthetic knee is the most suitable type of prosthetic knee for transfemoral amputee in Thailand as it is able to establish stability by itself and operates without the need for energy from an external source.

The hydraulic prosthetic knee consists of two parts. The first part is a stance phase controller, which provides stability while walking and reduces risk of falls. The second part is a swing phase controller, which provides suitable knee angle at various speeds and helps the amputee to walk naturally. The operations of the swing phase controller in a hydraulic prosthetic knee are performed by a hydraulic system. In some prosthetic knees, the stance phase controller is integrated with a swing phase controller to produce a prosthetic knee that is smaller and lighter such as Mauch knee [5]. However, these knees are complex and expensive, which leads to limited access for amputees in Thailand. In addition, some prosthetic knees that separate the stance phase controller from the swing phase controller are still difficult to manufacture and expensive [8, 9]. It can be seen that the main problem is the complicated and expensive swing phase controller.

This paper presents a design of a hydraulic system that is simple and cheap to ensure that it is readily accessible to amputees in Thailand. Nevertheless, it is still able to adjust knee angle appropriately at various speeds for each amputee.

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II. CONCEPTUAL DESIGN

Hydraulic System

Most of the hydraulic systems in commercial hydraulic prosthetic knee have a similar hydraulic circuit, although some systems also include additional components to improve their performance. In our design, we use the general hydraulic circuit that is used in commercial hydraulic prosthetic knee because it is simple and enough to help an amputee to walk naturally on a flat ground as shown in figure 1. However, hydraulic components that are used in the circuit will be designed and built by ourselves (except check valves) because commercial hydraulic components are expensive and too large. Furthermore, hydraulic oil that is used in the circuit is ISO VG 32 hydraulic oil to reduce the cost of the prosthetic knee.

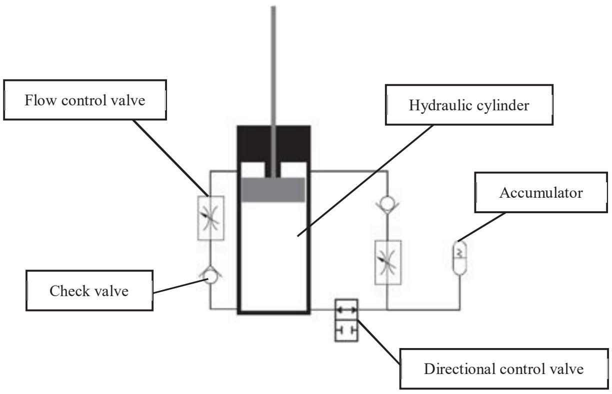

Figure 1. The simple hydraulic circuit in new design.

The hydraulic component that is the most important is a hydraulic cylinder because it contains other hydraulic components and demonstrates an appearance of a hydraulic system. In this research, the cylinder is be manufactured by a machining process only to be simple and enable other hydraulic components to be installed internally by using few parts to make the system is inexpensive and compact. Another component that is important is a flow control valve. This valve has a role to adjust the friction force appropriately at various walking speed for each amputee. All of hydraulic components is shown in figure 1.

A. Design Specification

First, the design of the hydraulic system was based on calculations for walking in the sagittal plane only because most movement of the knee joint is in this plane. Second, the design was based on calculation for walking on a flat ground. Third, this hydraulic system was designed for an amputee who weighs in the range of 45-80 kg only. Finally, the maximum pressure of the hydraulic system did not exceed 40 bar because there was not too much pressure in the system and it corresponded to the maximum pressure that a check valve can handle.

III. DETAIL OF DESIGN

The primary design of the hydraulic system began with the hydraulic cylinder because it was a key components to overcome these problems. The pivots of hydraulic cylinder were designed from a comparison with commercial hydraulic prosthetic knee. After that, we calculated the hydraulic cylinder force by Free Body Diagram (FBD) at a thigh as shown in figure 2. Fig. 2 shows that an amputee cannot establish a knee moment because of limb loss. So, a hydraulic cylinder force will help to compensate the losing knee moment. If the body weight and center of mass of a shank were not changing, reaction forces would be not changing too. Therefore, the hydraulic cylinder force could be determined to be:

$$M = F_{Hyd} L \tag{1}$$

Where
M = Knee moment
F_{Hyd} = Hydraulic cylinder force
L = Arm length of the hydraulic cylinder

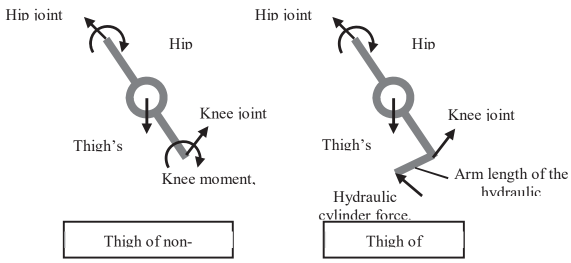

Figure 2. Reaction forces at a thigh of non-amputee and amputee.

In the calculation, we used the walking data that based on the research of Gabriele Bovi et al. and calculate all five speeds for young and adult as shown in table 1 [10].

TABLE I
WALKING SPEED OF YOUNG AND ADULT

	Young speed (%BH/s)	Adult speed (%BH/s)
Very slow	53.69	49.26
Slow	69.26	69.79
Self-selected	87.71	71.36
Medium	89.69	87.33
Fast	117.87	115.44

The result showed that the diameter of the cylinder was 30 mm for maximum pressure that did not exceed 40 bar. To decrease the unutilized areas, we designed the cylinder to permit the axes of the cylinder, accumulator, and directional control valve to be on the same alignment because the cylinder would be manufactured easily and was compact. Moreover, the cylinder can be molded by machining process only. The flow control valve was

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designed to could be adjusted from the outside. All of the hydraulic components were designed to use few parts and their dimension would be based on the size of commercial seals in Thailand. Furthermore, the components were made of aluminum alloy 7075 to be lightweight and high strength. The hydraulic cylinder in this is 40 mm x 54 mm x 110 mm and weighs 0.45 kg. When all of the hydraulic components are assembled, this newly designed hydraulic system weighs 0.56 kg, which is half the weight of commercial hydraulic prosthetic knees. Fig. 3 illustrates the complete design of the hydraulic system.

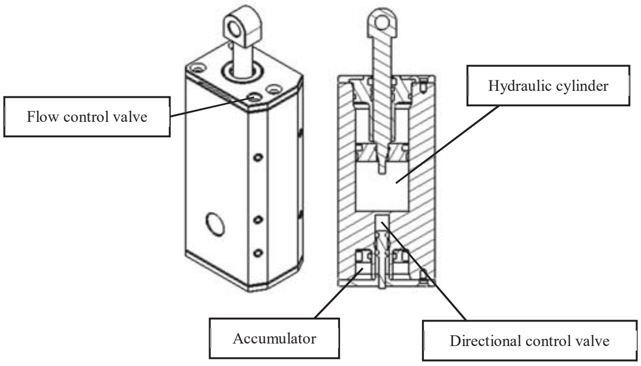

Figure 3. Complete design hydraulic system.

IV. HYDRAULIC CYLINDER FUNCTION

To determine the performance of the new hydraulic system, we calculated the knee angle that was established by this system at the various walking speeds of different amputees. The weights of the amputees used in the calculation were 45 and 80 kg because these were the limits of the amputees that were described above. The calculation was performed by Matlab computation program as shown in figure 4. The input data of the system was the F_{Hyd} that was calculated from M. The output was the displacement of hydraulic rod that related with the knee angle. In the calculation, we used hydraulic oil temperature at 32ºC and used the flow control valves to adjust friction force appropriately at self-selected speed. For other parameters of the hydraulic components, such as the discharge coefficient of the valves, used the default value that was given by program. However, this calculation would not use the stance phase controller to calculate the knee angle in the stance phase.

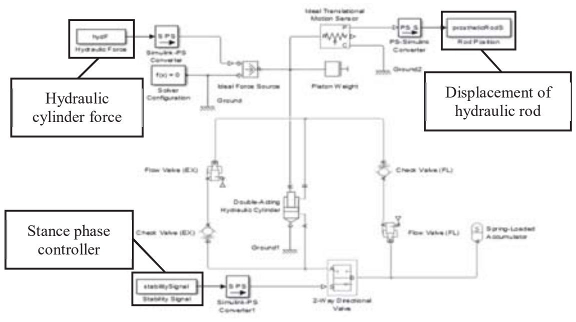

Figure 4. The calculation of the hydraulic system in Matlab computation program.

Assuming that the hydraulic system did not have friction force. Therefore, we would obtain the equation of motion in the following form:

$$m\ddot{x} + c\dot{x} + kx = F_{Hyd} \qquad (2)$$

Where
m = Piston mass
c = damping coefficient
k = spring constant in an accumulator
x = displacement of hydraulic rod
F_{Hyd} = Hydraulic cylinder force

Then, we calculated the knee angle from the displacement of hydraulic rod at various speeds. The results is shown in figure 5, it can be seen that the different of the maximum knee flexion of the prosthetic knee at 45 kg (dashed line) and prosthetic knee at 80 kg (dotted line) was not significant. However, they were quite difference from the actual knee (solid line). The most obvious difference could be seen at very slow and slow walking speeds for the young amputees and at the very slow and fast walking speeds for the adult amputees.

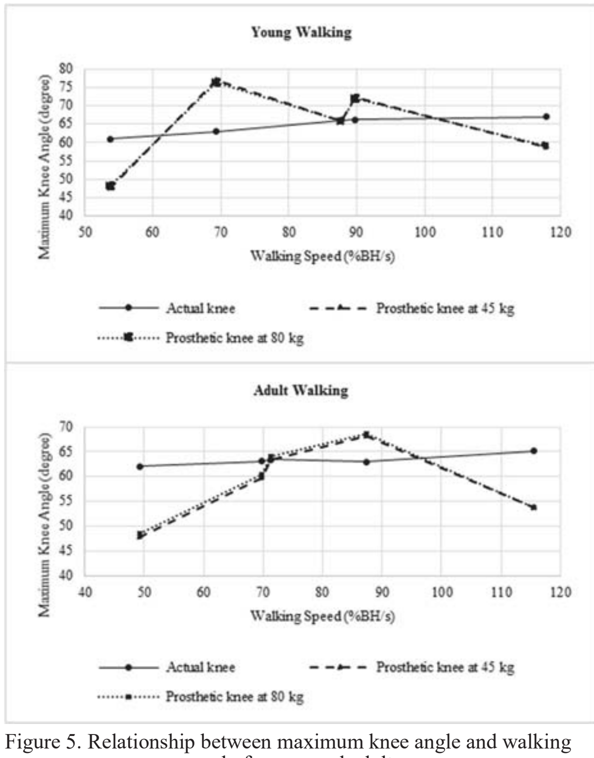

Figure 5. Relationship between maximum knee angle and walking speed of young and adult.

In order to see the difference more clearly, a comparison between the maximum knee angle of

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prosthetic knee and actual knee is illustrated in Table 2. The gray boxes indicate that the different between the maximum knee angle of prosthetic knee and actual knee was more than 15 percent. This show that walking with prosthetic knee at these speeds was quite different from natural walking. As a result, the designed hydraulic system would help an amputee to walk naturally in a narrow walking speed ranges only. Furthermore, suitable speed ranges of young amputee was faster than speed ranges of adult amputee.

TABLE II
THE COMPARISON BETWEEN MAXIMUM KNEE ANGLE OF PROSTHETIC KNEE AND ACTUAL KNEE

	Walking speed (%BH/s)	Maximum knee angle		Error (%)
		Prosthetic knee	Actual knee	
Young (45 kg)	53.69	47.76	60.92	21.60
	69.26	77.05	62.91	22.48
	87.71	65.78	66.02	0.36
	89.69	72.43	66.23	9.36
	117.87	58.69	67.04	12.46
Young (80 kg)	53.69	48.39	60.92	20.57
	69.26	76.46	62.91	21.54
	87.71	65.68	66.02	0.51
	89.69	72.12	66.23	8.89
	117.87	59.13	67.04	11.80
Adult (45 kg)	49.26	47.72	62.09	23.14
	69.79	59.76	63.04	5.20
	71.36	63.47	63.38	0.14
	87.33	68.20	62.99	8.27
	115.44	53.85	65.16	17.35
Adult (80 kg)	49.26	48.51	62.09	21.87
	69.79	60.40	63.04	4.19
	71.36	64.03	63.38	1.02
	87.33	68.54	62.99	8.81
	115.44	53.81	65.16	17.42

V. RESULTS AND DISCUSSION

Our hydraulic system was simple and cheap because it was manufactured entirely by the machining process only. In addition, it was compact because the design permits the axes of the hydraulic cylinder, directional control valve, and accumulator in to be in the same alignment. However, it was a little bit smaller than the system in commercial hydraulic prosthetic knees. Due to the limited pressure in the hydraulic cylinder, size, and weight could not be reduced any further. This problem can be solve with several methods, such as changing the pivots of hydraulic cylinder and using the special seals. The changing the pivot of the hydraulic cylinder is a method to reduce hydraulic cylinder force that affect the diameter of hydraulic cylinder. The other method is using the special seals. This method will reduce the size of hydraulic components in hydraulic cylinder. However, it will increase the price of the hydraulic system instead.

From the result of the calculation in Matlab computation program, our hydraulic system was able to establish the maximum knee angle similar actual knee in a narrow range only. Because the maximum knee moment in the swing phase that was be using for input data had not a ratio at various walking speeds that related to the maximum knee angle as shown in figure 6. This incidence occurred from an amputee changed a posture of walking at various speeds. So the maximum knee moment in the swing phase would change too. The method that reduce the error of the maximum knee angle is using more appropriate spring in the accumulator. Furthermore, this spring should be able to adjust spring stiffness to be suitable for each amputee. When spring and flow control valves worked together, the knee angle that is established by the hydraulic system will be more similar to natural knee angle.

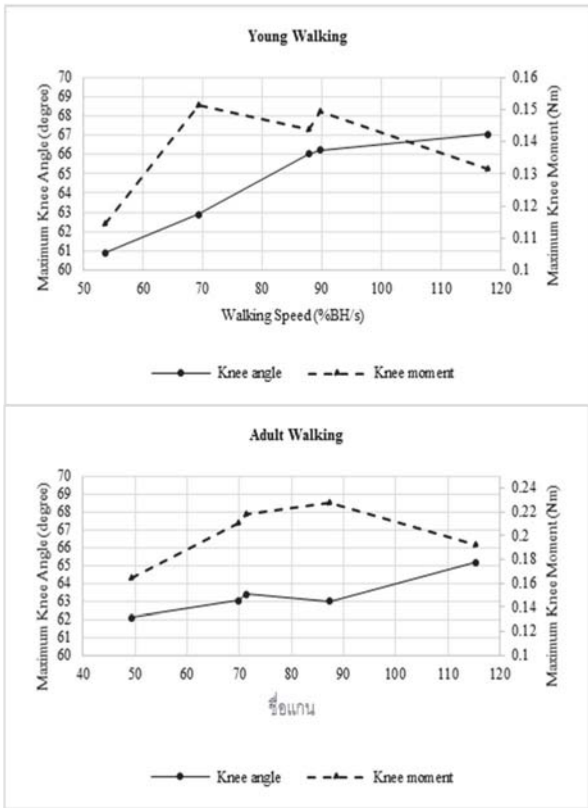

Figure 6. Comparison between the rate of change of maximum knee angle and maximum knee moment at various walking speed of young and adult.

VI. CONCLUSION

The hydraulic system presented in this paper was designed for use in a hydraulic prosthetic knee that would

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be more affordable and accessible to transfemoral amputees in Thailand. The newly-designed hydraulic cylinder in the hydraulic system was manufactured from a block of material by using a machining process only and other hydraulic components can be mounted in the cylinder by using few parts. As a result, the design of the hydraulic system is simple and cheap. However, it can assists amputees to walk naturally in a narrow walking speed ranges and suitable speed ranges of young amputee was faster than speed ranges of adult amputee.

This research has some limitations, such as calculations which used the default value of the hydraulic components. As a result, the performance of the manufactured hydraulic system may be different from the calculations. In future research, we will edit these faults to minimize this difference. We will also develop the hydraulic system to furthคer reduce its size and to make it easier for amputees to walk naturally in a wider walking speed ranges.

VII. ACKNOWLEDGMENT

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