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Finite Step Model Predictive Control Based Asymmetrical Γ- Source Inverter with MPPT Technique

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Abstract:- This paper presents techniques of maximum power point tracking (MPPT) implemented with finite step model predictive control (FSMPC) for the application of Asymmetrical Γ -source inverter. Incremental conductance MPPT algorithm and FSMPC model is developed to control the output current of the grid-tied Inverter. Both steady-state and transient results show that the high efficiency and robust response of the proposed control technique. Impedance-source inverters are inverters with voltage buck- boost capability that cannot be achieved by the traditional inverters. Their boost capability is introduced by shorting their phase-legs without causing damages. Impedance-source inverters are therefore less prone to false triggering caused by electromagnetic interference. The asymmetrical Γ -source inverters proposed in the paper, whose gain is raised by lowering their turns ratio towards unity. Input current drawn by the proposed inverters is smoother and hence more adaptable by the source.

Keywords:- MPPT, FSMPC, Asymmetrical, Γ -source, Incremental conductance.

I. INTRODUCTION

Maximum power produced by photovoltaic system can be extracted by the implementation of DC-DC buck boost conversion stage to adjust the solar panel output voltage level. The main target of the Maximum Power Point Tracking (MPPT) algorithm is to produce the appropriate input reference for the controller. This controller controls the converter output voltage and makes it follow the Maximum Power Point (MPP) which is located at the knee of the photovoltaic I-V characteristics.

There are number of existing algorithms used for MPPT. They vary in cost, range of operation, complexity, speed of convergence, and applications [1-3]. The incremental conductance method adjusts the PV array output terminal voltage according to the MPP based on the incremental and instantaneous conductance of the photovoltaic module [5]. It has advantage of simplicity, fast responds to changing atmosphere condition; as well as avoids the disadvantages of oscillation. Hence it is chosen to be implemented for Asymmetrical Γ-Source grid-connected inverter in the application of PV power generation. Another interesting attempt is to couple the two inductors on a single core, which to a great extent resembles a two-winding transformer. The thought of changing the winding turn's ratio is then introduced to raise the inverter voltage gain and modulation ratio.

The proposed inverters use one coupled transformer, one inductor and two capacitors, which are more than components used by the trans-Z-source inverters. The components used are however the same if a low-pass filter is included with the latter for input current filtering.

Unlike the trans-Z-source inverters though, gain and modulation ratio of the asymmetrical Γ-source inverters are raised by lowering their transformer turns ratio Asymmetrical Γ-Source, rather than increasing it. The range of variation can in fact be derived as Asymmetrical Γ-Source, which would help to keep the winding turns low. Current drawn by the proposed inverters is also smoother, and hence less disturbing to the source. These features have been confirmed by testing in experiments.

II. PHOTOVOLTAIC MODULE

The simplest equivalent PV panel is a current source in parallel with a diode. The output of the current source is directly proportion to the sunlight irradiance level. And the parallel diode determines the I-V characteristics of the solar cell. To make the model more sophisticated, a shunt resistance may be included in parallel with the diode. For this research work, a moderate complexity is used.

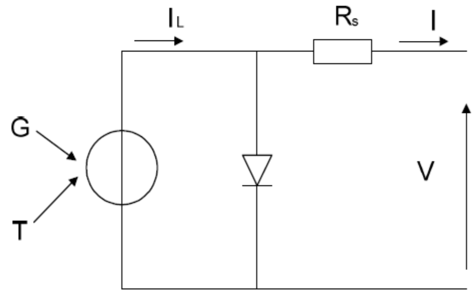


Fig. 1 Equivalent circuit diagram of a typical PV module

This model includes temperature dependent photo-current I_L, diode saturation current I_o, series resistance R_s and parallel diode. The equations which describe the I-V characteristics of the solar cell are:

$$I = I_L - I_0 (e^{\frac{q(v+IR_s)}{nkt-1}}) ....(1)$$

The constants in the above equations like open circuit voltage V_{oc} (T1) at temperature T_1, and short circuit current I_{sc} can be get from the manufacture's equipment datasheet. This paper takes commercially available solar panel.

The MPP will be located at the knee of the I-V curve, where the operation voltage V_m and operation current I_m make the slope of the P-V curve equals to zero holds at the maximum power operation point. And at the left side of the MPP, differentiation of dP/dV is positive

III. MPPT TECHNIQUE

The incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right, ΔV/ΔP=0 (ΔI/ΔP=0) at the MPPΔV/ΔP>0 (ΔI/ΔP=0) at the MPPΔV/ΔP<0 (ΔI/ΔP=0) at the MPP. By comparing the increment of the power vs. the increment of the voltage (current) between two consecutive samples, the change in the MPP voltage can be determined.

Similar schemes can be found in, in both P&O and INC schemes, how fast the MPP is reached depends on the size of the increment of the reference voltage. This paper proposes some modification in INC methods so that the tracking under irradiation profiles containing slopes is good.

The incremental conductance method is also often used in PV systems. This method tracks the MPPs by comparing the incremental and instantaneous conductance of the solar array. This method requires more conversion time, and a large amount of power loss results.

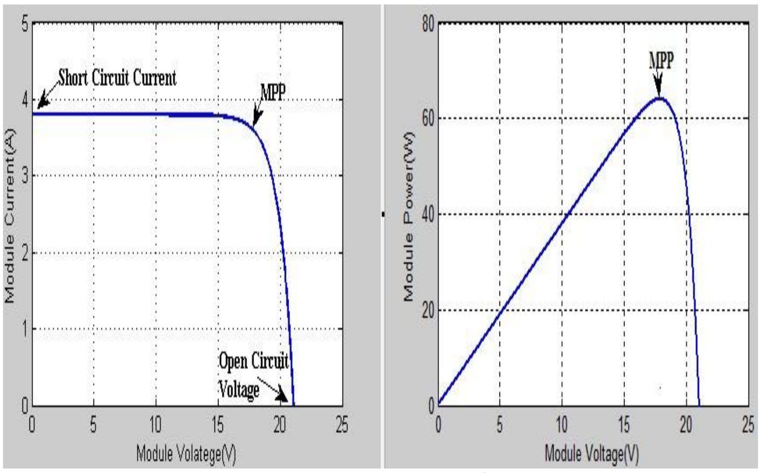


Fig. 2 Illustrations of MPP under 25°C Sun irradiation

The MPP is located at the knee of the I-V curve, where the operation voltage V_m and operation current I_m make the slope of the P-V curve equals to zero.

$$\frac{dp}{dV}\Big|_{(V=V_m)} = 0..................(2)$$

The algorithm is carried out each settled sampling time, which depends on the frequency of atmosphere changing. This determines the output current reference of grid tied inverter.

It would be discussed in details in the following sections. The error selection depends on the amount of I-V value changes during steady-state oscillations and risks of fluctuating at similar operation points.

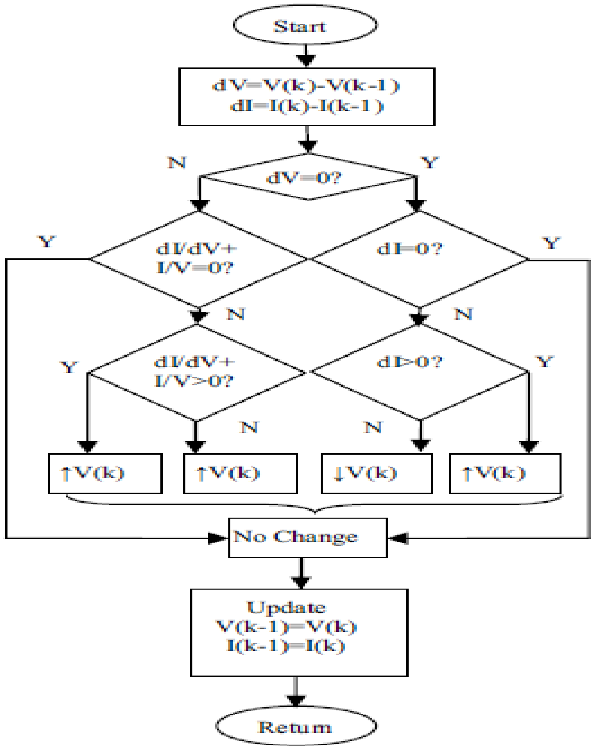
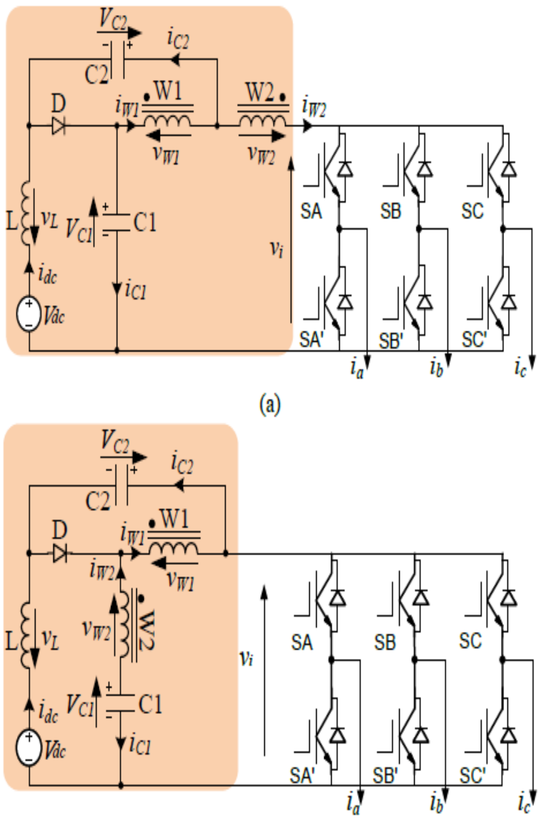


Fig. 3 Flow chart of proposed MPPT method

IV. ASYMMETRICAL Γ -SOURCE INVERTERS



(b)

Fig. 4 Asymmetrical Γ -source inverters when in configuration (a) 1 and (b) 2

The asymmetrical Γ -source inverters proposed here, In common, they use one coupled transformer, two capacitors and an inductor, which are nearly the same as the traditional Z-source inverter except for the coupled transformer. Comparing with the trans-Z-source inverters, the number of components used is the same if an external second-order LC filter is added in shunt with the source for filtering purposes [6]. Adding the external filter would however not raise the trans-Z-source gain, and hence would not solve the second concern of high turns ratio at high gain. The asymmetrical Γ -source inverters would, on the other hand, have their gain raised and turns ratio lowered at high gain. Respective details are described as follows.

A. Asymmetrical Configuration:

In first asymmetrical Γ -source inverter proposed, where the coupled transformer and capacitor clearly form a Γ -shape. Operation of this asymmetrical Γ -source inverter is similar to the traditional Z-source and trans-Z-source inverters. That means it can assume the usual eight non-shoot-through active and null states, and the unique shoot-through state needed for voltage boosting. It can therefore be controlled by the same modulation parameters and method, but has some unique features revealed upon studying their states and equivalent circuits. Beginning with the shoot-through, it is triggered by turning on two switches from the same phase-leg. The short- circuit, thus, formed naturally causes input diode D to reverse-bias, and capacitors C1 and C2 to release their stored energy to the transformer and inductor [6].

B. Asymmetrical Configuration

In the second asymmetrical Γ -source inverter proposed, whose coupled transformer and capacitor again form a Γ -shaped network. The Γ -shaped network can be shorted without damages [6]. When returned to its non-shoot-through state, its equivalent circuit and governing expressions would change.

V. FINITE STEP MODEL PREDICTIVE CONTROL (FSMPC)

The first step of this control program is extracting the input voltage and current of the PV panel. Then the MPPT algorithm calculates the voltage V_m, current I_m as well as the corresponding maximum power at MPP and feeds the results into FSMPC. After getting the MPP operating voltage V_m and current I_m, together with grid output voltage and current, the FSMPC decides the switching signals of the inverter. Finally the inverter switches based on the signals produced by FSMPC and injects power into the grid. FSMPC control is chosen for its fast dynamic response and suitable for fast changing environmental condition. The main purpose of FSMPC is to precalculate the behaviour of a specific model and therewith to choose an optimal value of a control variable. Based on the implementation steps of FSMPC, first the reference (load voltage or current of power converters for example) is set by designer; second the predicted variables are to be generated by a modulation stage; next the predicted variables are used to be compared with reference variable, and the one closest to the reference will be chosen.

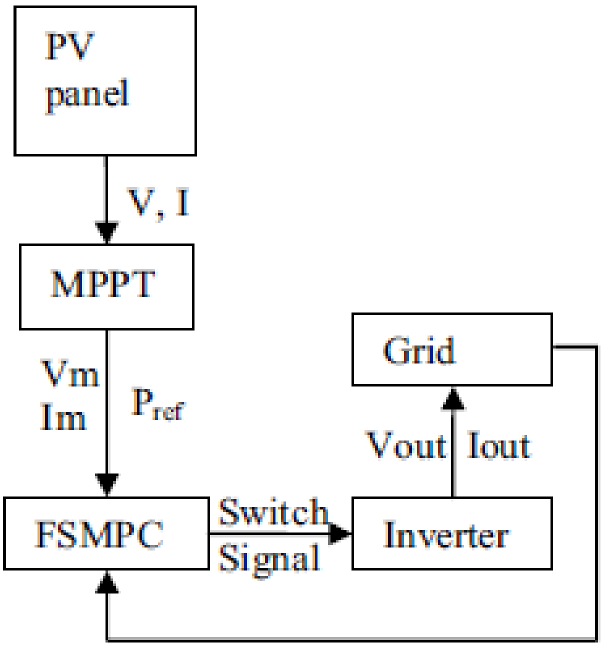


Fig. 5 Flow chart of control program

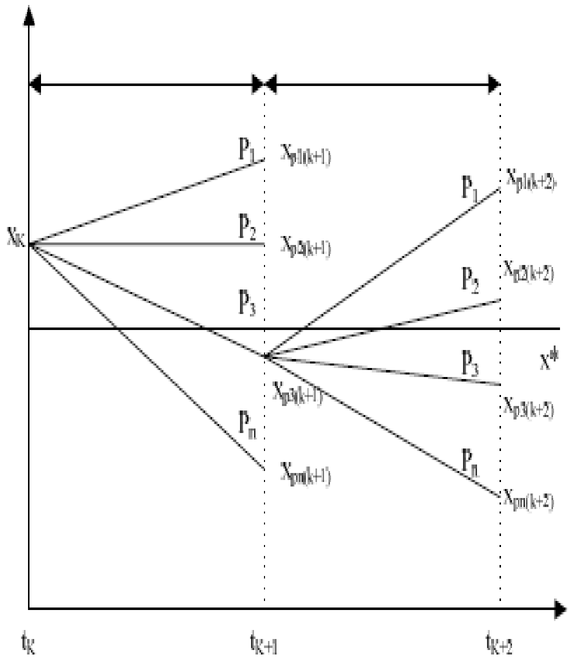


Fig. 6 Control strategy of MPC

Where x* is the reference signal, x is system variable to be controlled. P1, P2…Pn are control actions, and , Xp1(K+1),Xp2(K+1)…X_{pn}(k+n) are the predicted variables derived based on previous system variables and control actions. Initialed by system variable, prediction starts from time, predicts the next sample time variables. With different control actions, a set of predicted system values can be derived, among which, the one nearest to reference value will be chosen and its corresponding control action will be used as system control for time scope to tk to tk+1. Then set k=k+1, pick the reference variable and do the predicting action again for the next sample time. FSMPC control allows multivariable system subjecting to constraints by formulating a control model of the object.

VI. SIMULATION RESULT

The simulation is carried out on MATLAB platform with PLECS toolbox; MPPT algorithm sampling time T_{sm} is set to be 0.1s so that the program has sufficient time to run into steady state, the sample time of FSMPC T_S=20μs, using 6 msx60 solar panel connected in series, reference AC output peak value $\mathbf{V_{out}}$=110V Z-source network inductor inductance $L_1=L_2$=10mH with resistance $R_{L1}=R_{L2}$=0.5Ω capacitance $C_1=C_2$=1000μF grid peak voltage $e_a=e_b=e_c$=110,load inductor L=10mH with inductor resistance R_L=0.5Ω.The PV module is modeled according to I-V and P-V characteristics as shown in section II. The produced voltage and current are fed into the Z-source inverter and FSMPC controller at the same time. In order to test the dynamic response of the control algorithm, the illumination level changes from 1 Sun to 0.6 Suns and temperature changes from 25°C to 75°C at 0.4s and they change back to initial value at 0.5s. Initially with 1 Sun illumination at temperature 25°C, the MPPT algorithm tracks the maximum power point and regulates 107.46/6=17.91V voltage and 0.5773A current for each msx60 solar panel. The input power is 84.471W and the calculated output mean power is 200W. It is shown that this program has high efficiency of 98%. Noting that this only consider the passive components such as inductors and capacitors' power loss without considering the switching devices power loss. During 0.4s to 0.5s, the illumination level changes to 0.6 Suns and assuming an extreme temperature condition as 75°C. The solar panel output voltage is regulated to be 81.66/6=13.61V and corresponding current is 2.1356A, thus the input power changes to 174.393W and the output average power changes to 163.5W, achieving efficiency to be 93.75%.

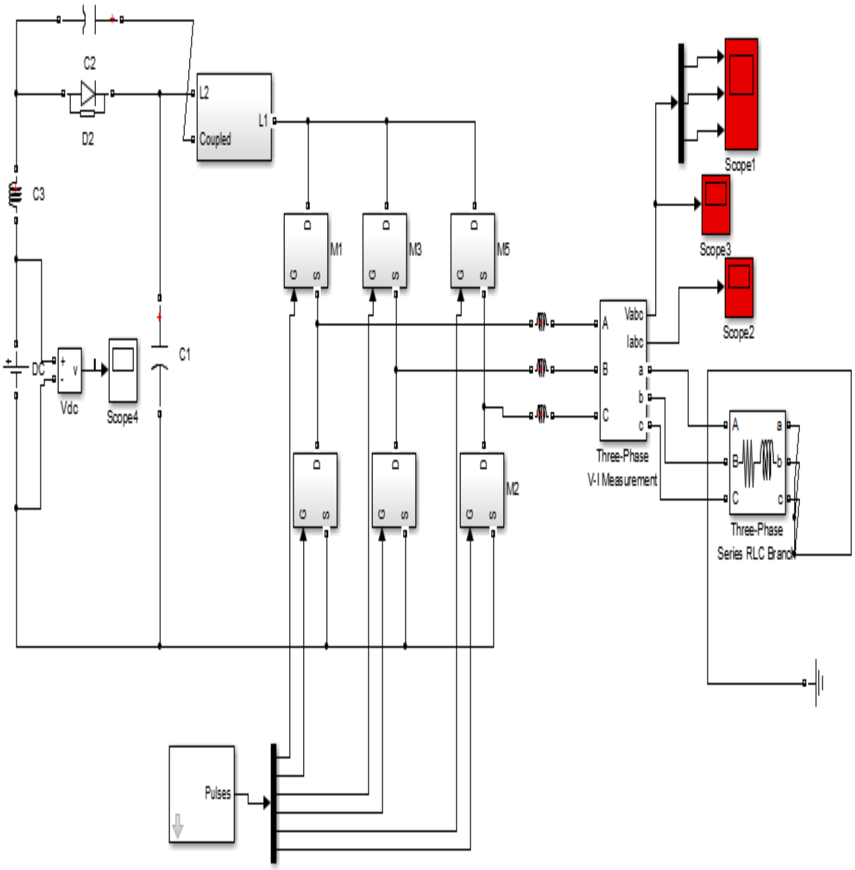


Fig. 7 Γ - Source Inverter Simulation Block Diagram

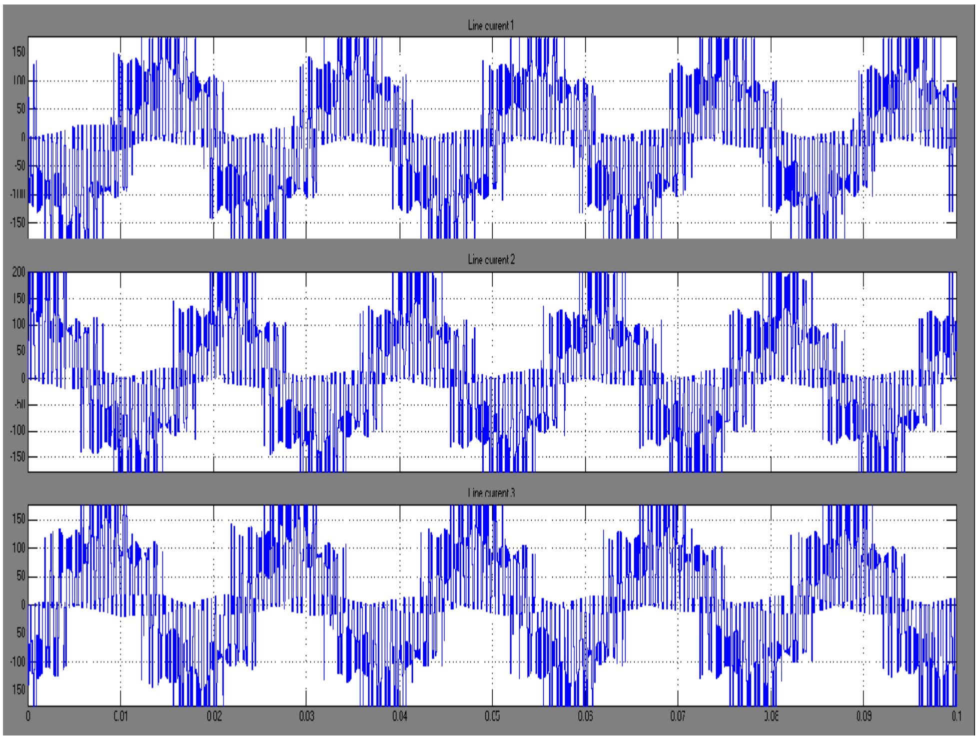


Fig. 8 Output of Individual Currents of Γ - Source Inverter

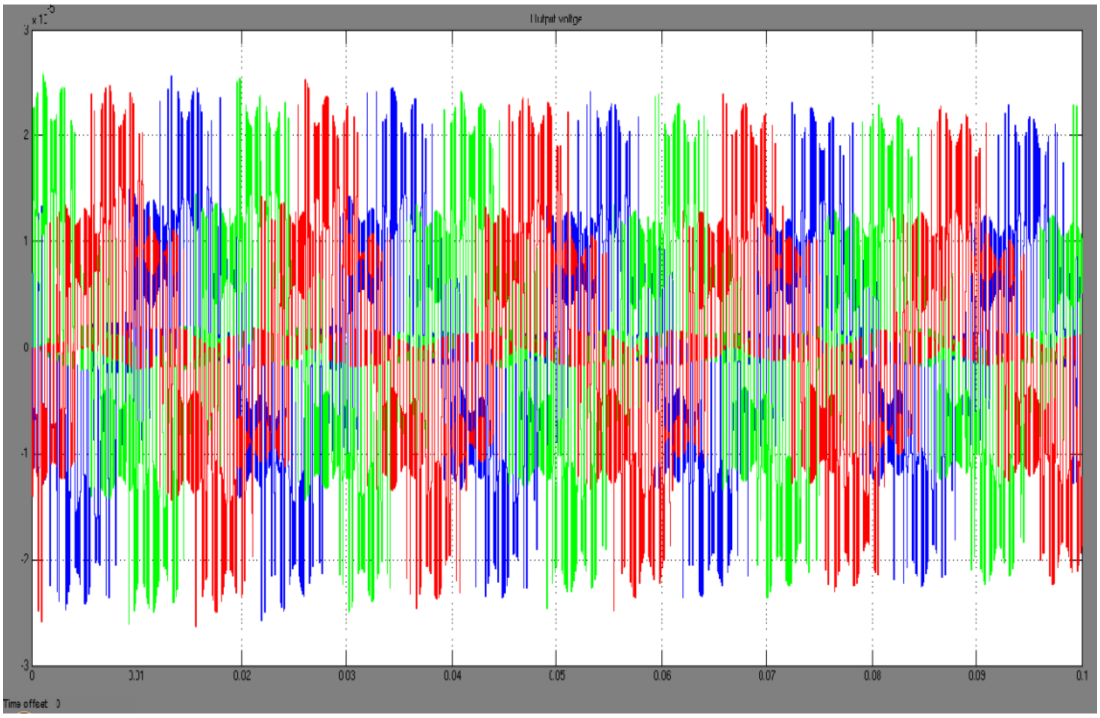


Fig. 9 Simulation of Output Voltage of Γ - Source Inverter

FINAL SIMULATION

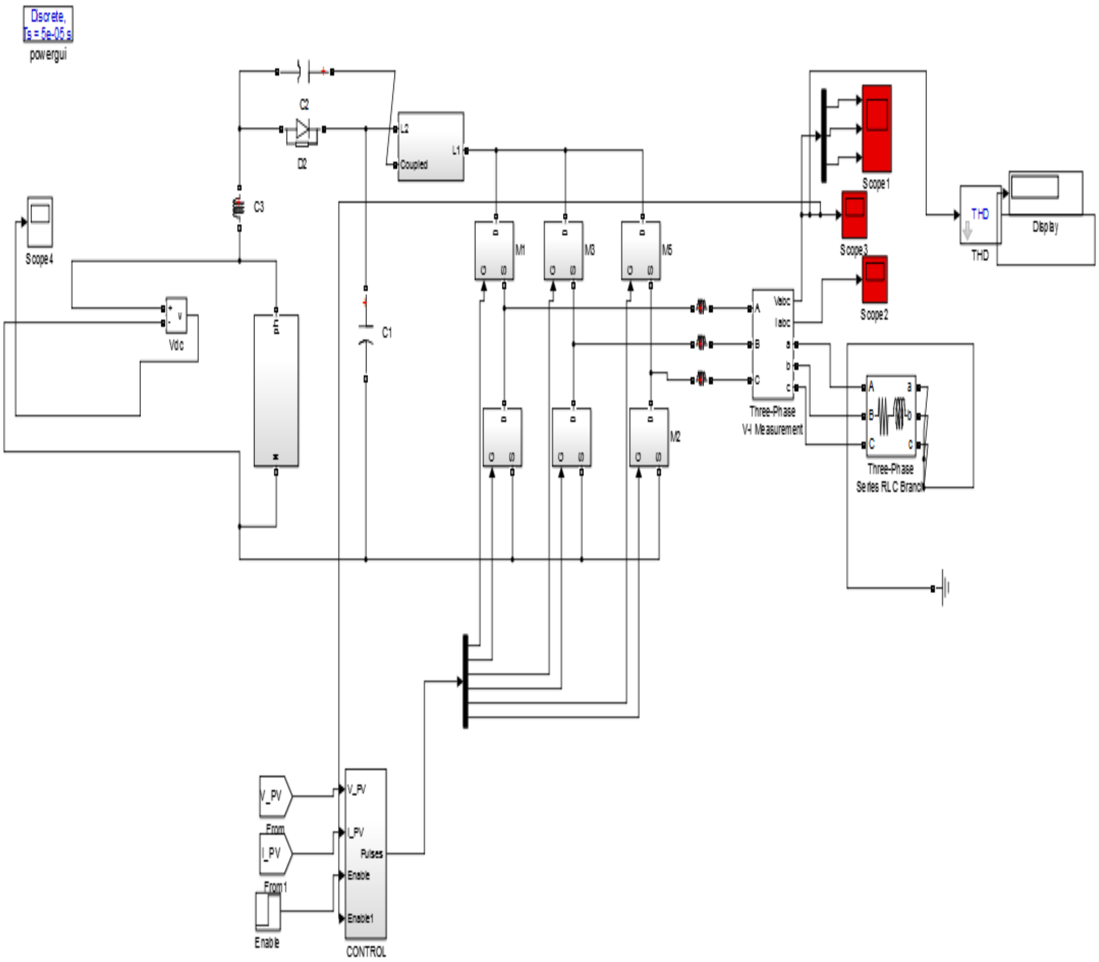


Fig 10. Simulation Block Diagram of FSMPC with MPPT (Inc)

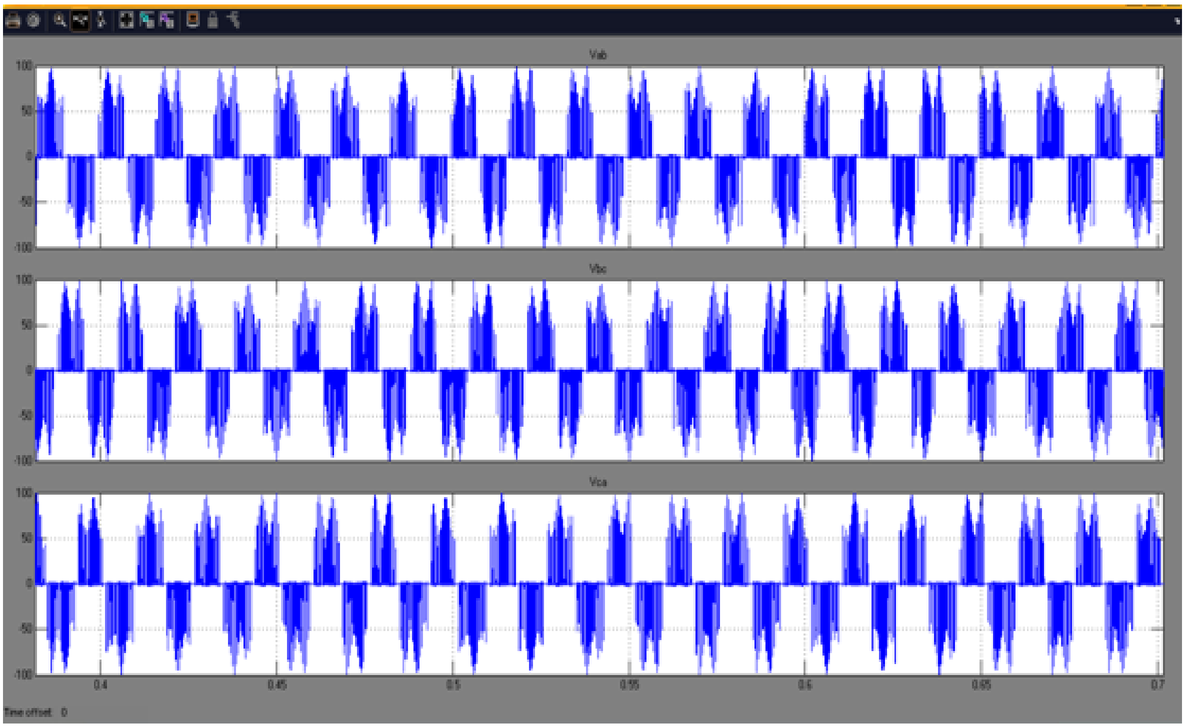


Fig. 11 Simulation of Output Line Voltages of FSMPC With MPPT (Inc)

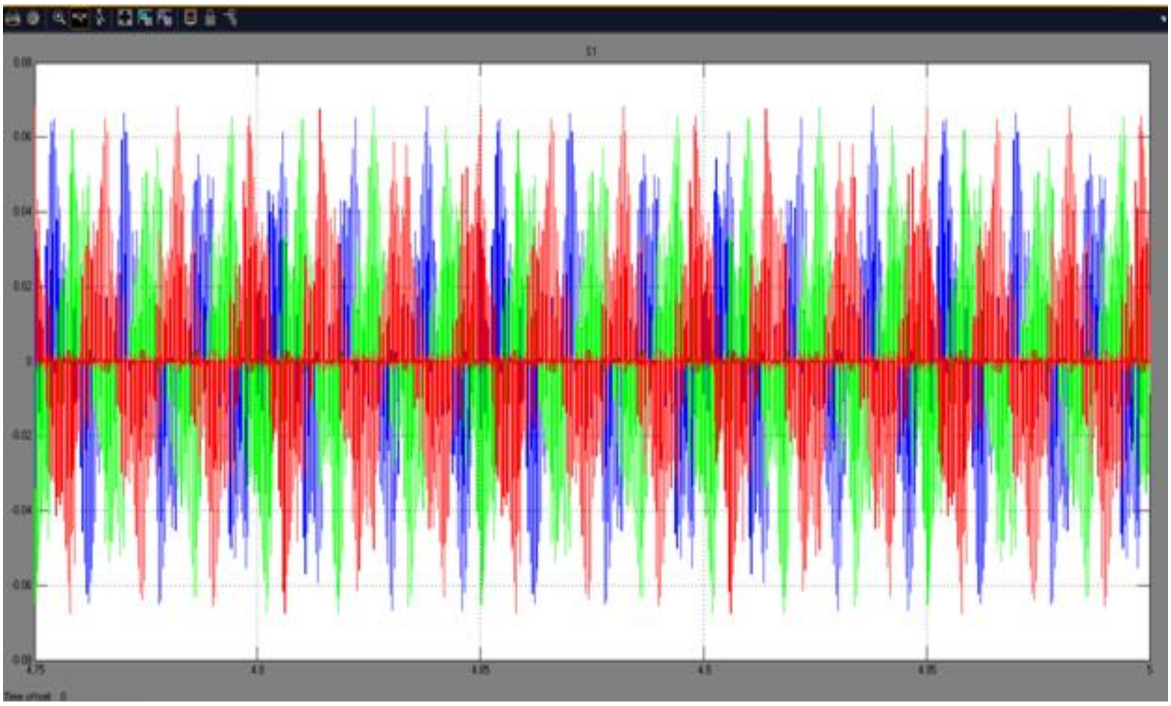


Fig. 12 Simulation of Output Current of FSMPC with MPPT

VII. CONCLUSION

In this paper, MPPT technique for Γ -source inverter through finite step model predictive control strategy is done. MPPT algorithm tracks the MPP and feeds the corresponding operation voltage Vm and current Im into the FSMPC controller. FSMPC controller collects information of MPP and produces the suitable switching signals to control the switching devices so as to achieve the optimal power output. The FSMPC show fast dynamic response regards to quickly changing operation condition and indicates its usefulness in fast changing atmosphere. Another consideration respecting to transformer less PV power generation systems is leakage current issue. Some possible ways to solve this problem is to design more sophisticated inverter configurations or use isolation transformer, which will be includes in the future work.

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